EDRI

Proceedings of Collaborative National Workshop on

Sustainable Land Management Research and Institutionalization of Future Collaborative Research

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Edited
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Sustainable Land Management Research and Institutionalization of Future Collaborative Research

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Foreword

The workshop on *Sustainable Land Management Research and Institutionalization of Future Collaborative Research*, hosted by the Department of Economics of Mekelle University and sponsored by the Environmental Economics Policy Forum for Ethiopia (EEPFE) of the Ethiopian Development Research Institute (EDRI), was held on 8-9 August, 2008. The workshop drew together participants from agriculture and environment Bureaus, University and research institutes and development organizations.

Sixty five participants representing researchers, policy makers and practitioners, both from the public sector (e.g. Bureau of Agriculture and Rural Development, Bureau of Finance and Economic Development, Regional Research Institutes, etc) and local and international NGOs, involved directly or indirectly in Sustainable Land Management (SLM) participated in the workshop., The presence of His Excellency Dr. Tewelde-Berhan Gebreegziabher, Director General of the Ethiopian Environmental Protection Authority, as guest of honor , added importance to the workshop, both in terms of profile and content.

The overall objective of the workshop was to take stock of the existing knowledge and help outline directions for possible future work in SLM. The workshop offered an opportunity to share knowledge and experiences and identify gaps for future research and policy intervention. The specific objectives were:

1) Share the region's experiences in development policies and strategies, approaches and strategies in developing and promoting technologies and impediments for effective implementation of policies and strategies;
2) Share experience on currently available research outputs and on-going research activities on SLM including policies ;
3) Identify research gaps of policy relevance;
4) Promote inter-institutional and cross-sectoral cooperation and networking efforts between Mekele Uinversity, EEPFE/EDRI and relevant institutions in the Tigrai National Regional State that have actual and potential involvement in SLM research and capacity building; and
5) Device mechanisms for improved policy-research linkage and to institutionalization of SLM database for effective dissemination of research results to policy makers in particular and the public at large.

The workshop allowed for a great degree of interaction among the participants, especially in the smaller group sessions namely: Land and Water management; Bio-diversity; and Socio-economic and policy issues, all focused on SLM. The group discussion were conducted on identifying SLM research work done so far, research and knowledge gaps, networking and advocacy, influencing policy makings on SLM and institutionalization of future collaborative SLM research and capacity building.

The major recommendations of the group discussion included: a) Inventories of SLM research work so far done and data collected for the same activities; b) Translating the workshop summary and major findings to the local language to effectively communicate the outcomes of the workshop to policy makers and development practitioners and scale up the dissemination of research outcomes; c) Create a platform that facilitate policy dialogue on

SLM, coordinate and facilitate SLM research information flow to all stakeholders, identify research and knowledge gaps on SLM, and avoid duplication of research on the same area.

The papers presented, the questions and issues raised during the various sessions and the summaries of the group discussions are all compiled into a workshop proceeding. This proceeding, besides compiling the state of knowledge and communicating research outcomes to relevant stakeholders, it will also serve as a useful resource material for further research in SLM in Tigray, in particular, and in Ethiopia, in general.

The workshop was concluded with vote of thanks by Drs Menale Kassie and Zenebe Gebreegziabher and commitments to communicate the workshop outcomes to all stakeholders and establish a forum for synergy in SLM researches, institutionalization of future collaborative researches, and effective communication of research outcomes to policy makers. HE Dr. Tewelde-Berhan also expressed his gratitude to all the participants and requested them to keep on their dedication they reflected on the two days workshop for a better world and better Ethiopia.

The organizers express their appreciation to Associate Professor Gunnar Köhlin, Director of the Environment for Development (EfD) initiative who has committed a large sum of resources for this workshop through the EfD initiative. Without his support and encouragement, this workshop would not have been possible. The organizers also express their appreciation to Professor Mitiku Haile, President of Mekelle University and Dr. Kindeya Gebrehiwot, Academic Vice President of Mekelle University, Dr. Mahmud Yesuf, coordinator of the EEPFE , Mr. Mezgebe Mehiretu , Head of Administration and Finance of EDRI and Mrs. Freweini Berhane secretary of the forum for their active role in organizing the workshop and handling administrative matters.

List of Abbreviations

WFP	World Food Program
MERET	Managing Environmental Resources to Enable Transition to more sustainable livelihoods
IUCN	International Union for Conservation of Nature
CBIWSM	Community Based Integrated Watershed Management
GTZ SUN	German Technical Cooperation Sustainable Utilization of Natural resources Tigray project
REST	Relief Society of Tigray
IPMS/ILRI	Improving Productivity and Market Success of Ethiopian Farmers/International Livestock Research Institute

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Welcome Speech

Menale Kassie (PhD)
Research Fellow
Environmental Economics Policy Forum for Ethiopia/EDRI

Honourable Director of the Ethiopian Environmental Protection Authority, Dr. Tewelde-Berhan Gebreegziabher, friends and colleagues, on behalf of the Environmental Economics Policy Forum for Ethiopia of the Ethiopian Development Research Institute, I warmly welcome you all at the workshop. It is a privilege and honour for Environmental Economics Policy Forum for Ethiopia to sponsor and co-organize this important workshop.

The Environmental Economics Policy Forum for Ethiopia is one of the six Environment for Development (EfD) initiative centers of Sida funded project through Goteborg University. Established in 2003, the Environmental Economics Policy Forum for Ethiopia has the mission to provide quality environmental Economics policy advice to the government and others based on quality objective research and to engage in capacity building to reduce poverty and contribute to sustainable development.

The Forum undertakes collaborative and independent macro and micro level research on environment, sustainable land management, and related issues. The Micro level researches so far focused in the Amhara regional state (East Gojam and South Wello) and partly in Tigary regional state. However, the forum has the ambition to expend its working territory to other regions by creating Sustainable Land Management (SLM) platform in collaboration with major stakeholders.

We believe that the Forum research outcomes and outcomes from other research institutes are not properly communicated with policy makers and development agencies. Hence, it is difficult to assume that we meet our mission.

This workshop will review and discuss findings from different research institutes. We will not try to anticipate all of the findings and discussions to come over the next two days. However, we expect this workshop will propose strategies that will assist sustainable research information flow to decision makers and development agencies of the region. As the prime sponsoring agencies of this workshop, I would like to reassure you that EEPF would continue to play a major role in organizing research information flow Forum in all regions of the country and will provide support to establish SLM platform in each region.

I want to extend my sincere thanks to those who have made this workshop possible.

First, Associate Prof Gunnar Kohlin of Goteboreg University of Sweden and Director of the Environment for Development (EfD) initiative who committed a large sum of resources for this workshop through the EfD initiative. Without his support, this workshop would not have been possible. He expressed his willingness to support such kind of workshop and the establishment of SLM platform in each region.

Second, I would like to extend my warm thanks to Dr. Zenebe Gebereegziabher of Mekelle Univeristy, Dr. Fitsum Hagos of International Water Management Institute, Mr. Teshaye Woldgiorgise and Yesfu Mohmadnur of Mekelle University who worked very hard to make the workshop a reality.

Third, I would like also to extend my sincere thanks to Dr. Mahmud Yesuf, coordinator of the forum, Mr. Mezgebe Mehirtu of EDRI Administration and Finance head and W/o. Freweini Berhane of the forum secretary for their unreserved help in the administration part of this workshop.

Third, I thank those who travelled long distance (Dr. Salvatore Di Falco, Dr. Wilfred Nyagena, Hoseana Gebru and participants from Addis) to attend this workshop and share their research outcomes.

I hope that the research and this workshop will help regional and national policy makers to develop strategies to better serve leaders and poor farmers in their mission to eliminate poverty and land degradation in Ethiopia. I wish us all success in this effort.

Thank you.

Welcome Speech

Aregawi Gebremichael
Dean, Faculty of Business and Economics
MekelleUniversity

Your Excellency Dr Tewolde-Berhan Gebre-Egziabher, Director General, Environmental Protection Authority, dear honourable guests and workshop participants, on behalf of the Faculty of Business and Economics it gives me a pleasure to welcome you all to this important workshop. According to my understanding this workshop is organized by the EEPFE/EDRI and the Department of Economics, Faculty of Business and Economics, Mekelle University. The Department of Economics is one of the leading Departments in Mekelle University with regard to research, consultancy and community services. It is obvious to all of us that research has to be conducted in light of the societal needs and development strategies of a country. Moreover, the findings of the researches should be communicated to policy-makers, development agencies, and the public at large so that they make informed decisions and in order to make a difference.

Your Excellency, honourable guests, and workshop participants, the workshop is expected to create common understanding on the available policy and strategies and implementation barriers of the Tigray region; share experience on currently available research outputs on agriculture and natural resource issues including policies as well as identify gaps and future research interventions; examine the role of research and development institutions on the Tigray National Regional State in future collaborative research and capacity building; promote inter-institutional and cross-sectoral cooperation and networking efforts between Mekelle University, EEPFE and relevant institutions in the Tigray that have actual and potential involvement in research and capacity building endeavors; and create strong platform to bridge the gaps between research, extension, and policy making process.

I believe that the workshop is a good opportunity to create close collaboration with the EDRI and other national and international organizations.

I wish you fruitful deliberations!

Thank you.

Opening Speech

Abdelkader Kedir (PhD)
Associate Vice President for Research and Graduate Programs
Mekelle University

Your Excellency Dr Tewelde-Berhan Gebreegziabher!

Dear Participants and Honorable Guests!

It gives me an immense pleasure and it is an honor for me to give an opening speech at this important Workshop.

Mekelle University has been engaged in academic, research and community services since its establishment. Today's workshop on the theme 'Sustainable Land Management Research and Institutionalization of Future Collaborative Research' is one aspect of its triple role and commitment in serving the society at large and the region in particular.

Your Excellency! Dear Participants and Honorable Guests!

Ethiopia is typically an agrarian country, with agriculture continuing to be the largest sector in its economy. Agriculture contributes over 40 percent of GDP (Gross Domestic Product), about 80 percent of employment, more than 80 percent of commodity export earnings and 70 percent of raw materials supply for agro-based industries. It is quite obvious that enhanced productivity of the agricultural sector rests on sustainable management and use of the country's land resource. In this regard, today's workshop is of particular relevance in the sense that it deals with the core issue of 'sustainable land management'. It also fits with the broader 'agricultural development led industrialization' (ADLI) strategy of the country.

Your Excellency! Dear Participants and Honorable Guests!

It is reminded that different institutes and individuals have carried out extensive research to assess the problems of land degradation, their causes, remedies and impacts on agricultural development and sustainable resource use. However, these research results are hardly known to policy makers and development agencies of the region. Although research is important to make informed decision on development interventions, stakeholders have hardly benefited from empirical research. Therefore, I believe that this workshop will overcome this problem, identify issues for future research, and ensure information flow to stakeholders in the region, particularly on what has been done so far on sustainable land management (SLM) research in the region.

Your Excellency! Dear Participants and Honorable Guests!

I have come to know that a total of 23 papers (invited + contributed) will be presented in this two days workshop organized by Mekelle University and the Environmental Economics Policy Forum of the Ethiopian Development Research Institute (EEPF/EDRI). And I believe that this will be an excellent avenue to create a common understanding on existing policies and strategies of the region and implementation barriers as well as to share experience on currently available research outputs on sustainable land management. I also believe that it will create a strong platform to bridge the gap between research, extension, and policy making processes.

I expect that at the end this workshop will identify future research needs and suggest on implementation mechanisms including partnership arrangements (through creating strong collaborative research platform). I also expect that the outputs of this workshop will be disseminated to all stakeholders in the region in the form of a proceeding and policy briefs of some of the research outputs.

Finally I would like to thank the organizers from both sides who worked day and night to make this workshop happen

I wish you all fruitful deliberations,

I hereby declare the workshop open.

I now call HE Dr Tewelde-Berhan Gebreegziabher to deliver his keynote speech for the Workshop.

Thank you.

Keynote Speech

'Sustainable Land Management: Research and Policy Challenges'*

HE Tewolde Berhan Gebre Egziabher
Director General
Environmental Protection Authority

1. Introduction

Of all the living species, it is we, humans that have the greatest impact on the biosphere. Our impact on the atmosphere, climate change, is already affecting the whole biosphere. However, since we are terrestrial, it is the land that has received our impact the longest. And since we are gathered here today to look specifically at land management, I will touch on climate change only obliquely to the extent that it interacts with land management and land degradation.

Land degradation is of particular importance to Ethiopia because the Ethiopian environment is mountainous and thus very easy to degrade. The main economic sector in Ethiopia is, and for thousands of years has been, agriculture; and agriculture is the main human agent for causing land degradation.

The terms "organic agriculture" and "ecological agriculture" were coined in the second half of the 20th century to qualify the crop and domestic animal production system that has sustained us for 10,000 years. The terms were needed to contrast the farming that has always been with its new petrochemical-based modification, industrial agriculture. I prefer the second term. This is because the term "organic" is now being used to imply that artificial chemical inputs, whether petrochemical or not, should never be used in agriculture. But I see no problem with the occasional chemical input into the agricultural ecosystem when that input will help to quickly reestablish stability. My more fundamental objection is to the added expense. Since ecological agriculture has thus established its credentials for 10,000 years, for me the real question is, "Can the decades only old intruder, industrial agriculture, continue to satisfy human needs into the indefinite future, especially now that the chemical inputs it uses are largely derived from petroleum, and petroleum is getting very expensive?"

You can, however, legitimately ask if ecological agriculture can feed the population size of the present world, which is much larger than that which had been at any time before industrial agriculture intruded into its domain. This question implies that ecological agriculture cannot produce as much as industrial agriculture presently does. It is a legitimate question, and it must be answered. I know that other speakers will answer this question in this workshop. An at least equally legitimate question is, "Can this new comer, industrial agriculture, continue satisfying human needs in a sustainable biosphere for the coming 10,000 years and more?" I must now try to answer this critical question. Therefore, I need to

* Keynote speech delivered at the Sustainable Land Management Workshop, Mekelle, 8-9 August 2008, based on a lecture on "Can Organic Agriculture Feed the World?", given to the Soil Association in London on 12 July 2005.

start by looking at agriculture and ecological stability for the simple reason that stability is a pre-requisite for thinking of perpetuity.

2. Agriculture and Ecological Stability

A natural terrestrial ecosystem is approximately stable because its functional components, the producers, consumers, decomposers, soil, water, air and temperature positively respond to negative feedbacks trigerred by changes induced from outside. In the ecological agricultural ecosystem, the crop plants and their weeds are the producers. Human beings, domestic animals and at least some wild animals, including many in the soil, are the consumers. Soil fungi and bacteria are the decomposers. The humus binds the inorganic particles into units that determine the soil's structure. Air and water become optimally available in the crop plant root zone because of the thus optimised soil structure. The soil particles, especially the humus, also maintain the appropriate pH and supply plants with nutrients[1]. When humus is in this way allowed to remain dominant in the soil, much carbon is sequestered thus mitigating climate change. In contrast, industrial agriculture reduces soil humus, degrades soil structure and transfers the carbon that had been in the humus in the soil into the atmosphere, thus exacerbating climate change.

2.1 Agriculture and Niche Simplification

Unaided by informed ecosystem management, even ecological agriculture as it has mostly been practiced does not fully obey these rules that ensure ecological stability and sequester carbon. All forms of agriculture, including ecological agriculture as has mostly been practiced, cause niche simplification. But industrial agriculture does so the most. It is also in its market-oriented nature to reject the comprehensively informed management that would have led to the ecosystem itself ensuring its own stability.

In agriculture, our interest is the maximization of biomass production in the crops and/or domestic animals which we use for food or for other purposes. Therefore, agriculture reduces the number of species growing in the farm.[1] In nature, species that grow together complement one another to combine together and fully exploit the different niches of their ecosystem. For this reason, though intensive chemical inputs may become productive in a given season, sustained productivity over years is not possible with the monocultures that are the norm in industrial agriculture,[2] i.e. when only one of the green plant niches is occupied. The occupation of a critical minimum number of green plant niches is necessary for ecological stability, also referred to as homeostasis, and the increase in the number of species will thus raise production because more room for growth becomes available in the same area. The minimum number of complementing species for maximizing production is small, but that for ecological stability or homeostasis is much larger.[2]

The species of crops and domestic animals the biomass of which we want to maximize are smaller in number than those that naturally grow in that ecosystem. This means that even when based on a polyculture, agriculture reduces niche utilization. Therefore, it also correspondingly reduces the positive responses to the negative signals induced by disturbances of the natural homeostatic processes and thus also reduces biomass yields. For this reason, the agricultural ecosystem normally fails to adjust as effectively as the natural ecosystem it has replaced and land degradation sets in. That is why losses of structure and fertility of the soil occur.[3] The hydrological cycle also gets disrupted, often resulting in soil salinization,[4] and even more often in increased runoff and soil erosion.[5]

Many civilizations have been eclipsed by such agriculturally induced devastations, e.g. owing to salinization in the Tigris and Euphrates Valleys, and owing to soil erosion and sedimentation in Ephesus[6] and the rest of Asia Minor.

2.2 Techniques Used by Farming Communities for Compensating for the Loss of Ecosystem Components

Over the thousands of years of the history of ecological agriculture, farming communities have learnt various biological and physical methods of coping with the problem of land degradation, which is the continuing degradation of the components of the ecosystem. Two examples are terracing and fallowing. But perhaps the most significant examples are those that make the conscious use of species with special traits to provide positive reactions to the negative feedbacks induced by inappropriate agricultural practices. For example, mixed farming,[7] i.e. combining crop and animal production, enables manuring, or better still, the making and use of high quality compost to build up soil fertility. They do so by helping keep biological production, consumption and decomposition in tune in the farm. Their application at the time of planting provides crops with nutrients optimally beginning at the start of the growing season, thus maximizing the biological production that is wanted by agriculture. Turning manure, human waste and other biological materials into compost clears them of weed seeds, pests, diseases and parasites. Therefore, a systematic making and use of compost both maximizes the availability of nutrients to crops, and builds up the ecosystem's homoeostasis.

Deep rooted crops return leached nutrients up to the surface soil from where they become available to the next crop generation. Leguminous plants, including crops, fix nitrogen to replace what is denitrified and lost to the atmosphere. Sorghum, barley and similar crop species are deep rooted and, besides bringing up nutrients to the surface, withstand dry spells which agriculture exacerbates by deforesting the land and thus changing the microclimate. Deforestation exacerbates waterlogging as well. Teff and similar species slow down their own growth to survive waterlogging, and rice even grows optimally under waterlogged conditions. The positive impacts of agricultural biodiversity on the ecosystem can thus be made to occur simultaneously by planting the species in polycultures and/or sequentially by crop rotation in monocultures or even in polycultures.

The physical methods developed by farming communities reduce or prevent soil erosion, loss of water, excess water, or even bring water from afar or from under the soil for irrigation. Both irrigation and drainage can influence the physics and/or chemistry of the soil, e.g. by causing salinization.[4] They have thus caused much loss of good soil and biodiversity. But, in combination with appropriate biodiversity and a high soil humus content to maintain good soil structure and thus also fertility, they can be used sustainably. High soil humus content also sequesters carbon and helps maintain the climate stable. It also helps crop species remain resistant to diseases and pests.[8]

2.3 Industrial Agriculture: Creating the Ecosystem Market

Industrial agriculture abandons trying to bring about homoeostasis into the agricultural ecosystem. Instead, it tries to produce a homogenous environment of marketable components irrespective of the diversity and complexity of the pre-existing ecosystems. To achieve this, it uses irrigation extensively even where it is not needed. It thus creates a captive market for pumping and irrigation equipments. It also creates contracts for building dams, drilling bore holes and making irrigation and drainage canals. In this way, it geographically extends the age-old problems associated with irrigation.

It divorces animal production from crop production. It disposes of both animal and human wastes and plant residues as if they were poisonous. It plants single variety monocultures as a continuum over very extensive areas. This reduces nutrient cycling and ecological disruption thus becomes inevitable. One indicator of such an ecological disruption is the regular and quick collapse of the uniform crop variety that is in use over a wide area as a monoculture. The collapse occurs owing to emerging vulnerabilities to diseases and pests.[9] This keeps breeders specially trained to keep out diversity and produce uniformity employed. It also gives chemical companies that produce and supply pesticides and herbicides a captive market. Both the breeders and suppliers of agrochemicals are now increasingly the same multinational companies.[10] This is understandable since combining both sectors enables the breeding of varieties that can be relied upon to need the agrochemicals. By so doing, industrial agriculture marginalizes the farming community breeders [11] who have been maximizing diversity to adapt agriculture to ecosystem complexity and have thus given humanity the various crops and the thousands of varieties of each crop as well as the ecological methods of using diversity to increase yields and forestall diseases and pests.

Thus marginalized, they lose confidence in their proven and customarily acquired systems and become dependent on the monocultures and helpless when confronted by the diseases and pests that they used to prevent effectively.

Nutrients are leached out and washed away and have to be replenished externally at very short intervals. This gives chemical companies that produce and supply fertilizers a captive market.

Soil structure deteriorates and compaction becomes a serious problem. This gives agricultural machinery companies a captive market. The natural components of the ecosystem are thus replaced by tradable artificial components that are bought and sold in the market.

The replacement agricultural ecosystem that these purchased replacement ecosystem components of industrial agriculture constitute is not stable. Unlike the natural components, these replacement components fail to respond to feedbacks effectively. Therefore, the more they replace the natural components, the less homeostatic the agricultural ecosystem becomes. This is because of their inability to replicate the complexity of interactions in the natural soil.[12] In this way, they steadily destroy the natural components of the agricultural ecosystem and make themselves indispensable in the steadily degrading land.

The suppliers of these replacement components want to increase their profit and they often come up with highly simplistic quick-fixes for the market-making fundamental agricultural ecosystem flaws which they have created. The most recent quick-fix, genetic engineering, is being championed not as a means of increasing homeostasis and yields in stable agricultural ecosystems of high innate soil fertility, but as a means of producing crops that will grow in degenerating agricultural ecosystems.[13] The logical end result of degeneration is destruction. If genetically engineered crops could grow in an environment under destruction, they would have become harmful enough since they would have lulled us into accepting the situation until it becomes too late to reverse. As it is, so far, genetically engineered crops have been used only to put more disruptive factors into the industrial agricultural ecosystem: poison to some invertebrate animals in the case of Bt transgenic crops, and universal poison to other plants in the case of herbicide tolerant transgenic crops. No transgenic crops with other traits have been cultivated extensively. Transgenic crops with other traits are thus so far merely a tantalysing promise.

3. Research and Policy Implications

The impacts of industrial agriculture impinge upon, and are themselves modified by, other sectors of the globalizing economic system. As you know, agrochemicals are derived from petroleum. You will recall that recently, the price of petroleum went up above 140 U.S. dollars per barrel. Predictions are that it will continue to rise further. Do you think that we can continue to depend on petrochemical-based industrial agriculture? It is my considered opinion that industrial agriculture in financially poor Ethiopia is dying on its track. Even in the financially rich industrialized world, it has to undergo a serious reorientation and converge with ecological agriculture if it is to continue contributing to human development.

This can be done only if it is made to contribute to maximizing the biomass that we require while at the same time strengthening the homeostasis of the agricultural ecosystem to match that of the natural ecosystem. Will ecological agriculture do this for us more easily and more effectively?

The answer is yes, but only if we take it seriously and do all the research and development to compensate for the time that we have lost on industrial agriculture. This will obviously require appropriate management policies to bolster rather than shunt the natural cycles that improve the functioning of the ecosystem as a whole, including those parts of it that are not cultivated. In this way, ecological and industrial agriculture would harmonize and the schism in agriculture of the last 5 decades would disappear.

Can this be done? Will research and conducive policies suffice to produce the needed harmony? Why not? Previous farming communities have been learning from their past mistakes and have been successively and successfully harmonizing agriculture with ecological stability for thousands of years. With our increased scientific knowledge based on systematic research, we should much faster do much better than they have been doing.

Unfortunately, I realize, as I am sure that all of you do, that agricultural research in the last 5 or so decades has globally ignored ecosystem stability and focused on selecting varieties that maximize yields under irrigation and chemical fertilizers. What is needed is a commensurate amount of research on land management for maximizing innate soil fertility, on sustaining the thus maximized soil fertility, and on selecting crop varieties that maximize yields under increasing innate soil fertility. Breeding for crop varieties that are adept at grabbing chemicals before they are washed away to pollute water bodies should stop. There would then be no doubt that the results would be agricultural systems that are better than petrochemical based industrial agriculture with its inbuilt land degrading impact. But of course, in contrast to industrial agriculture, these agricultural systems would cost less money to maintain, would minimize pollution and would remain sustainable into the indefinite future.

Therefore, if it is given all the attention in research and policy focus for effective management that industrial agriculture now enjoys, I am sure that the renovated ecological agriculture will feed the world. I am also sure that, unless ecological agriculture is renovated and re-expands and tames industrial agriculture, land degradation will expand even further than it has already done and the human component of the biosphere will soon shrink. And, if climate change, which is being exacerbated by industrial agriculture, is not curbed, there will be no biosphere as we now know it and no land as we now have it, let alone food as we now love it.

Thank you all for hearing me out.

by Cambridge University Press: Cambridge, p. 443.

2. **Ibid**, pp. 402-405, and p. 448.
3. **Ibid**, pp. 326-452 give additional information on how this soil deterioration occurs.
4. Salinization as a consequence of irrigation, especially when water drainage is not properly carried out, is a well documented phenomenon. Therefore, even though it may at first sound counter-intuitive to associate excess salts with excess water, it is lack of proper drainage that causes simultaneous waterlogging and salinization, and land lost to both is usually lumped together. Brown, L. R., and C. Flavin, 1997, **Vital Signs, 1997,** World Watch Institute: Washington, p. 42 state that 2 million hectares of irrigated land are lost annually to waterlogging and salinization. Pretty, J. N., 1995, **Regenerating Agriculture,** Earthscan Publications Ltd.: London, pp. 126-127, gives the lower estimate of 1.5 million hectares per year. But either figure is equally frightening.
5. World Resources Institute, United Nations Environment Programme, United Nations Development Programme and The World Bank, 1998, 1998-99 **World Resources- A Guide to the Global Environment,** Oxford University Press: Oxford, p. 157, state that soil is being eroded globally at a rate of 16 to 300 times than it is being formed. This shows that we are eating up nature's investment and investing in death for future generations.
6. On 24 September 1995, the participants of the "Revelation and the Environment, AD 95-1995" symposium visited the ruins of the ancient city of Ephesus. While in the ruins of the city, dug out by archaeologists, we were told that it was soil eroded from the surrounding hills that had sedimented out and buried the city. The hills were now mostly rocky.
7. Howard, A., undated, **An Agricultural Testament,** The Other India Press: (Reprinted. First published in London in 1940), pp.1 and 32-38 describes the system. Note that there is no mixed faming in industrial agriculture. It is, however, extensively used by farming communities of the South, including Africa.
8. Unless it is owing to our lack of access to the complete literature, modern papers and books on soil science do not deal with the health implication of soil organic matter (humus). But it may also be because modern authors are so engrossed with ecosystem replacement agrochemicals for dealing with crop diseases and pests that they do not focus on natural cures. However authors that published before agrochemicals were as widely used as now wrote on the issue. Howard, A., **Ibid**, pp. 143-174, shows the importance of high humus content and a balanced agricultural ecosystem in keeping crops physiologically fit and thus not succumbing to diseases and pests. He argues that the use of agrochemicals for fighting diseases and pests is of limited efficacy since the diseases and pests adapt to the chemicals. More recently but still before agrochemicals became so ubiquitous, Russel, E. W., 1961 **Soil Conditions and Plant Growth,** Longman, Green and Co. Ltd.: London, has repeated the same basic theme, with more precise information, pp. 210-221 on how a balanced soil microflora helps, and pp. 523-534 on how soil organic matter helps by keeping plants healthy and resistant to pests and diseases. In Tigray, Northern Ethiopia, we have noted that tef grown on soil where compost has been applied withstands tef shoot fly, while that grown on chemically fertilized soil is severely attacked.
9. Fowler, C., and P. Mooney, 1990. **Shattering: Food, Politics, and the Loss of Genetic Diversity,** The University of Arizona Press: Tucson, Arizona, p.135, report that between 1974 and 1977, new barley varieties in the U. K. were losing their resistance about every 3 years.
10. Fowler, C., and P. Mooney, 1990. **The Threatened Gene: Food, Politics and the Loss of Genetic Diversity,** The Lutterworth Press: Cambridge, pp. 115-139.
11. The specially trained plant breeders who produce the homogenous varieties for industrial agriculture have been denying that farming communities are breeders and that they merely

N., (Ed.), 1995. **Population and Food in the Early Twenty-First Century: Meeting Future Food Demand of an Increasing Population**, International Food Policy Research Institute: Washington D. C., pp. 221-222, recognizes both as breeders and distinguishes their contributions as "professional plant breeding" and "plant breeding by farmers".

12. Pretty, J. N., 1995. o*p. cit*., pp. 26-93, Conway, G. R. and Pretty, J. N., 1991. **Unwelcome Harvest**, Earthscan Publications Ltd.: London, pp. 17-369, Heywood, V. H., and R. T. Watson, 1995 *op. cit*., pp. 326-452, Shiva, V., 1991. **The Violence of the Green Revolution**, Third World Network: Penang, Malaysia, pp. 103-150, among many others, have described the specifics of how this loss of homeostasis occurs.

13. The United Nations Development Programme, 2001, **Human Development Report 2001**, Oxford University Press: New York, p. 35, states, "Biotechnology offers the only or the best 'tool of choice' for marginal ecological zones... home to more than half of the world's poorest people..." In the next paragraph, the UNDP states, "There is a long way to go before biotechnology's potential is mobilized." In so saying, the UNDP admits that biotechnology as 'the only tool' has not been tested in marginal areas to prove itself as the best tool, or even as any tool. Therefore, it is only a dream to state that it is "The only tool". Each of us can dream, of course, including those manning the UNDP. But dreams cannot become food. We know that there has not been even one successful transgenetic crop developed for the marginal areas of the poor and used extensively enough to prove itself. Assuming that biotechnology could indeed produce adequate food in marginal areas, how are "the world's poorest people", who are mostly not even monetized, nor even literate in their own languages let alone in English, going to deal with the intricate negotiations with patent holders, who will most probably be all foreign and from the North, in order to use patented transgenic varieties, and how are they to pay the royalties? In spite of a discussion on IPRs (see pp. 102-109) the UNDP is silent on the issue. This certainly turns its dream into a nightmare!

Background

Soil erosion, nutrient depletion and deforestation are common environmental problems in the Ethiopian Highlands, not least in the Tigray region of Ethiopia (Hagos, et al. 1999; Desta et al., 2000). Land degradation also poses a serious problem on the livelihood of rural producers. Land degradation is, in fact, generally regarded as a source of pervasive poverty for farmers in many developing countries.

The proximate causes of land degradation are apparent and generally agreed: declining use of fallow, inappropriate farming practices, steep topography, highly erosive soils and rainfall intensity etc are some of the major direct causes of soil erosion. High soil erosion compounded by limited recycling of organic and limited application of inorganic soil nutrients have also exacerbated the problem of nutrient depletion in the region. Understanding the underlining causes, rather than the proximate ones, have greater use for policy making. Factors underlying these direct causes include increasing population pressure, poverty, fragmented land holdings and insecure land tenure, and limited policy focus given to agriculture (Hagos, et al. 1999; Desta et al., 2000).

The impact of land degradation are far reaching, beyond causing increased run-off and soil loss, it has serious impacts in causing decline in agricultural productivity and there by affecting food security and the growth of the overall economy. Although estimates of the costs of erosion are scanty, exiting estimates are alarming. In economic terms, soil erosion in 1990 was estimated to have cost (in 1985 prices) nearly ETB 40 million in lost agricultural production (i.e. crop and livestock) while the cost of burning dung and crop residues as fuel was nearly ETB 650 million. Thus in 1990 approximately 17% of the potential agricultural GDP was lost because of soil degradation. The permanent loss in value of the country's soil resources caused by soil erosion in 1990 was estimated to be ETB 59 million. This is the amount by which the country's soil stock should be depreciated in the national accounts or which should be deducted (as capital depreciation) from the country's Net National Income (Sutcliffe, 1993; Bojo and Cassells, 1995).

Deforestation is also going unabated because of growing demands for construction, fuel wood and farm land. In many areas of the Ethiopian highlands, the present consumption of wood is in excess of sustainable growth. Estimates of deforestation, which is mainly for expansion of rain fed agriculture, vary from 80,000 to 200,000 hectares per annum (EPA, 1997). The Ethiopian Forestry Action Program (EFAP) estimated the full value of forest depletion in 1990 to have been about ETB 138 million or some 25% of the potential forestry GDP of ETB 544 million (EFAP, 1993). This indicates the degree of mining of the natural vegetation and its impacts on soil and water resources (i.e. through run off and erosion) with wide implications on biodiversity and the environment. Although specific estimates for the region are missing, there is a general consensus that the deforestation is a serious problem, if not more given the fragile nature of the ecosystem, in the region as in the whole county.

In light of the problems posed by land degradation on the livelihood of rural producers in Ethiopia, policy makers, development agents, and researchers alike have followed a two-conservation investments and reforestation programs have become important tasks of development agents, governmental or non-governmental ones. Various public- and private-led, albeit mediocre on the later given the magnitude of the problem, measures have been going on to avert soil erosion and deforestation in northern Ethiopia (see Hagos et al, 1999; Gebremedhin, 1998; Hagos and Holden, 2006). The wider impacts of these interventions on the state of the environmental and productivity still remain inadequately researched and documented, not to mention various cases studies that document success cases here and there. One exception is a work done by Nyssen et al (2008) who documented the region-wide effect of soil and water conservation on vegetation cover using time series aerial photos.

Relatively speaking, a lot has been done in terms of understanding the specific roles of the set of underlining factors in influencing farmers' behavior in managing land and water in different contexts in Tigray and elsewhere in Ethiopia (Gebremedhin and Swinton, 2003; Gebremedhin et al., 2003; Hagos and Holden, 2006; for a review see Yesuf and Pender, 2005). In spite of the proliferation of socio-economic literature on sustainable land management practices and their impacts on food security and poverty allevvation, these results remain poorly communicated to policy makers. In response to this, the environmental Economics Policy Forum for Ethiopia hosted in the Ethiopian Development Reserach Institute and funded by Sida through Gothenburg Univeristy and has the role of doing research on environmental economics and poverty allevation, intitated this workshop. The main objective of the workshop was to narrow the research-policy linkage gap and encourage informed decision making through desminating and communicating policy relevant sustainable land management research outputs.

The specific objectives of the workshop were:

1. To take stock of available and on-going sustainable land management research and draw possible policy implications and inform these conclusions to policy makers;
2. Identify possible research gaps of policy relevance; and
3. Device mechanisms for improved policy-research linkage and institutionalization of strategies for effective dissemination of research results to policy makers in particular and the public at large.
4. Promote inter-institutional and cross-sectoral cooperation and networking efforts between, EEPFE/EDRI, Mekele Univeristy, Bureau of Agriculture, and relevant institutions in the region that have actual and potential involvement in research and capacity building endeavours.
5. Create common understanding on existing policies and strategies of the Tigray region and implementation barriers.

The workshop papers covered issues ranging from soil conservation-tree planting-biodiversity and institutional issues. The papers presented fall into six broad themes: SLM: practice, challenges and development strategies; Investments in land and water; land investment technologies their economics and impact; biodiversity and productivity; tree planting and conservation; and sustainable land management and livelihood. In total, 90

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Session I.

Sustainable Land Management: Research, Practice and Development Strategies

Development Strategies in Tigray: Challenges and Opportunities

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1. Regional Development Strategies

Since 2003, the Regional state has developed & implemented two strategic plans. The first strategic plan lasted for three consecutive years as part of its implementation period. The main objective stated in the three years strategic plan of 2003-2005 was achieving food security at Household level both in rural and urban areas. In rural areas as agriculture is the main sources for the livelihood of rural households, the focus of the strategy was on the development of household farming system through effective packaged support components. As far as food security in urban areas is concerned, the strategy was to tackle micro and small scale business constraints as it was an area neglected for many years, regardless its contribution to employment and incomes. Apart from, serious emphasis has been given to the infrastructural and social development support components.

The second Regional strategic plan of the 2006 to 2010, which is currently on its third year of implementation period, has not made any sort of deviation in terms of objective or major policy change but it has included with emphasis growth strategies as part of the PASDEP. The strategy has also considered the importance of intensification in household farming through the development of irrigation infrastructure both small and large scale to enhance land and labor productivity.

Major strategic elements considered in both strategic plan implementation includes the following:

1. Applying package based support program to rural households with the specific purpose of improving their low level earning to the level set as a millennium development goals of achieving an income of one dollar per day per person.

   1.1 Under the package program both crop and livestock support components are (extension agent) and infrastructure. Hence 3 generalist extension agents and depending on the situation of irrigation capacity either 2 or 1 additional extension agent are assigned to support household irrigation development.

1.4 Establishing Farmers Training centers at all village level to closely demonstrate farmers with the application of new technologies, know-how and farmer to farmer learning.

1.5 Improved provision and delivery of inputs through union cooperatives to address market failure on the one hand and to link the farming sector to better markets on the other.

1.6 Provision of improved varieties from the perspective of improving crop and livestock productivity. An effective strategy of improve seed provision is made by encouraging farmers to produce improved seed and supply it to the government at an agreed price with risk insurance from the government.

1.7 Provision of credit to rural households at a fair rate to realize effectively the working system of implementing the package program. Regional government sought to give guarantee to micro credit institutions and cooperatives.

1.8 Hand in hand with the intensified package support or the full package support a minimum package is designed to support for the non package beneficiaries. The essence of the minimum package support is to encourage farmers do better those traditional farming activities like using animal dug for manure, weeding, better ploughing & others.

1.9 Encouraging and closely supporting farmers to develop business plan for better farm management.

2. The second major strategy involves provision of basic services to improve rural household welfare.

   2.1 Provision of adequate health services with an emphasis to preventive strategy like malaria prevention & control. Effective coverage of bed net distribution to rural households has been taken as major component of the strategy. As far as HIV/AIDS prevention and control strategy is concerned, full scale coverage of VCT is the key.

   2.2 Building Health facilities like health posts at all village level as satellite organ to the woreda based health center.

   2.3 Training and recruitment of health extension workers to closely support rural households to improve hygiene & sanitation. Assigning two health extension agents at village level is the key to the strategy.

   2.4 Provision of potable water to rural areas by constructing shallow and deep wells, and spring development with better community based management.

   2.5 Provision of school facilities and adequate teachers at all levels to achieve full coverage of net enrolment rate by 2015. Under this strategy local governments are suppose to build schools in collaboration with communities and the role of the regional government focus on the provision of teachers and text books. Moreover, education package program has been taken as a strategy to improve connect villages with woreda centers through dry weather roads.

3.3 Rural electric power supply program support including for irrigation development purpose.

3.4 Rural based telecommunication service provision supports through facility development.

3.5 Provision of irrigation infrastructure like the development of small scale dam construction.

4. Environmental Rehabilitation and development support strategies.

4.1 Area enclosure strategies to rehabilitate indigenous trees by prohibiting grazing and cutting trees through community by laws.

4.2 Soil and water conservation works both with the provision of free labor and under the safety net support programme to build community and household assets.

4.3 Reforestation development program through establishment of seedling sites in near by areas and provision of adequate inputs.

5. Gender mainstreaming has been taken as key strategy in the implementation of all sorts of development endeavors.

5.1 Accommodating all female head rural households in the package programme to be full beneficiaries of the support.

5.2 Improving girls' participation at all levels of education.

5.3 Provision of enhanced maternity service to mothers & family planning.

6. Strategy to establish grass roots support under the norm of the social fabric to disabled body, orphans and others social groups.

7. Small scale and micro business development strategies.

7.1 Rendering adequate support to small scale and micro business through proper institutional support.

7.2 Application of the one stop shop service development centers through micro & small business extension.

7.3 Prevision of entrepreneurship training to small and micro business as well as specific skill development support delivery.

7.4 Provision of adequate credit services at reasonable rate.

7.5 Promoting the concept of incubation centers to train adequately & effectively micro-business & let them graduate in multi purpose business management.

8. Urban development strategies

8.1 Ameliorating the urban housing backlog through condominium development.

8.2 Implementing condominium based housing projects through micro-business cooperatives to generate more income and employment to urban unemployed youth.

10. Good governance strategies

   10.1 Designing supports to enhance service delivery at grass root level.

   10.2 Provision of adequately trained man power and designing better working systems.

   10.3 Establishing and further strengthening institutional capability of grass root public bodies for better accountable system.

   10.4 Provision of basic infrastructure like the woreda net and equipment such as computers, scanners etc for effective communication purpose.

2. Major Achievements

2.1 Economy

Overall regional economic performance measured by growth in real GDP has registered 10.07% growth on average annually. Growth in the value added at constant basic prices of 1999/2000 was registered 17.5%, 11.1%, 15.9%, 18.8% in the consecutive years of 2003/04, 2004/05, 2005/06 and 2006/07. The average growth registered during the last four years was 15.8 percent. Similarly, agriculture, industry and service value added growth registered averagely 10.8%, 7.4%, 10.3% respectively. The percentage contribution of these sectors at constant basic prices during the last four years averaged 47.2%, 19.4%, 33.4% respectively.

2.1.1 Agriculture

The contribution of agriculture in terms of employment is estimated to be 80% of the labor force and the sector is mainly dominated by small holder farming households who are with little market orientation. However, since 2003/04-2006/07 consecutively a high growth in crop production, has been registered 27% (2003/04), 14% (2004/05), 38% (2005/06), 13% (2006/07).

According to the 2006/2007 report of the regional bureau of agriculture & rural development, the coverage of irrigation agriculture has tremendously improved to about 30000ha due to the last four years concerted effort and focus made by the regional government. In the year 2007/2008 region wide it was planned to raise the irrigation agriculture to about 40000 hectares. However, compared to the estimated regional potential of irrigable land (300,000 ha) the current utilization rate is very small.

There are quite encouraging changes observed in terms of farm management in the implementation of the house hold based irrigation development strategies. One among which is farmers have used variety seeds, fertilizer, drip technologies, high valued crops. This does show that farmers' market orientation is enhancing with the opportunity of having an access to irrigation infrastructure.

In the rain fed agriculture, small holders land productivity range from 8.5 to 15.8 quintal per

Even in the rain fed agriculture the use of modern agricultural inputs is enhancing with the strengthening of extension service delivery at the grass root level. Each kebelle has at least three extension agents with different specialization and farmers training center to demonstrate new technologies, capabilities and enhance farmers' basic skills in farm management. Apart from this, the growing market responsiveness is enhancing farmers' tendency for taking risks particularly reflected in the utilization of agricultural inputs.

In aggregate terms the regional use of urea and dap has shown tremendous improvement, for example, in the year 2002/03 the total amount distributed to farmers in quintal been 88972 quintals. However, the demand registered for the 2008/09 production year is estimated to be about 280000 quintals. This change has been observed in a situation where by prices of fertilizer are steadily rising.

In the previous years (2003-2005 G.C), besides supporting irrigation development, farmers were provided with agricultural inputs including:

- improved seeds, 27080 quintals
- chemical fertilizers, 81445 quintals

As per the household package program underway effectively since 2004, livestock is one major component. Household farmers are delivered with exotic breed to improve the productivity of livestock products such as meat and milk. Specific attention has also been given to poultry farm management and bee keeping. The use of modern bee hives is one component in the package. Even the strategy of introducing zero grazing at small farmers' level has been considered depending on the potential and farmers inclination in some areas. However more effort has to be exerted to change the traditional livestock management practice with better market oriented exercises.

In the past few years with the household package development support, farmers were provided with exotic breads of cow, oxen, hen, goat, sheep etc… A success has been scored in terms of the small remnant management at household farmers' level. Most of the farming households have started to generates income from livestock fattening and bee keeping. With the positive response of the market for livestock, particularly with the rising price of honey, farmers have shown growing interest to buy modern bee hives. The current demand alone is estimated to be about 48000 modern bee hives. This is a tremendous change in a region were the total stock for modern bee hives was less than 5000 before six to seven years.

All the above developments have aggressively been achieved after the formulation of clear house hold based extension package program. The Extension Intervention Program was designed with the objectives of the MDGs of bringing rural house holds income in line with the one dollar per person target. Some impact assessment results have indicated that, 40 and 65% of the house hold beneficiaries of the 1997 and 1998 E.C have respectively attained the bench mark income. The changes on the accumulated assets and housing conditions also indicated that about 1622 house holds in 1996 E.C. and 1132 HHs in 1997 have increased their mean holdings of sheep, goats, poultry, bee, hives, cows and oxen by protect and rehabilitate the environment

Soil and Water Conservation

Historically, soil and water conservation activities were taken as part of the environmental rehabilitation strategy during the struggle under the TPLF leadership. Consecutively, communities developed their own by laws to contribute free labor for soil and water conservation works for about 20 working days. These by laws are now fully operational through out the region. According to some estimates about 75% of the arable land has been treated with soil and water conservation. Apart from under the support of the productive safety net program special emphasis has been given for environmental rehabilitation works. Hence 25 rural weredas are beneficiaries of the program. Communities and house holds have realized effectively the importance of environmental and household asset building. More concerted effort is required to further strengthen the ability of house holds to with stand moderate shocks. Among the benefits that actually generated in terms of environmental rehabilitation includes that big gullies have turned out to be suitable top soil. Indigenous trees have drastically revived, dried up streams began to stream and the ground water level is improving. For example, in some localities farmers are tapping underground waters with simple hand dug wells. Farmers are cutting and caring bundles of grass as forage to their livestock

The following exemplary figure could help us to understand the extent depth of environmental endeavors that are underway in the regional state.

1. In 2002/03 , 16,578 hectares
2. In 2003/04 52,262 hectares
3. In 2004/05 50,000 hectares

The above mentioned figures are in terms of area enclosure of the rehabilitation of the degraded land in the region. The following seedlings were also planted in the region

1. In 2002/03 , 16 million seedlings
2. In 2003/04 29 million seedlings
3. In 2004/05 31 million seedlings

According to the environmental impact assessment made by scholars in Mekelle University, Tigary has retained its environmental status back to the environmental situation which was 30 years ago. In tangible terms specific areas have changed tremendously their environmental situation which is improving the livelihood of communities reflected in terms of improved grazing land, water source, and forest products.

2.1.2 Urban development

The share of urban population is growing at an increasing rate for quite a number of reasons. However, the livelihoods of the majority urban dwellers largely depend on the informal limited compared to the scale of unemployment problem. Micro and small enterprises are considered to be the basic components in reducing unemployment and alleviating poverty in urban areas both nationally and regionally. In the year 1999 E.C. (2006/2007) with the focus given to small and micro business development coupled with the condominium housing projects about 24782 new jobs were created.

To enhance the development of the informal sector, 46 one stop shop service centers have been opened in all towns in the region. The centers are linked with an extension service delivery where by extension agents are supposed to assess the specific potential and constraints of a micro business and to ultimately support them in business plan development. The service shop, apart from issuing licenses, providing land and link with markets, it develops a sound data base system to broadly support micro businesses.

To ameliorate the growing housing problems of urban areas, a housing development program of constructing 33000 housing units in all urban areas has been launched since 2006/2007. The program is designed as well to curb the urban unemployment problem through establishment of cooperatives that will participate in the housing construction project. In this case encouraging developments can be cited from the 2006/2007 implementation exercise. For the cited year, about 4160 housing units are under construction to be finalized and transfer by the end of June 2008. In the year 2007/2008, about 5000 housing units are to be constructed; already the implementation exercise is underway. By consolidating, the lessons learned from the earlier implementation exercise, the implementation the 2007/08 is to be faster. As both projects are under parallel implementation their contribution to generate employment and income is by far higher.

2.2 Social

2.2.1 Gender issues

As stated in the rural sector, 30% of households are women headed. This itself requires due attention to fight all sorts of stereo types that women face. There are some endeavors made so far to enhance women's participation in the process of poverty alleviation program implementation. For example; in the household based rural package program all women headed households are taken to be beneficiaries. However, rural women constraints are beyond the economic enclave entailing many social and biological components. The same holds true to women living in towns.

So far the regional government has given due attention to improve the condition of women and to speed up their participation in the ongoing development endeavors. In education, women's participation particularly at the primary and junior secondary has an equal share as that of males' participation. In terms of empowerment, women's participation is the regional wereda and kebelle councils is close to 50%.

2.2.2 Health services

The basics strategy under health services is preventive health care with health extension referral to their respective satellite facilities. With the context of the facilities and the respective standards, taking in to account health professionals as well; the current health service coverage is estimated to be 75%.

2.2.2.1 Health Institutions:

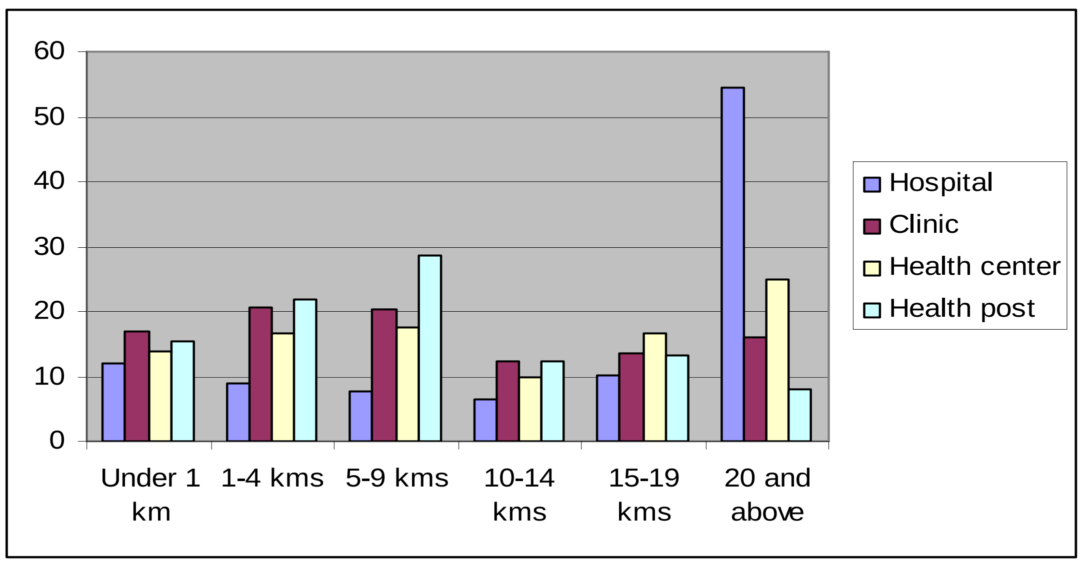
In the budget year of 1999, (2006/2007)

1. 14 of hospitals: 5 zonal hospitals, 7 district hospitals,2 private hospitals
2. 40 Health centers
3. 611Health posts

According to Welfare Monitoring Survey Conducted by CSA in 2004 following is percentage distribution household to nearest health service

Health institution	Under 1 km	1-4 kms	5-9 kms	10-14 kms	15-19 kms	20 and above
Hospital	11.94	8.8	7.84	6.33	10.05	54.34
Clinic	17.04	20.58	20.33	12.39	13.39	15.85
Health center	13.8	16.71	17.49	9.76	16.74	24.86
Health post	15.46	21.89	28.53	12.35	13.1	8.14

As indicated in the table above 50% and 24.86% of the population need travel 20 kms and above to get the service from hospitals and health centers while 20.58% and 21.89% the population need to travel 1-4 km to get services from clinics and health post.

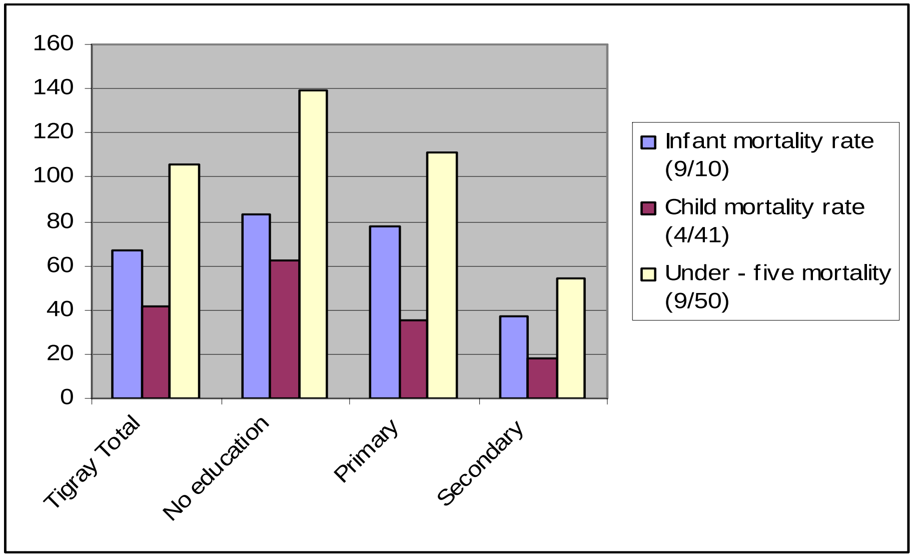


Based on the facilities, personnel and the access parameter considerable improvement in terms of health coverage has been achieved. Apart from this with the strategy of house hold health extension package development remarkable changes in malaria morbidity decline and population.

1. Infant mortality (9/10): the probability of dying between birth and the first birth day.
2. Child mortality (9/41): the probability of dying between exact ages one and five.
3. Under - five mortality (9/50): the probability of dying between birth and the fifth birth day.

	Infant mortality rate (9/10)	Child mortality rate (4/41)	Under - five mortality (9/50)
Tigray Total	67	42	106
No education	83	62	139
Primary	78	35	111
Secondary	37	18	54

Source: Demographic and Health survey, 2005



Mortality declines markedly as mother's education increases. Children born with no education suffered the highest mortality.

As expected, mother's education is inversely related to a child's risk of dying. Under-five mortality among children born to mothers with no education (139 per 1,000 live births) is more than twice that of children born to mothers with secondary and higher level of education (54 per 1,000 live births). The beneficial effect of educating mothers is obvious for all childhood mortality rates.

In the Demographic and health survey of 2000, it was reported, the Infant mortality rate, Child mortality rate, Under-five mortality 103.6, 73, 169 per 1000 respectively. Here we can see that in five years time infant mortality, Child mortality, and Under-five mortality reduced by 76, 31, and 63 per 1000 respectively. This improvement can be attributed to factors such as increment in food production, improving health condition, expansion of facilities deep into the remotest parts of rural areas. During the downfall of the derge regime the regional score was by far the lowest compared to the national average.

As per to the estimate of educational statistics annual abstract prepared by the bureau of education, the growth of gross enrolments rate for primary education indicates an annual compounded growth rate of 3.88%. This has been substantiated by the fact that within five years, i.e., 1990 E.C to 1994 the gross enrolments rate for grade 1-8 rose form 55.86% to 75.24%. Specifically in the year 1993 the gross enrolments rate rose by almost 90%. The 1998 statistics for primary education gross enrolments rate is 99.77% showing 11.3% growth from the previous year. In terms of sex the gross enrolments for girls is 100.01%. Enrolments rate for grade 1-4 for both sexes is 120.09% and 120.09% for girls' enrollment. And the following vital indicators of education show how much attention is given to education by the regional government of Tigray.

Teacher Student Ratio

In the year 2006/2007

1 – 8	940,314 students : 21950 teachers, 1:43
9 – 12	110,440 students : 2527 teachers, 1:43

Gross Enrollment in Formal Education

In 1999,

- **1-4 :-** 621,947 students, average of 126 %: males129 % , 125 % females
- **5-8:-** 318,367 students, average of 77 %: 75 % males and 79% females
- **1-8:-** 940,314 students, average of 104 %: 104% males and 104% females
- **9-10:-** 87,421 students, average of 45%: 50% males and 40.5% for females
- **11-12:-** 20,019 students, average of 10.9 %: 12 % males and 9.5 % females

Net Enrolment of Formal Education

In the budget year of 1999,

- **Grade 1:-** average 85.21 %: 84.9 % males and 85.6% for females
- **1-4:-**average 100 %: 99.7 % males and 100 % for females
- **5-8:-** average 50.63 %: 47.37 % males and 54.01 % for females
- **1-8:-** average 90.5%: 89.07 % males and 91.98 % females
- **9-10:-** average 16.7%: 18 % males and 15.2 % females

2.2.4 Water supply and sanitation

According to 2006/07 report the rural water supply coverage was estimated to be 46% and that of urban areas 64%. The expected coverage of the 2007/08 for rural areas is 56% and for urban areas 70%. Accordingly short, medium and long term intervention has been designed in regard to the major urban areas to maintain water supply from all perspectives.

3. Infrastructure

The estimated regional rural road network for feeder roads is about 1280km. and the to the national grid. With regard to telecommunications services about 46 towns have been automated and many of rural villages are to benefit from the wireless telephone service with the expansion of the broad band

4. Good Governance

Good Governance is typically defined under the terms of accountability, transparency and participation. In line with these principles regional democratic institutions have been built at all levels, for example, the regional, wereda and kebelle councils are established to check the balance of the executive and to address specifically local issues, priorities etc…

The regional government has three tiers of government

- Regional
- Wereda
- Kebelle (Tabia)

Each layer has its own executive, judiciary and legislative body. The wereda exercise their own right by preparing their own plan and allocating their own resources. Budget is allocated to weredas in a block grant and the wereda councils set their priorities.

In the past few years the regional government under the auspices of the good governance package has supported grass root public bodies in terms of system development, technology (information communication technology, wereda net, school net,), personnel training, personnel recruitment, finance, etc…

Effective community-based organizations, such as farmers association, cooperatives, in which Tigray is a model, are improving governance by educating and sensitizing the public about their rights and entitlements under public programs.

To improve governance in urban areas, urban governance package has been implemented. The program entails both institution building and infrastructure development. Among other things under the concept of institution building land management, planning and budgeting, revenue rising, justice and other components are well addressed. Restructuring measures and capacity building have been considered seriously to improve governance.

In a nutshell, both in the rural and urban areas, improved governance is supposed to enhance people's participation at all levels. With the development of various package components, that are implemented at all levels, it has been observed improved participation of communities in school management, construction, water point management, etc…. Moreover, under the umbrella of strengthening social accountability, civil society organizations are becoming more involved in understanding the budget process.

Concluding Remarks

2. To run such house hold based supports in turn requires effective and active participation from the side of the beneficiaries. With the development of various governance packages and capacity building supports to grass root public and civic organs remarkable changes have been achieved. For example farmers who were previously refusing to take heavily subsidized fertilizer under the forced measure are now taking it even at higher market prices. Thus voluntary participation under the auspices of good governance is a mandatory component of development.

3. Apart from the house hold focused support endeavors, growth related development efforts are more to complement to the poverty alleviation strategy. The second Regional Development Plan has properly considered growth based development supports in line with the federal PASDEP. As part of this strategy, the regional government has developed institutional supports for the development of growth corridors both in the south and in the west.

4. The infrastructure development component largely reflected by the development of rural roads, rural electrification, telecommunications services and others have been effective tools in realizing the poverty reduction strategies. All the current wereda centers and all sub-wereda centers are connected to the main road by feeder roads called RR 30. And almost all kebelles are connected to wereda centers by community roads.

5. The human resource development component has been taken as part and parcel of achieving both objectives of poverty eradication and growth. In line with this education and health have been given top priority. The scored achievements in terms of food security are well supported by the success of education and health.

6. These successes could be more sustainable with full involvement of all stake holders and their concerted effort. The role of the government should be complemented properly. In the past development years many of our development partners support was complementary. It is for this reason that the achievements were effectively realized.

7. Appreciating the endeavors, there are significant development components still demanding special attention and focus. For example, improving quality of education and health services.

8. Building capacities at all levels remains to be important development component for the coming years. All level public organs luck proper implementation capacities in all aspects. This needs special attention and further strengthening.

9. The gap in infrastructure and delivery of basic services such as potable water supply to both rural and urban areas requires potential resources as reflected in the federal PASDEP and in the Regional Development Plan. Here as well concerted support from donors remains to be one of the vital sources.

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land management (SLM) practices and rural development in Tigray

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Introduction

As it is commonly said land degradation is a severe problem in the densely populated highlands of Ethiopia. This is caused as a result of soil erosion from cultivation on steeply sloping terrain, mining of soil fertility due to continuous cultivation with limited application of inorganic or organic sources of soil nutrients, and deforestation and overgrazing of rangelands. This in turn has contributed to chronic poverty and drought problems in the country.

In view of this, the country has considered eradicating this widespread land degradation problem and ensures the sustainable livelihood and the environmental safety of its people.

Many literatures and studies have defined sustainable land management as the management of the land without damaging ecological processes or reducing biological diversity. It requires the maintenance of the following key components of the environment:

1. biodiversity: the variety of species, populations, habitats and ecosystems;
2. ecological integrity: the general health and resilience of natural life-support systems, including their ability to assimilate wastes and withstand stresses such as climate change and ozone depletion; and
3. natural capital: the stock of productive soil, fresh water, forests, clean air, ocean, and other renewable resources that underpin the survival, health and prosperity of human communities.

Land is often managed for multiple benefits, such as agricultural production, biodiversity conservation, water quality, soil health and supporting human life. To ensure long-term sustainability, land managers need to consider economic, social and environmental factors.

Overview of the Region

The region land use system has been mainly traditional - i.e. free grazing and fuel wood collection, extended cultivation - including steep lands, and slash cultivation is still very common - especially to the western part of the region are seen to be the common practices. Similarly the farming system and practices is mainly:

a. Cereal dominated crop production
b. Low input support and low soil fertility management

Thus, comprehensive program of implementation is designed that includes among others,

- Community based integrated watershed management
- Farmland forestry
- Farm land conservation - involving the community and the individual holders
- Area closure management - with definitive ownership and the utilization?
- Water harvesting - both household level and the community level practices
- State forest management
- Hillside and gully management through distribution
- Peri-urban plantation
- Community forest/ reforestation, etc

Which, all are involving a multiple of technologies and innovation.

SLM practices: the role for rural development

Strategies and approaches to up-scale SLM in Tigray

Different strategies are being used to scale up and out SLM/NRM in the region. These include:

- Participatory approach- involving all stakeholders from the outset
- Integrated approach- both institutional and discipline wise
- Encouraging local knowledge and/ but also linking to standardized technical measure or modules
- The WFP/MERET - CBIWSM guideline, GTZ SUN project management module, etc.
- Forestry management guidelines developed
- Experimenting new technologies at pilot level (watershed focused)
- Identifying and establishing system of scaling up/out for any good success story – a very recent development as initiated through the cooperation of IPMS/ILRI
- Ensuring effective follow up support and the monitoring system-regular reports, Subject Mater Specialist (SMS) field assessment, etc.

The region, through mobilizing its community and good support by the donor groups (MERET-WFP, GTZ SUN, Irish support, REST, etc) has managed to carry out some important land and natural resources management programs. This programs and activities include:

1. Farmland SWC conservation

Over the last one decade or so, the region has managed to cover (over 805368 ha, 79%) of the cultivated areas using different SWC measures - through mobilizing the farming

7.1 million quintals (1996/97E.C.) and 17.1 million quintals (1999/2000E.C.)

- The study has also indicated there is high deviation (only 33% effective) in the technical standards - foundation, height & width of bunds, the compaction, etc.
- Some 37% (296689 ha) of the physically treated farm lands (e g., The plateau from L/Maichew to Medebay Zana is a good example) are also covered by different kind of biological technologies (fruit trees, fodder shrubs, and grasses) and hence contributing, much to the livelihood of the rural community and the agroecologcial change.

2. Watershed management

The science has been there as an agenda for the last two decades in the region as well in the country. However, a special attention was only given - both by the government and the bureau during the last three to four years. Thus, a net area of about 352,924ha (6.8% of the region) is defined as area of IWSM and covered adequately with the different SWC measures.

3. Agro-forestry management

Traditional agro-forestry

Despite the years of malpractice and the deforestation, a good traditional forestry management has been initially observed in the Zonghui (Maikinetal) area and through the extensive extension support this was made to scale out to other areas too. By today, this has come to be the common practice to most of the woredas, but also very common mainly in the central zone and the eastern zone woredas.

Modem agro-forestry in practice

On the other hand, in view of realizing substantive modem forestry establishment in the region, an average of 50 million seedlings were annually raised and planted using the different strategies. Below are some of the strategies the rigreon follow to scale-up and cale out this practice:

Homestead agro-forestry management - using ponds and tankers

These days a good number of the farmers in the region are practicing some kind of tree crop management especially in their homestead. 'There are some who have managed to plant up to 3000 seedlings.

Farmstead agro-forestry

This practice has become very common in most of the areas with good water harvesting practices. On the other hand, efforts are also being made to plant fodder crops along terraces in farmlands, institutionalize the traditional grazing land practice in the Eastern Zone, and the hillsides management practices (distributing the hillsides to individual farmers for managing it using any kind of tree crop system). This practice is also expanding from time to time with the support of GTZ - SUN Tigray and other projects. The result is enourgaing.

4. Public/ State forest management

There is about 171, 275 ha Natural forest priority areas (Hugumberda Grat Kahsu state forest 21,654ha, Dese-a state forest - 118,635ha, and Hirmi - 30,987ha of which about 10% is cultivated area). A management plan for all the state forests and the wildlife reserve has been prepared well over a decade ago. However, no good effort is made yet to implement the package (standard) mairily due to budgetary reasons. As an alternative the region is considereing establishing enterprises and the joint forest management.

Moreover, the region is also endowed with good potential woodland (especially incense and gum trees) in 5 woredas, namely Kafta Humera, Wolkayiet, Tahtai Adiabo, Asgede Tsimbla and Tselemti. Thses areas covera total more than one million hectares. In view of ensuring the sustainable management and utilization of this potential, an implementation modality and guideline is developed in 1993 EC, which some how is on the process of implementation. There is also one potential wildlife reserve/park area - Sheraro Kafta - covering about 150,000 hectares. The federal has appreciated the effort and the status of park. Effort is being started to get the parak recognized by by the IUCN. Efforts are also ongoing to build the community awareness and sensitization in view of reducing agricultural encroachment, forest clearing and forest fire protection.

As this resource is believed to have a good potential for the ecotourism purpose, mechanisms are being devised to incorporate it as part of the livelihood support systems in the region - through project design for controlled hunting, tour operators (with collaboration to the tourism commission), and live trading.

5. Area closure

A good effort is made in the closure areas management. Up to now quite a good investment is made in this area covering over 224,000 ha. However, the over all effect and benefit is found to be very encouraging especially compared to the effort put on mainly when we see there is still poor ownership and the utilization system. However, recently good changes are seen in the use and management of these resources through the apicultural practices and the cut and carry practice for animal feed. In support of this initiative the Bureau of Agriculture is also now developing management and utility guideline for area closure and community forest.

6. Community forest management

- Reforestation of over 112,000ha is found to have adequately covered as a result of the continued efforts in plantation.
- There are some good signs developed these days in using it for apicultural practice, cactus management, etc.

7. Private commercial forest

Alaje forestry development enterprise (18,006ha)

Generally there is good potential for involving investors - at least in the geographic and agro-ecologic context. But the problems are:

- Traditional land use practice is pervasive,
- Poor social attitudes towards private investment, and
- Limited or no administrative and political measures taken to overcome this problem.

8. Water harvesting

Moisture is assumed to be the number one problem in the production and the productivity factor of the region (SAERT, 1996). Thus, a serious attention is given by the region to the introduction and implementation of number of technologies (micro-dams, diversions, spring development, micro-ponds, community ponds, surface and under ground water tankers, dugout ponds, deep trenches, etc,) and practiced in the field. In view of this, during the last four to five years, more than 90,000 small ponds are constructed (physically completed) and about 51,000 of these small ponds are funcational - for irrigation and livestock watering. An encouraging effort is also being made in the development of shallow well, surface and underground water tankers, spring developments, etc.

9. Zero grazing practice

This has started at pilot level in 2004. It is also commonly practiced in some tabias of the region.

Challenges and Constraints Encountered

a. Geophysical challenges

- Ragged and undulating topography - adding up to the challenge of management and aggravating soil erosion
- Geology (Shallow earth/soils) - poor soil water retention capacity
- Location: influence of the Sahara desert and costal aridity, are just few to mention.

b. Technical and technolocal gaps

- There is critical shortage in the biological technologies - fruits, fodder and forage and the forestry - as resulted from the poor research support.
- Inadequate system and capacity of identifying appropriate technologies and the management,
- Limited capacity in envisaging new ideas, and the improvisation,
- Limited effort and the commitment to enforce technical standards in the practices of the community - i.e., expertise support in the,

- In the fodder production and range land management
- Use of water harvesting activities - ponds; etc.
- Poor effort and the capacity of designing exit mechanism for any successful story of the NRM programs - such like Gergera watershed

c. Human resource capacity: staff, know how, skill and commitment

I. The region had experienced a very serious man power and the skill shortage for up to the very recent time (1999 E.C.)

II. Limited exposure and experience in the technical staff

III. Poor understanding and or appreciation of the different NRM strategies by these experts and the local administration

   a. Poor implementation of the strategy for using the common resources (safety net and the SWC mobilization force) for community asset building:- the case of Dugum

   b. Poor implementation of the hillside management strategy- the case of tabia Atsela

d. Socio-economic challenges

- Poor economic power - both the government and the farming community
- Declining trend in donor support
- High restrictions on the financial systems
- Difficulty to introduce different supporting mechanisms such as the seedling pricing, forestry fund, etc.
- Serious landlessness problem
- The urge for clearing area closures and reforestation areas for cultivation is increasing - Hintalo Wajerat, Enda Mehoni, etc.
- Push for interring the state forests (Higumberda Grat Kahsu, etc.)

e. Political administrative and institutional issues

"Policy is a statement of intent to achieve a desired outcome, (but) unless it can be translated into action, it remains merely opinion." Policy therefore embodies both plans and their implementation with the aim of bringing about positive changes within society (Katerene, Jan. 1991).

- Absence of land use and forestry policy - the policy is not clearly defined and lacks the enforcement.
   a. Encouraged continuous abuse in the land management- gully side farming, destroying bunds established, etc
   b. No good offence in the encroachment to new areas (wet land, forest)
- Lack of ownership in the communal lands and Trees

a. In-effective implementation of the established legislations, guidelines/or directives, community by laws, etc.
b. Often lacks the timely and firm decisions - implementing the land distribution in the case of Boswellia land, effecting the forestry law, etc.
c. Poor sense of understanding to the intent of the law and the capacity of implementation
d. There is high push for any kind of false reason and excuse (specially the justice people) - that the farmers are poor and there is also cultural barrier,

Commonly observed counter productive 'actions

- Objections for the effecting of forestry check points (SZ, 2004)
- Some suggests the tree cutting should be controlled at the spot level

f. Social and cultural problems

- Traditional land use and the natural resources management
- Free grazing and animal movement - including crop aftermaths
- Free collection of forest products and construction material (fuel wood, sand,
- stone, etc) which often leads to: serious soil and land degradation
- Rest staff contributing to fuel wood illegal trafficking
- Fuel wood smuggling in Tahtai Maichew and the surrounding by camels
- The case of Mekele is quite astonishing and an open secret to everybody.
- Fuel wood smuggling around Mekele by donkeys, carts, pick ups and medium trucks (ISUZU).

g. Social awareness and knowledge base

- Poor awareness and knowledge base -,at all level of the society.
- Poor working culture - high reluctance for any good initiation, new technologies, etc. given through the extension 'service
- High dependency syndrome - as a result of the continued aid support
- Impacts often lack deep rooting and the continuity - there is frequent observation for going back
- 0 The case of Aiba grazing land management, earth back filling of completed ponds in Alaje, Raya and S.Samre, and converting area closures and reforestation areas into farming land (H. Wajerat, E. Mehoni), etc.
- There is frequent abuse of technologies - even proven successful
- Sales of pond plastic, fertilizer, cement, bee hive, etc.
- Breaking dam for any simple case in Enderta,
- Cultivating rehabilitated gully sides (Abreha Weatsbeha)

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Water Conservation (SWC) Program in Tigray: Processes, Technology Packages and Approach

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Abstract

Soil erosion, water quality deterioration, declining productivity of agricultural lands are very serious aspects of the environmental degradation in Ethiopia. Hence, conserving soil and water and using the land in a sustainable way should be the concern of everybody. Particularly in Tigray's context where land degradation is severe, rainfall is highly erratic, and drought is a recurring phenomenon, the issues of soil conservation, water harvesting, and environmental rehabilitation should receive high priority. In this regard massive public soil and water conservation activities have been underway in Tigray, since the late 1980s. By way of reviewing conservation extension in Ethiopia, this paper assesses and documents experiences of the people based or public soil and water conservation program in Tigray. Specifically, three dimensions of the experiences are considered: the processes involved the technology packages of the program, as well as the issue of individual versus group approach.

Keywords: public SWC program, processes, technology packages, approach
JLE *classification*: Q2; Q24; Q25

1. Introduction

Since their very existence human beings have been dependent on nature for their livelihoods. In order to satisfy their basic needs, i.e., food, clothing, and shelter so as to survive, they have been interacting with nature. During the early days of hunting and gathering, there was a considerable harmony between human beings and the environment. Through course of time, however, the relationship gradually lost its harmony and it became more exploitative than could be offset by the natural rate of regeneration. Wright has clearly described that the situation (harmony) changed drastically with the start of domestication and settled way of life. That is, when the human race discovered ways to plant and harvest some of their preferred food crops in one favorable location (Wright, 1984). This, then eventually resulted in interruptions to the natural processes. Land degradation, desertification, drought recurrence, etc are all the outcomes of the disturbances to the natural processes due to the prolonged unwise interference of human beings with the natural environment.

Likewise, in Ethiopia, soil erosion, water quality deterioration, declining productivity of agricultural lands are very serious aspects of the environmental degradation. Hence, negligible. With the collapse of the former (Derg) regime and the adoption of the Interim Charter, however, major shifts have come both in policy and emphasis. Since then, considerable efforts have been made to minimize the problem (hazards) of erosion, increase agricultural productivity, and to rehabilitate the degraded environment in the region.

By way of reviewing conservation extension in Ethiopia, this paper assesses and documents experiences of the people based or public soil and water conservation program in Tigray. The specific objectives are: one, to assess the public soil and water conservation program in Tigray and draw some important lessons; two, evaluate the current approach to soil and water conservation in the region and suggest on further courses of action. The assessment is based on key informant interviews and group discussions. That is, both primary and secondary information relevant to the topics of interest were collected. Assessment/data covered twelve woredas and two tabias were selected from each woreda for field observations and interviews. Questionnaire was developed and informants were purposely identified to generate the necessary primary information. Semi-structured interviewing technique was used and a group of 5 to 6 farmers were consulted at each *tabia*[1]. Group discussions were also held at each woreda with the *Baitos* (executive body) to verify data collected at *tabia* level and generate additional information on various issues.

The paper is organized as follows. In the next section, we begin with conservation extension in Ethiopia, the processes in the people based soil and water conservation program is presented in section 3. Then, in section 4, we present the technology packages. In section 5, the approaches, and then section 6 concludes.

2. Conservation Extension in Ethiopia

2.1. Country perspective

Three periods are quite discernible as regards to conservation extension in Ethiopia, i.e., pre-1968, between 1968 and 1991, and post-1991. It is reminded that 1968 was a year underlying a relative change in emphasis both to agriculture, in general, as well as to conservation, in particular. Before the year 1968 agriculture received no attention. It was after 1968, i.e., in the third five year plan, that the agriculture sector got due consideration (Nickola, 1988; Tatto, 1993). Although it can be regarded as a start, agriculture extension during the pre-1968 period was very limited and so fragmented. For example, in the 1950s the very limited agricultural extension activities were handled by the academic institutions such as Alemaya College of Agriculture, Jimma and Ambo Schools of Agriculture, as part of the program for which they were initiated. Later on, in 1960 the mandate of agricultural extension service was handed over to the Ministry of Agriculture. Although the Ministry of Agriculture was there even before 1960, it was focusing on establishments of modem crop, livestock and poultry farm by government and individuals. With the transfer of mandate, the extension activities of the Ministry were focusing on organizing youth clubs in schools and educating the members about horticulture, poultry production etc (Tesfai et.al, 1996). However, in all cases, besides their inherent weaknesses in terms of lacking a well conceived national program, etc, nothing can be said to have been done with respect to soil and water

During the period 1968-1991, the agriculture sector has undergone several rearrangements. And so does agricultural extension. In the time due attention was given to agriculture sector in the third five year plan (1968-73) two main strategies were outlined to develop the sector. One, establishment of large scale commercial farms, with respect to achieving rapid results particularly in industrial & export crops production. Two, comprehensive package approach was the strategy opted with regard to development of the peasant agriculture (Stahl, 1974; Nickola, 1988). Within the framework of the comprehensive package approach, projects were initiated amongst which were CADU (Chilalo Agricultural Development Unit latter ARDU) and the WADD (Wellaita Agriculture Development Unit). In addition to some research works, the main purpose of these comprehensive package projects was promotion of the adoption process of the allegedly relevant technologies through the provision of extension credit and marketing services.

At the time of designing the comprehensive package projects, the intention was to reach out the entire farming population of the country through the expansion of similar approach. But later on it came to be clear that it would be very costly from both financial and manpower grounds to replicate the approach allover the country. Thus, an alternatives strategy, that is, the Minimum Package Project, was designed & launched in 1971 so as to reach a large number of farmers with a relatively minimum cost. It was also followed by another Minimum Package Project (MPP-II) effected in 1978-1982. The minimum package project, were said to have reached larger number of farmers with some form of extension as compared to the 'Comprehensive Package Projects' (Nickola, 1988). However, besides their structural weakness, differences in approach, and the limited results achieved in terms of technology transfer as well as changing the livelihoods of poor farmers; nothing was embodied in both the comprehensive and minimum package projects as regards soil and water conservation.

The other attempt next to the comprehensive and minimum package project was the Peasant Agriculture Development and Extension Project known by the abbreviation PADEP. The country was divided into eight agricultural development zones for the purpose of PADEP. Having learnt from the weaknesses of the previous intervention development agents (DAs) were already assigned below Woreda at service co-operatives (SCs) level. The Training and Visit (T and V) system was the extension approach adopted. Three years (1986\87-1988\89) strategy of food self sufficiency was also designed within the framework of PADEP. The so called high potential woredas were the focal points of PADEP. The manpower support (deployment) as well as input provision was also geared towards these Woredas (Nickola, 1988; Tesfai et al., 1996). Towards the end of MPP-II and the beginning of PADEP soil and water conservation as a function was already institutionalized in the structure of the Ministry of Agriculture up to the provincial and, to some extent, *Awraja* (district) levels. By September 1986 about 500,000 ha of farmland and 175,000 ha of hillsides were reported to have been treated with conservation bunds (soil and stone) and terraces (Nickola, 1988). However, little has been done in terms of conservation extension and all these achievements were the results of the food for work (FFW) programs rather than mere extension.

In the aftermath of the civil war, i.e, in the post -1991, however, significant shifts have come in many of the policy respects. The previously neglected cultural, linguistic and ethnic been drafted wherein soil and water conservation and land husbandry are well emphasized (NCSS, 1994) and there is the Environmental Protection Authority which was non existent in the former regimes.

2.2 Region perspective

It has been indicated that the period before 1968 was characterized by the total absence of attention to agriculture. Except for its provision/supply of food through the traditional technique of production, no technical support was given to agriculture. And neither did to land management and improvement. By and large, nothing was also known about extension during this period as far as the region- Tigray is concerned. However, so far as the problem of land degradation (erosion) was there, indigenous attempts were taking place to combat the problem. These indigenous (traditional) conservation techniques varied in approaches from mechanical (ethno- engineering) to biological (agronomic) practices. All these techniques were also developed in the interaction of people with their environment (Gebreegziabher, 1997).

As a consequence of what was happening at country level, both the comprehensive and minimum package approaches were also attempted in Tigray in the 1970s. Tahtay Adyabo & Hadegti Agricultural Development Unit abbreviated as TAHADU was the comprehensive package project that was attempted in Tigray. It was initiated to give relief to the population pressure on the highlands of the region by resettling them in the lowland as well as by giving land to the shifting cultivators in the lowlands. It was also undertaking activities such as organizing farmers into peasant associations (PAs) and provision of ox, seeds and implements on credit basis so as to boost up production. Demonstrations were also held on improved crop and livestock production practices. For instance, rotational grazing system was said to be demonstrated during that time (Gebreegziabher, 1997). Hadegti (Sherraro) and Tahtay Adyabo (Bademe) areas of the former Shire *Awraja* were the focus areas of TAHADU.

On the other hand by the virtue that they are along all weather road the Awrajas such as Adwa, Axum etc.. were also "Minimum Package Project" (MPP)- areas. As a result demonstrations which were more of agronomy were taking place in these areas since 1970. Some conservation activities were also taking place on hillsides and to some extent arable lands dominantly on food for work basis during the 1970s. TAHADU seems to have involved some elements of conservation. For instance, it have had a section for land use planning. The practice of rotational grazing also looks to embody the concern for environment protection. However, it was not as such well articulated and directed towards that end. Hence, in both the comprehensive as well as the minimum package attempts, little can be said to have been done with respect to conservation extension (Gebreegziabher, 1997).

The other important experience as far as agricultural extension in Tigray is considered was that of TPLF[2] which was being undertaken from 1980 onwards. Before the fall of Derg regime agricultural extension services were been provided to farmers in the liberated areas of Tigray by the TPLF Department of Agriculture. But, the extension package was dominantly reliant (based) on local knowledge's and resources. That is, it was mainly environmental awareness and minimizing further degradation of the natural resources by carrying out massive soil and water conservation and reforestation activities through mass mobilization was one of the objectives of the extension service.

In Tigray too, the concerns about the environment have increased after the fall of the Derg regime, i.e., in the post-1991 period. For instance, a symposium on the theme 'Combating Environmental Degradation in Tigray', which involved 51 institutions and about 170 people was held in Mekelle in April 1992 (Hurni and Perich 1992). In the symposium, enhancing soil and water conservation was emphasized as the most important way out or option for rural development in the region. The region has also recently formulated its own regional conservation strategy so as to sustainably use its natural, human, and cultural resources as well as to rehabilitate the degraded environment (RECC, 1996). During the transition period soil and water conservation activities were been handled by the separate institution, Tigray Region Bureau of Natural Resources Development and Environmental protection. Then, it came to be merged with the Bureau of Agriculture since July 1995 and named as Tigray Region Bureau of Agriculture and Natural Resources (BoANRs) (Gebreegziabher, 1997). Currently, the responsibility of conservation extension is under the Bureau of Agriculture and Rural Development.

3. Processes

3.1 Pre-planning phase

The on going people based soil and water conservation program in Tigray involves four different phases (processes) of which the pre-planning (pre-preparatory) phase is the first one. The tasks or activities undertaken within this particular phase are preparing training manual and giving training and orientation to woreda SWC technicians and development agents; strengthening of grassroots level institutions; and screening of production cadres(contact farmers). The grassroots institutions' commissioned for soil and water conservation include *baito* (executive body) members; contact farmers; representative of women, youth, and farmers associations; and the extension agent for the area. Hence, in view of the evaluation results of the achievements of the past year and observation of the current situation, the strengthening of grassroots institutions includes identifying constraints, absentee, less efficient, etc. members and replacing them by new or better ones. The screening of production cadres (contact farmers) also involves identifying missing or less efficient ones and advising them or replacing them by better ones.

3.2 Planning (preparatory) phase

It is the second phase in the process. It is also the phase where the actual conservation planning and preparatory jobs are performed. The activities that are expected to be accomplished in this phase are assessment of treated and untreated land area; conservation tools assessment; assessment of potentially active human power; training of contact farmers\technicians or markers and preparing the plan for the year as well as presenting it (the plan) at the village gathering. The assessment of treated and untreated land area sense that it gives a clue about the size of. the treated and untreated (area that needs treatment) for planning purposes as well as about the type of conservation techniques that may be possibly needed/recommended for the area under consideration.

Conservation tools assessment is important to identify (know) tools at hand from those lost or broken ones and in order to look for the (means) mechanisms of bridging the gap (balance) between the needed vis-à-vis the available ones. The assessment of human power is also important to arrive at the potential participants for the year. In this respect, care are often taken to replace members due to old age, health problem, pregnancy, etc. In addition, each of the respective grassroots level associations (Women, Youth & Farmers) undertake their own human power assessment. It also involves. the grouping or assigning of the potentially available human power into different work groups.

Then, by bringing together (integrating) the three assessments, that is, land, tools (material) and human power, the soil and water conservation plan for the year is developed (formulated). The plan is presented to the village (*kuhset*) gatherings (assembly) so that it can be commented upon, approved or even rejected. The plans are also reviewed at *tabia* as well as woreda council levels. Except for the problems of illiteracy at the grassroots level and occasional participation problem, preparations of soil and water conservation plans mostly follow the bottom-up perspective. Conservation plans may also mainly constitute maintenance work in cases of special conditions.

3.3 Implementation phase

It is the phase where soil and water conservation plans are translated in to action. It is a phase where people are mobilized and actual conservation works are performed. It includes marking (surveying) of the whole area planned to be treated in the year, distributing (handing) it to the various work groups formed based on piece rates, and undertaking the conservation work of the recommended conservation techniques. Surveying or marking of the area to be treated is carried out by farmers trained for the purpose. And the job of the production cadre (contact farmer) is to follow-up of the activities of the work groups and verifying whether the different conservation techniques are being made as per the recommended dimensions, quality, and quantity (as per norm).

The people based soil and water conservation program in the region also embodies evaluation (follow-up) in all its levels (phases). However, more emphatically, monitoring and evaluation is an important and integral part of the implementation phase. Activities and progress achieved are evaluated at work group, *kushet* and *tabia* levels- daily, weekly and fortnightly, respectively.

3.4 Finalization phase

Finalization phase is the formal (completion) phase in the process. It is the phase where formal winding up of the soil and water conservation activities of the year is carried out. It includes ranking of different *tabias*, *kushets*, work groups, as well as individuals with worthy achievements and awarding of the high ranking ones with different type of incentives. The ranking performance for the year. Incentives such as blankets were given to individual farmers while tools such as axe and hoe are given to the work groups. But, in central Tigray, the incentives given were found to remain at *tabia* and contact farmers level. The reason behind seems to be the belief that motivating the leaders (group) will sufficiently induce motivation of the group members. The woreda administration together with *tabia baito* makes the ranking of the *tabias* and high ranking *tabias* are awarded with certificates. In Sahartee Samre Weoreda, southern Tigray, once the rankings are done, the incentives given were found to be purely moral. That is, acknowledgements and words of praise are given to the high ranking *tabias*, *kushets* as well as work groups. And the reason for doing so was found to be that even the ranking into top, middle, and low performers by itself has an important moral implication in the culture of the people. Hence, the ranking by itself was said to be sufficient to induce the spirit of competition among communities, groups and individuals.

4. Technology Packages

4.1. Physical measures

As it might be obvious, the technological packages that can be delivered to farmers as regard to soil and water conservation are mechanical (physical) and/or biological. Hence, although it seemed to have been largely dominated by physical structures initially, the treatment (conservation) measures (elements) included in the program, be it for cultivated or uncultivated land, are usually grouped into two broad categories as 'physical' (mechanical) and 'biological' measures. Included within the 'physical' measures are the level soil and stone bunds, in the case of cultivated land. In the case of uncultivated lands the physical conservation measures recommended (practiced) are hillside terraces, trench bunds, check dams, micro basins, etc (Gebre-Michael, 1996). Moreover, nowadays very important technologies are deep trenches, percolation ponds, and stone faced trenches. Check dams and sediment storage (SS) dams are used in the treatment of gullies, while the micro-basin are dominantly practised in the plantation sites. The SS dam is a recently introduced technology and built with concretes. The idea is that farmers can take away the fertile soil sediment stored in the SS dam for use on their field and the water stored for irrigation. The booklet entitled 'Soil and Water Conservation for Woreda Technicians', which was published in Tigrigna by TPLF (1980E.C.) also recommends that when deemed necessary cut-off drains can be used in natural grazing lands, for removal of excess run-off, in order to assure its safety and protect it from being damaged (eroded) by flood (TPLF, 1980 E.C).

Informants interviewed in Tabia Selam of Hawzien woreda, eastern Tigray, have also indicated that an attempt was made to introduce *Fanya Juu* type of terrace around their areas. But it got abandoned as it was rejected by farmers, not only, due to the wider space it consumes or wider- base it needs relative to the other narrow-based terraces in the package, but also, due to the high amount of labor it demands; a case similar to what has happened at the early stage of introducing soil and water conservation in Machakos district, Kenya (Tiffen *et al*., 1994).

way of conserving soil and water has been very limited, it is getting momentum in the region. However, perhaps needless to mention that it is the integration of these two measures that will change the area into productive land. The technical recommendations or treatment elements so far included within the category of biological measures as far as the region is concerned are: planting drought tolerant plants such as *Sisal* spp, *Euphorbia* spp, cactus, etc[3]; planting elephant grass; composting; and manure application. The indigenous conservation practice of leaving un-ploughed strips at intervals in the cultivated fields is also considered as one element of the biological measures. It is also known as 'grass strip' (Gebre-Michael, 1996). The above mentioned drought tolerant plants seem to be the most publicized biological measures. These drought tolerant plants are also recommended to be used as fences as well as in the treatment of gullies. Area closure has also been another component (element) of the biological package (Gebre-Michael, 1996). The SWC handbook entitled 'Soil and Water Conservation to Woreda Technicians' has also well emphasized 'area closure' as an important treatment or conservation technique to recuperate the completely degraded lands in the region. In addition, although it has hardly appeared in the reports, trash line was also one of the recommended techniques of biological conservation (TPLF 1980 E.C). And since very recently there are attempts of introducing grass sowing on conservation (soil) bunds. It is obvious that the agronomic (cultural) measures (practices) are part of the group of "biological" measures. But more importantly, some studies reveal that the agronomic practices: crop rotation, contour ploughing, inter cropping, etc., are common traditions in the region (TPLF, 1980 E.C.; Gebre-Michael, 1996). However, the agronomic practices seem to be the least emphasized (overlooked) in the package despite their prevalence as indigenous practices.

On the other hand, inappropriate tillage was described by most of the respondents as one of the causes for the land degradation (erosion) problem in the region. Biological measures would also include agro-forestry practices. From the seedlings annually raised in the forestry nurseries 5% were reported to be used for agro-forestry purposes. The species most commonly recommended in this regard were *Sesbania* and *Luceana* irrespective of verifying whether they are appropriate to the situations in Tigray. And the intention was to plant these spp. on conservation bunds. However it has not been effective in getting integrated with the soil and water conservation. Except for the recent attempts of planting local spp. such as *Olia europeae* on conservation structures (in cultivated land) in the project areas identified for organically based farming, the least has been done to include local or indigenous spp. in the packages.

Flexibility is an important measure (criterion) for the quality of development interventions. Rural development intervention in the past have been blamed for their rigidities and for their blanket, i.e., across the boarder, type of recommendations which failed to consider or fit into the diversity of local situations. Hence, they turned out to be counter productive (Reij, 1991). Thus, an attempt was made to look into the extent to which the public SWC program was flexible to adjust to the diversity of local situations existing in the rural setting of the region on the basis personal judgments upon the field observation as well as interviews or discussions with key informants. Hence, the program was found to have certain degree of flexibility to respond to the specific local situations in the different parts of the region. For activities are undertaken, people in these area usually work on the maintenance of the traditional water harvest systems '*maegel*' and '*felleg*'. Similarly, in Erob woreda- eastern Tigray- land allocations were made for individuals interested to make the indigenous conservation practice of the area, i.e., '*daldal*' on the communal wastelands. That is, by making bench terrace in the hilly areas '*daldal*' enables to reclaim or create additional land for cultivation.

5. Individual versus Group Approach

Since the period of TPLF until now public soil and water conservation activities in Tigray are largely being carried out on group basis or group approach, through mass mobilization. Nonetheless, diversity of opinion are forwarded as regards to the sustainability of the 'group approach' given the extent of the land degradation (erosion) problem to be redressed in the region. Whereas the 'individual approach' is seen as a possible alternative approach particularly as regards to conservation of cultivated lands, the 'group approach' remains to be the sole option as regards to conservation of the vast uncultivated land. In view of these facts an attempt was made to include the issue in the enquiry in order to assess as to which approach 'individual' versus 'group' is better according to the understanding or experience and judgment of farmers. Moreover, it would also be of interest to bring into light the practical strengths and weaknesses of each approach and to get broader perspectives of the issue.

Among the strengths of the 'group approach' are: (i) the convenience it has in guiding and monitoring SWC activities; (ii) its inclusivity, i.e., the convenience it has to include or take care of land that of the weaker ones due to old age, health, etc; (iii) soil and water conservation by nature entails group work or approach in the sense that however a farmer conserves or treats all his/her holdings including those outside the backyard, but it can never be sustained unless, otherwise, his neighboring farmers upstream simultaneously treat their fields or holdings; (iv) the opportunities it gives to carry out activities that can not be imagined to be undertaken individually; (v) for people are not equally endowed with knowledge and abilities of doing something, it has good qualities in integrating or pooling together the knowledge and abilities or skill of different individuals; and (vi) the greater target achievement, i.e., in quantitative terms, it has an important quality of covering wider area within a short period of time. The main issues mentioned on the weakness side of this approach include: (i) that most of the workload falls upon few hardworking (devoted) individuals; (ii) lower work efficiency, somebody seating others standing while some are working, looking for each other not to work, etc; (iii) lower work quality; and (iv) its drawbacks in sustainability and in integrating water/moisture conservation into the farming system.

Among the strengths of the 'individual approach' are: (i) higher work quality, that is, there is greater sense of ownership and, hence, higher quality in building the conservation structures; (ii) greater sustainability, i.e., since the individual has committed resources on it, necessary precautions and even maintenance jobs are taken care of by the individual, (iii) the convenience it has in integrating soil and water conservation activities as part of the farming

That is, it is obvious that there is a trade off between work quality and quantity or volume achievement. Hence, it was mentioned that the individual or private approach does not enable to cover or treat wider area of land within short period of time, mainly, for everybody will be concerned on the quality.

A very interesting argument discovered in the course of the survey, forwarded by women respondents, was the idea that the 'individual (private) approach' would have been better than the 'group approach' could most likely have a gender connotation. They argued that such a view could possibly originate or emanate from gentlemen who do not like to see their wives involving in community and development affairs, who undermine the role of women in intra-as well as supra- household matters, or even those whom the issue of the weaker members of the community is none of their business.

Still, within the context of 'group approach' "there are also strands of views from the farmers side which revolve around the way how the work groups should be organized. For example, there is a view which suggests what if the work group formation is left for a voluntary pairing with anybody you would like to pair, which is traditionally called as '*lefintee*'? On the other hand, there is also another view which says what if the group formation is made on family basis? Having these issues in mind, it has also been tried to look into or assess whether or not these are plausible options. Nonetheless, although the traditional '*lefinttee*' way of forming work groups (i.e., pairing with who ever you like) could be envisaged to have an important merit particularly with respect to work quality, probably in an extent not lesser than that of the 'individual (private) approach', it was found to have got potential limitations. Firstly, it has the probability of going or pairing with persons beyond the watershed, that is, outside the *kushet* and *tabia* boundaries. That is, it entails difficulties in implementing a given watershed management plan, for they won't face or share the problem equally. Secondly, for the pairing is based on the anticipation of equivalent labor exchanges among the members, it is likely to fail to maintain the balance between the stronger and the relatively weaker or less able ones in the community. Thirdly, in most cases, the tradition of '*lefintee*' is associated with the culture of organizing '*ofera*' or '*debo*', that is, the preparing of some meals and local drinks for those who participate in the operation. Hence, it might involve some potential harms of inducing social differentiation among rich and poor farmers. That is, it might not be free from the social biases of searching (pairing with) peers.

In addition, an informant who has a long stay with the job of soil and water conservation indicated that group formation on '*lefintee*' basis was tried in 1989 by the TPLF Department of Agriculture around Zongi area Central Zone but was abandoned for it failed to have a full or complete catchments context. That is, for ever body was only interested hurry in getting back his labor expenditure, they went on starting here and there with none of it being completed. What farmers mean by the idea of group formation on 'family basis' is that taking the entire family, that is, husband, wife, children, etc. as one work group (unit). Nevertheless, this type of group formation was mentioned to have the potential limitation of being very fragmented and dispersed in guiding and monitoring the SWC activities. That is, despite the possible merits it involves on sustainability and work quality that could be clear from the outset, it was seen to have no basic difference with the 'individual approach'.

informants that the current grouping is mostly based on neighborhood so that every member of the group can call each other when departing for conservation activities and thereby avoid the problem of somebody being very early comers while the others are too late. However, it must be very clear that there are certain failures of misplacing or assigning a husband, the wife including children of one family in to different groups. Besides, the current grouping seems likely to lack a full catchments context.

6. Conclusions

By way of reviewing conservation extension in Ethiopia, this paper assesses and documents experiences of the people based or public soil and water conservation program in Tigray. Considerable experiences could be shared or expanded to other regions, particularly, in terms of the processes involved as well as the technology packages of the program. Moreover, whereas the 'individual approach' is seen as a possible alternative approach particularly as regards to conservation of cultivated lands, the 'group approach' appears to be the sole option as regards to conservation of the vast uncultivated land. Hence, the following lessons could be drawn as regards to the 'group' versus 'individual' approach to soil and water conservation.

Firstly, it has been described that the current work groups or group formation do not necessarily embody the catchments context. And the implication of this is that the problem (erosion hazard) will not be equally shared among every member of the workgroups. Hence, rearrangements in the existing group formations so that. each work group qualifies the catchments context (approach) can possibly help to alleviate at least part of the failures.

Secondly, it was also pinpointed that there exist a misplacing or assigning of the husband, the wife including children of single family or household into different groups. This was also found to result on grievances and complaints on the existing grouping procedure. Hence, resolving these issues by making the group formation procedure accommodate or take care of the problem should also be one aspect of the strategy.

Thirdly, and more importantly, it has been revealed that there exist traditional form of group-work such as '*lefentee*', in the different localities of the region. It was also indicated that there are some tendencies towards pairing with whoever you like, that is, to exercising '*lefentee*' in the area of soil and water conservation. But, these traditional ways of group formation were also indicated to have certain practical and potential limitations or weaknesses. Hence, a question may be raised that within the group-approach whether the group formation should be left free so that farmers can get paired with whoever they like or should there be some limited administrative or regulatory element so that the weaknesses can be taken care of? In this regard, it appears to be important to include some administrative or regulatory element in the group formation.

Fourthly, with respect to the limitations in work quality of the current approach it may be envisaged that it can be ameliorated either by enforcing certain strict quality control measures for which every work-group should abide by or through education and raising

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Basis of Soil Erosion Risk in the source region of the Blue Nile river using RUSLE model, Remote Sensing and GIS: case study in the Muga watershed

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Abstract

Considering the watershed conservation work, it is not feasible to take whole area at once. This calls to divide the watershed in small units, which is micro-watershed, by considering its drainage system. As the soil erosion intensity of micro-watersheds may not similar, they can be prioritized for conservation work. A GIS and Remote Sensing (RS) simulating model using a universal soil loss equation (USLE) was applied to assess soil erosion and prioritize the micro-watersheds on the basis of soil erosion risk in the Muga watershed of Choke Mountain in east Gojam zone, Amhara region. The result of the analysis depicted that the amount of soil loss from each parcel of land in the Muga watershed ranges from 0.006 to137.93 t / ha /year and this result falls within the ranges of the findings of FAO (1984). The mean annual soil loss of the Muga watershed is 15.28t/ha/year and this result is greater than the average annual rate of soil loss in Ethiopia (12 tons/hectare/year). Since protecting and conserving the entire watershed is costly, MW1, MW2, MW5, MW27, MW28, and MW29 are prioritized for conservation. 38% of the micro-watersheds in the study area require immediate attention with regard to application of soil conservation practices. The prioritized micro watersheds are found at the pick of Choke Mountain and at the foot of Muga River.

Keywords: USLE, Soil Erosion, GIS and Remote Sensing

1. Introduction

Soil erosion and consequent degradation of agricultural land is a serious environmental and socio-economic challenge in the highlands of Ethiopia that harbor 88 and 75% of the human and livestock populations respectively, and constitute 43 % of the countries and dominated by high soil fertility that covers 95% of the cultivated lands. In these areas only, an annual

Watershed deterioration is the common phenomena in most parts of the world. Among several causes for this, improper and unwise utilization of watershed resources without any conservation work is the leading and this is more severe in developing countries (FAO, 1985). The watersheds of Choke Mountain are good example of such deterioration (Weldeamlak and Sterk, 2003).Soil and water conservation (SWC) measures have been extensively carried out during the past three decades under various packages by governmental and non-governmental organizations to lessen the problems of soil erosion (Wegayehu and Drake, 2001). However, it is widely recognized that conservation works have often failed to meet the objectives anticipated. This is mainly attributed to a wider range of technical, socio-economic, and policy constraints that make the recommended technologies inappropriate to local conditions. But in particular, conservation plans and strategies have not been prepared based on the assessment of the spatial variability of soil erosion hazard and prioritization of watershed for soil conservation works. While considering the watershed conservation work, it is not feasible to treat the entire watershed at once due to financial and organizational constraints; this calls to divide the watershed in small units that is sub watershed, by considering its drainage system. Therefore vulnerable areas are prioritized and then undertaken development.

Since soil erosion is a diffuse process which occurs at widely varying rates over the landscape, direct measurement of soil erosion at many points across a region is impractical. Consequently, researchers commonly use erosion prediction models to make regional assessments of erosion in selecting conservation methods for specific fields. Because of the fact that most process-based erosion prediction models in general are not well tested and require many input parameters, the empirical erosion prediction models continue to play an important role in soil conservation planning. Sonneveld et.al (1999) urges that in case of Ethiopia and many other developing countries the application of these process-based models is not practically applicable due to their large data requirement.

The present study pertains to the analysis of prioritization of micro-watersheds on the basis of soil erosion risk. This study would help estimate soil loss and map soil erosion risk zones and prioritize micro-watersheds for conservation and thereby, maximize benefits of soil erosion control from minimum inputs enhancing efficiency of process of restoring the resource base. This study integrated Universal Soil Loss Equation (USLE) empirical model, and the technique of the Geographic Information System (GIS) and Remote Sensing to quantify soil erosion in the Choke Mountain watersheds. Geographical Information Systems (GIS) have the advantage of assessing soil loss more quickly, less expensively, with automation at finer spatial resolution.

Soil erosion is a spatial phenomena, thus geo-information techniques play an important role in erosion modeling. Remotely sensed data and existing maps provide a lot of data for model input. Generally geo-information techniques offer the following advantages in erosion modeling: (1) Fast and cost effective estimates, (2) Possibilities to investigate larger areas, (3) Greater possibilities of continuous monitoring of these areas, (4) Possibilities to refine the soil erosion model depending on the required output scale i.e. rough global to more precise local scale.

to reduced productivity even on marginal lands, needs information which should be supplied in an accurate and timely effective manner. GIS and Remote Sensing are an answer to this problem (Belaid, 1991).

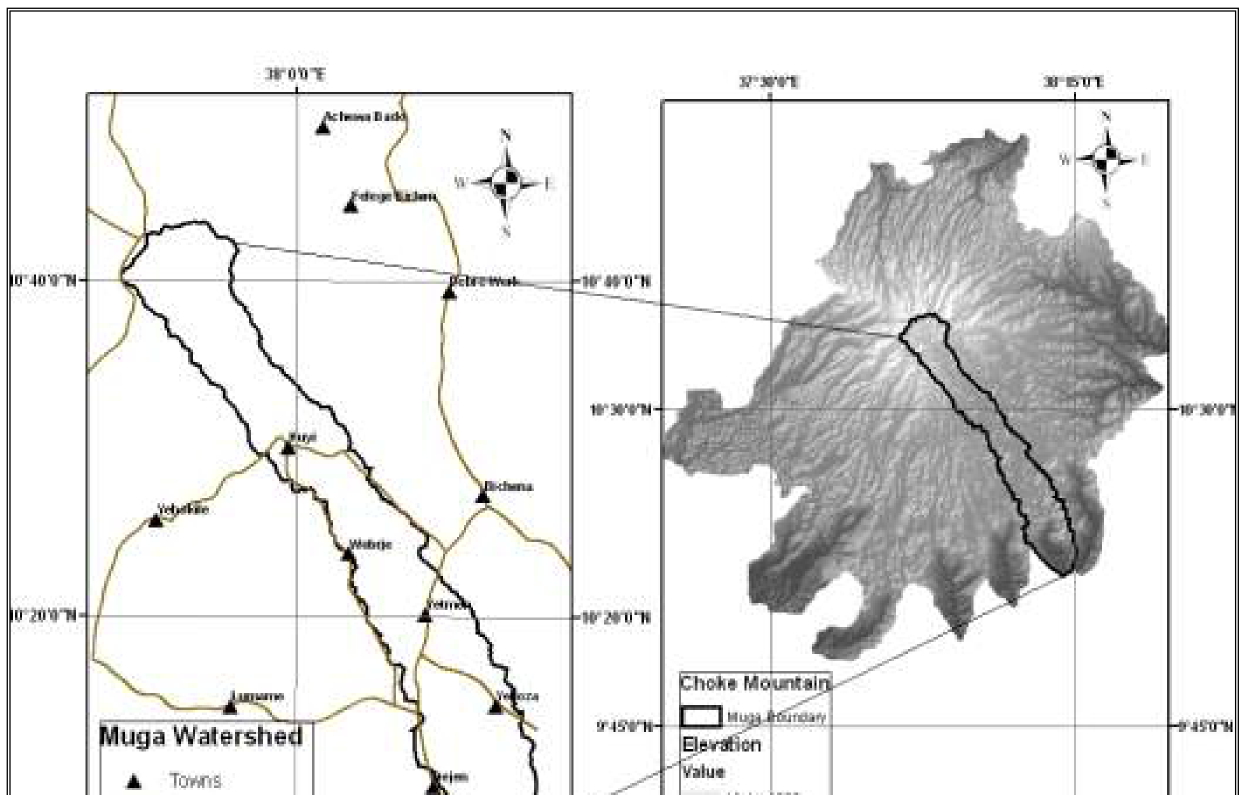
Spanner *et al*. (1983) used a GIS to predict soil erosion. They used the universal loss equation (USLE) including LANDSAT data and collateral data to accurately map soil loss in a GIS environment. Bocco and Valenzuela (1988) used an integrated method based on GIS and image processing for soil erosion in ILWIS environment. They improved image classification and mapping eroded land, using the GIS technique.

2. Material and Methods

2.1 Study Area Description

Muga watershed (study area), one of the choke mountain watershed, is located in the northern highlands of Ethiopia, within 10°6′30′′N to 10°43′30′′N and 37°49′00′′E to 38°16′30′′E (Figure 1). It covers an area of 701.63 km². The agroclimatic zone of Muga is mostly wet dega and moist dega, with mean annual rainfall of 1445 mm and mean elevation of 2594masl. Geologically, the Muga watershed is largely coverd by Blue Nile Basalt and Tarmaber Basalts.

Figure 1 *Study Area (Location Map)*



- Monthly rainfall data for eight stations of the period 1994 to 2003 in the study area

Soil map classified based on FAO soil classification was obtained from Ministry of Water Resources

Information on type, spatial extent and geo-coordinates of conservation measures implemented in the study area

Topographic maps 1: 50, 000 scale (1037-B4, 1037-D2, 1038-A3, 1038-C1, 1038-C3) and 1: 250, 000 scale (NC 37-6)

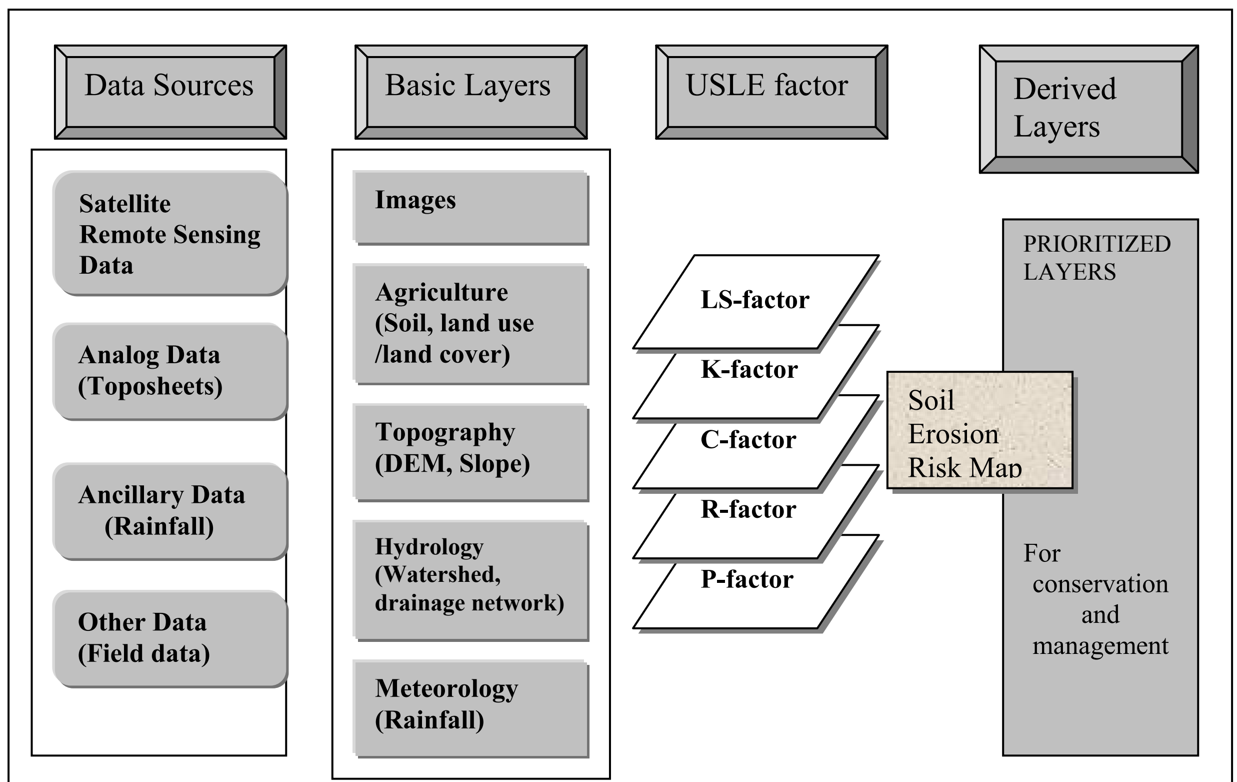
2.3 Methodology

Universal Soil Loss Equation was adopted for the evaluation of soil erosion-proneness of micro-watersheds. The universal soil loss equation is an empirical model developed by Wischmeir and Smith (1978) to estimate soil erosion from fields. All of the parameters of this model are achievable through GIS and Remote Sensing in environment. Hence the USLE model was chosen for this study. Mathematically the equation is denoted as:

Where A is the mean annual soil loss, **R** is the rainfall erosivity factor, **K** is the soil erodability factor, **L** is the slope length factor, **S** is the slope steepness factor, **C** is the crop management factor and **P** is the erosion control practice or land management factor.

$$\mathbf{A\ (tons/ha/year) = R * K * L * S * C * P}$$

Figure 2 *Flow diagram showing overall methodology adapted for USLE*



erosion in Ethiopia. He even modified some factors of the USLE for Ethiopian condition. In this paper the analysis of each process factors will be derived as follows:

2.3.1 Derivation of Rainfall Erosivity Factor(R)

The soil loss is closely related to rainfall partly through the detachment power of raindrop striking the soil surface and partly through the contribution of rain to runoff (Morgan, 1994). The most suitable expression of the erosivity of rainfall is an index based on kinetic energy of the rain. There are different ways of analyzing the R factor. For instance,

R = 9.28 * P – 8838. Mean annual erosivity (KE > 25) where P is mean annual

- Precipitation [Morgan (1974) cited in Morgan (1994)]

R = 0.276 * P *I_{30}. Mean annual E_{I30}, where P is mean annual precipitation [Foster et.al (1981) cited in Morgan (1994)]

R = 0.5 * P (in US unit) and R = 0.5 * P *1.73 (in Metric unit). [Roose (1975) cited in Morgan (1994)]

The above formulas have been applied in different parts of the world. The first equation appears to work well for Peninsular Malaysia, where as the application for other countries is less satisfactory. Especially with the annual rainfall below 900mm the equation yields estimates of erosivity, which are obviously meaning less (Morgan, 1994). In line with this, the second equation needs the value of I_{30} for calculating of erosivity factor, which is difficult to get in context of the study area.

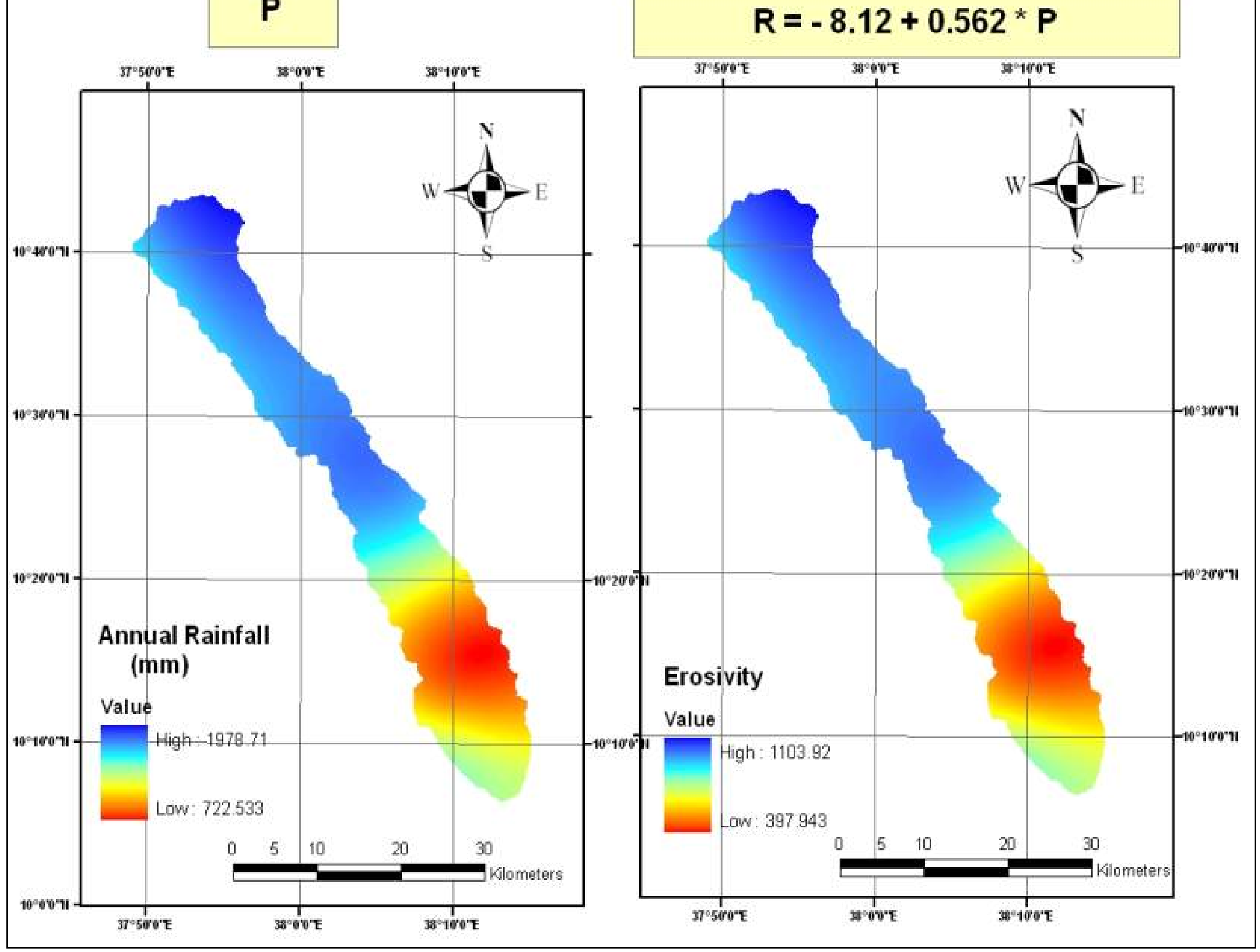
However, rainfall kinetic energy and intensity data are not available most cases. Therefore, the erosivity factor R was calculated according to the equation given by Hurni (1985), derived from a spatial regression analysis (Hellden, 1987) for Ethiopian conditions based on the easily available mean annual rainfall (P). It is given by a regression equation:

$$\mathbf{R = -8.12+0.562*P}$$

Where, P is the mean annual rainfall in mm and R is the erosivity factor.

Ten years (1994 – 2003) rainfall data of ten stations were used to get the mean annual rainfall (P) and the calculated erosivity factor (R) for the study area.Those rain gauge stations that are found within a distance of 25Km from Muga watershed were taken in to consideration for the analysis.

Each grid cells of mean annual rainfall was calculated based on equation adapted for Ethiopia to get the R-value (Rainfall Erosivity) using Spatial Analysis tool in Raster Calculator, ArcGIS-9.1 software (Figure 3).



2.3.2 *Derivation of Soil Erodibility Factor (K)*

Soil Erodability Factor (K) is defined as mean annual rainfall soil loss per unit of R for a standard condition of bare soil, recently tilled up-and-down with slope with no conservation practices and on a slope of 5 $_0$ and 22 m length (Morgan, 1994). The value of K ranges from 0 to 1. Hellden (1987) developed a USLE for Ethiopian condition by adapting different sources and proposed the K values of the soil based on their color (Table1).Factor data for Ethiopia have been prepared by the Soil Conservation Research Project (SCRP) and are reproduced (SCRP, 1996).This is shown in Table 2 below.

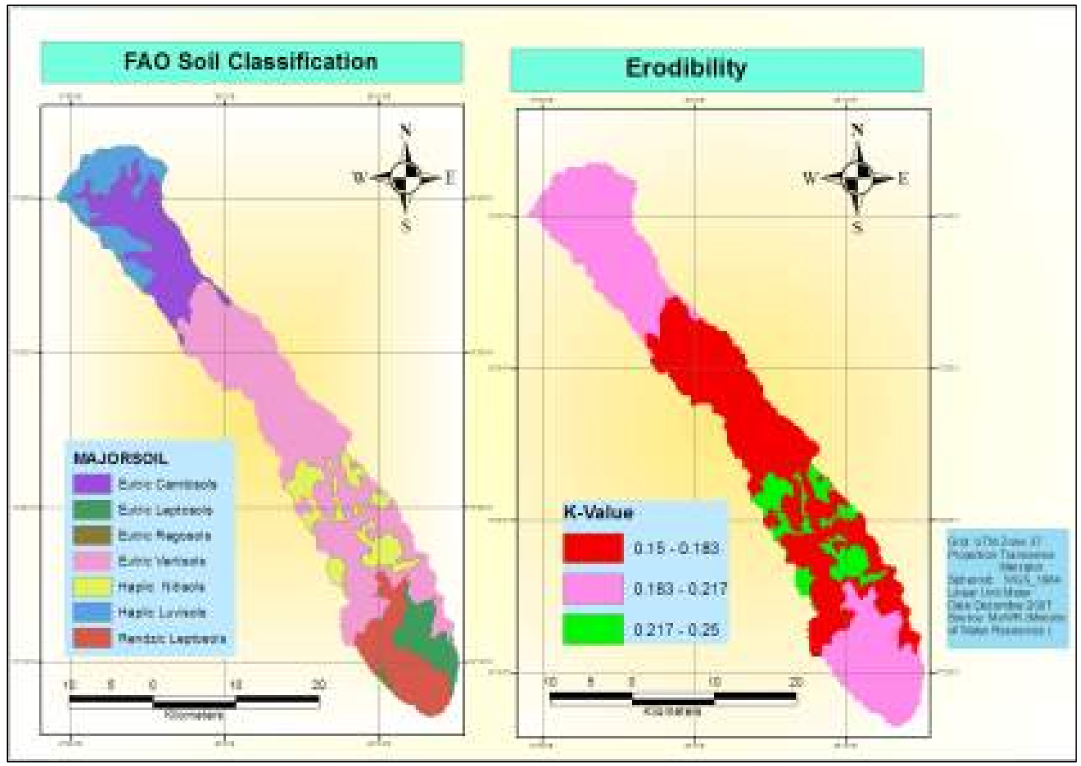
Table 1 *Soil Erodibility Factor (Hellden, 1987)*

Soil color	Black	Brown	Red	Yellow
K factor	0.15	02	0.25	0.3

Since the soil data of the study area are in their geomorphological name, an attempt were made to classify the soil types of the study area based on their color by referring the FAO soil database. The soil map of the study area was collected at a scale of 1: 250 000 from Abbay

1	Eutric Fluvisols	Mostly brown but variable	0.2
2	Eutric Vertisols	Dark grey or Black	0.15
3	Eutric Cambisol	Brown or Dark brown	0.2
4	Eutric Leptosols	Brown to yellowish brown	0.2
5	Haplic Alisols	Reddish brown	0.25
6	Haplic Luvisols	Brown / Reddish brown	0.2
7	Haplic Nitosols	Reddish brown	0.25
8	Chromic Luvisol	Brown / Reddish brown	0.2
9	Lithic Leptosols	Brown to yellowish brown	0.2
10	Eutric Regosols	Brown	0.2

Figure 4 *Derivation of Erodiblity factor (R)*



2.3.3 Derivation of Slope Length Factor (LS)

The LS factor characterizes the effect of topography on erosion in USLE. By using DEM with finer resolution, it is possible to calculate both slope length 'L' and slope gradient 'S' rather than having to use as has been the case in the past, resulting in far greater accuracy than in previous assessments (Wischmeier and Smith, 1978). Contours at 20 m intervals were digitized from a1: 50 000 scale topographic map and from this contour TIN is created and converted to DEM (Raster) with 100m out put cell size. The topographic factors (L, S) are given by:

$$S = 65.4 \sin^2 \theta + 4.56 \sin q + 0.0654,$$

where θ is the angle to horizontal, in the USLE but

$S = 10.0 \sin \theta + 0.03$ slopes < 9%

$S = 16.8 \sin \theta - 0.50$ slopes ≥ 9% in the RUSLE.

In the USLE, m varies from 0.6 for slopes > 10 % to 0.2 for slopes < 1 %.

In modelling erosion in GIS, it is common to calculate the LS combination using a formula such as

LS = (Flow Accumulation * Cell Size/22.13)^0.4 * (sin slope/0.0896)^1.3

where Flow Accumulation is the number of cells contributing to flow into a given cell and Cell Size is the size of the cells being used in the grid based representation of the landscape. This formula is based on the suggestion by Moore and Burch (1986) that there was a physical basis to the USLE L and S factor combination.

Moore and Wilson (1992) observed that the product of L and S in the RUSLE could be approximated by

$$LS = (As/\ 22.13)^{0.6} (\sin\theta\ /\ 0.0896)^{1.3}$$

where As is the upslope contributing area divided by the width of the contour that that area contributes. The equation considers m = 0.6 and n = 1.3. For erosion at a point, Griffin et al. (1988) modified and recommended the following formula.

$$LS = (X/22.1)^{0.6} (\sin(S)*0.01745/0.09)^{1.3}$$

Where X = slope length (m) and S = slope gradient (%)

X = (Flow accumulation * Cell value)

By substituting X value, LS equation will be:

$$LS = (\text{Flow accumulation} * \text{Cell value} / 22.1)^{0.6} (\sin(S)*0.01745\ /\ 0.09)^{1.3}$$

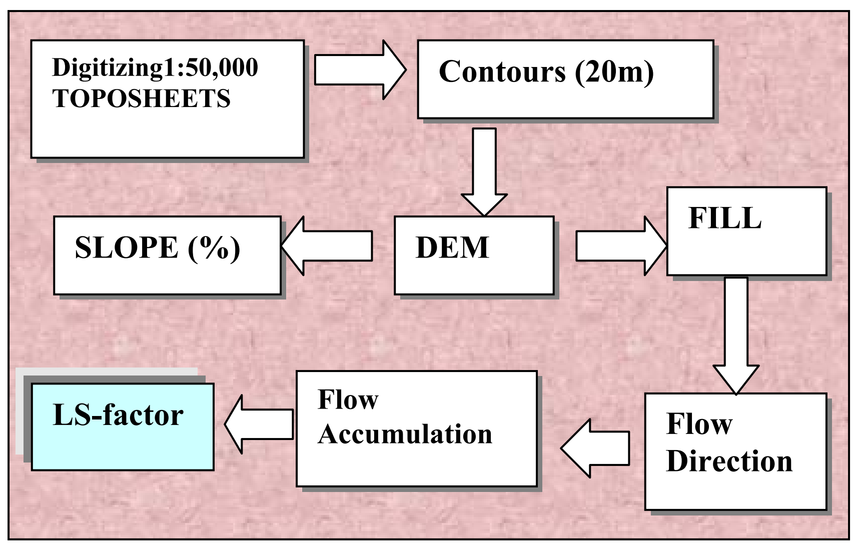


Figure 5 Flow diagram for derivation of Slope length factor (LS)

LS= Pow ((Flow Accumulation)*Resolution/22.1,0.6)* pow(sin(slope)*0.01745) / 0.09, 1.3)

2.3.4 *Derivation of Land Cover/Land Use factor (C)*

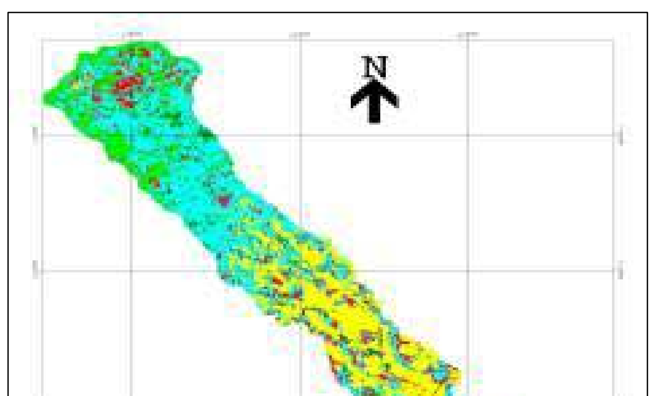
The Land Cover/Land Use factor (C) represents the ratio of soil loss under a given land cover/land use to that of the base soil (Morgan, 1994). As Nyssen, (1997) commented, the land cover factor 'C', is of paramount importance in the determination of erosion hazard assessment because of the large difference between its minimum and maximum values therefore slight mistakes in land cover mapping can result in large over or under estimations of soil loss. For this reason up-to-date and accurate land use/land cover map was used for analyzing the c-value.

After changing the classified vector data to grid, a corresponding C-value was assigned to each land use classes using Reclasfy method in ArcGIS 9.1 as given by the table below (Table3) With regard to the cultivated unit of the map, the C-value varies annually. However, barley, sorghum and maize are the dominant crops with teff important but not dominant. Therefore an intermediate factor (0.15) was selected.

Table 3 *Crop Management (C) Factor in Previous Studies*

No.	Land cover/use Class	Source	C-factor
1	Forest	Hurni,1985	0.01
2	Scrub land	CGIP,1996	0.02
3	Grass land	CGIP,1996	0.01
4	Dense grass	Hurni,1985	0.01
5	Degraded grass	Hurni,1985	0.05
6	Crop land/wooded crop land	CGIP,1996	0.15
7	Crop land teff as a main crop	Hurni,1985	0.25
8	Cropland, cereals/pulses	Hurni,1985	0.15
9	Cropland, wheat/barley	CGIP,1996	0.15
10	Cropland, sorghum/maize	Hurni,1985	0.10
11	Afro-alpine	BCEOM,1998	0.01
12	Open scrubland	CGIP,1996	0.06
13	Bush land	BCEOM,1998	0.1
14	Bare land	BCEOM,1998	0.6

Figure 6 *Land use/Land cover Map from Imagery Acquired on 08/03/ 2003*



4.5 Derivation of Erosion Management Practice Factor (P-value)

The erosion management practice, P value, is also one factor that governs the soil erosion rate. The P-value ranges from 0-1 depending on the soil management activities employed in the specific plot of land. These management activities are highly depends on the slope of the area. Wischmeier and Smith (1978) calculated the P-value by delineating the land in to two major land uses, agricultural land and other land. The agricultural land sub-divided in to six classes based on the slope percent to assign different P-value (Table4).

***Table 4** P-value (Wischmeier and Smith, 1978)*

Land use type	Slope (%)	P-factor
Agricultural land	0-5	0.1
	5-10	0.12
	10-20	0.14
	20-30	0.19
	30-50	0.25
	50-100	0.33
Other land	All	1.00

During the fieldwork, ground truth data were collected for different management and conservation practices opted in the study area. In addition to the GPS readings, the observation sites were marked on the topomaps as well as FCC on 1:50000 scales. For the ground truth sites at various locations, information with reference to type of practice opted was noted. The surrounding land uses were also sketched for each ground truth site and influence of slope in adopting practice is noted from the toposheet. Ground truth sites dominated by the specific practices viz., contour bunding, graded bunding or contour terraces, bench terracing etc. were marked on the FCC and topographic maps.

***Table 5** Support practice factor values (Deore, 2005)*

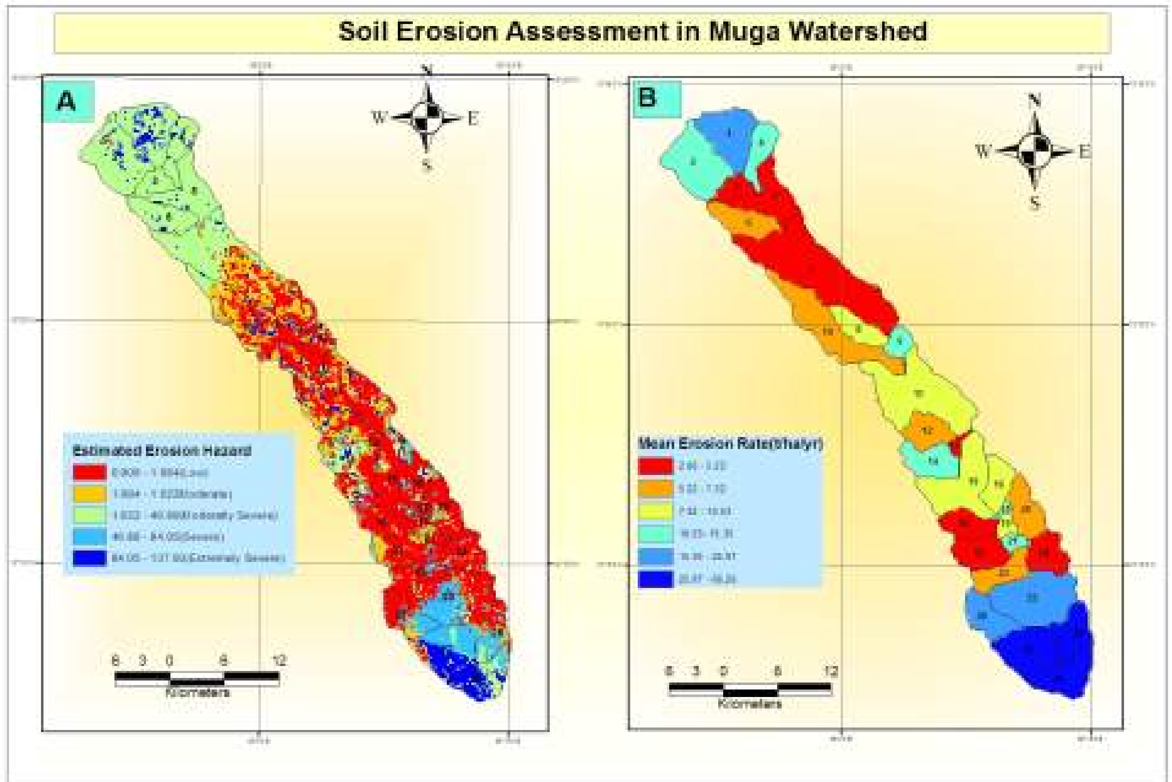
Sr.No	Slope (%)	Contouring	Terracing and contouring
1	1 – 2	0.6	-
2	3 – 5	0.5	0.1
3	6 – 8	0.5	0.1
4	9 – 12	0.6	0.12
5	13 – 16	0.7	0.14
6	17 – 20	0.8	0.16
7	> 21	0.9	0.16

Slope map, field information and landuse/ land cover map were used to choose suitable

Result and Discussion

All the layers viz. R, K, LS, C and P with 100 X 100 m out put cell size were generated in GIS and were crossed to obtained the product, which gives annual soil loss (A) for the Muga drainage basin. These values gave annual soil loss per hectare per year at pixel level. Based on the analysis, the total amount of soil loss in the Muga drainage basin is about 1,038,448.98 ton per year from 6414.143 hectare. As shown in the figure 7A, the amount of soil loss of each parcel of land in the basin ranges from 0.006 to137.93 t/ha/year. The mean annual soil loss of the Muga watershed is 15.28 t/ha/year. The average annual rate of soil loss in Ethiopia is estimated to be 12 tons/hectare/year, and it can be even higher on steep slopes with soil loss rates greater than 300 tons/hectare/year or 250 mm/year, where vegetation cover is scant (USAID, 2000).

Figure 7 *Micro-watershed wise soil loss in Muga watershed*



The result of study also falls within the ranges of the findings of FAO (1984). According to the estimate of FAO (1984), the annual soil loss of the highlands of Ethiopia ranges from 1248 – 23400 million ton per year from 78 million of hectare of pasture, ranges and cultivated fields through out Ethiopia. Previous studies conducted on soil erosion assessment in Ethiopia shows different rate of soil erosion. For example, Hellden (1987),calculated mean total soil loss for Ethiopia of 150 t/ha/yr at Mertule Mariam, and studies conducted by FAO,(1986), in the Ethiopian high lands shows 100t/ha/yr soil loss from cropped lands taking in to consideration the redeposit. Another study conducted by Soil Conservation Research Program (SCRP) at Anjeni research station revealed that the annual soil loss rate to be 131 – 170 t/ha (SCRP, 1996). Another study by Solomon Abate (1994), shows soil loss

The spatial locations of the high spot area for soil erosion in the study revealed that the potential soil loss is typically greater along the steeper slope banks of tributaries. Other high soil erosion areas are dispersed through out the basin and are typically associated with high erosion potential land uses. The plain area of the basin shows the least vulnerable to soil erosion. Prioritization of micro-watersheds has been done on the basis of mean annual soil loss (Figure7-B). Extremely severe erosion is observed in three micro-watersheds (MW28, 27 & 29) and more than 40% of the micro-watersheds are categorized under severe erosion (Table6) this is mainly due to steep slopes. This has concealed the magnitude of micro watershed-wise soil erosion problem in the Muga basin. It is, therefore, necessary to prioritize these MWs for adoption of conservation measures. More than 3/4th of the micro-watersheds fall in ≤ mean soil loss category (15.28t/ha/yr). Estimated values of micro-watershed wise soil loss are classified on the basis of mean (15.28 t/ha/yr) soil loss as follows:

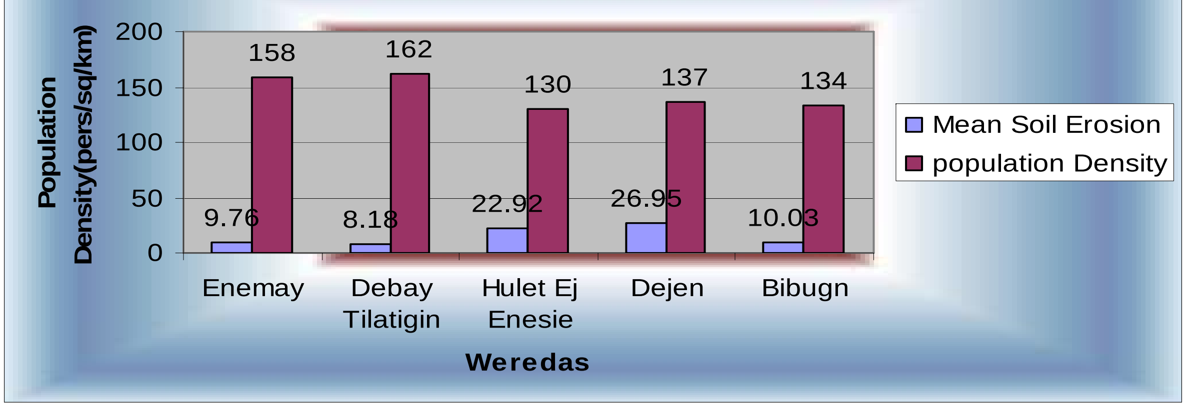
Table 6 *Classification of Micro-watersheds*

Mean Soil loss(t/ha/yr)	Class	Micro-watersheds	Area(ha)
2.06 – 5.22	Very Low	3, 5, 7, 13, 18, 22, 24	1892.707
5.22 – 7.32	Low	6, 10, 12, 20, 23	756.063
7.32 – 10.53	Moderate	8, 11, 15, 16, 19	1302.131
10.53 – 15.35	Moderately Severe	2, 4, 9, 14, 17, 21	888.19
15.35 – 25.97	Severe	1, 2, 5, 26	899.042
25.97 – 66.26	Extreme	28, 27, 29	676.01

Since the Muga watershed consists of about five woredas of Amhara region, an attempt was also made to see which of these woreda has highly affected by soil erosion. As shown in the figure 8 Dejen and Hulet Ej Enesie are the most highly affected areas. Besides their area coverage, the topographic ruggedness, intense rainfall and poor vegetation coverage contributed to the high rate of soil erosion in the above-mentioned woredas.

Land degradation in Ethiopia has often been attributed to the high human population densities. Some of the highland areas, such as Wolaita, do have high densities (250sqkm).Yet the problem of land degradation is not as exacerbated in the most densely populated areas of Ethiopia as in relatively less densely populated areas (e.g., northern highlands) (UNEP 1991).The population density of Debay Tilatgin wereda is high (162pers/sqkm) but the amount of mean soil loss is the least (8.18 t/ha/yr) and this can clearly be seen in the figure 8 in the study area.

Figure 8 *Relationship between Erosion and population density in the study area*



The problem of protecting the land from degradation has been framed in the debate over population pressure and expansion of agricultural land (Swinton, 2000). In the literature the effect of population pressure on natural resource conservation has taken two divergent views. The idea of the Malthusian hypothesis (Gillies et al, 1996) is that the increase in population in a geometric fashion followed by the increase in the demand for natural resource. However, the supply of these natural resources is increase only linearly. Thus, in the Malthusian thesis population is regarded as a threat to natural resources (Gillies et al, 1996).

In contrast to this view, the BOSERUP thesis advocates population pressure is a significant factor for the intensification of agriculture and hence for the adoption of improved farming practices (Boserup, 1965). This view is clearly anti-Malthusian. Increase in the number of population results in increase in the value of land. This induces even the poor peasants to invest in soil erosion controlling measures (Boserup, 1965). Hence, increase in population through its effect in increase in demand for food and for land will eventually lead to conservation investments to occur (Tiffen et al., 1994). The anti-Malthusian idea indicates how private property rights develop over the long run in response to population growth.

As such the increase of one person in the population might require only a quarter of a hectare of land to feed. But to maintain the animal to plough that land, one hectare of additional grazing land is required. So again it is not the cultivated land that accentuates the problem of erosion but the demand for grazing land. All these land cover changes have their own significant contribution to the current state of erosion. But whether the extension of cultivation is the main cause of land degradation in Ethiopia is a question which needs closer investigation. The small pieces of land are less prone to erosion and their aggregate contribution to erosion is likely to be much less than that usually attributed.

Table 7 *Annualtotal soil loss rate from each land use/land cover classes and their percentage of the total*

Land use/Land cover classes	Soil loss (tons/year)	%
Afro-alpine	30642.9	2.68
Forest	5952.3	0.52

Total	1141871.5	100

The soil loss rate factors for each land use/land cover factors were developed by Anjeni research unit of the Soil Conservation Research Program (SCRP) from ten years of average values of test plots and experimental plots under different land use, soil types, slope steepness, shape and aspect condition (Hurni, 1987 as quoted by Gete, 2000).

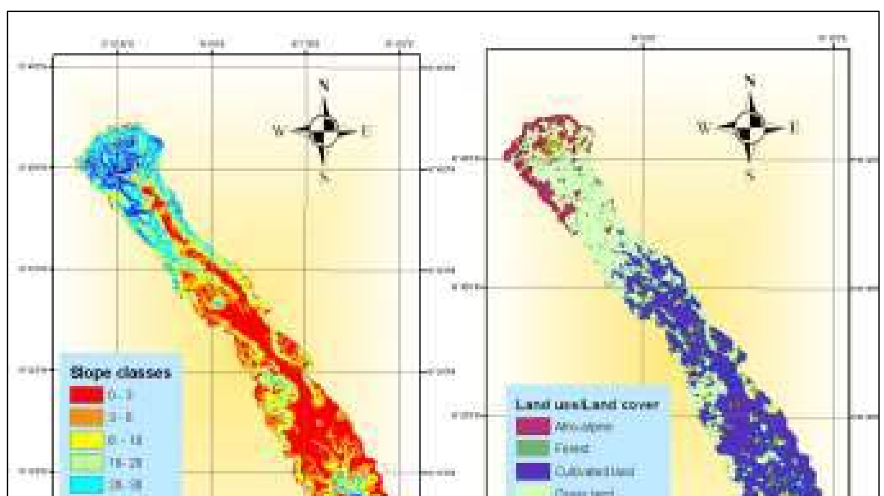
*Table **8** Annual soil loss rate factors used for annual soil loss prediction and data sources (Gete Zeleke, 2000).*

Land use/land cover classes	**Soil Loss Rate Factor (t/ha/yr)**	**Source**
Forest land	1.00	Hurni, 1987
Cultivated land	131-170	Anjeni RU
Grass land	6.93	Anjeni RU
Bush land	5.00	Hurni, 1987
Bare land	243.49	Anjeni RU
Shrub land	5.00	Hurni, 1987

Bare land cover is associated with the highest soil loss rate factor value (Table 8) and the highest annual total soil loss (Table 7).The next highest annual total soil loss rate is observed in areas where grass land cover is dominating. Mostly grass lands in the study area are communal and hence they are degraded.

The total soil loss rate that is observed under cultivated land is intermediate. One reason for this could be; most of the cultivated lands are under slopes < 3% (Figure 9).The topographic effect on erosion is minimized.

Figure 9 *Distribution of cultivated land on slope classes.*



Conclusions

Conservation work in the Muga watershed area should be started according to the priority list of Table 1.6. Intensive soil conservation activities like Slope stabilization, slope failure protection, gully control by check dam, reforestation, are required for the first ranking micro-watersheds (MW1, MW2, MW5, MW27, MW28). Fifth ranking micro-watershed needs little attention, like maintaining the crown cover and protection of the existing forest along with managed agriculture. Other micro-watersheds should be treated by intermediate activities according to their ranks. The prioritized micro watersheds are found at top of Choke Mountain and at the foot of Muga River. If this scenario continues with out improvement, it will not take longer time to see these areas reaching zero soil life time (beyond recovery).The effect will not only be regional but also national. Hence an integrated watershed management is highly required.

This study demonstrates the effectiveness of the Remote Sensing and GIS technologies in assessment of the spatial variability of soil erosion hazard and prioritization of micro-watershed for soil conservation works. The outcome of this type of studies not only necessary but also a vital concern to achieve sustainable land management for decision makers to guard against land degradation and for future development projects in the study area. Finally, it can be said that remote sensing and GIS in combination with USLE model can be used as appropriate tools for micro-watershed prioritization.

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Impacts of Water Harvesting in Ethiopia: Implication for food security and resource management

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Background

Ethiopia has been facing chronic food shortages during the past decades. As agriculture is largely rain fed, it is often subjected to risks due to recurrent drought. Variations in rainfall and weather conditions cause considerable volatility in agriculture growth. In this regard, the risk and Vulnerability Assessment (2003), estimated about 50% of the population are considered chronically poor, an additional 27 % move in and out of poverty in tandem, and 14% who are not poor now have a high probability of falling into poverty in the future with a single shock. The Government has given much attention both in PRSP I and PASDEP, to develop irrigated agriculture.

A major issue in productivity and associated food security of rural households is perceived to be water scarcity and reliability. Water harvesting has been widely promoted as an important means of overcoming moisture-associated production constraints and attendant household welfare problems. Consequently, varieties of water harvesting technologies have been adopted in Ethiopia during the last five years. So many deep wells, ponds, dams and diversion ditches have been constructed to ensure food security and increase income of farmers from high value crops.

The impacts of water harvesting campaign have been variable. There are localities where water harvesting has resulted in achieving food security and become commercial farmers. There are also localities where farmers become so discouraged by the loss they incurred on construction of water harvesting structures. From the outset successful areas are in those where high value crops are grown and well marketed. Lack of skill for proper selection and implementation of the structures, high cost of construction and market have caused poor performance in many localities across the nation.

This implies in depth understanding of biophysical and socio-economic factors that govern prioritization of geographic areas for intervention and selection of appropriate water harvesting systems for each of those geographic areas. In addition targeting of agro-ecologies and socio-economic conditions would improve to maximize effectiveness of water harvesting interventions.

Research has been finalized at the Ethiopian Development Research Institute (EDRI) seeking mappable. The results of the EDRI study will empirically validate the importance of these factors in different settings.

The context-dependent impact of water harvesting technologies, once established by econometric analysis, will be used to formalize a set of recommendation domains for different water harvesting technologies – i.e., geographically delineated areas where profitability is positive. Superimposed upon the frame of profitability will be impact on food insecurity. Building upon the already obtained results from EDRI's study, in this study will combine the biophysical factors, institutional and markets including infrastructures and come up in concrete terms targeting proven technologies on certain development domains.

The results of such analysis in the context of a development domain should concretize our understandings of factors describing the conditionality of water harvesting successes in economic and food security terms. As an aid to policy design and implementation, we must gain some understanding of how well we can build targeting frameworks that capture these conditions. Thus, we will evaluate how well spatial targeting may enhance the effectiveness of WH within the context of broader policy objectives.

But global relationships may be misleading. Here we use "global" to indicate relationships that a constant through space, and which may be contrasted with "local" relationships, which are measured – and which may vary – on a location-specific basis. Thus, an important part of the proposed work is the evaluation of local outliers in what may otherwise be well-understood relationships that determine implementation strategies. We will seek to identify whether such anomalies may provide insights into why logical targeting frames may sometimes yield unsuccessful implementations.

Objectives

1. Assess the spatial determinants of success and limitations of water harvesting interventions.

Materials and methods

Sampling Design

The four major administrative regions have been systematically selected due to the high level of water harvesting intervention during in the past years. From the four regions, 17 zones have been randomly selected, which included 30 Woredas and 187 Pas. From each PA a minimum of 10 households and a maximum of 15 households have been interviewed. Those households have been selected randomly from those who have been included in the water harvesting extension package.

Data collection and compilation

Primary data: The following data have been included in the questionnaire

- Value gained per hectare

Secondary data

Environmental variables

  - Mean annual rainfall
  - CV of annual rainfall
  - Length of growing period
- Moisture index calculated as CV divided by the mean
- Georeferencing of the selected Kebeles
- Aggregation of the household records at Kebele level for geographical consideration
- Extraction of environmental variables from the existing GIS data

Data Analysis using OLS and Geographically Weighted Regression (GWR)

In a typical Linear Regression model applied to spatial data we assume a stationary process:

$$y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots \beta_n X_{ni} + \varepsilon_I \quad (1)$$

Using the Ordinary Least Square (OLS) method, the parameter estimates obtained in the calibration of such a model are constant over space:

$$\beta' = (X^T X)^{-1} X^T Y \quad (2)$$

This means that any spatial variations in the processes being examined can only be measured by the error term.

GWR enables to determine the degree of relationship among dependent and independent variables at each geographic space. Parametric estimates are made at each regression point from defined neighboring data points. Spatial weights are assigned for each data points based on its relative distance from the regression point.

The GWR model is written as:

$$Y = b_0 + \Sigma_j X_{ij} a_j + \varepsilon \quad (3)$$

Where Y is the dependent variable, X is the independent variable, a is the regression coefficient, is an index for the location, j is an index for the independent variable and ε is the error term (Fotheringham *et al,* 2002).

Weighting of data points from the regression points

For the adaptive bandwidth spatial weights matrix a bi-square function is used so that, w_{ij} = $[1 - (d_{ij}/b)^2]^2$ if *j* is one of the k^{th} nearest neighbors of *i* and *b* is the distance from *i* to the k^{th}

Information Criterion has been used to determine the bandwidth i.e. number of nearest neighbouring woredas to be used in estimating local parameters at each data point.

$$AIC = 2n \ln(\sigma') + n \ln(2\pi) + n[n+ Tr(\mathbf{S})] / [n - 2 - Tr(\mathbf{S})] \quad (4)$$

where n is the number of data points, σ′ is the estimated standard deviation of the error term, and Tr(**S**) is the trace of the hat matrix.

The local r-square value

The local r-square value shows how much of the variability in the dependent variable is explained by the independent variables at each regression point. Essentially, it measures how well the model caliberated at regression point i can replicate the data in its vicinity or neighbourhood. The formula for the local r-square statistic, r_i^2

$$r_i^2 = (TSS^w - RSS^w)/TSS^w \quad (5)$$

Where TSS^w is the geographically weighted total sum of squares, defined as

$$TSS^w = \Sigma_j W_{ij} (yj-\tilde{y})^2$$

RSS^w is the geographically weighted residual sum of squares, defined as

$$RSS^w = \Sigma_j W_{ij} (yj -\hat{y})^2$$

Where W_{ij} describes the weight of data point j at regression point i.

The t-value

In GWR it is possible to compute standard errors for the parameter estimates at any of the geographic locations or regression points. This helps to consider the degree to which the estimate varies within the study area. It enables to calculate confidence intervals for the estimates. The t-values are normally calculated at 1.96 and 2.58, which correspond to 95 % and 99% confidence levels, respectively. A positive 1.96 t-value shows that the regression coefficient lies in the range of the mean value plus one standard error, while 2.58 shows the mean plus two standard errors. Similarly, negative t-values show the mean estimate minus one standard error for the 1.96 and two for 2.58.

Testing individual parameter stationarity

A GWR estimate of the coefficient of interest is taken at each of the n data points and the variance (or standard deviation) of these estimates is computed. Of course, even if the parameter of interest did not vary geographically, one would expect to see some variation in

However, it would be difficult, if not impossible; to compute this distribution analytically and therefore a Monte Carlo approach is adopted. For a given number of times, say, n, the geographical coordinates of the observations are randomly permuted against the variables. Note that since we are only questioning the geographical variability of the observations we do not permute the independent variables against the dependent variable. Thus, we have n values of the variance of the coefficient of interest which we use as an experimental distribution. We compare the actual values of the variance against this list to obtain an experimental significance level.

Results and Discussion

Impact of environmental conditions on physical performance of water harvesting

Amount and variability of moisture is the most essential factor for planning water harvesting. Priority areas for water harvesting are those where moisture is limiting due to less availability of total moisture or limitations due to its variability. Pastoral areas where annual rainfall is less than 300 mm, rain-fed agriculture is not possible. In those areas irrigation and river diversion are appropriate. However, in moisture-insufficient areas with mean annual rainfall of 300 mm to about 700 mm, the total amount is limiting and highly variable. In this areas water harvesting has a significant effect to achieve food security and enable commercial farming. On the other hand, in moisture reliable areas water harvesting is not necessary either for food security or commercial farming.

Results of this study revealed that the number of ponds and the amount of water harvested had not been significantly determined by any of the considered environmental factors. This implies that critical consideration has not been given to those factors at the planning stage. On the other hand, the area of land that has been irrigated and the duration that the harvested water lasted had been significantly determined by moisture variability (Table 1). The area of land that can be irrigated with the harvested water has been explained better by LGP and moisture index. Duration of harvested water was better explained by the variation of rainfall and moisture index. When the variability of rainfall is higher the duration of harvested water to last has increased. In areas where the length of growing period has been long and moisture variability stable the water the area and duration have been significantly higher. This is due to the impact of evapo-transpiration and erratic distribution of rainfall, which made moisture unavailable for longer period.

Table 1 *OLS regression coefficients among physical performance of water harvesting and environmental variables*

Environmental Variables	Total number of ponds ($r^2 = 0.05$)	Amount of water harvested (cubic m) ($r^2 = 0.03$)		Area that has been irrigated		Duration of water harvested (months	
	b	b	P≥ 0.05	b	P≥ 0.05	b	P≥ 0.05
Annual precipitation	0.013	-0.32	**0.046***	-0.000	0.524	0.90	0.37

Impact of environmental conditions on economic returns

The ordinary least square regression showed that environmental variables had no significant impact on gross margin per hectare and value harvested per hectare (Table 2)

***Table 2** Regression coefficients among environmental variables and returns to water harvesting*

Environmental Variables	Gross margin per ha	Value per ha
Annual precipitation	-0.0970	0.0632
Annual precipitation cv	0.0468	0.0200
Annual precipitation cv/Annual precipitation	0.0419	0.0027
LGP	-0.0671	-0.0715

Table 3 GWR estimation coefficient

Variables	Coeffiecnts	Std.err
landholdin	9524.703	10225.36
_Iagpot_2	7272.705	28104.22
_Iagpot_3	11161.29	22439.4
_IagpXland~2	-23228.11	13479.4
_IagpXland~3	-9666.518	10561.64
popd2004	-81.58702**	38.73847
_IagpXpopd~2	88.36819	53.95099
_IagpXpopd~3	-14.65466	47.36039
_Ireg_id_3	-24970.45	11277.77
_Ireg_id_4	-10739.84**	12241.7
_Ireg_id_7	-4283.867	11050.08
_cons	14139.4	22998.7
R-sqaure	0.154	
Model sinificance test (F-tst)	2.83***	
Number of observations	183	

The GWR analysis however indicated that there is strong relationship between gross margin and length of growing period. Particularly, in the central and eastern parts of the country there is higher local r-square value (Figure 1). On the other hand length of growing period has not been so important in the northern parts of the country. In the northern and central parts of the country, length of growing period has negative impact on gross margin. This implies that the most profitable water harvesting interventions are found in areas where the growing period is shorter. On the other hand in Amahra, southern and eastern parts of the country the profitability of water harvesting increases with increasing duration of the

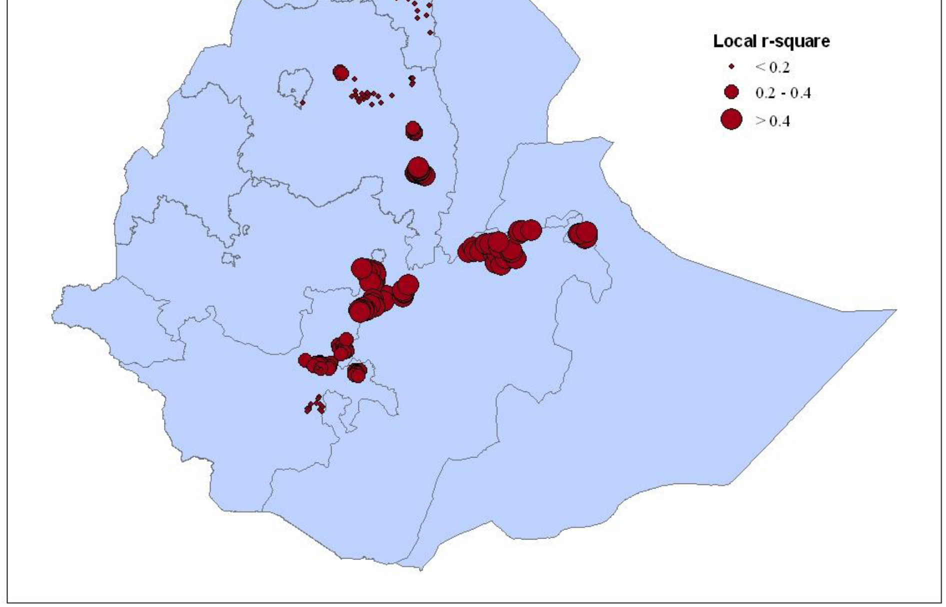


Figure 1 *Local r-square value for the GWR between profitability and length of growing period*

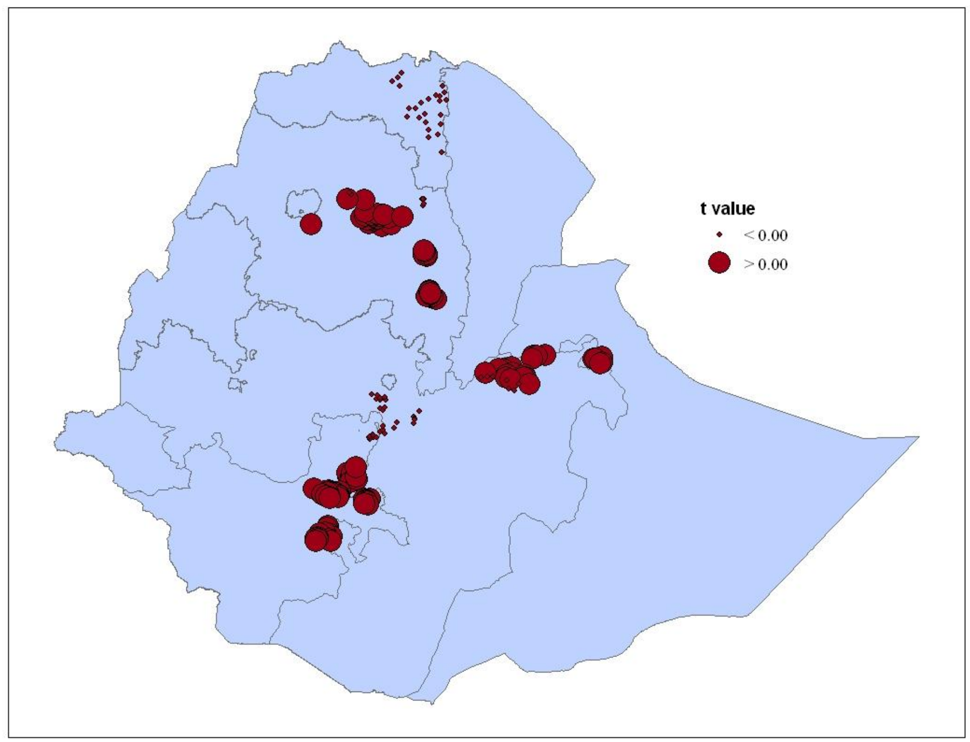


Figure 2 *t value for the GWR between Gross margin and length of growing period*

Impact of labour and accessibility on economic returns

Before analyzing the impact of labour and accessibility, it would be interesting to visualize

Labour supply is a critical input for the water harvesting intervention in any part of the country. The construction of ponds and its implementation demands about 400 – d0-0 man days per pond (Mills, 2004). Labour availability affects production of both high value crops such as vegetables and crop production depending on the location and types of ponds. In rain-fed agriculture farmers concentrate on plot farms far from the homestead. With the division of labour between men and women, women often concentrate on vegetable production nearer to the homesteads. In most farming systems, farmers face shortage of seasonal labour due to overlapping of the activities o f irrigated crops with that of the rain-fed crop.

Both OLS and GWR analysis revealed that gross margin has been significantly (P=0.05) determined by population density (Figure7). On the contrary, costs of pesticides and fertilizer did not have significant impact on gross margin. There has been positive relationship between population density and gross margin in the northern and southern part of Ethiopia, while in the central and eastern part of the country population density had a negative impact on profitability of water harvesting (Figure 8). This is because there is more land available in the north and the south than the central and eastern part of the country.

The value of products from water harvesting has not been significantly determined by population density, while accessibility to Addis Ababa had significant impact on the value of water harvesting (Figure 9). Particularly, in the eastern part of the country access to Addis was very important, which had positive impact on value of water harvesting (Figure 10). In Figure 10, negative t-values should be considered as positive while positive values as negative, due to the fact that the unit of measurement is the time taken to a market place, which becomes short when there is high accessibility. Accordingly, access to markets was very crucial in the eastern part of the country.

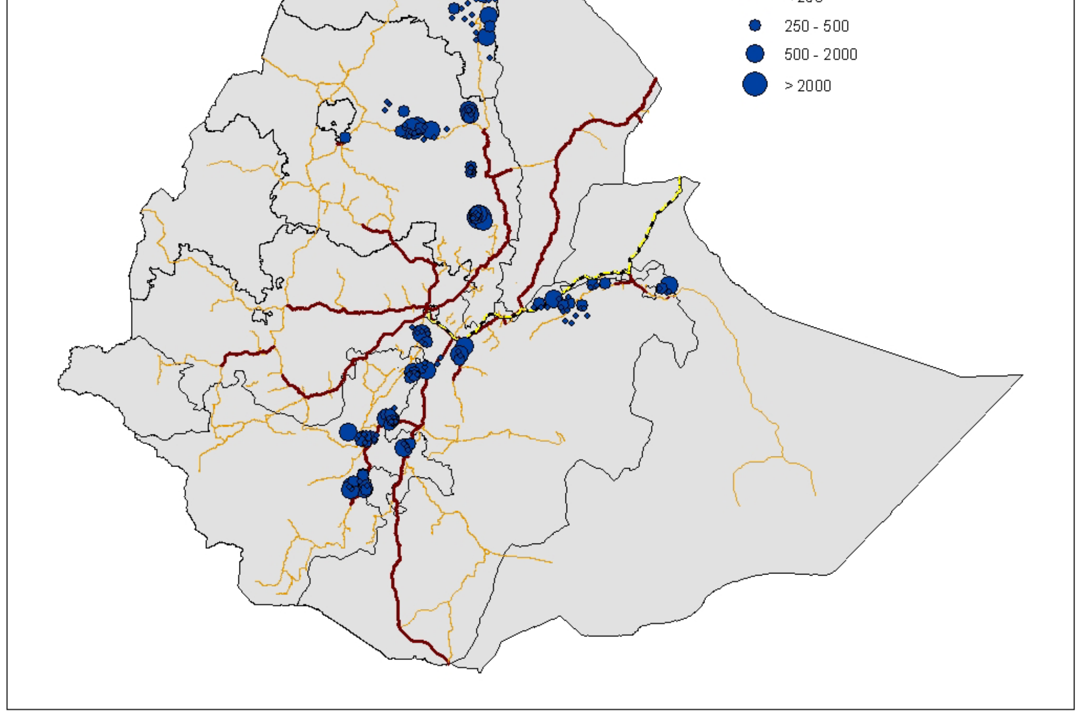
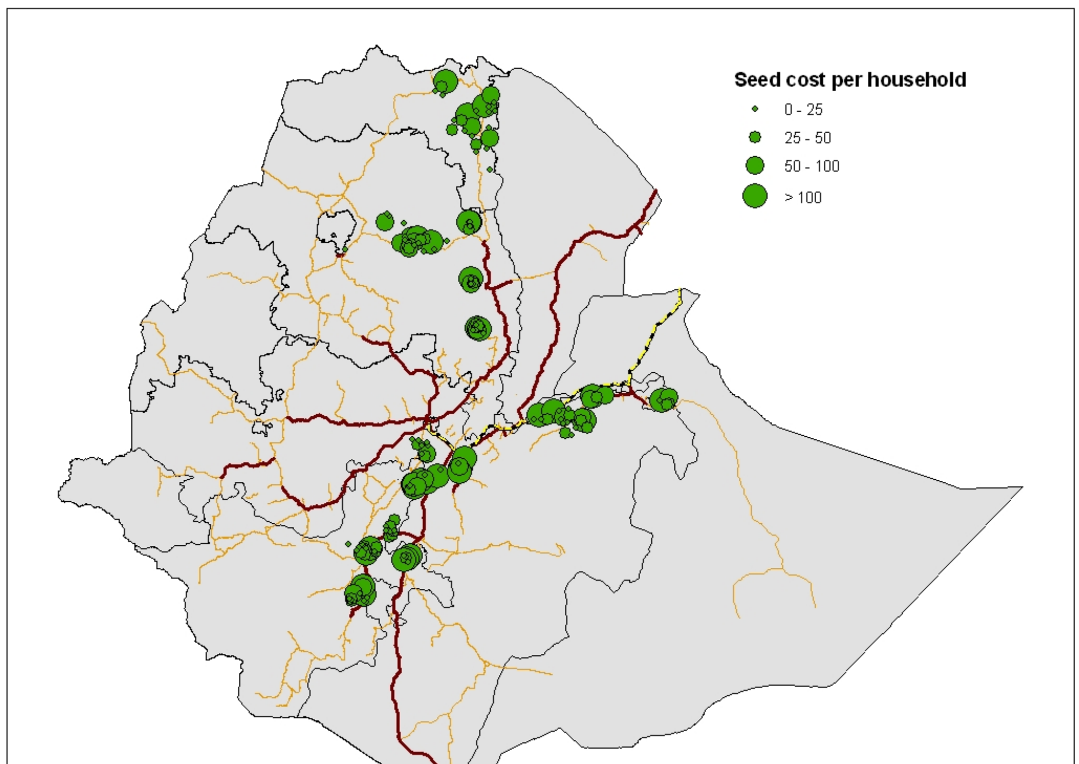


Figure 3 *Average cost of labour cost per household used for water harvesting*



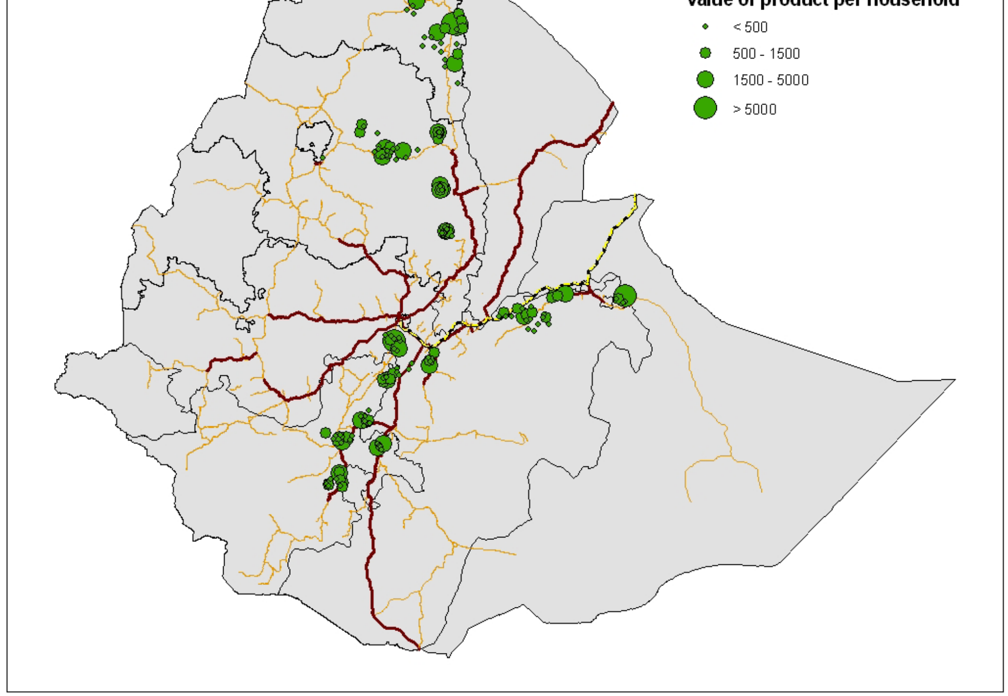


Figure 5 *Average value of product per household from water harvesting*

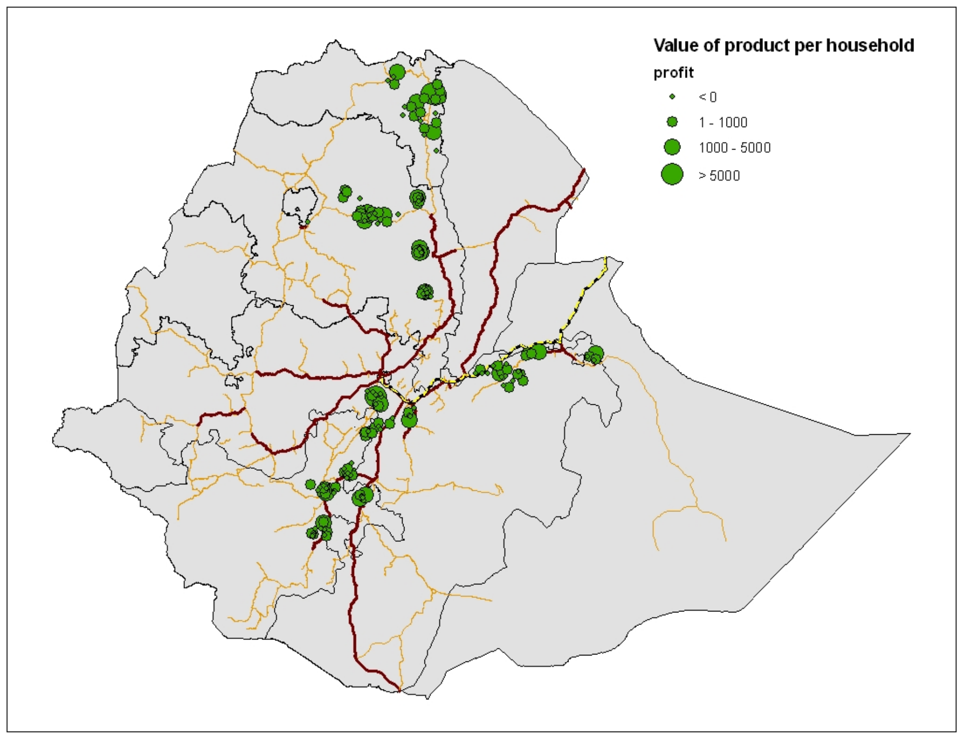


Figure 6 *Gross margin of water harvesting in the selected study areas*

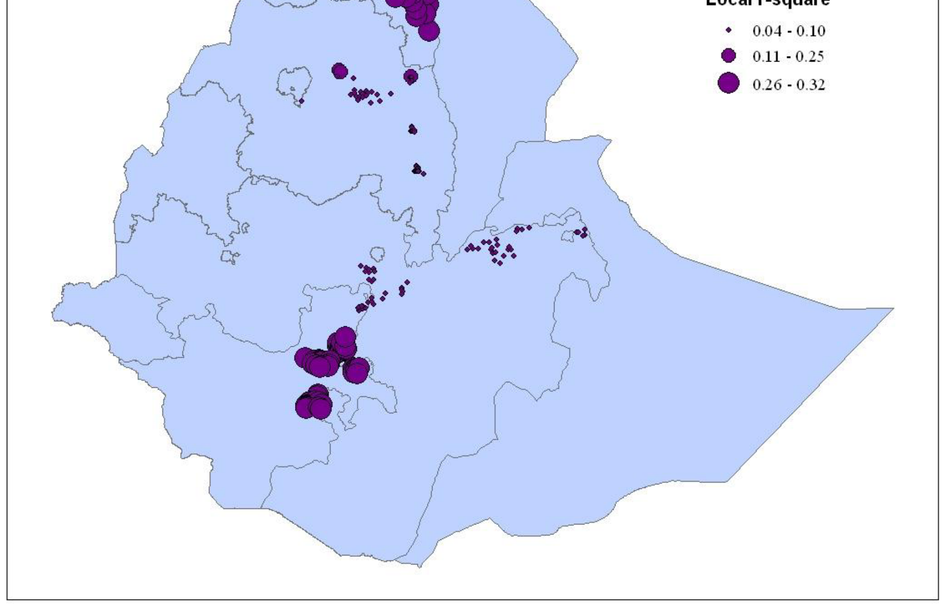


Figure 7 *GWR between profitability and population density*

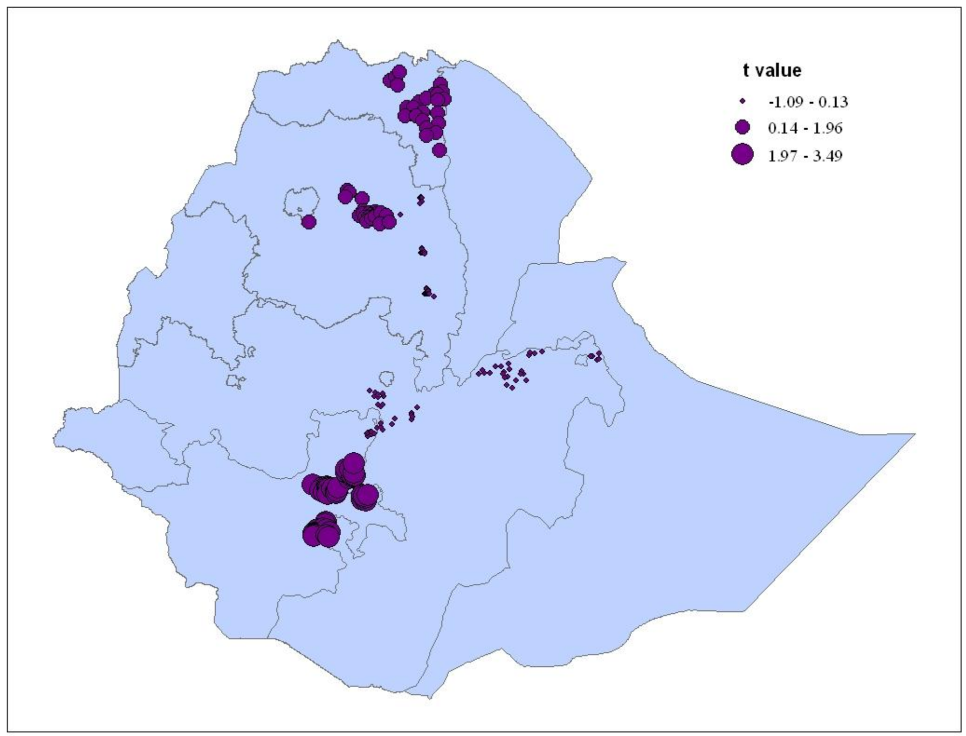


Figure 8 *t value for the GWR between profitability and population density*

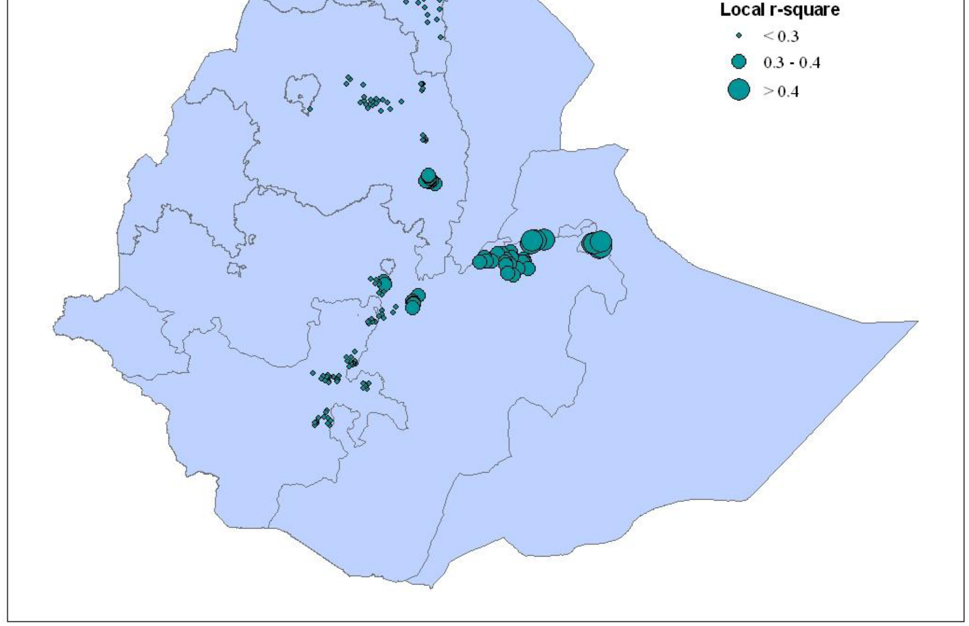


Figure 9 *Local r-square for GWR between value per hectare and accessibility to Addis Ababa*

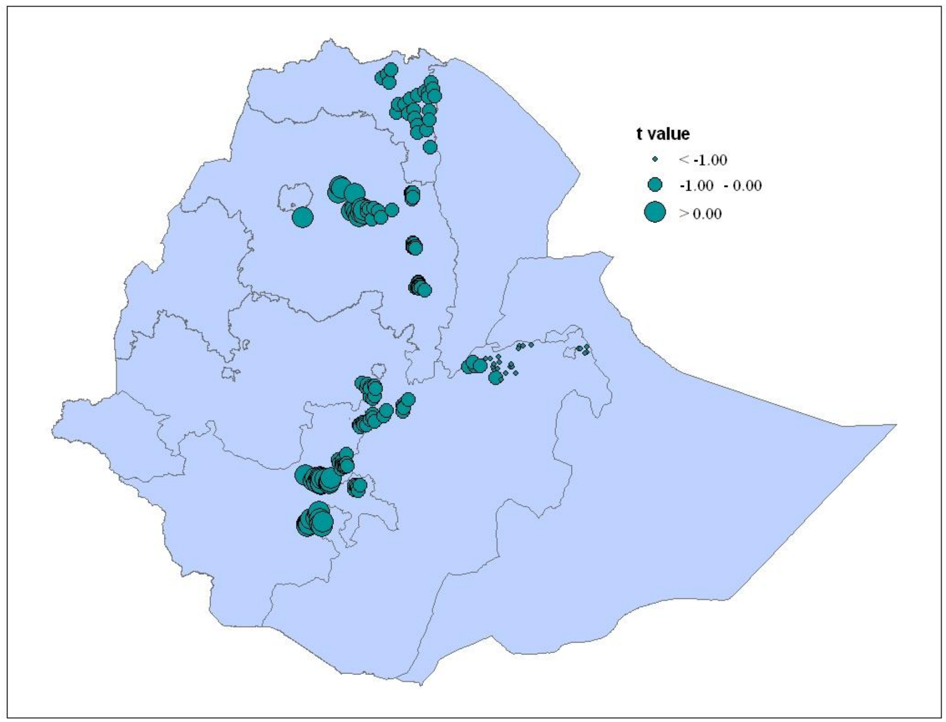


Figure 10 *t value for GWR between value per hectare and accessibility to Addis Abeba*

Conclusion

Critical consideration has not been given to amount and distribution of moisture in planning determined by population density. This implies that labour supply and cost of labour is very crucial factor in water harvesting.

Access to markets is more essential determinant of economic returns in eastern part of the country.

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Agricultural Water Management Technologies in Ethiopia

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Abstract

Farmers in rural Ethiopia live in a shock-prone environment. The major source of shock is considered to be the persistent fluctuation in the amount and distribution of rainfall. The dependence on rainfall increases farmers' vulnerability to shocks while also constraining farmers' decision to use yield-enhancing modern inputs. This exacerbates household's vulnerability to poverty and food insecurity. As a response, the government of Ethiopia has embarked on massive investment in low cost agricultural water management technologies (AWMTs). Despite these huge investments, their impact remains hardly understood.

The main focus of this paper is to explore whether adoption of selected AWMTs has led to significant reduction in poverty and inequality and if they did identify which technologies have higher impacts. To explore the impact of adoption on poverty we followed different approaches: mean separation tests, propensity score matching and poverty analysis. We used a unique dataset from a representative sample of 1517 households from 29 kebeles in four regions of Ethiopia for the study. Out findings indicated that there are significantly low poverty levels among users of AWMTs compared to non-users. We also found significantly lower inequality among users of AWMTs. Our study results also indicated that there is significant difference between technologies in terms of their poverty impact. Accordingly, deep wells, river diversions, and micro dams are the most promising technologies in terms of reducing poverty. On the other hand in-situ technologies do not seem to significantly contribute to poverty reduction. Finally, our study identified the most important determinants of poverty, besides access to AWMTs, on the basis of which important policy recommendations are drawn.

1. Introduction

Farmers in rural Ethiopia live in a shock-prone environment. The major source of shock is considered to be the persistent fluctuation in the amount and distribution of rainfall (Awulachew, 2006; Namara et al., 2006). The dependence on rainfall increases farmers' vulnerability to shocks while also constraining farmers' decision to use yield-enhancing modern inputs. This exacerbates household's vulnerability to poverty. Poverty in Ethiopia is, in fact, mainly rural in character (MoFED, 2006). Small-scale farmers are the largest group of poor people in Ethiopia (MoFED, 2006). As a response, the government of Ethiopia has developed after 2002/2003. There are currently an estimated 56,032 ha is of modern small scale schemes in Ethiopia, comprising micro dams and river diversions (Awulachew et al. 2007). This has required huge financial input from the government, whose food security budget has increased from year to year to promote different types of water harvesting technologies. Despite these huge investments, their impact remains hardly understood save the anecdotal evidences gathered here and there (Rämi, 2003).

The CA of Water Management in Agriculture (IWMI, 2007) states that "Improving access to water and productivity in its use can contribute to greater food security, nutrition, health status, income and resilience in income and consumption patterns. In turn, this can contribute to other improvements in financial, human, physical and social capital simultaneously alleviating multiple dimensions of poverty" (P.149). While evidence on the impact of irrigation on poverty is plenty (Hussain, 2007; Huang, et al., 2006) there is scarcity of evidence in the literature that a qualified discussion of the impact of different forms of AWMTs. The few existing evidences from elsewhere seem to support that. Namara et al., (2007) and Narayanamoorthy, A., (2007), both from India looking into the poverty impact of micro-irrigation and ground water irrigation respectively, documented significant impact on household wellbeing by increasing household food production and income.

In this study, we explored whether adoption of AWM technologies has led to such improvements and if so we identified which technologies have relatively higher impact. We used welfare indicators such as per capita income and expenditure per adult equivalent to measure these improvements. To explore the impact of adoption of AWMT on poverty we used simple and complex statistical techniques ranging from simple mean separation tests, estimation of average treatment effects using propensity score matching and poverty analysis (more on this later). Hence, the paper quantified the effect on poverty of successfully adopting AWMT. We analyzed the state of poverty and inequality among sample farm households with and without access to agricultural water management technologies while also understanding the correlates of poverty using a multivariate regression model. The paper also quantified the average treatment effect of using AWMTs.

We used a unique household level data of 1517 households from 29 kebelles (also known as peasant associations) in 4 regional states in Ethiopia, where these technologies are widely used. The survey was conducted during Oct-Dec. 2007. The paper is organized as follows. First we introduce the definitions and procedures followed to measure poverty. Section three outlines the methodological approaches used in this paper to measure impact. In section four we present statistical summary and mean separation test results of important variables; the findings of the matching econometrics; and the poverty estimates and their decomposition by different socio-economic variables, and stochastic dominance tests and inequality measures. Section five presents the results of the determinants of poverty analysis from a multivariate regression analysis. The final part concludes and draws policy recommendations.

2. Definition of concepts

political and social rights, lack of empowerment to make or influence choices, inadequate assets, poor health and mobility, poor access to services and infrastructure, and vulnerability to livelihood failure (World Bank, 2001).

Often distinction is made between absolute and relative poverty. Relative poverty measures the extent to which a household's income falls below an average income threshold for the economy. Absolute poverty measures the number of people below a certain income threshold or unable to afford certain basic goods and services. Absolute poverty is a state in which one's very survival is threatened by lack of resources. Consideration is also necessary of the dynamics of both chronic and transient poverty, and of the processes which lead people to escape from or fall into and remain trapped in poverty (Carter et al., 2007). Another related concept is equity, which is usually understood as the degree of equality in the living conditions of people, particularly in income and wealth, that a society deems desirable or tolerable. Thus equity is broader than poverty and is defined over the whole distribution, not only below a certain poverty line. The meaning of equity encapsulates ethical concepts and statistical dispersion, and encompasses both relative and absolute poverty. Hence, ideally any assessment of poverty impact must consider impacts on these varied dimensions of poverty and their interactions (Namara et al., 2007b).

Nevertheless, while recognizing that poverty is a multidimensional phenomenon consisting of material, mental, political, communal and other aspects, the material dimensions of poverty expressed in monetary values is too important an aspect of poverty to be neglected (Lipton, 1997). Given the fact that there is 'a lack of consensus regarding the measurement of other forms of deprivation', the approach followed in this paper is ultimately grounded on the notion of some minimum threshold below which the poor are categorized (Lipton, 1997). There is growing recognition that poverty may adequately be defined as private consumption that falls below some absolute poverty line. This is best measured by calculating the proportion of the population who fall below a poverty line (the headcount) and the extent of shortfall between actual income level and poverty line (the depth or severity of poverty). The poverty line is usually based on an estimated minimum dietary energy intake, or an amount required for purchasing a minimum consumption bundle.

3. Methodological Issues

Data sources

This study is part of a comprehensive study on Agricultural Water Management Technologies in Ethiopia. The study includes inventory of Agricultural Water Management Technologies and Practices in Ethiopia and assessment of the poverty impacts of most promising technologies. The study was conducted during Oct- Dec. 2007 and was implemented by the International Water Management Institute (IWMI) with support from USAID. The socio-economic survey data, on which this paper is based on, is gathered from a total sample of 1517 households from 29 study sites (peasant associations) in 4 Regional states. The PAs were selected based on the presence of identified promising technologies. Then the households from each PA were selected based on the criterion of their access to

	rainfed		wells	wells	diversion	dams	
Amhara	281	8	45	10	28	13	5
Oromia	219	12	23	68	68	1	2
SNNPR	217	68	55	0	14	25	0
Tigray	143	47	91	1	40	35	18
Total	**860**			**657**			

Assessing poverty impact

The poverty impacts of AWMT were assessed using simple and complex statistical techniques. The simple statistical techniques involved using simple mean separation tests on key variables (per capita income, expenditure per adult equivalent, income from cash crop sales, perceived changes in food security, farm input use and asset holding). We also examined the impact of AWMT on household well being, where well being is measured as per capita household income, using matching econometric techniques. Finally we undertook poverty analysis using well established poverty analysis techniques to explore whether those with access to AWT are relatively better-off compared to those without access. We briefly describe the matching and poverty and inequality analysis approaches used below.

Propensity score matching

One of the problems of assessing impact is to find comparable groups of treated and control groups, i.e. users and non-users of AWMT. Matching econometrics provides a promising tool to do just that while estimating the average treatment effects (Ravallion, 2004).

Matching is a method widely used in the estimation of the average treatment effects of a binary treatment on a continuous scalar outcome. It uses non-parametric regression methods to construct the counterfactual under an assumption of selection on observables. We think of having access to AWM technologies as a binary treatment, income per capita as an outcome, and households having these technologies as treatment group and non-user households as control group. Matching estimators aim to combine (match) treated and control group households that are similar in terms of their observable characteristics in order to estimate the effect of participation as the difference in the mean value of an outcome variable.

Following the literature of program evaluation, let Y_1 is the per capita income when household i is subject to treatment $(C=1)$ and Y_0 the same variable when a household is exposed to the control $(C=0)$. The observed outcome is then

$$Y = CY_1 + (1-C)Y_0 \tag{1}$$

When $C=1$ we observe Y_1; when $C=0$ we observe Y_0. Our goal is to identify the average effect of treatment (using AWMT) on the treated (those households who have access to the technologies) (ATT). It is defined as

$$ATT = E(Y_1 - Y_0 | C=1) = E(Y_1 | C=1) - E(Y_0 | C=1) \tag{2}$$

literature is that no-treatment state approximates the no program state[4]. For matching to be valid certain assumptions must hold. The primary assumption underlying matching estimators is the Conditional Independence Assumption (CIA). CIA stated that the decision to adopt is random conditional on observed covariates X. In notation,

$$(Y_1, Y_0) \perp C | X \tag{3}$$

This assumption imply that the counterfactual outcome in the treated group is the same as the observed outcomes for non-treated group

$$E(Y_0|X, C=1) = E(Y_0|X, C=1) = E(Y_o|X) \tag{4}$$

This assumption rules out selection into the program on the basis of unobservables gains from access. The CIA requires that the set of X's should contain all the variables that jointly influence the outcome with no-treatment as well as the selection into treatment. Under the CIA, ATT can be computed as follow:

$$ATT = E(Y_1 - Y_0|X, C=1) = E(Y_1|X, C=1) - E(Y_0|C=1) \tag{5}$$

Matching households based on observed covariates might not be desirable or even feasible when the dimensions of the covariates are many. To overcome the curse of dimensionality, Rosenbaum and Rubin (1983) show that instead of matching along X, one can match along $P(X)$, a single index variable that summarizes covariates. This index is known as propensity score (response probability). It is the conditional probability that household i adopts AWMT given covariates:

$$p(X) = pr(C=1)|X \tag{6}$$

The ATT in equation (5) can then be written as

$$\text{ATT} = E(Y_1|P(X), C=1) - E(Y_0|P(X), C=1) \tag{7}$$

The intuition is that two households with the same probability of adoption will show up in the treated and untreated samples in equal proportions. The propensity score (pscore) is estimated by a simple binary choice model; in this paper a binary Logit model is used. Once the pscore is estimated, the data is split into equally spaced intervals of the pscore. Within each of these intervals the mean pscore and of each covariate do not differ between treated and control plots. This is called the balancing property. For detail algorithm of pscore matching see Dehejia and Wahba (2002). If the balancing property is not satisfied higher order and interaction terms of covariates can be considered until it satisfied. Since pscore is a continuous variable exact matches will rarely be achieved and a certain distance between treated and untreated households has to be accepted. To solve this problem treated and control households are matched on the basis of their scores using nearest neighbour, kernel and stratification matching estimators. These methods identify for each household the closest propensity score in the opposite technological status; then it computes investment effect as the mean difference of household's income between each pair of matched households. For

Poverty analysis

When estimating poverty following the moneymetric approach to measurement of poverty, one may have a choice between using income or consumption as the indicator of well-being. Most analysts argue that, provided the information on consumption obtained from a household survey is detailed enough, consumption will be a better indicator of poverty measurement than income for many reasons (Coudouel et al. 2002). Hence, in this paper we estimate poverty using expenditure adjusted for differences in household characteristics.

We used the Foster-Greer-Thorbecke (FGT) class of poverty measures to calculate poverty indices. The FGT class of poverty measures have some desirable properties (such as additive decomposability), and they include some widely used poverty indices (such as the head-count and the poverty gap measures). Following Duclos et al. (2006), the FGT poverty measures are defined as

$$\mathrm{P}(z;\alpha)=\int_0^1\left(\frac{g(p;z)}{z}\right)^{\alpha}dp \qquad (8)$$

where z denotes the poverty line, and α is a nonnegative parameter indicating the degree of sensitivity of the poverty measure to inequality among the poor. It is usually referred to as poverty aversion parameter. Higher values of the parameter indicate greater sensitivity of the poverty measure to inequality among the poor. The relevant values of α are 0, 1 and 2.

At α =0 equation 8 measures poverty incidence or the head count ratio. This is the share of the population whose income or consumption is below the poverty line, that is, the share of the population that cannot afford to buy a basic basket of goods, food or non-food or both depending on which one is interested in.

At α =1 equation 8 measures depth of poverty (poverty gap). This provides information regarding how far off households are from the poverty line. This measure captures the mean aggregate income or consumption shortfall relative to the poverty line across the whole population. It is obtained by adding up all the shortfalls of the poor (assuming that the non-poor have a shortfall of zero) and dividing the total by the population. In other words, it estimates the total resources needed to bring all the poor to the level of the poverty line (divided by the number of individuals in the population). Note also that, the poverty gap can be used as a measure of the minimum amount of resources necessary to eradicate poverty, that is, the amount that one would have to transfer to the poor under perfect targeting (that is, each poor person getting exactly the amount he/she needs to be lifted out of poverty) to bring them all out of poverty (Coudouel et al. 2002).

At $\alpha = 2$ equation 1 measures poverty severity or squared poverty gap. This takes into account not only the distance separating the poor from the poverty line (the poverty gap), but also the inequality among the poor. That is, a higher weight is placed on those households further away from the poverty line.

We calculated these indices using STATA 9.0 and tested for difference between poverty profiles between groups following approaches suggested by Kwakani (1993) and Davidson and the percentile ratios, among others.

The inequality indices differ in their sensitivities to income differences in different parts of the distribution. The more positive *a* is, the more sensitive GE (a) is to income differences at the top of the distribution; the more negative *a* is, the more sensitive it is to differences at the bottom of the distribution[5]. In the Atkinson inequality index, the more positive, i.e. $e > 0$ (the 'inequality aversion parameter') is, the more sensitive A (*e*) is to income differences at the bottom of the distribution. The Gini coefficient is most sensitive to income differences about the middle (more precisely, the mode) (for details see Litchfield, 1999; Deaton, 1997). To assess the inequality among the different farm household groups, we calculated the Atkinson class A (*e*); the Gini-coefficient, and the percentile ratios on consumption expenditure per adult equivalent, disaggregated by their access to different AWMT.

In summary the analysis of poverty and inequality followed six steps. First, we have chosen household consumption expenditure as welfare measure and this was adjusted for the size and composition of the household. Second, the consumption poverty line is set at 1821.05 Birr (1USD=9.2 Birr), an inflation-adjusted poverty line of the baseline poverty line of ETB 1075 set in 1995/96 as measure of welfare corresponding to some minimum acceptable standard of living in Ethiopia (MOFED, 2006). We also used an inflation-adjusted poverty line of 1096.03 as absolute food poverty line based on the corresponding 1995/96 food poverty line. These lines were chosen to enable meaningful comparison of poverty levels in Ethiopia between various groups and over time (in reference to earlier studies). The poverty line acts as a threshold, with households falling below the poverty line considered poor and those above the poverty line considered non-poor. Third, after the poor has been identified, poverty indices such as head count, poverty gap and poverty gap squared were estimated. Fourth, we constructed poverty profiles showing how poverty varies over population subgroups (example users Vs non-users) or by other characteristics of the household (for example, level of education, age, asset holding, location, etc.). The poverty profiling is particularly important as what matters most to policymakers is not so much the precise location of the poverty line, but the implied poverty comparison across subgroups or across time. We undertook ordinal poverty comparisons using stochastic dominance tests to test the robustness of the poverty orderings. This is important because the estimation of the poverty line could be influenced by measurement error. Furthermore, we analyzed income inequality among sample households by their access to AWMT. Lastly, we explored the determinants of poverty using multivariate regression analysis. We analyzed the correlates of poverty against household and demographic factors, specific individual/household head characteristics, asset holdings including adoption of and use AWM technologies, village level factors, and policy related variables (access to services). By doing so, the marginal impact of access to AWM technologies on poverty was assessed while controlling for other possible covariates.

4.1 Summary and separation tests

We report the results of the mean separation tests of important variables for users and non-users. This statistical test result could serve as some indicative measures of the differences in important variables between users and non-users, which may be considered as indicative measures of the impact of access to AWMT. However, we will be required to do a more systematic analysis of impact before we could draw definite conclusions on impact of access to AWMT. Accordingly, we found statistically significant difference in mean values of important variables as reported in Table 2 below.

As could be seen from the mean separation test, there is statistically significant difference ($p < 0.000$) in agricultural income (both crop and livestock) among users and non-users of AWMT. Those with access to AWMT were also found to have significantly higher share of their produce supplied to the market ($p<0.000$) implying increased market participation. Furthermore, those with access to AWMT have higher use of farm inputs. Accordingly, the value of fertilizer, seed, labor and insecticide use and the size of loan from microfinance institutions are significantly higher for users compared with non-users. This may imply that because of access to AWMT, there is increased intensification of agriculture. This is expected to have wider economy wide effects e.g. on input and factor markets. Surprisingly, users were also found to have significantly higher asset endowments such as male adult labor, oxen, livestock (in TLU) and land holding, which may imply that those with access to AWMT have managed to build assets. On the other hand, it may also mean that households with better resource endowments may been targeted by the program (or due to self-selection) secured access AWMT, an issue we may not be able to tell in the absence of baseline data.

Table 2 *Mean separation tests of some important variables of households with access and without access to AWMT*

Variable name	Non-user of AWMT (n= 641)	User AWMT (n= 876)	p-value*
	Mean (SE)	Mean (SE)	
Value of fertilizer used	274.9 (27.0)	399.5 (32.7)	0.0053
Value of seed used	272.1 (31.1)	698.1 (204.1)	0.0762
Value of labor used	600.9 (34.7)	1114.3 (67.6)	0.0000
Value of insecticide used	19.6 (3.1)	75.4 (19.7)	0.0161
Loan size (cash)	1293.4 (108.0)	1688.9 (102.5)	0.0083
Crop income	302.3 (16.4)	682.5 (57.0)	0.0000
Livestock income	51.6 (5.37)	67.3 (4.25)	0.0201
Agricultural income	352.9 (7.2)	749.7 (57.2)	0.0000
Non-farm income	63.7 (4.36)	67.0 (4.95)	0.6276
Consumption expenditure per adult equivalent (monthly)	39.2 (4.46)	40.8 (3.71)	0.7739
Face food shortage	0.373 (0.019)	0.354 (0.016)	0.4475
Market share	0.07 (0.01)	0.15 (0 .012)	0.0000
Oxen units	1.18 (0.047)	1.71 (0.055)	0.0000
Livestock units (in TLU)	3.27 (0.113)	4.64 (0.15)	0.0000
Land holding in (timad)	5.12 (0.163)	7.143 (0.19)	0.0000
Labor endowment (adult labor)	2.961 (0.059)	3.054 (0.051)	0.2340

The problem with such mean separation tests is non-comparability of the two sub-samples and that we did not control for the effect of other covariates. Hence, we will systematically analyze if access to AWMT has led to significant effects on income and poverty using matching (by creating comparable groups) and up to date poverty analysis techniques in the subsequent sections.

4.2 Average Treatment effects

The matching estimates where the treated and control households are matched on the basis of their scores using nearest neighbor, kernel methods and stratification matching estimators, show that there is significant effect on household income from owning AWMT. Important to note is that out of the 1517 households only about 947 are comparable (see Table 3). The estimated ATT is also positive in all the cases and is about ETB 780. This indicated that access to AWMT technologies leads to significant increase in per capita income.

Table 3 *Results of matching method to measure impact of AWMT on household income (bootstrapped standard errors)*

Kernel Matching method			
Treatment (n)	**Control (n)**	**ATT**	**t-test**
699	394	788.674 (218.78)	3.605***
Nearest Neighbor Matching method			
699	247	760.048 (255.73)	2.972***
Stratification method			
699	394	785.326 (227.53)	3.451***

We now turn to poverty analysis using consumption expenditure per adult equivalent.

4.3. Poverty profiles and decomposition

Using the absolute overall poverty line of ETB 1821.05, about 48 percent of the individuals in user households have been identified as poor. On the other hand, about 62 percent of the individuals in non-users were identified as poor. The test results also show that there is significant difference in poverty levels between users and none users. Our calculation shows that there is about 22% less poverty among users compared to non-users. In other words, individuals with access to AWMT are in a better position to meet their consumption requirements, food and non-food. There is also significant difference in poverty gap and severity of poverty among users and non-users, implying that access to AWMT are effective instruments to narrow the poverty gap and inequality (see Table 4). However, this also implies that the level of poverty has increased compared to baseline overall poverty of about 39 % in 2004/05 (MoFED, 2006; p. 23) calculated based on poverty line of ETB 1,075. However, we feel that this seemingly significant increase in poverty has to do with the failure to adjust the poverty line to account for price changes in the cited document.

	value	SE	Value	SE	Value	SE
Access to AWMT						
Users (n= 876)	0.478	0.017	0.198	0.009	0.1110	0.007
Non-users (n= 641)	0.623	0.018	0.282	0.011	0.167	0.009
z-statistic[*]	-484.2***		-381.6***		-282.0***	
Types AWMT[6]						
Pond (n= 196)	0.561	0.035	0.218	0.017	0.107	0.011
z-statistic[7]	-193.5***		-170.8***		-146.2***	
Shallow wells (n= 251)	0.565	0.031	0.266	0.019	0.168	0.016
z-statistic	-233.0***		-172.3***		122.1***	
Deep wells (n=93)	0.312	0.048	0.113	0.021	0.0550	0.013
z-statistic	-109.2***		-107.8***		-98.0***	
River diversion (n= 291)	0.403	0.029	0.1440	0.013	0.071	0.009
z-statistic	-258.0***		-235.5***		-189.0***	
Micro-dams (n= 63)	0.484	0.063	0.1910	0.032	0.101	0.022
z-statistic	-71.6***		-63.0***		-53.3***	
In-situ technologies						
Users (n= 368)	0.614	0.025	0.253	0.014	0.141	0.0110
Non-users (n= 373)	0.521	0.0148	0.2300	0.008	0.134	0.007
z-statistic	-296.2***		-220.9***		-150.5***	
Water application technologies[8]						
Flooding (n= 533)	0.429	0.021	0.159	0.010	0.079	0.007
Manual (n= 284)	0.567	0.029	0.274	0.018	0.171	0.015
Water withdrawal						
Treadle pump (n=101)	0.524	0.049	0.183	0.023	0.088	0.014
z-statistic	-111.0***		-103.4***		-63.4***	
Motor pump (n=127)	0.228	0.037	0.068	0.0135	0.027	0.007
z-statistic	-155.7***		-172.7***		-171.0***	
Water input						
Supplementary (n= 270)	0.56	0.030	0.262	0.18	0.16	0.15
z-statistic	-245.0***		-24.5***		-17.4***	
Full irrigation (n= 579)	0.437	0.020	0.16	0.009	0.077	0.006
z-statistic	-322.7***		-287.0***		-231.7***	

We disaggregated users by the type of AWMT to measure the poverty impact of specific technologies. As could be seen from the reported results, all ex-situ technologies considered in this study were found to have significant poverty reducing impacts. However, deep wells, compared to the reference, i.e. rain fed system. On the other hand, use of in-situ AWMT was found to have no significant poverty reducing impacts. On the contrary, those using in-situ AWMT are found to have higher poverty levels in terms of the head count, poverty gap and severity of poverty indices. We do not have any *a priori* reason for this result and studying-situ conservation measures were hitherto used as mere soil conservation measures.

We also considered disaggregating poverty levels by type of water withdrawal and application technologies. The most common withdrawal and application mechanisms include gravity flooding (63.30 %), manual (33.7 %), treadle pump (6.66 %), and motor pump (8.37 %). Sprinkler (0.20 %) and drip (0.20%) are hardly practiced although there are signs of households picking up gradually. Accordingly, those using motor pumps have significantly lower poverty level compared to treadle pump users. In fact as a result of using motorized pumps, there is more than 50 percent reduction in the incidence of poverty mainly due to scale benefits. As far as, water application technologies are concerned, households using gravity were found to have significantly lower poverty levels compared to those using manual (using cans) applications. Furthermore, we disaggregated poverty by the type of water use, that is whether water is used for supplementary or full irrigation. Our results show that those who use AWMT for full irrigation have significantly lower poverty levels compared to those using supplementary and non-users. This implies that supplementary irrigation could contribute to poverty reduction; a significant contribution comes, however, from full irrigation. This will have an important implication on technology choice for an effective poverty reduction.

We also estimated poverty profiles using an absolute food poverty line of ETB 1096.02. Accordingly, 23 percent of the users and 34 percent of the non-users respectively are identified as food poor. These indices could be taken as food security indices. This implies that the level of food security has increased compared to 38% in 2004/05 (MoFED, 2006; p. 27) calculated based on poverty line of ETB 647.81. However, we feel that the food poverty line used should have been adjusted to account for price changes to make meaningful comparisons.

When disaggregated by type of AWMT, as in the case of overall poverty, deep wells, river diversion and micro dams have relatively higher impact on reducing food poverty. Ponds and wells, although have led to significant reduction (compared to non-users), they have relatively lower poverty reducing impacts. However, in-situ AWMT have not led to significant reduction to food insecurity.

	value	SE	Value	SE	Value	SE
Access to AWMT						
Users (n= 876)	0.2340	0.015	0.086	0.007	0.049	0.005
Non-users (n= 641)	0.349	0.018	0.137	0.009	0.081	0.007
z-statistic*	-286.4***		-231.3***		-181.8***	
Types AWMT						
Pond (n= 196)	0.275	0.032	0.071	0.011	0.028	0.006
z-statistic[9]	-116.2***		0.00		-144.9***	
Shallow wells (n= 251)	0.311	0.029	0.143	0.017	0.094	0.014
z-statistic	-137.0***		0.0		-69.7***	
Deep wells (n= 93)	0.151	0.037	0.0380	0.0130	0.017	0.008
z-statistic	-3.8***		0.0		-73.2***	
River diversion (n= 291)	0.158	0.021	0.047	0.008	0.023	0.006
z-statistic	-179.6***		0.0		-128.9***	
Micro-dams (n= 63)	0.234	0.053	0.081	0.022	0.039	0.014
z-statistic	-47.0***		0.0		-39.7***	
In-situ technologies						
Users (n= 368)	0.302	0.024	0.111	0.012	0.062	0.009
Non-users (n= 373)	0.279	0.013	0.109	0.007	0.064	0.005
z-statistic	-156.7***		-117.2***		-85.1***	
Water application technologies						
Flooding (n= 533)	0.176	0.016	0.056	0.006	0.027	0.005
Manual (n= 284)	0.341	0.028	0.144	0.015	0.091	0.0128
Water Withdrawal technologies						
Treadle pump (n=101)	0.227	0.042	0.062	0.013	0.020	0.005
z-statistic	-490.7***		0.1		-104.6***	
Motor pump (n= 127)	0.0470	0.019	0.014	0.007	0.006	0.003
z-statistic	-490.8***		0.0		-149.3***	
Water input						
Supplementary (n= 270)	0.333	0.028	0.138	0.016	0.086	0.013
z-statistic	-496.6***		0.1		-75.8***	
Full irrigation (n= 579)	0.174	0.0158	0.053	0.006	0.025	0.004
z-statistic	-490.7***		0.1		-155.8***	

When we disaggregate food poverty levels by type of water withdrawal and application technologies, those using motor pumps have significantly lower poverty level compared to treadle pump users and gravity flooding irrigators have also significantly lower poverty levels compared to manual users. Furthermore, households using AWMT for full irrigation have relatively lower food poverty compared to those using water for supplementary irrigation.

poverty profiles of households by other socio-economic variables. We used variables such as sex of the household head, education status of the head, asset holding (mainly labor, farm and oxen holding) and access to services like formal credit and location dummies (in this case regions). We tested for differences in poverty across socio-economic groups using statistical tests. The results are reported in Table 6.

The regional decomposition of poverty shows that users of AWMT in Oromia and Amhara have significantly lower poverty levels in incidence, depth and severity of poverty compared to users in Tigray and SNNPR. This may show the successful use of AWMT in Oromia and Amhara having significant impact on poverty reduction. Not surprisingly, poverty seems to be closely related to asset holding. Households with oxen holding greater or equal to the mean holding displayed significantly lower poverty levels. Ox holding is considered an important economic asset not only because it is a major source of traction power but also a source of saving and social prestige in Ethiopia. Similarly, households with operated farm holding greater than the mean holding, depicted lower poverty levels than those having farm holding less than the mean. Female-headed households have apparently higher poverty levels in terms of the incidence, depth and severity of poverty.

Table 6 *Poverty decomposition by other socio-economic variables (users only and poverty line = ETB 1821.05)*

Variables	Incidence ($\alpha = 0$)		Depth ($\alpha = 1$)		Severity ($\alpha = 2$)	
	value	SE	Value	SE	Value	SE
Tigray region (n= 244)	0.606	0.031	0.215	0.015	0.102	0.009
z-statistic	-230.5***		-202.0***		-179.3***	
Amahra region (n= 273)	0.329	0.028	0.117	0.012	0.056	0.008
z-statistic	-258.7***		-2.42.8***		-198.9***	
Oromia region (n= 190)	0.258	0.032	0.081	0.012	0.036	0.007
z-statistic	-205.2***		-216.0***		-193.4***	
SNNPR region (n= 169)	0.810	0.030	0.446	0.026	0.301	0.023
z-statistic	-205.6***		-115.4***		-78.6***	
Female-headed (n= 81)	0.568	0.055	0.205	0.028	0.107	0.020
Male-headed (n= 768)	0.463	0.018	0.191	0.009	0.106	0.007
z-statistic	-67.9***		-55.4***		42.8***	
Education level of head						
Illiterate (n= 787)	0.59	0.175	0.27	0.011	0.162	0.008
Informal education (n= 239)	0.47	0.03	0.174	0.015	0.085	0.009
z-statistic	-56.9***		-127.4***		-0.2***	
Primary complete (n= 327)	0.49	0.027	0.203	0.015	0.119	0.012
z-statistic	-62.8***		-165.9***		-125.3***	
Junior complete (n= 119)	0.48	0.046	0.20	0.024	0.106	0.017
z-statistic	-45.3***		-76.9***		-57.3***	
10 & above complete (n= 29)	0.44	0.094	0.187	0.055	0.121	0.046
z-statistic	-18.0***		-17.4***		-13.7***	
Primary occupation						
Farming (n= 834)	0.48	0.017	0.195	0.009	0.11	0.006
Non-farming (n= 33)	0.57	0.087	0.28	0.049	0.158	0.034
z-statistic	-35.7***		-31.5***		-25.7***	

Below average (n= 691)	0.48	0.02	0.18	0.009	0.092	0.006
Above average (n= 826)	0.59	0.17	0.28	0.011	0.174	0.008
z-statistic	-89.6***		-390.3***		-343.4***	
Variables	Incidence ($\alpha = 0$)		Depth ($\alpha = 1$)		Severity ($\alpha = 2$)	
	value	SE	Value	SE	Value	SE
Labor holding (male)						
Below average (n= 568)	0.64	0.02	0.29	0.012	0.175	0.010
Above average (n= 949)	0.48	0.016	0.202	0.008	0.113	0.006
z-statistic	-352.5***		-264.2***		-183.8***	
Credit access						
With access (n= 447)	0.52	0.023	0.226	0.003	0.131	0.010
Without access (n= 1070)	0.55	0.015	0.240	0.008	0.139	0.006
z-statistic	-355.1***		-620.8***		-211.6***	

Education was also found to have significant effect on poverty levels of users. Accordingly, households with heads that have informal training or higher educational attainment have lower poverty levels compared to illiterate heads. There is also a significant difference in incidence, depth and severity of poverty depending on whether households have access to formal credit. This may have to do with the fact that households with access to AWMT may use credit to purchase farm inputs. Perhaps surprisingly, households whose primary occupation is farming have significantly lower poverty in terms of the incidence, depth and severity of poverty compared to those having non-farming as their primary occupation. The later mainly constitute landless farmers who make a living mainly from off/non-farm employment though they are also engaged in agricultural by renting in/sharecropping in land.

4.5 Dominance tests

Poverty comparisons can, however, be sensitive to the choice of the poverty line. The important issue in poverty analysis is that the poverty line yields consistent comparisons (Ravallion, 1994). Stochastic tests to test the robustness of ordinal poverty comparisons prove to be useful in poverty analysis (Atkinson, 1987). The idea of standard welfare dominance is to compare distributions of welfare indicators in order to make ordinal judgment on how poverty changes (spatially, inter-temporally or between groups) for a class of poverty measures over a range of poverty lines (Ravallion, 1994; Davidson and Duclos, 2000). Hence, we need to undertake ordinal poverty comparisons using stochastic dominance tests to test the robustness of the poverty orderings. The idea here is to make ordinal judgments on how poverty changes for a wide class of poverty measures over a range of poverty lines.

Comparing the head count ratios between users and non-users of AWMT, the different orders of stochastic dominance tests established unambiguously that poverty is significantly lower among users compared to the non-users (Figure 1). This confirms that the incidence of poverty is significantly lower among users compared with non-users.

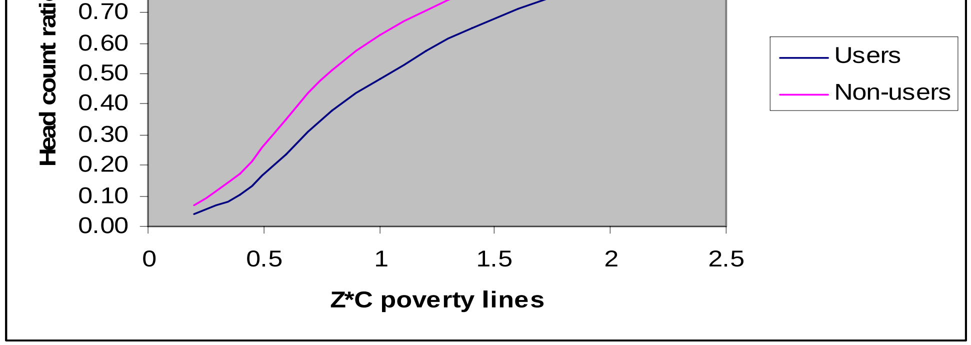

Figure 1 *First-order stochastic dominance*

Similarly, in terms of the depth and severity of poverty, the second and third order stochastic dominance tests showed that there was a significant difference in poverty gap and severity between users and non-users (see Figures 2 and 3). The results are robust for the different poverty lines considered. Hence, we could conclude that access to AWMT has led to significant reduction in poverty. More interestingly, AWMT are not only poverty reducing but also inequality reducing, as could be seen from the third order stochastic dominance.

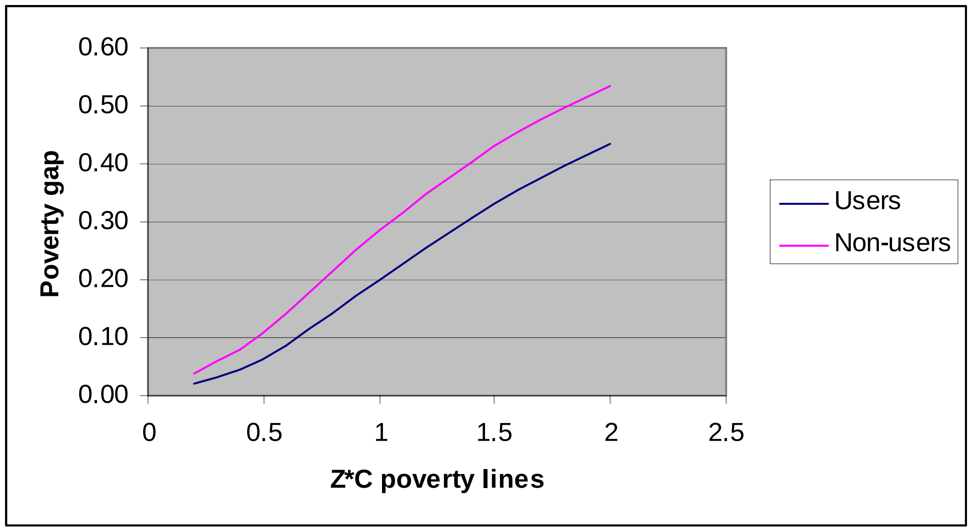

Figure 2 *Second-order stochastic dominance*

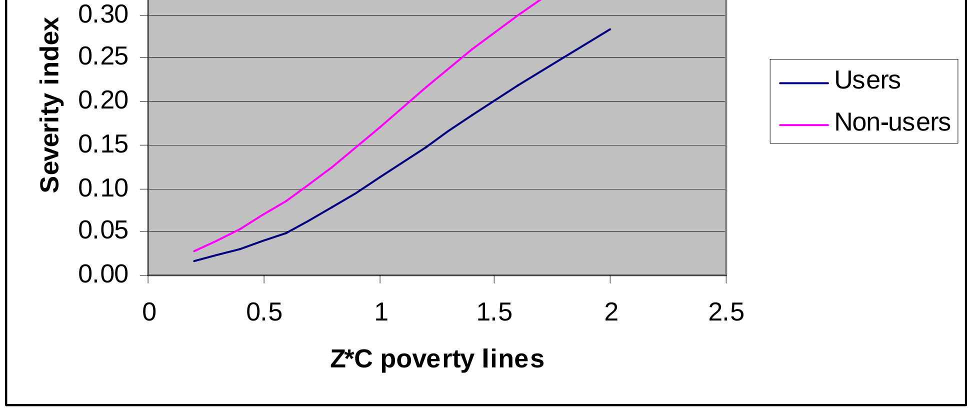

Figure 3 *Third-order stochastic dominance*

4.6 Inequality measures

Three results of the inequality estimates are reported below. As could be seen from the estimated Gini-coefficients one could see that inequality is lower among users compared with non-users. This seems to be very true in almost all technologies considered. The exception is micro dam users that have a reported Gini-coefficient of 0.73 which is far higher than the Gini-coefficient for non-users (0.54). Possible explanation could be related to distribution of water within the scheme (e.g. head vs. tail end problems) causing high disparity in income.

Table 7 *Estimated inequality measures of expenditure per adult equivalent*

		Atkinson's index (A(e))	**Percentile ratios**					
Categories	**Gini**	A(0.5)	A(1)	A(2)	p90/p10	p75/p25	P75/p50	P25/p50
Overall		0.229	0.39	0.84	8.04	2.81	1.70	0.61
Users	0.475							
Non-users	0.538							
Overall		0.221	0.37	0.79	7.30	2.79	1.71	0.61
Pond	0.49							
Shallow well	0.45							
Deep well	0.42							
Diversion	0.38							
Micro dams	0.73							

5. Determinants of poverty correlates

An analysis of poverty will not be complete without explaining why people are poor and

$$W_i = Y_i / Z \quad (9)$$

where Z is the poverty line and Y_i is the consumption expenditure per adult equivalent. Denoting by X_i the vector of independent variables, the following regression

$$LogW_i = \beta' X_i + \varepsilon_i \quad (10)$$

could be estimated by OLS. In this regression, the logarithm of consumption expenditure (divided by the poverty line) is used as the left-hand variable. The right hand variables in the regressions include: (a) household characteristics household head, including sex, level of education (using five tiered categories), primary occupation of the household (farming vs. non-farming) and consumer worker ratio; (b); asset holding: oxen holding, livestock size (in TLU)[10] and farm size, adult labor (by sex) all in per adult equivalent terms; c) access to different services and markets: credit, non-farm employment, access to market proxied by distance to input markets, seasonal and all weather roads, distance to major urban markets; and d) village level characteristics mainly agro-ecology.

The β coefficients in equation (10) are the partial correlation coefficients that reflect the degree of association between the variables and levels of welfare and not necessarily their causal relationship. The parameter estimates could be interpreted as returns of poverty to a given characteristics (Coudouel et al., 2002; Wodon, 1999) while controlling for other covariates, the so-called *ceteris paribus* condition. We used regression techniques to account for the stratified sampling technique and, hence, adjust the standard errors to both stratification and clustering effects (Deaton; 1997; Wooldrige, 2002) and thereby deal with the problem of heteroskedasticity. We also tested for other possible misspecifications (e.g. multicollinearity) using routine diagnostic measures. The results are reported below in Table 8.

The F-test results indicate that the hypothesis of no significant β coefficient (except the intercept) is rejected (p < = 0.000); the coefficients are jointly significantly different from zero. As could be seen from the results in Table 8, most of the coefficients are significantly different from zero. The goodness of fit measure indicates that about 25 percent of the variation in the model is explained by the chosen model. Given the data used is survey data, this measure is not atypical.

Reporting on the significant variables, water input from AWMT has a significant effect on household welfare. Particularly, households that use AWMT as supplementary or full irrigation have significantly better wellbeing compared with those who depend on rainfed agriculture. This result corroborates the evidence on the positive and poverty reducing impact of AWMT in Ethiopia.

While controlling for all other variables, households with more asset holdings are found to have significantly higher wellbeing (i.e. less poverty). This is particularly true with oxen

Ethiopia and the poor functioning of the labor market.

Access to services is also found to have significant effect on household wellbeing. In this line, distance to input (fertilizer and seed) markets have a significant negative (at 1 percent level of significance) effect on household wellbeing while controlling for all other factors. Distance to water source has also a negative and significant effect on household welfare which may imply that those with access to water closely to home are better off. This underlines the fact that access to water for productive and consumptive uses, poverty reduction and sustainable livelihoods for rural people are all intimately linked (IWMI, 2007). Accesses to credit markets also have a significantly positive effect on household welfare, albeit at 10 percent level of significance. On the other hand, households distance to all weather roods has a significant and positive effect on wellbeing. The result is counter intuitive; one possible explanation could be households who are able to produce for the market transport their produce to distant but more attractive markets (see Hagos et al., 2007).

Few household level covariates and agro-ecology (a village level covariate) were also found significant in explaining household wellbeing *ceteris paribus*. Accordingly, age of the household head has a negative effect on household welfare and this effect increases with age as we could see from the non-linear age coefficient. Our results also show that households with more dependents (compared to producers), i.e. higher consumer-worker ratio, are worse off. Education attainment of the household head has also a positive and significant effect on household welfare. Accordingly, compared to illiterate household heads, household with informal education (church and literacy program) and primary complete have a significantly positive effect on household wellbeing. The coefficients for junior high and high school complete have also the expected positive sign but were not significantly different from zero. Contrary to usual expectation, we did not find a significant difference between male-headed and female-headed in terms of welfare while controlling for all other relevant factors. Agroecology, which could be a good proxy of the agricultural potential of geographical area, was found to have a significant effect on poverty. Accordingly, households located in highland (dega) were found to have higher poverty compared to lowlands. This could be indicative of the suitability of AWMT in relatively low land compared to highlands.

Table 8 *Determinants of poverty (Regression with robust standard errors)*

Dependent variable: log(welfare)			
Variable name	**Coefficient**	**Standard error**	**t-value**
Household characteristics			
sex of head (Male-headed)	-0.045	0.077	-0.59
Age of head	-0.025	0.009	-2.81***
Age squared	0.0002	0.0001	2.48***
Informal education (reference illiterate)	0.162	0.056	2.90***
Primary complete(reference illiterate)	0.111	0.063	1.77*
Junior high complete (reference illiterate)	0.119	0.108	1.10
Secondary and above (reference illiterate)	0.195	0.198	0.99
Framing (reference non-farming)	-0.063	0.129	-0.49

Other forms of livestock per adult equivalent (in TLU)	0.118	0.058	3.10

Table 8 Continued

Agricultural water management technologies (reference= rain fed)			
Supplementary irrigation	0.171	0.074	2.31**
Full irrigation	0.281	0.050	5.59***
Other uses (livestock and domestic)	-0.120	0.127	-0.95
Access to factor markets			
Off-farm employment	-0.048	0.049	-0.99
Credit access	0.088	0.051	1.71*
Distance to input distribution center	-0.002	0.001	-3.17***
Distance to all weather road	0.002	0.001	2.55***
Distance to local wereda center	0.001	0.001	1.28
Distance to water source	-0.003	0.001	-4.81***
Village level factors			
Agro-ecology (Weina Dega)	-0.058	0.047	-1.23
Agro-ecology (Dega)	-0.700	0.116	-6.05***
_cons	1.114351	0.273	4.07***
Number of obs = 1421 F(25, 1420) = 15.45 Prob > F = 0.0000 R-squared = 0.2517 Number of clusters = 1421			

6. Conclusions and recommendations

AWMT have been identified as important tools to mitigate adverse effects of climatic variability and to reduce poverty. Huge resources are being allocated to develop and promote diverse low cost technologies in many developing countries including Ethiopia. In the last few years, thousands of low cost AWMT have been developed for use by smallholders. In spite of these huge investments, their impacts remain unknown.

The main objective of this paper was to explore whether adoption of selected AWMTs has led to significant reduction in poverty and inequality and if so identify which technologies have higher impact. The importance of such study is to identify technologies that are promising for future investments.

Our results show that there is significant reduction in poverty from AWMT. In fact, our calculations show that there is about 22% less poverty among users compared to non-users of AWMT. The magnitude of poverty reduction is technology specific. Accordingly, deep wells, river diversions and micro dams have led to 50, 32 and 25 percent reduction in poverty levels compared to the reference, i.e. rain fed system. This may imply that there is a need to benefits. This implies that promotion of modern water withdrawal and application technologies could enhance poverty reduction. But this will also have important impact on choice of technology, i.e. macro than micro-water harvesting technologies. We found the poverty orderings between users and non-users are statistically robust. Furthermore, both from the poverty analysis (severity indices) and inequality measures we have found that AWMT are not only effectively poverty-reducing but also equity-enhancing technologies. Equitable development is good for the poor and for better performance of the economy (Ravallion, 2005).

While poverty analysis techniques do not have in-built mechanisms of creating comparable groups, and hence, could lead to attribution bias[11]. Our results from the propensity score matching, however, indicated that the average treatment effect of using AWMT is significant and has led to an increase in income which amounts to average income of ETB 780.

While access to AWMT seems to unambiguously reduce poverty, out study also indicated that there are a host of factors that could enhance this impact. The most important determinants include asset holdings, educational attainment, underutilization of family labor and poor access to services and markets. To enhance the contribution of AWMT to poverty reduction, there is, hence, a need to: i) build assets; ii) human resource development; and iii) improve the functioning of labor markets and access to markets (input or output markets). These areas could provide entry points for policy interventions to complement improved access to AWMT in Ethiopia.

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Adoption in the Northern Ethiopian Highlands

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Abstract

Land degradation in the form of soil erosion and nutrient depletion presents a threat to food security and sustainability of agricultural production in many developing countries. Governments and development agencies have invested substantial resources to promote soil conservation practices as part of an effort to improve environmental conditions and reduce poverty. However, limited rigorous empirical work has been done on the economics of soil conservation technology adoption. This article investigates the impact of stone bunds on value of crop production per hectare in low and high rainfall areas of the Ethiopian highlands using cross-sectional data from more than 900 households, with multiple plots per household. We have used modified random effects models, stochastic dominance analysis (SDA) and matching methods to ensure robustness. The parametric regression and SDA estimates are based on matched observations obtained from nearest neighbor matching using propensity score estimates. This is important, because conventional regression and SDA estimates are obtained without ensuring that there actually exist comparable conserved and non-conserved plots on the distribution of covariates. We use matching methods, random effects and Mundlak's approach to control for selection and endogeneity bias that may arise due to correlation of unobserved heterogeneity and observed explanatory variables.

We find that the three methods tell a consistent story. Plots with stone bunds are more productive than those without such technologies in semi-arid areas but not in higher rainfall areas, apparently because the moisture conserving benefits of this technology are more beneficial in drier areas. This implies that the performance of stone bunds varies by agro-ecology type, suggesting the need for designing and implementing appropriate site-specific technologies.

1. Introduction

rigorous empirical work on the economics of soil conservation. This article attempts to partly close this gap by assessing returns to the use of stone bunds in high and low rainfall areas in the Ethiopian highlands.

As is well-known, the distribution and amount of rainfall varies both spatially and temporally across and within African countries. It is therefore likely to be important to consider the distribution of rainfall when making a variety of decisions, including those related to soil conservation. In fact, almost half of Africa, which is home to more than 14% of the low-income countries in the world, is arid or semi-arid, and over 90 percent of agricultural production is rain-fed (Fischer *et al.*, 2004; WDI, 2005). Since rainfall is often inadequate and there are extreme fluctuations in the availability of water, food production in these agro-ecological zones is a serious challenge (Fischer *et al.*, 2004). Furthermore, climate change will likely cause rainfall variability in many African countries that are already at least partly semi-arid and arid. This will likely seriously affect the sustainability and productivity of agriculture unless farm households adopt appropriate mitigation mechanisms such as soil and water conservation (SWC) technologies that will conserve the available rain (IPCC, 2001).

Whether SWC technologies in general increase yield may depend on the agro-ecology and the technology in question. Sutcliffe (1993), for example, concluded that physical soil conservation activities are justifiable in moisture stressed areas of the Ethiopian highlands, where water conservation plays an important role in increasing yield. The implication is that agro-ecological conditions may be a particularly important determinant of SWC profitability. Despite the likely importance of rainfall patterns for determining whether SWC technologies improve the welfare of farming households, there has been very little economic research that explicitly incorporates this feature into the analysis. Indeed, similar soil and water conservation technologies, such as stone bunds, soil bunds and *fanya juu*[12] are promoted in Ethiopia, and many other countries, without accounting for the performance of these technologies in different agro-ecologies.

The contributions of this article to the literature are the following. First, earlier studies did not analyze plots with and without conservation that were similar in terms of the distribution of covariates. As a result, they might have analyzed incomparable observations, possibly leading to biased conclusions concerning impacts of conservation. Our regression and stochastic dominance analysis estimates are based on matched observations, unlike previous econometric studies where all observations were pooled (e.g. Benin, 2006; Holden et al., 2001; Kassie and Holden, 2006; Pender and Gebremedhin, 2006; Shively, 1998a, b).

Second, since our statistical tests reject the assumption of homogeneous impacts implicit in the econometric approaches of other studies, use a switching regression approach in our econometric analysis, which allows for differential impacts of covariates on conserved and non-conserved plots. Third, our data are cross-sectional with multiple plots per household, which allows us to control for unobservable household characteristics influencing outcomes. We also control plot quality characteristics using a detailed data set in which many potentially important plot quality characteristics were measured. Finally, we compare the

2. Literature Review

The literature contains a number of empirical studies that examine impacts of soil conservation measures on mean yield in developing countries using cross-sectional data (e.g., Bekele, 2005; Benin, 2006; Byiringiro and Reardon, 1996; Holden et al., 2001; Kaliba and Rabele, 2004; Kassie and Holden, 2006; Pender and Gebremedhin, 2006; Shively, 1998a, b,1999). Byiringiro and Reardon (1996) use farm level data in Rwanda and find that farms with greater investments in soil conservation have much greater land productivity than other farms. The type of conservation, however, is not specified. In the Philippines, using data collected at farm level Shively (1998a, b) finds positive and statistically significant impact of contour hedgerows. In Lesotho, Kaliba and Rabele (2004) find positive and statistically significant association between wheat yield and short- and long-term soil conservation measures.

Several studies have used econometric analysis of cross-sectional survey data to estimate the impacts of SWC measures in the Ethiopian highlands. In one local jurisdiction in northern Ethiopia, Holden et al., 2001 find that SWC measures (soil bunds and *fanya juu* terraces) have statistically insignificant impacts on land productivity in all regressions (but a negative coefficient in almost all regressions). Benin (2006), based on a survey of 434 households representing the highlands of the Amhara region as a whole, finds significant positive impacts of stone terraces on crop yields (a 42% increase in average yields due to stone terraces) in reduced form regression for lower rainfall parts of Amhara region, but insignificant impacts in the structural regression, suggesting that the impacts of stone terraces were due to enabling more productive use of inputs. By contrast, Benin finds insignificant impacts of stone terraces on yields in the high rainfall parts of the region. Kassie and Holden (2006) find that in a high rainfall area of Ethiopian highlands in western Amhara, compared with nonconserved plots those with *Fanya* juu conservation structures have lower yield,. Consistent with Benin's (2006) finding of positive impacts of stone terraces in lower rainfall areas of Amhara, using a survey of 500 households representing the semi-arid highlands of Tigray, Pender and Gebremedhin (2006) find higher crop yields on plots with stone terraces (an average increase of 23%).

Studies based on farm level trials in the Ethiopian highlands also find differences in yields and economic returns in different agro-ecological zones. Shiferaw and Holden (2001) and Gebremedhin et al. (1999) used a cost-benefit analysis to evaluate the economic benefits of structural and biological conservations in different parts of the northern Ethiopian highlands. Shiferaw and Holden (2001), using results of farm trials from the Soil Conservation Research Project in two high rainfall highland sites (Anjeni in western Amhara and Andit Tid in eastern Amhara), conclude that structural technologies (graded bund and *fanyajuu* terraces) have very low payoffs and do not seem to offer sufficient economic incentives for poor farmers to make the necessary investments. They show that investment in grass strips is promising (positive net present value) only in Anjeni. By contrast, based on on-farm research evidence collected in the semi-arid central Tigray region Gebremedhin et al. (1999) estimate that stone terraces yield a 50% rate of return. These farm-level trial results, A few studies have used stochastic dominance analysis to assess impacts of SWC measures on the distribution of yields. Using nonexperimental farm-level data collected in the Philippines, Shively (1999) compared observed yields obtained from farmers' fields with and without contour hedgerows and found that the hedgerow technology did not constitute an unambiguously dominant production strategy compared to plots without hedgerows. Bekele (2005), using results of farm trials from the Soil Conservation Research Project in a low rainfall area of eastern Ethiopia, found that plots with physical conservation (level bunds) unambiguously dominate those without such structures. Kassie and Holden (2006) use cross-sectional farm-level data from a high rainfall area in northwestern Ethiopia and find that yield distributions without conservation unambiguously dominate those with conservation (graded *fanya juu*) for all yield levels. Again, the results from the Ethiopian highlands suggest that SWC measures perform better in lower rainfall environments.

These studies, however, suffer from a number of methodological problems, which can either under- or overestimate impacts of technologies on crop production. First, comparisons are not based on comparable observations, which can yield biased estimates (Heckman et al., 1998). Second, all studies assume a single equation model where technology has only intercept effects and the same set of variables equally affect both technology adopters and nonadopters, without testing this assumption empirically. Third, except for Shively (1998b, 1999) and Kassie and Holden (2006), none of the remaining studies account for the endogeneity of technologies and possible self-selection. Fourth, none of the studies account for unobserved heterogeneity that might impact results. For example, in addition to having the limitation of small sample size (50 households), Kaliba and Rabele (2004) did not control plot characteristics. If there is asymmetric distribution in plot quality across plots and households and correlation between conservation and plot quality, estimation of conservation impacts on yield may lead to inconsistent estimates. The cost–benefit analysis used in some studies is a partial analysis since it did not capture the effects of important variables such as conventional inputs and household characteristics and endowments.

3. Methodology: Estimation challenges, techniques, and procedures

3.1. Estimation challenges and techniques

Assessment of the productivity gains from soil conservation based on non-experimental observations is not an easy task, because we do not observe the outcome of plots with conservation had they not had conservation structures. In other words, the counterfactual is not observed. Further, farmers are not randomly assigned to the two groups (adopters and nonadopters) but make the adoption choices themselves, or they might be systematically selected by development agencies based on their propensity to participate in the adoption of technologies.

Second, farmers (or development agencies) are likely to select plots non-randomly based on their quality attributes (often unobservable). Therefore, adopters and nonadopters may be

Two-step Heckman (Heckman, 1979) and matching (Heckman and Robb, 1985) approaches are possible solutions to the selection problem. The Heckman two-step approach assumes that selection is affected by unobservable variables ("selection on unobservables"), whereas the Heckman and Robb approach assumes selection on observables. The Heckman two-step approach addresses selection on unobservables by imposing distributional and functional form assumptions (the outcome equation is usually linear) and extrapolating over regions of no common support where no similar conserved and nonconserved plot observations exist. The evidence from Heckman *et al*. (1998), Dehejia and Wahba (1999; 2002) and Smith and Todd (2005) suggests that avoiding functional form assumptions and imposing a common support condition can be important for reducing selection bias.

Conventional regression and stochastic dominance analysis estimates are usually obtained without ensuring that there actually exist comparable conserved and non-conserved plot observations in terms of the distribution of covariates (i.e. lack common support), possibly resulting in substantial biases (Ibid). To deal with this problem, our regression and stochastic dominance analyses are based on matched samples of conserved and nonconserved plots. The basic idea of propensity score matching is to match observations of conserved and nonconserved plots according to the predicted propensity of the plots to have conservation. Comparisons are therefore between conserved and nonconserved plots with characteristics that are similar and relevant to the technology choice. This reduces the potential for bias from comparing noncomparable observations, although there still may be selection bias caused by differences in unobservables.

A remaining econometric issue is that even if there is no selection bias problem or we can account for the selection process, using a pooled sample of adopters and nonadopters (dummy regression model where a binary indicator is used to assess the effect of soil conservation on productivity) may be inappropriate. This is because pooled model estimation assumes that the set of covariates has the same impact on adopters as nonadopters (i.e., common slope coefficients for both regimes). This implies that soil conservation has only an intercept shift effect, which is always the same irrespective of the values taken by other covariates that determine yield. However, for our sample a Chow test of equality of coefficients for adopters and nonadopters of stone terraces rejected equality of the nonintercept coefficients at much greater than the 1.0% significance level.[13] This supports the idea of using a regression approach that differentiates coefficients for adopters and nonadopters.

We use parametric switching regression and non-parametric techniques to overcome the econometric problems and assure robust results. The non-parametric methods include stochastic dominance analysis and propensity score matching. The parametric regression equation to be estimated using multiple plots per household is:

where y_{hp} is value of crop production per ha[14] obtained by household h on plot p, depending on its conservation status (C_{hp}); u_h captures unobserved household characteristics that affect crop production, such as farm management ability, average land fertility, etc; e_{hp} is the random variable that summarizes the effects of plot specific unobserved components on productivity, such as unobserved variation in plot quality and plot specific production shocks (e.g. plot level variation in rainfall, frost, floods, weeds, pests and diseases infestations); x_{hp} includes both plot-specific and household-specific observed explanatory variables and β is a vector of parameters to be estimated.

3.2. Estimation procedures

To obtain consistent estimates of the effects of conservation, we need to control unobserved heterogeneity (u_h) that may be correlated with observed explanatory variables. One way to address this issue is to exploit the panel nature of our data (repeated cross sectional plot observations per household), and use household specific fixed effects. The main shortcoming of using fixed effects in our case is that we have many households with only a single plot. Those households therefore do not play a role in a fixed effects analysis. Random effects and pooled OLS models are consistent only under the assumption that unobserved heterogeneity is uncorrelated with the explanatory variables. As an alternative, we use the modified random effects model framework proposed by Mundlak (1978), whereby we include on the right hand-side of each equation the mean value of plot-varying explanatory variables. Mundlak's approach relies on the assumption that unobserved effects are linearly correlated with explanatory variables as specified below.

2) $u_h = \bar{x}\gamma + \eta_h, \; \eta_h \sim \text{iid}(0, \sigma_\eta^2)$

where $\bar{x}$ is the mean of plot-varying explanatory variables within each household (cluster mean), γ is the corresponding vector coefficients and η is a random error unrelated to the $\bar{x}'s$. In our case, it is most important to include average plot characteristics, such as average plot fertility, soil depth, slope, and conventional input use, which we believe have a greater impact on production and technology adoption decisions. The vector γ will be equal to zero if the observed explanatory variables are uncorrelated with the random effects.

The selection process in the parametric switching regression model can be addressed using inverse Mills ratio derived from the criterion equation (probit model), which addresses the problem of selection on unobservables. However, the criterion models turned out to be insignificant (i.e., the overall model significance test [Wald χ^2] is insignificant) both for the cases with and without Mundlak's approach as well as for both regions. This is perhaps not surprising since we use matched samples obtained from a nearest neighbor propensity score matching. The inverse Mills ratio derived from such insignificant models assuming functional form identification (nonlinearity of the first step probit estimators) was marginally significant (at 10%) only for two models of the 16 models estimated. This may imply that by addressing selection on observables using propensity score matching, we may have also available from the authors. If the unobserved plot component (e_{hp}) is correlated with the decision to adopt stone bunds and other observed regressors, parameter estimates from equation (1) will be inconsistent and if we do not control for these factors we will not be finding the true effect of conservation.

Controlling for plot heterogeneity is a bit more difficult than addressing household heterogeneity, but fortunately our data set offers a richer characterization of plot quality and it is likely that observed plot quality would be positively correlated with unobserved plot quality. In terms of plot characteristics, the data set includes plot slope, position on slope, plots size, soil fertility, soil depth, soil color, soil textures, presence of gullies, plot distance from homestead, rainfall, altitude, and input use by plot. Including these variables in our model addresses the issue (Assunção and Braido, 2004; Fafchamps, 1993; Levinsohn and Petrin, 2003). The idea of using input use to control for plot heterogeneity is that farmers may respond to positive and negative shocks by increasing or decreasing their input use.

With regard to using the matching method, matching on every covariate is difficult to implement when the set of covariates is large. To overcome the curse of dimensionality, Rosenbaum and Rubin (1983) show that if matching on the vector x_{hp} is valid, so is matching on the propensity score. This allows matching on a single index rather than on the multidimensional x_{hp} vector. The propensity score is defined as the conditional probability that plot p receives conservation treatment given the covariates.

Our main goal in the matching method is to identify the average treatment effect on the treated (ATT) plots and obtain matched treated and non-treated observations. This is achieved using a two-step procedure. In the first step, we use a probit model to estimate the propensity score, which is defined as the conditional probability that plot p receives conservation treatment given the covariates. In the second stage, we use nearest neighbor matching based on propensity scores estimates as an input to obtain the ATT. The nearest neighbor matching method, as compared to other weighted matching methods such as kernel matching, allows us to identify the specific matched observations that entered the calculation of the ATT and which will be used for parametric regressions and stochastic dominance analysis.

Matching methods assume that the selection process is based only on observable characteristics (i.e. the conditional independence). To adjust for unobservables we include the means of plot varying covariates following Mundlak's approach and Wooldridge's (1995) panel data sample selection estimation method. Controlling the above econometric problems and incorporating equation (2) into (1), the expected yield difference between adoption and non-adoption of stone bunds is estimated as:

$$3)\ E(y_{hp1} \mid x_{hp}, u_h, C_{hp} = 1) - E(y_{hp0} \mid x_{hp}, u_h, C_{hp} = 1) = x_{hp}(\beta_1 - \beta_0) + \overline{x}(\gamma_1 - \gamma_0).$$

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parameter of interest in the parametric regression analysis. Equation (3) will also be estimated without including the second term of the right hand side equation (without the Mundlak approach) for comparison purposes and to generate a greater degree of confidence in the robustness of the econometric results.

Finally, we check multicollinearity and non-linearity problems for all regression models. Multicollinearity is inevitable for regression analysis with mean of plot varying explanatory variables, although it is not a problem if the goal were simply to predict a dependent variable from a set of explanatory variables. because the maximum variance inflation factor (VIF) is less than 10. Graphical (augmented component residual plot) and statistical test (ovtest) indicate that nonlinearity is not a problem in the regression analysis. Results are corrected for clustering and bootstrapped standard errors are adjusted for clustering used for the endogenous switching regression models.

4. Data sources and types

The data used in this study are from a farm survey conducted in 1999 and 2000 in the Tigray and Amhara regions of Ethiopia. Plots analyzed were located above 1500 meters. The Amhara region dataset includes 435 farm households, 98 villages, 49 *kebeles*[16] and about 1365 plots after deleting missing observations for some variables, while the Tigray dataset include 500 farm households, 100 villages, 50 *kebeles* and 965 plots after deleting missing observations.[17] Using the nearest neighbor matching method based on propensity scores estimates and Mundlak's approach, we are left with a sample of 382 (232 conserved and 150 non-conserved plots) and 573 (390 conserved and 183 non-conserved plots) plots in the Amhara and Tigray region, respectively. Without using Mundlak's approach we are left with a sample of 391 (232 conserved and 159 non-conserved plots) and 590 (390 conserved and 190 non-conserved plots) plots in the Amhara and Tigray region, respectively.

Tables 1 and 2 present the descriptive statistics by region for the two subsamples before and after matching and the subsamples of conserved and nonconserved plots after matching. To conserve space, descriptive statistics for the data without using Mundlak's approach are not reported. About 37% of the sample plots in Tigray and 17% in the Amhara region had stone bunds. Soil bunds are also used on some plots, but there are not enough observations to run parametric regressions.

	(2145.045)	(1715.694)	(1718.517)	(1708.725)
Plot size, ha	0.271	0.284	0.305	0.239
	(0.226)	(0.216)	(0.224)	(0.191)
Other plot size (total farm size plot size)	0.813	0.793	0.795	0.789
	(0.774)	(0.870)	(0.993)	(0.519)
Middle slope position	0.221	0.281	0.310	0.219
Bottom slope position	0.245	0.276	0.272	0.284
Not on slope position	0.422	0.295	0.262	0.366
Deep soil plots	0.374	0.356	0.359	0.350
Medium soil plots	0.417	0.485	0.495	0.464
Brown soil plots	0.147	0.176	0.192	0.142
Gray soil plots	0.231	0.264	0.254	0.284
Red soil plots	0.389	0.384	0.382	0.388
Gently slope plot	0.305	0.393	0.415	0.344
Steep slope plot	0.091	0.136	0.146	0.115
Loam soil plots	0.357	0.414	0.421	0.399
Clay soil plots	0.305	0.304	0.300	0.311
Sandy soil plots	0.108	0.115	0.118	0.109
Moderately eroded plots	0.280	0.328	0.356	0.268
Severely eroded plots	0.065	0.094	0.097	0.087
Fenced plots	0.048	0.056	0.056	0.055
Gully plots	0.035	0.042	0.041	0.044
Walking plot distance to residence, hrs	0.315	0.303	0.281	0.350
	(0.365)	(0.388)	(0.375)	(0.411)
Household altitude, masl	2176.428	2163.726	2170.431	2149.437
	(339.661)	(320.252)	(317.159)	(327.166)
Fertilizer use, kg/ha	41.682	39.878	43.408	32.353
	(97.997)	(102.641)	(114.779)	(69.775)
Seed use, kg/h	157.134	129.370	129.279	129.564
	(244.867)	(145.267)	(141.872)	(152.650)
Labor use, days/ha	75.845	64.861	63.964	66.771
	(112.606)	(54.914)	(55.658)	(53.392)
Oxen use, days/ha	29.652	26.873	27.082	26.428
	(35.820)	(14.989)	(16.237)	(11.929)
Rented in plots	0.133	0.096	0.097	0.093
Reduced tillage plots	0.124	0.120	0.131	0.098
irrigated plot	0.036	0.009	0.008	0.011
Walking residence distance to market, hrs	2.872	3.137	3.132	3.150
	(2.320)	(2.529)	(2.405)	(2.781)
Male household head	0.902	0.911	0.913	0.907
Household head age	48.398	49.349	49.628	48.754
	(12.672)	(12.296)	(12.173)	(12.566)
Family size, number	5.997	6.084	6.138	5.967
	(2.065)	(1.997)	(1.987)	(2.019)
Education between grade one & two	0.079	0.087	0.092	0.077
Education above grade 3	0.056	0.051	0.046	0.060
Oxen holding, number	1.418	1.358	1.326	1.426
	(0.912)	(0.867)	(0.869)	(0.860)
Other cattle, number	3.605	3.234	3.185	3.339
	(3.660)	(3.352)	(3.438)	(3.168)
Small ruminant, number	5.876	5.874	5.708	6.230
	(9.014)	(8.604)	(8.523)	(8.788)
Pack animals, number	0.997	0.902	0.926	0.852
	(1.493)	(1.378)	(1.513)	(1.035)
Mean annual rainfall, mm	649.783	652.657	653.736	650.357
	(100.883)	(95.923)	(93.003)	(102.093)
Population density, /km2	141.640	148.858	151.729	142.741
	(69.559)	(72.901)	(75.156)	(67.636)
N	935	573	390	183

Mean1 = Refers to mean and standard deviations (sd) of variables from total sample before matching
Mean2= Refers to mean and sd of variables from total matched sample

	(4007.41)	(1368.983)	(1117.251)	(1678.262)
Male household head	0.954	0.982	0.983	0.980
Family size, number	6.817	6.605	6.591	6.627
	(2.567)	(2.142)	(2.156)	(2.125)
Household head age	44.789	46.644	47.151	45.860
	(12.408)	(12.592)	(12.183)	(13.204)
Livestock holding, TLU	2.931	2.526	2.332	2.825
	(2.416)	(1.938)	(1.774)	(2.139)
Education level	2.592	2.534	2.603	2.427
	(3.375)	(3.246)	(3.186)	(3.345)
Walking Residence distance to market, hrs	2.322	2.956	2.892	3.055
	(3.030)	(3.214)	(2.693)	(3.893)
Plot slop, degree	5.552	8.042	8.034	8.053
	(6.003)	(7.122)	(5.609)	(8.996)
Black soil plots	0.308	0.380	0.358	0.413
Brown soil plots	0.277	0.335	0.362	0.293
Gray soil plots	0.070	0.089	0.086	0.093
Deep soil plots	0.240	0.147	0.138	0.160
Medium soil plots	0.536	0.586	0.591	0.580
Moderately eroded plots	0.304	0.526	0.556	0.480
Severely eroded plots	0.098	0.113	0.108	0.120
Clay soil plots	0.122	0.073	0.078	0.067
Loam soil plots	0.432	0.361	0.362	0.360
Sandy soil plots	0.117	0.154	0.147	0.167
High fertile plots	0.108	0.045	0.039	0.053
Medium fertile plots	0.694	0.702	0.724	0.667
Walking plot distance to residence, hrs	0.283	0.274	0.254	0.305
	(0.807)	(0.340)	(0.276)	(0.421)
Walking plot distance to main road, hrs	1.301	1.442	1.437	1.449
	(1.028)	(1.122)	(1.135)	(1.106)
Gully plots	0.045	0.063	0.052	0.080
Plot altitude, masl	2344.017	2395.906	2377.013	2425.127
	(468.414)	(485.541)	(454.888)	(529.724)
Population density, persons /km2	143.897	141.832	141.328	142.613
	(84.268)	(89.612)	(87.558)	(92.992)
Mean annual rainfall, mm	1980.048	1899.536	1851.093	1974.461
	(592.056)	(645.389)	(601.234)	(703.814)
Fertilizer use, kg/ha	92.196	47.124	39.732	58.557
	(209.972)	(125.669)	(115.928)	(139.034)
Seed use, kg/ha	152.800	147.893	186.232	88.596
	(730.379)	(1034.306)	(1323.488)	(118.622)
Labor use, days/ha	123.106	96.233	94.613	98.740
	(227.831)	(101.152)	(98.510)	(105.393)
Oxen use, day/ha	56.555	48.103	45.878	51.545
	(64.738)	(46.480)	(41.515)	(53.222)
Rented in plots	0.108	0.050	0.052	0.047
Reduced tillage plots	0.146	0.264	0.284	0.233
Plot size, ha	0.385	0.418	0.431	0.398
	(0.350)	(0.274)	(0.276)	(0.271)
other plot area (total farm size - plot size)	1.396	0.968	0.962	0.978
	(1.127)	(0.625)	(0.617)	(0.639)
N	1320	382	232	150

* See note for Table 1.We do not find statistically significant differences in input use between conserved and nonconserved plots, with one exception: fertilizer use is significantly higher (to a marginal degree at 10%) on nonconserved plots.

community labor for constructing 29% of stone bunds in Amhara and 55% in Tigray region. In Tigray, a combination of private and mass mobilization investment was used for 4% of stone bunds during 1997 to 1999. The rest were built through other investment sources such as food for-work programs. There is no statistically significant mean yield difference between plots having private versus mass mobilization investments (ETB 36 (SE = 167) per ha and ETB 73 (SE = 312) per ha in Amhara and Tigray region, respectively), though the estimated difference in mean yield favors privateinvestments.

The mean plot altitude, which is associated closely with temperature and rainfall, is 2,176 and 2,344 meters above sea level for Tigray and Amhara regions. Average annual rainfall is about 1980 millimeters per year in Amhara and 650 millimeters in the Tigray region.[19] Rainfall in our Amhara study sites therefore averages approximately three times that of Tigray. Differences across the two regions are therefore very large. The mean population density, however, is similar across the two regional subsamples at 142 to 144 persons per square kilometer. Fertilizer use averages about 40 kilograms per hectare in Tigray and 47 in Amhara for matched sample households.

In addition to these variables, plot characteristics, household endowments and indicators of access to infrastructure are included in the empirical model based on the guidance of economic theory and previous empirical research. In the presence of missing and/or imperfect markets households' initial resource endowments and characteristics may play a role in investment and production decisions (Holden *et al.*, 2001; Pender and Kerr, 1998) and are therefore included.

In the empirical model, variables such as inputs (e.g. fertilizer use and improved seed use per hectare) are potentially endogenous variables.[20] We do not believe this is a problem, however, because explanatory variables that explain input use are also included. In addition, our modified random effects estimation approach helps to control for unobserved effects that may correlate with input use decisions[21]. Nevertheless, to assure robustness we estimate the parametric switching regression models with and without these variables.

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[18] In Amhara, we asked about investments made on plots between 1991 and 2000 including the source (e.g., whether due to private investment, labor mass mobilization campaigns, food-for-work, or other), amount, and costs of investment. In Tigray, the survey asked for comparable information during the years 1997, 1998, and 1999. These figures reflect the flows of recent investments and do not fully account for the entire stock of SWC investments on the surveyed plots, since many plots had SWC investments on them by 1991 in Amhara and 1997 in Tigray. Hence, it is not possible to estimate the economic impacts of SWC investments by the source of investment, since we do not have this information for all plots. We also do not have information on the age of past investments and in many cases the age of investments may vary even on the same plot, since additional investments on plots may occur from year to year.

[19] The mean rainfall data are based long-term rainfall averages, spatially interpolated using a climate model (Corbett and White, 1998). The minimum and maximum rainfall averaged over the Amhara region for the last 50 years (1953–2003) was 1303 and 2457 mm, respectively. Even the minimum average rainfall in Amhara is higher than the maximum annual rainfall (994 mm) of the drier region, Tigray.

20 In the propensity score matching procedure, conventional inputs are not included directly (although variables influencing inputs are included) because the matching procedure requires including those variables that simultaneously affect the adoption decision and the outcome variable, agricultural yield or productivity (Heckman et al., 1998). We do not expect input use per

5.1. Matching method: Propensity scores and nearest neighbor matching estimates

The objectives of using propensity score matching are to estimate the ATT and obtain matched treated and non-treated observations to use in switching regression and SDA. The propensity score matching method was estimated with and without Mundlak's approach, although the statistical evidence found in the correlation between observed explanatory variables and unobserved effects (Tables 3 and 4), which suggests that ignoring this feature might lead to biased estimates. To save space the propensity score estimates are not discussed, though the results along with the matching variables are reported in Tables 3 and 4. Table 5 provides the nearest neighbor matching estimates. The outcome variable is the value of crop production per ha (hereafter referred to as yield).

Table 3 *Propensity score estimates of stone bunds adoption in Tigray region*

Explanatory variables	With Mundlak's approach	Without Mundlak's approach
Deep soil plots	-0.046	0.173
	(0.164)	(0.130)
Medium soil plots	0.027	0.309**
	(0.171)	(0.133)
Gently slope plot	0.265	0.350***
	(0.180)	(0.129)
Steep slope plot	0.356	0.438**
	(0.278)	(0.195)
Brown soil plots	-0.074	0.221
	(0.267)	(0.196)
Gray soil plots	-0.228	0.024
	(0.287)	(0.192)
Red soil plots	-0.405	-0.238
	(0.257)	(0.182)
Loam soil plots	0.117	0.257
	(0.248)	(0.182)
Clay soil plots	0.344	0.233
	(0.260)	(0.184)
Sandy soil plots	0.511	0.434**
	(0.319)	(0.222)
Moderately eroded plots	0.146	0.152
	(0.156)	(0.110)
Severely eroded plots	0.217	0.234
	(0.285)	(0.202)
Plot distance from residence	-0.747***	-0.434***
	(0.203)	(0.137)
Rented in plots	-0.282	-0.385***
	(0.187)	(0.143)
Reduced tillage plots	0.201	0.101
	(0.225)	(0.147)
Gully plots	0.025	0.017
	(0.354)	(0.259)
Ln(Plot size)	0.593***	0.329***
	(0.126)	(0.062)
Ln(other plot size)	0.306	-0.058
	(0.274)	(0.060)
irrigated	-0.913**	-0.872**
	(0.435)	(0.365)
Fenced plots	-0.054	0.130
	(0.274)	(0.211)
Middle slope position	0.219	0.006
	(0.247)	(0.173)
Bottom slope position	0.193	-0.090
	(0.245)	(0.172)

	(0.026)	(0.023)
Male household head	0.080	0.155
	(0.180)	(0.164)
Ln(Household head age)	0.400**	0.285
	(0.175)	(0.004)
Ln(Family size)	0.229*	0.042*
	(0.131)	(0.024)
Education grade one & two	0.414**	0.305*
	(0.183)	(0.174)
Education above grade 3	0.061	-0.058
	(0.229)	(0.219)
Joint Chi2 test for significance of 44.45***		
mean of plot varying explanatory variables (vector γ)		
Constant	-9.596**	-9.622**
	(4.480)	(3.963)
Wald chi2	280.893***	227.750***
Pseudo R-squared	0.2211	0.1793
Number of observations	935	935
* p<0.10, ** p<0.05, *** p<0.01		
Standard errors are in parenthesis		

Table 4: Propensity score estimates of stone bunds adoption in Amhara region

Explanatory variables	With Mundlak's approach	Without Mundlak's approach
Plot slop in degree	0.029**	0.029***
	(0.013)	(0.008)
Black soil plots	0.118	0.293**
	(0.185)	(0.131)
Brown soil plots	-0.087	0.252*
	(0.195)	(0.130)
Gray soil plots	-0.333	0.171
	(0.260)	(0.188)
Deep soil plots	0.002	-0.074
	(0.235)	(0.188)
Medium soil plots	0.155	0.071
	(0.170)	(0.125)
Moderately eroded plots	0.545***	0.646***
	(0.147)	(0.106)
Severely eroded plots	0.127	0.218
	(0.242)	(0.172)
Clay soil plots	-0.601**	-0.226
	(0.247)	(0.179)
Loam soil plots	-0.120	-0.133
	(0.163)	(0.109)
Sandy soil plots	-0.274	-0.138
	(0.208)	(0.150)
High fertile plots	-0.123	-0.386
	(0.308)	(0.238)
Medium fertile plots	0.355**	0.058
	(0.179)	(0.128)
Plot distance to residence	-0.210	-0.235*
	(0.175)	(0.140)
Plot distance to main road	-0.160	0.023
	(0.166)	(0.016)
Gully plots	0.089	-0.193
	(0.305)	(0.222)
Rented in plots	0.044	-0.183
	(0.239)	(0.191)
Reduced tillage plots	-0.293	0.348***
	(0.315)	(0.119)

Residence distance to market	[illegible]	[illegible]
	(0.236)	(0.048)
Male household head	0.683**	0.743***
	(0.291)	(0.278)
Family size	-0.009	-0.020
	(0.024)	(0.022)
Household head age	0.012***	0.013***
	(0.005)	(0.004)
Education level	0.024	0.015
	(0.016)	(0.015)
population density	-0.002**	-0.162*
	(0.001)	(0.091)
Ln(rainfall)	-1.344***	-1.074***
	(0.246)	(0.195)
Joint chi2 Significance of mean of	55.10***	
Plot Varying explanatory variables (vector γ)		
Constant	8.238***	3.787*
	(1.800)	(2.126)
Wald chi2	341.005***	278.746***
Pseudo R2	0.2778	0.2271
Number of observations	1320	1320
* p<0.10, ** p<0.05, *** p<0.01		
Standard errors adjusted for clustering effects are in parenthesis (adoption model)		

*Table 5: Propensity score matching estimates of conservation effects (Dependent variable: value of crop production per ha, ETB/ha)**

Conserved plots		Matched Non-conserved plots	ATT	Std. Err.	T
With Mundlak's Aprroach					
Tigray region	390	183	412.034	140.867	2.925
Amhara region	232	150	-178.897	177.460	-1.008
Without Mundlak's approach					
Tigray region	390	190	298.822	141.694	2.109
Amhara region	232	159	-145.584	149.784	-0.972

* Bootstrapped standard errors used to take into account the estimated propensity score used in the second stage (nearest neighbor matching estimator)

Our estimates show the existence of a positive yield premium of Ethiopian Birr (ETB) [22] 412 (US$ 59) and ETB 299 (US$ 47) per ha with and without the Mundlak approach, respectively, for conserved plots compared to non-conserved plots in the Tigray region only, which is our low rainfall area[23]. These estimated impacts are large relative to the average value of crop production in the Tigray highlands, which averaged ETB 1614 per ha in the survey sample (see Table 1). All else equal, the total benefits that would have been obtained, had the matched non-conserved plots had been covered with stone bunds, was about ETB 52 million (US$ 7 million) and 38 million (US$ 6 million) with and without the Mundlak approach, respectively[24].

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[22] The official exchange rate averaged about 7 ETB per U.S. dollar in 1998.
[23] This result is consistent with results using alternative matching methods such as kernel (ATT = 333.805 (SE =111.649)***)

Mundlak approach, respectively)[25].

5.2. Stochastic dominance analysis estimates

Stochastic dominance analysis is used to compare and rank distributions of alternative risky outcomes according to their level and dispersion of returns (Mas-Colell et *al.,* 1995). The comparison and ranking is based on cumulative density functions. Unlike matching and linear regression models, the entire density of yields is examined in SDA instead of focusing only on mean yield. Like the propensity score matching method, SDA makes no assumption about relationships between the regressors and outcome variables and does not require distributional assumptions.

The SDA estimates are based on matched observations to control for impacts of other factors on production apart from stone bunds. The SDA therefore determines the difference in the yield distribution between the two states (conservation and no conservation) that is due only to technology effects. Figs. 1-4 show cumulative density functions for yields obtained on conserved and non-conserved plots. As the graphs illustrate, the cumulative distribution of yield with conservation is entirely to the right of that without-conservation for Tigray region, indicating that yield with conservation unambiguously first-order stochastically dominates the yield distribution without conservation. The nonparametric Kolmogorov-Smirnov statistics test for first-order stochastic dominance (or test for the vertical distance between the two CDFs) confirms this result with [D = 0.1270 (p = 0.028)**] and D = 0.2471 (p =0.011**) without the Mundlak approach[26]. The results imply that the chance of getting higher yields is greater for plots with conservation than plots without conservation, given a matched sample of conserved and non-conserved plots.

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survey is about 37 and 63 percent, respectively. We assume all untreated plots in the region need conservation and will be treated only by stone bunds. We also assumed that the proportion of matched untreated plots that are comparable to treated plots, which is about 20 percent for both with and without the Mundlak approach would also hold if we consider in the analysis the population (all plots) of treated and untreated plots in the region. Based on this the total benefit of investing in untreated plots = total cropland area*0.63*0.2* the estimated per ha benefit of treatment (ETB 412 or 299). However, further research on this is essential.

25 This result also is consistent with kernel [ATT = -115.248 (SE =130.245)] and stratification [ATT = -106.628 (SE= 133.132)]

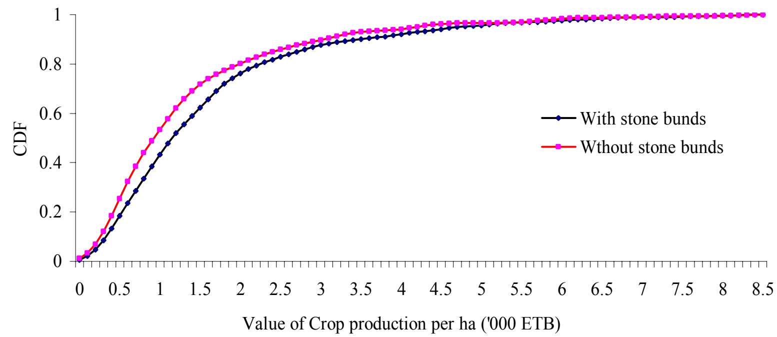

Figure 3. CDF for impacts of stone bunds on value of crop production in Tigray region with Mundlak approach: First order stochastic dominance analysis

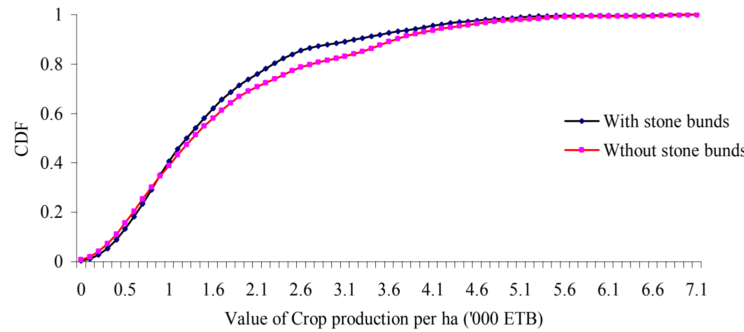

Figure 2. CDF for impacts of stone bunds on value of crop production in Amhara region with Mundlak approach: First order stochastic dominance analysis

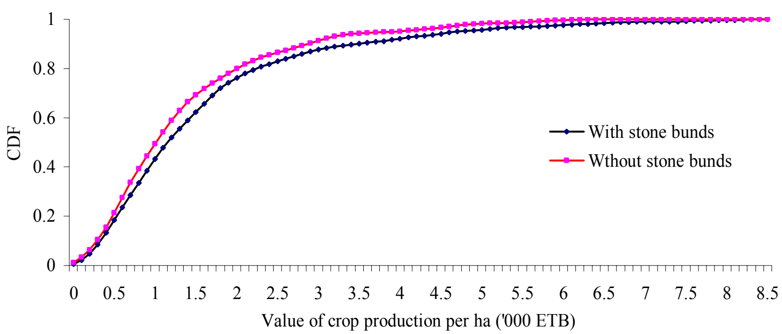

Figure 3. CDF for impacts of stone bunds on value of crop production in Tigray Region without Mundlak approach: First order stochastic dominance analysis

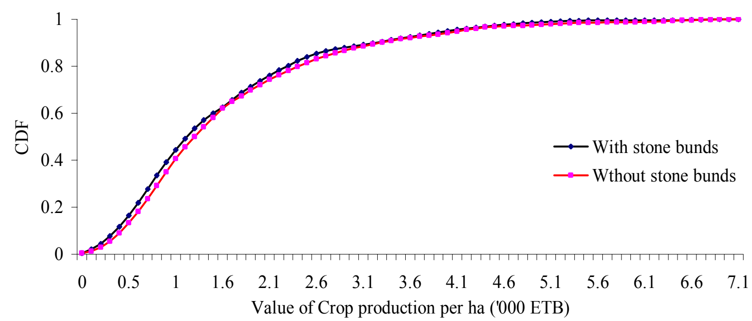

Figure 4. CDF for impacts of stone bunds on value of crop production in Amhara region without Mundlak approach: First order stochastic dominance analysis

However, we do not see this dominance for the Amhara region and indeed it appears that the yield distribution of non-conserved plots first-order stochastically dominates the yield distribution of conserved plots. However, results from a Kolmogorov-Smirnov test for first order stochastic dominance analysis indicate that there is no statistically significant difference between the two distributions [$D=0.0915$ ($p=0.431$) with and $D=0.1571$ ($p=0.353$) without the Mundlak approach]. These results agree with those from the propensity score nearest neighbor matching approach.

5.4. Parametric Regression Estimates

The modified random effects models[1] are based on matched observations that are similar in the distribution of propensity scores and covariates. The structural and reduced form of the model estimated with and without Mundlak approach, although our statistical evidence indicates that the vector γ is statistically different from zero; implying that there is a correlation between observed regressors and unobserved random effects. The dependent variable is the natural logarithms of the value of crop production per hectare.

Our parameter of interest is the mean yield gap between conserved and non-conserved plots. In the interest of brevity, we do not discuss the details of the estimated coefficients of the explanatory variables of the exogenous switching regressions but these results are available in Tables 6-9. We also estimate endogenous switching regression models, but to save space these regression results are not given, though the predicted yields are reported.

Table 6 *Determinants of value of crop production with Mundlak's approach in Tigraya region (the dependent variable is in natural logarithm)*

Explanatory variables	Model 1	Model 2	Model3	Model4
Deep soil plots	-0.131	-0.498**	-0.139	-0.462**
	(0.107)	(0.215)	(0.115)	(0.196)
Medium soil plots	-0.362***	-0.606***	-0.386***	-0.709***
	(0.130)	(0.202)	(0.134)	(0.183)
Gently slope plot	-0.282**	-0.246	-0.237*	-0.307*
	(0.116)	(0.152)	(0.123)	(0.177)
Steep slope plot	-0.259*	-0.203	-0.270*	-0.335
	(0.139)	(0.303)	(0.140)	(0.302)
Brown soil plots	-0.166	-0.394*	-0.173	-0.371
	(0.176)	(0.213)	(0.171)	(0.291)
Gray soil plots	-0.070	-0.896***	-0.088	-0.930***
	(0.213)	(0.231)	(0.207)	(0.235)
Red soil plots	-0.071	-0.695**	-0.069	-0.699**
	(0.177)	(0.296)	(0.175)	(0.322)
Loam soil plots	-0.025	0.713***	-0.000	0.810***
	(0.133)	(0.225)	(0.129)	(0.226)
Clay soil plots	0.120	0.689***	0.149	0.697**
	(0.180)	(0.265)	(0.182)	(0.275)
Sandy soil plots	-0.110	0.666**	-0.083	0.676**
	(0.189)	(0.304)	(0.184)	(0.295)
Moderately eroded plots	0.098	-0.255	0.082	-0.129
	(0.084)	(0.185)	(0.095)	(0.205)
Severely eroded plots	0.003	0.226	0.025	0.346
	(0.172)	(0.295)	(0.172)	(0.334)
Plot distance to residence	-0.196	-0.314*	-0.333**	-0.310*
	(0.139)	(0.163)	(0.156)	(0.183)
Reduced tillage plots	0.471***	-0.118	0.336**	-0.169
	(0.153)	(0.231)	(0.154)	(0.267)

1 We use modified random effects models for each specification except for the regression model without conservation with potential endogenous conventional inputs (third column of Table 7) of the Amhara region data set of the Mundlak approach where we used pooled OLS due to insufficient observations to run the random effects model on matched samples.

Table 6 Continuted

Gully plots	0.050	0.005	-0.030	0.086
	(0.354)	(0.232)	(0.332)	(0.272)
Ln(Plot size)	-0.247***	-0.351***	-0.379***	-0.594***
	(0.081)	(0.125)	(0.088)	(0.149)
Ln(other plot)	-0.265*	-0.392	-0.368**	-0.714**
	(0.159)	(0.271)	(0.176)	(0.315)
Fenced plots	0.014	0.564**	0.009	0.447
	(0.179)	(0.277)	(0.184)	(0.317)
Middle slope position	0.123	-0.773**	0.133	-1.047***
	(0.120)	(0.325)	(0.120)	(0.335)
Bottom slope position	0.144	-0.774**	0.166	-1.047***
	(0.124)	(0.358)	(0.126)	(0.351)
Not on slope position	-0.089	-0.706**	-0.096	-1.006***
	(0.145)	(0.325)	(0.158)	(0.356)
Rented in plots	-0.146	0.024	-0.219*	0.049
	(0.119)	(0.187)	(0.126)	(0.235)
Residence distance to market	-0.035	-0.076*	-0.042*	-0.072**
	(0.028)	(0.039)	(0.025)	(0.035)
Male household head	0.664***	0.847***	0.478**	0.984***
	(0.214)	(0.291)	(0.226)	(0.243)
Ln(Household head age)	0.014	-0.316	-0.005	-0.290
	(0.179)	(0.345)	(0.203)	(0.310)
Ln(Family size)	-0.057	-0.371**	-0.005	-0.431**
	(0.137)	(0.188)	(0.136)	(0.178)
Education between grade one & two	-0.049	0.158	-0.010	0.140
	(0.183)	(0.375)	(0.169)	(0.344)
Education above grade 3	-0.057	0.361	0.040	0.465
	(0.239)	(0.364)	(0.228)	(0.355)
Population density	-0.001	0.001	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Ln(rainfall)	0.442	-1.007*	-0.044	-0.922*
	(0.493)	(0.573)	(0.412)	(0.492)
Ln(household altitude)	-0.745*	-0.628	-0.103	-0.166
	(0.450)	(0.570)	(0.450)	(0.565)
Oxen holding	-0.062	-0.064	-0.053	-0.088
	(0.064)	(0.108)	(0.061)	(0.103)
Other cattle	0.032*	0.068**	0.042**	0.076***
	(0.017)	(0.028)	(0.018)	(0.026)
Small ruminant	0.011*	0.001	0.004	-0.004
	(0.006)	(0.009)	(0.006)	(0.009)
Pack animals	-0.065	-0.102	-0.058	-0.085
	(0.043)	(0.095)	(0.045)	(0.085)
Ln(fertilizer use)	0.013	0.005		
	(0.020)	(0.044)		
Ln(seed use)	0.254***	0.171**		
	(0.070)	(0.081)		
Ln(labor use)	0.102	0.058		
	(0.072)	(0.110)		
Ln(oxen use)	0.005	0.297*		
	(0.102)	(0.171)		
Joint chi2 test for significance of mean of plot	40.99**	41.47**	29.08*	43.51***
Varying explanatory variables (vector γ)				
Constant	8.651**	17.928***	7.582*	14.557**
	(4.285)	(6.691)	(4.442)	(6.377)
Model Wald chi-square test	470.621***	448.395***	240.997***	309.971***
Overall R-squared	0.3870	0.5892	0.3027	0.5678
Number of conservations	390	183	390	183
* p<0.10, ** p<0.05, *** p<0.01				
Standard errors adjusted for clustering are in parenthesis				

Note: Model 1, regression estimates with conservation including potential endogenous conventional inputs.
Model 2, regression estimates without conservation including potential endogenous conventional inputs.
Model 3, regression estimates with conservation without potential endogenous conventional inputs.
Model 4, regression estimates without conservation without potential endogenous conventional inputs.

***Table 7** Determinants of value of crop production without Mundlak's approach in Tigray region (the dependent variable is in natural logarithm)*

Explanatory variables	Model1	Model2	Model3	Model4
Deep soil plots	-0.096	-0.130	-0.087	-0.112
	(0.100)	(0.194)	(0.109)	(0.195)
Medium soil plots	-0.323***	-0.248	-0.309**	-0.246
	(0.121)	(0.192)	(0.124)	(0.193)
Gently slope plot	-0.313***	0.077	-0.288***	0.133
	(0.097)	(0.177)	(0.106)	(0.184)
Steep slope plot	-0.270**	0.178	-0.274**	0.005
	(0.131)	(0.299)	(0.132)	(0.287)
Brown soil plots	0.051	0.129	0.038	0.128
	(0.146)	(0.283)	(0.144)	(0.334)
Gray soil plots	-0.063	0.225	-0.027	0.205
	(0.170)	(0.287)	(0.165)	(0.296)
Red soil plots	0.018	0.146	0.054	0.092
	(0.146)	(0.273)	(0.143)	(0.274)
Loam soil plots	-0.012	-0.042	-0.016	0.119
	(0.127)	(0.306)	(0.128)	(0.305)
Clay soil plots	0.138	-0.196	0.089	-0.009
	(0.151)	(0.284)	(0.153)	(0.286)
Sandy soil plots	-0.039	-0.185	-0.053	0.011
	(0.160)	(0.317)	(0.158)	(0.324)
Moderately eroded plots	0.030	-0.210	0.022	-0.167
	(0.081)	(0.172)	(0.084)	(0.170)
Severely eroded plots	0.025	-0.210	0.011	-0.206
	(0.150)	(0.248)	(0.155)	(0.256)
Plot distance from residence	-0.183	0.195	-0.324**	0.183
	(0.128)	(0.171)	(0.142)	(0.193)
Rented in plots	-0.135	-0.099	-0.239**	-0.128
	(0.112)	(0.152)	(0.118)	(0.200)
Reduced tillage plots	0.457***	0.120	0.337**	-0.014
	(0.141)	(0.205)	(0.132)	(0.238)
Gully plots	0.097	-0.368	0.098	-0.407
	(0.300)	(0.402)	(0.271)	(0.347)
Ln(Plot size)	-0.238***	0.006	-0.320***	-0.224***
	(0.054)	(0.082)	(0.056)	(0.086)
Ln(other plot size)	-0.167**	0.037	-0.208***	-0.030
	(0.065)	(0.089)	(0.074)	(0.100)
Fenced plots	0.014	0.740***	0.030	0.858***
	(0.139)	(0.229)	(0.142)	(0.289)
Middle slope position	0.092	0.013	0.107	-0.201
	(0.096)	(0.244)	(0.098)	(0.282)
Bottom slope position	-0.017	0.067	0.014	-0.152
	(0.109)	(0.247)	(0.113)	(0.295)
Not on slope position	-0.181	-0.044	-0.126	0.040
	(0.129)	(0.239)	(0.133)	(0.256)
Distance to market	-0.039	-0.065*	-0.052**	-0.067*
	(0.024)	(0.033)	(0.024)	(0.034)
Male household head	0.544**	0.554***	0.416*	0.792***
	(0.214)	(0.207)	(0.226)	(0.184)
Ln(Household head age)	-0.009	-0.290	0.016	-0.326
	(0.185)	(0.221)	(0.205)	(0.216)
Ln(Family size)	-0.100	-0.047	-0.008	-0.079
	(0.133)	(0.163)	(0.134)	(0.179)
Education grade one & two	-0.026	0.054	-0.029	0.233
	(0.151)	(0.240)	(0.144)	(0.229)
Education above grade 3	0.047	-0.088	0.102	-0.130
	(0.199)	(0.333)	(0.223)	(0.292)
Population density	-0.000	-0.001	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Ln(rainfall)	0.288	-0.860*	-0.375	-1.648***
	(0.373)	(0.443)	(0.372)	(0.436)
Ln(altitude)	-0.854**	-0.895**	-0.627	-0.434
	(0.388)	(0.445)	(0.415)	(0.480)
Oxen holding	-0.068	-0.114	-0.047	-0.112
	(0.065)	(0.078)	(0.063)	(0.082)
Other cattle	0.033**	0.048***	0.045***	0.053***
	(0.016)	(0.017)	(0.016)	(0.019)

Table 7 Continued

Small ruminant	**0.012****	**0.003**	**0.006**	**-0.003**
	(0.005)	(0.005)	(0.005)	(0.005)
Pack animals	-0.039	0.024	-0.028	-0.007
	(0.041)	(0.036)	(0.039)	(0.047)
Ln(fertilizer use)	0.028	0.059**		
	(0.017)	(0.025)		
Ln(seed use)	0.255***	0.222***		
	(0.054)	(0.070)		
Ln(labor use)	0.034	0.182*		
	(0.068)	(0.098)		
Ln(oxen use)	0.090	0.317**		
	(0.090)	(0.147)		
Constant	9.921**	17.619***	13.654***	21.339***
	(3.947)	(5.023)	(4.118)	(5.576)
Model Wald chi-square test	262.851***	219.587***	161.142***	153.716***
Overall R-squared	0.3009	0.5195	0.2254	0.3911
Number of observations	390	190	390	190
* p<0.10, ** p<0.05, *** p<0.01				
Standard errors adjusted for clustering are in parenthesis				

Note: See note for Table 6.

Table 8 *Determinants of value of crop production with Mundlak's approach in Amhara region (the dependent variable is in natural logarithm)*

Explanatory variables	Model1	Model2	Model3	Model4
Plot slop in degree	-0.003	0.007	-0.012	0.017
	(0.011)	(0.015)	(0.013)	(0.014)
Black soil plots	-0.014	-0.172	0.102	-0.296
	(0.134)	(0.199)	(0.159)	(0.262)
Brown soil plots	0.071	-0.119	0.128	-0.327
	(0.161)	(0.262)	(0.189)	(0.300)
Gray soil plots	0.044	-0.229	0.196	-0.954**
	(0.217)	(0.431)	(0.220)	(0.409)
Deep soil plots	0.106	0.149	0.141	0.438
	(0.139)	(0.345)	(0.151)	(0.354)
Medium soil plots	-0.100	-0.044	-0.146	0.159
	(0.091)	(0.263)	(0.116)	(0.281)
Moderately eroded plots	-0.008	-0.005	0.096	0.136
	(0.135)	(0.226)	(0.149)	(0.238)
Severely eroded plots	0.023	-0.477	0.030	0.295
	(0.199)	(0.376)	(0.273)	(0.438)
Clay soil plots	-0.119	-0.129	-0.153	-0.188
	(0.174)	(0.391)	(0.209)	(0.366)
Loam soil plots	-0.139	-0.286	-0.106	-0.255
	(0.121)	(0.189)	(0.146)	(0.195)
Sandy soil plots	-0.136	0.279	-0.092	0.219
	(0.159)	(0.276)	(0.177)	(0.284)
High fertile plots	0.624**	-0.624*	0.572	-0.866**
	(0.313)	(0.338)	(0.351)	(0.408)
Medium fertile plots	0.164	-0.229	0.127	-0.170
	(0.109)	(0.224)	(0.144)	(0.251)
Plot distance to main road	-0.253**	0.194	-0.187	-0.020
	(0.123)	(0.233)	(0.142)	(0.235)
Plot distance to residence	0.295*	0.001	0.230	0.018
	(0.157)	(0.269)	(0.177)	(0.340)
Gully plots	-0.116	-0.123	0.037	-0.325
	(0.211)	(0.386)	(0.245)	(0.370)
Rented in plots	0.204	-0.013	0.231	-0.235
	(0.164)	(0.323)	(0.170)	(0.416)
Reduced tillage plots	-0.217	-0.207	-0.185	-0.299
	(0.278)	(0.670)	(0.391)	(0.685)
Plot altitude	0.000	0.001	0.000	0.001
	(0.000)	(0.001)	(0.000)	(0.001)

Table 8 Continued

Ln(plot size)	0.002	0.331	0.226	0.819***
	(0.227)	(0.364)	(0.270)	(0.268)
other plot area, ha	-0.283	-0.605	-0.329	-1.043
	(0.534)	(0.755)	(0.620)	(0.644)
Residence distance to market	-0.076	0.162	-0.253	0.326
	(0.152)	(0.419)	(0.171)	(0.486)
Male household head	-0.075	0.792	-0.179	1.329*
	(0.239)	(0.626)	(0.212)	(0.753)
Family size	0.017	-0.013	0.042	0.009
	(0.024)	(0.031)	(0.027)	(0.036)
Household head age	0.002	0.003	0.001	0.001
	(0.005)	(0.006)	(0.005)	(0.007)
Population density	-0.001	0.001	-0.001	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Ln(rainfall)	0.135	0.223	0.415	0.611
	(0.242)	(0.357)	(0.261)	(0.376)
Livestock holding	0.032	0.014	0.058**	0.103**
	(0.026)	(0.045)	(0.028)	(0.044)
Education level	0.011	-0.027	0.018	-0.036
	(0.013)	(0.018)	(0.014)	(0.023)
Ln(fertilizer use)	-0.008	0.043		
	(0.022)	(0.056)		
Ln(seed use)	0.189***	0.129		
	(0.048)	(0.100)		
Ln(labor use)	0.197*	0.416***		
	(0.102)	(0.148)		
Ln(oxen use)	0.245**	0.043		
	(0.113)	(0.160)		
Joint chi2/F test for	43.44**	1.77**	40.43***	31.60*
Significance of mean of plot				
Varying explanatory variables (vector γ)				
Constant	3.706**	2.119	3.480*	0.736
	(1.825)	(2.530)	(1.889)	(2.667)
Model Wald chi-square (F) test 581.768*** 6.11*** 253.184*** 249.412***				
Over all R-squared	0.5779	0.6508	0.4100	0.4576
Number of observations	232	150	232	150
* p<0.10, ** p<0.05, *** p<0.01				
Standard errors adjusted for clustering are in parenthesis				

Note: See note for Table 6.

Table 9 *Determinants of value of crop production without Mundlak's approach in Amhara region (the dependent variable is in natural logarithm)*

Explanatory variables	Model1	Model2	Model3	Model4
Plot slop in degree	0.009	0.010	0.004	0.012
	(0.007)	(0.007)	(0.008)	(0.009)
Black soil plots	0.057	-0.108	0.076	0.111
	(0.096)	(0.235)	(0.121)	(0.240)
Brown soil plots	0.111	-0.040	0.066	-0.193
	(0.098)	(0.201)	(0.121)	(0.212)
Gray soil plots	0.252*	0.460*	0.332**	0.024
	(0.130)	(0.254)	(0.152)	(0.340)
Deep soil plots	0.135	0.188	0.127	0.406
	(0.114)	(0.281)	(0.134)	(0.272)
Medium soil plots	-0.061	-0.301	-0.126	-0.111
	(0.078)	(0.274)	(0.095)	(0.226)
Moderately eroded plots	-0.072	-0.044	-0.012	-0.045
	(0.092)	(0.178)	(0.108)	(0.195)
Severely eroded plots	-0.175	-0.064	-0.038	-0.197
	(0.135)	(0.253)	(0.208)	(0.230)

Table 9 Continued

Clay soil plots	-0.125	-0.919**	-0.226	-0.660
	(0.153)	(0.400)	(0.182)	(0.430)
Loam soil plots	-0.108	-0.279**	-0.098	-0.323**
	(0.096)	(0.134)	(0.114)	(0.157)
Sandy soil plots	-0.200**	0.080	-0.158	0.129
	(0.097)	(0.213)	(0.103)	(0.240)
High fertile plots	0.603***	0.013	0.699***	0.152
	(0.201)	(0.269)	(0.259)	(0.328)
Medium fertile plots	0.171*	0.041	0.235**	0.052
	(0.096)	(0.184)	(0.110)	(0.226)
Plot distance to main road	-0.002	0.022	-0.007	0.025
	(0.016)	(0.018)	(0.018)	(0.017)
Plot distance to residence	0.194	-0.184	0.063	-0.309
	(0.120)	(0.243)	(0.150)	(0.296)
Gully plots	-0.010	-0.479*	0.083	-0.215
	(0.142)	(0.249)	(0.168)	(0.264)
Rented in plots	0.253**	-0.266	0.382***	-0.460*
	(0.118)	(0.334)	(0.135)	(0.239)
Reduced tillage plots	-0.122	0.092	-0.081	0.216
	(0.090)	(0.228)	(0.105)	(0.172)
Ln(plot altitude)	0.026	0.980	-0.194	0.276
	(0.218)	(0.625)	(0.284)	(0.637)
Ln(plot size)	0.018	0.053	0.299***	0.349***
	(0.080)	(0.129)	(0.079)	(0.117)
Other plot area	-0.170***	-0.136	-0.369***	-0.158
	(0.063)	(0.094)	(0.083)	(0.115)
Residences distance to market	0.007	-0.073	-0.022	-0.054
	(0.034)	(0.082)	(0.042)	(0.092)
Male household head	-0.098	0.377	-0.165	1.226*
	(0.276)	(0.498)	(0.246)	(0.671)
Family size	-0.006	0.052	0.028	0.051
	(0.022)	(0.035)	(0.028)	(0.037)
Household head age	0.003	-0.001	0.001	-0.007
	(0.005)	(0.007)	(0.005)	(0.007)
Livestock holding	0.054**	0.041	0.080***	0.109***
	(0.024)	(0.034)	(0.029)	(0.040)
Education level	0.014	0.011	0.016	0.006
	(0.012)	(0.023)	(0.012)	(0.025)
Ln(population density)	-0.082	0.115	-0.195**	-0.033
	(0.094)	(0.120)	(0.096)	(0.152)
Ln(rainfall)	0.203	-0.633*	0.432**	-0.125
	(0.154)	(0.345)	(0.187)	(0.347)
Ln(fertilizer use)	0.014	0.088**		
	(0.017)	(0.036)		
Ln(seed use)	0.187***	0.156**		
	(0.030)	(0.067)		
Ln(labor use)	0.207***	0.244**		
	(0.072)	(0.109)		
Ln(oxen use)	0.177**	0.135		
	(0.085)	(0.128)		
Constant	3.382*	1.159	5.963***	4.574
	(1.834)	(3.812)	(1.814)	(3.477)
Model Wald chi-square test	273.532***	100.905***	69.609***	312.106***
Overall R-squared	0.5025	0.4503	0.2978	0.2532
Number of observations	232	159	232	159
* p<0.10, ** p<0.05, *** p<0.0				
Standard errors adjusted for clustering are in parenthesis				

Note: See note for Table 6.

The predicted yields from equation (1) (augmented by equation (2)) are used to examine the mean yield gap between conserved and non-conserved plots. Results from exogenous switching regressions indicated that the mean difference in value of crop production between conserved and non-conserved plots is negative, but not statistically significant for the Amhara region (Table 10). However, it is positive and significant for Tigray, which is in line with the nearest neighbor propensity score matching and stochastic dominance estimates. The mean yields are significantly lower and less statistically significant without Mundlak approach. The results when the inverse Mills ratio is included in the models are consistent and robust (Table 11). There are not significant estimated yield differences between endogenous and exogenous switching regression models.

Table 10 *Linear random effects estimates of Conservation effect using exogenous switching regression method (Outcome variable: natural logarithm of the value of crop production per ha, ETB/ha)*

Model types	Predicted mean yield with stone bunds	Predicted mean yield without stone bunds	Predicted mean yield difference [SE}
A	B	C	D =B-C
1. With Mundlak' approach			
With conventional inputs			
Tigray Region	7.049661	6.900765	0.148896(0.0546877)***
Amhara region	7.131365	7.180364	-0.0489989(0.0635733)
Without conventional inputs			
Tigray Region	7.055725	6.889948	0.1657768(0.0499012)***
Amhara region	7.13041	7.180763	-0.0503531(0.0531618)
2. Without Mundlak's approach			
With conventional inputs			
Tigray Region	7.048979	6.954059	0.0949204(0.0481269)**
Amhara region	7.109128	7.1291	-0.0199722(0.0575745)
Without conventional inputs			
Tigray Region	7.049217	6.9527	0.0965163(0.0421308)**
Amhara region	7.113032	7.127191	-0.0141592(0.0449712)

Table 11 *Linear random effects estimates of Conservation effect using endogenous switching regression method (Outcome variable: natural logarithm of the value of crop production per ha, ETB/ha)*

Model types	Predicted mean yield with stone bunds	Predicted mean yield without stone bunds	Predicted mean yield difference[SE]
A	B	C	D =B-C
1. With Mundlak's approach			
With conventional inputs			
Tigray Region	7.049083	6.900649	0.1484342(0.0545335)***
Amhara region	7.13137	7.180364	-0.048994(0.0637001)
Without conventional inputs			
Tigray Region	7.05534	6.890594	0.1647462(0.0500222)***
Amhara region	7.130719	7.180539	-0.0498198(0.053696)
2. Without Mundlak's approach			
With conventional inputs			
Tigray Region	7.048994	6.953778	0.0952165(0.048139)**
Amhara region	7.110443	7.129291	-0.0188476(0.0571378)
Without conventional inputs			
Tigray Region	7.049198	6.952218	0.0969802(0.0421348)**
Amhara region	7.112892	7.112892	-0.0148513(0.0473643)

We therefore conclude from the results of three different methods that soil and water conservation is more productive in low rainfall than high rainfall areas. We believe this is due to greater benefits of moisture conservation in low rainfall areas, while in high rainfall areas moisture conservation may contribute to problems such as water logging, weeds and pests. This finding is consistent with those from other studies in the Ethiopian highlands

(Herweg, 1993; Benin, 2006; Kassie and Holden, 2006; Pender and Gebremedhin, 2006). Even though using physical structures for moisture conservation in high rainfall areas may not increase productivity in the near term, this does not mean that no conservation techniques are warranted. In fact, appropriate conservation measures (e.g. moisture drainage ditches) could help protect soils during extreme rainfall events.

6. Summary and Conclusion

The primary objective of this paper is to investigate the impact of stone bund adoption on crop yields using multiple plot observations per household in low and high rainfall areas of the Ethiopian highlands. Considering rainfall is important because rainfall varies substantially across and within countries, including those in SSA such as Ethiopia. It is therefore likely to be important to consider the distribution of rainfall when making decisions about SWC technologies and indeed agro-ecological conditions may be a particularly important determinant of whether SWC adoption increases household welfare. SWC technologies have been actively promoted in Ethiopia and many other countries without accounting for agro-ecological conditions.

We have used propensity score matching, stochastic dominance analysis (SDA), and parametric regression (modified linear random effects and pooled OLS models) to check the robustness of our results. The parametric regression and SDA estimates are based on propensity score matched samples obtained from a nearest neighbor matching method. This is important, because conventional regression and stochastic dominance analyses typically do not ensure that there actually exist comparable conserved and non-conserved plots on the distribution of covariates.

The estimates from the three methods tell a consistent story. Stone bunds have a positive and statistically significant productivity impact in low rainfall areas. For instance, the results from propensity score estimates show the existence of a crop value premium of ETB 412 (US$ 59) for conserved plots compared to non-conserved plots in low rainfall areas (Tigray region) of the Ethiopian highlands. This is the opportunity cost of not conserving plots, which is a significant amount of money compared to the average value of crop production in the Tigray highlands, which averaged ETB 1614 per hectare in the survey sample.

This yield effect is not observed in high rainfall areas, suggesting that the productivity impact of stone bunds is agro-ecology specific. This highlights the importance of developing and disseminating soil conservation technologies that are appropriately tailored to agro-ecological zones instead of making blanket recommendations that promote similar conservation measures to all farmers. For instance, in high rainfall areas moisture conservation using physical structures may not be important, but placing appropriate drainage measures could help soil protection during extreme rainfall events.

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The Impact of Compost Use on Crop Yields in Tigray, Ethiopia, 2000-2006 inclusive

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Introduction

History of crop cultivation in Ethiopia

Crop cultivation in Ethiopia has a long history of at least 5000 years (Clark, 1976), and implements for cutting and grinding seed have been found in stone age sites, such as Melka Konture by the Awash River in central Ethiopia, dating back much earlier. Just when crop cultivation started in Ethiopia has not been determined, but its long history is also reflected in the high agricultural biodiversity, including endemic crops, the best known of which is the cereal teff (*Eragrostis tef*). The high diversity in crop species and genetic diversity within crops is a reflection of the environmental and cultural diversity of Ethiopia (Engels & Hawkes, 1991).

Many crops that are known to have their centres of origin in the fertile crescent of south-west Asia, for example durum wheat (*Triticum durum*), now have their highest genetic diversity in Ethiopia. The treatment of *Triticum* for the Flora of Ethiopia and Eritrea recognizes a highly variable endemic species, *T. aethiopicum*, which is more usually considered as a subspecies or variety of *T. durum* (Phillips, 1995). Other important crops with high genetic diversity in Ethiopia include the cereals—barley (*Hordeum vulgare*), finger millet (*Eleusine coracana*) and sorghum (*Sorghum bicolour*); pulses—faba bean (*Vicia faba*), field pea (*Pisum sativum* including the endemic var. *abyssinicum*), chick pea (*Cicer arietinum*) and grass pea (*Lathyrus sativus*); oil crops—linseed (*Linum sativum*), niger seed (*Guizotia abyssinca*), safflower (*Carthamus tinctorius*) and sesame (*Sesamum indicum*); and root crops—enset (*Ensete ventricosum*), anchote (*Coccinia abyssinica*), 'Oromo or Wollaita dinich' (*Plectranthus edulis*), and yams (*Dioscorea* spp.). Over 100 plant species used as crops in Ethiopia have been identified (Edwards, 1991).

European travellers, e.g. Alvares at the beginning of the 16th century (Alvares, 1961) and later ones, describe the productivity and health of the highland agriculture—crops, domestic animals and people—and compare this with the depressed situation in much of Europe at that time. Poncet (1967), who visited Ethiopia between 1698 and 1700, described his experience with the words, "no country whatever better peopled nor more fertile that Aethiopia". He describes even the mountains he saw as all well cultivated "but all very delightful and covered with trees".

However, since 1974, Ethiopia has been portrayed as a food deficit country with its people and animals suffering from drought and famine. In January 2002, over 5 million people were identified as being food insecure, and this number had risen to around 14 million by the end of the year because of the failure of the rains in much of the eastern parts of the country.

Starting in the second half of the 19th century, efforts to build an administratively centralized Ethiopian state as a reaction to European colonialism in other parts of Africa systematically destroyed local community governance because it was suspected that such communities could become possible allies of colonialists. Loss of local governance undermined local natural resource management with loss of protection of woody vegetation, lack of repair of old terraces, and general undermining of any attempts at communal management of natural resources. The feudal landlord system was maintained with the bulk of the population existing as serfs. As Ethiopia entered into the world market, these landlords mined the land resources with nothing going back to the land. Civil war exacerbated these impacts. The most visible physical impacts have been gully formation eating away the soil with vegetation recovery prevented by free-range grazing and the unregulated felling of trees for firewood and other purposes.

There were no inputs in technologies or ideas to help these small holder farmers improve their productivity. They had to continue to rely for their survival on their indigenous knowledge and the rich agricultural biodiversity that they had developed, but were unable to continue effectively using collectively for fear of political reprisal.

Then, in 1974, Emperor Haile Selassie and the feudal system of control over farmers and their land was removed in a revolution that organized the whole population into local, nominally self-governing, organizations with their own elected officials. Under the military government, called the 'Derg', there were massive efforts at land rehabilitation through mass mobilization for soil and water conservation, planting of tree seedlings, and the provision of external inputs through cooperatives. However, administration remained centralized and coercive—overall productivity did not increase. The farmers continued to be ordered about and exploited as had been done under the over-centralized feudal regime. There were also frequent and disruptive redistributions of land. The farmers had no possibility for taking collective decisions on natural resources management and no interest or incentives to invest in improving their land.

In 1991, the military government was overthrown. A new constitution that required decentralization of power and encouraged local community governance was adopted in 1995. In 1993, the Sasakawa-Global 2000 approach was launched to provide high external inputs—principally chemical fertilizer—to farmers. As from 1995, this program was taken up by the National Extension Program of the Ministry of Agriculture and Rural Development. At the beginning, fertilizer cost was subsidized, but as from 1998, the subsidy has been removed and the local price of diammonium phosphate (DAP) and urea, the chemical fertilizers used in Ethiopia, has doubled. Overall grain production in the country as a whole has increased each year since 1998. However, this has not benefited the people living in the drought prone areas of the northeast and east, who continue to depend on aid. These people have become chronically food insecure requiring annual inputs of aid as food. Whilst this food may save lives, it does not and cannot replenish productive assets that would enable people to reduce their poverty.

ISD's project on sustainable agriculture

It was against this background that, in 1995, the Institute for Sustainable Development (ISD) developed a project to work with local farming communities of small holder farmers in Tigray using an ecological, low external input approach. The major challenges addressed in the project were to:

Restore soil fertility through making and using compost, and help farmers avoid debt paid for chemical fertilizer;

Improve biological and physical water and soil conservation in crop land including the control and rehabilitation of gullies;

Control, preferably stop, free-range grazing to allow more grass, herbs and trees to grow;

Include grasses and fast growing legumes in areas treated for soil and water conservation. The most successful has been the small multipurpose indigenous tree, *Sesbania sesban* planted for animal forage and compost biomass in the rehabilitated gullies and on the bunds between fields. There has also been a rapid reestablishment of indigenous plants, particularly shrubs and trees, in the hillsides protected from grazing animals.

Help local communities restore local control and effective management of their natural resources through the development and enforcement of their own by-laws.

Although Tigray has an area of over 50 thousand square kilometres, previously malaria prevented most of the population from living at the lower altitudes, but now all parts are being inhabited owing to effective malaria control measures. In 2003, the population of Tigray was estimated to be over 4 million, with most of the households being found above 1500 m altitude. Most households are rural practicing mixed crop/livestock agriculture. A socio-economic survey of some farming communities carried out by ISD in 2001 found that average cultivated land per household is less than one hectare usually distributed in 3-5 small separate parcels.

Average annual rainfall is 500-700 mm. The precipitation occurs mostly during a short summer (end of June to mid-September) rainy season, often falling as intense storms.

ISD started the project in 1996 with 4 local communities. By 2006, ISD was following up the project activities in 57 local communities in 12 of the 53 weredas (districts) in Tigray, the majority in the degraded lands of the central and eastern parts of the Region. A wereda (district), the lowest level of government administration, is divided into tabias. A tabia, with its elected representatives, runs the day-to-day affairs of the local communities under its jurisdiction.

From the beginning, the project has been implemented in partnership with the Tigray Bureau of Agriculture and Rural Development (BoARD) and has been funded by the Third World Network (TWN), an international NGO network with its head office in Penang, Malaysia. In 2006, TWN published the experiences of the Tigray Project (Hailu Araya & Sue Edwards, 2006). This included some of the data from monitoring the impact of compost and chemical fertilizer on crop yields in farmers' fields in Tigray. Up to and including 2005, yield data had been collected from 779 plots in farmers' fields.

In 2005 and 2006, the Swedish Society for Nature Conservation (SSNC) also provided funding to ISD for its work in Tigray. This included the publishing of a poster on the making compost to support the compost manual in Tigrinya (the local language) published in 2002 (Arefayne Asmelash, 1994 EC), and distributed to all 53 weredas of the Region.

In 2006, the FAO Natural Resources Department provided funding to help collect additional yield data from 195 plots in farmers' fields during the 2006 harvesting season, and pay for entry and statistical analysis of the data.

Materials and Methods

The objective of the project was to find out if an ecological approach could help restore soil fertility and raise crop yields, particularly for farmers in degraded areas. In 1998, yields were recorded from the fields of farmers in 4 communities that started work with ISD in 1996—(O) in Table 1. The results were encouraging (Annex in Edwards, 2003), and the BoARD requested ISD to continue to monitor the impact of compost on crop yields. Hence, starting from 2000, yields have been taken from plots in farmers' fields in 19 communities in 8 of the 53 weredas of Tigray Region. The majority of the communities (17) are found in the drought prone areas: Alamata of the Southern Zone (2 communities), and all parts of the Eastern (6 communities) and Central (9 communities) Zones of Tigray. The soils of these areas are generally poor and the rainfall is erratic. However, 2 communities are found in better endowed areas: Adi Abo Mossa in the valley of Lake Hashenge of Southern Tigray where the soils are deep, rainfall more reliable and some farmers have larger cultivated areas and large herds of cattle, and Adi Aw'ala in Western Tigray where the rainy season is generally 2-4 weeks longer than the rest of the Region. Adi Abo Mossa was included in the project because of a concern that increased use of chemical fertilizer could lead to eutrophication of Lake Hashenge.

***Table 1** List of local communities from which crop yield data were taken between 2000 and 2006 inclusive*

Zone	Woreda	Tabia	Community
Southern Tigray	Ofla	Hashenge	Adi Abo Mossa (O)
	Alamata	Lemat Seelam Beqalsei	Adi Abo Golgi Seelam Beqalsei
Eastern Tigray	Sa'esi'e Tsada Amba	Sendeda Mai Megelta Agamat	Tsebela Zeban Sas (O) Gu'emse (O)
	Kilte Awla'elo	Mai Weyni	Sherafo
	Atsbi-Wonberta	Hayelom	Gergera Enda Maino
Central Tigray	Tahtai Maichew	Mai Berazio	Adi Nefas (O)
		Akab Se'at	Adi Gua'edad
		Ruba Shewit	Adeke Haftu
		Mai Siye	Mai Tsa'ida
		Kewanit	Hagere Selam
		Adi Guara	Tselielo
		Adi Hutsa	Kenef
	Kolla Tembien	Guroro Miwtsa'e Worki	Shimarwa Adi Reiso
Western Tigray	Tahitay Adyabo	Adi Aw'ala	Adi Aw'ala
Total	8	18	19

Key – (O) refers to communities where work started in 1996/7, the others joined the project later.

The fields for taking the yield samples were selected with the farmers and chosen to represent the most widely grown crops, each of which had been grown with compost, or with chemical fertilizer, or without any input (the check). The amount of compost applied ranged from the equivalent of 5 to 15 tonnes per hectare. It was assumed that farmers had applied the recommended rates of urea and DAP, i.e. 120 kg/ha.

The method used to collect the yield data was based on the crop sampling system of FAO. Three one-metre square plots were harvested from each field to reflect the range of conditions of the crop. The harvested crop was then threshed and the grain and straw were weighed separately. For comparison, all yields were converted into kg/ha.

Most cereals are harvested leaving quite a long straw in the field (up to 20 cm) because domestic animals are put to graze in these fields as soon as the harvest has been collected. The data were recorded along with the name of the farmer, the crop and the treatment, the location and the date. The farmer kept the straw and grain. The harvested straw is important because it is the main source of animal feed during the dry season, and the animal manure and straw are important raw materials for making compost.

Results and Discussion

Between 2000 and 2006, grain and straw yield data were taken separately from 974 plots. The names of the 11 crops from which observations were recorded are given in Table 2. But 4 of these were dropped from the final statistical analysis because each had less than 10 observations. This left 7 cereal and 2 pulse crops in the final statistical analysis.

Table 2 *List of crops from which yield data were recorded, 2000-2006*

	Crop	**Scientific name**	**Remarks**
1	Barley	*Hordeum vulgare*	Many farmers' varieties are grown
2	Durum wheat	*Triticum durum*	The most widely grown wheat
3	Finger millet	*Eleusine coracana*	Not grown as widely as in the past
4	Hanfets	*Hordeum vulgare* + *Triticum durum*	A mixture of barley and durum wheat grown in areas prone to erratic rainfall and generally poor soils
5	Maize	*Zea mays*	Grown more for the fresh cobs than the grain
6	Millet	*Eleusine coracana*	The same as finger millet – less than 10 observations were recorded under this name
7	Sorghum	*Sorghum bicolor*	Grown more widely in the western lowlands than the highlands
8	Teff	*Eragrostis tef*	Ethiopia's endemic cereal with many varieties
9	Chick pea	*Cicer arietinum*	Not very widely grown – less than 10 observation were recorded
10	Faba bean	*Vicia faba*	The most widely grown pulse, also known as horse bean
11	Field pea	*Pisum sativum*	More often grown mixed with faba bean than by itself
12	Haricot bean	*Phaseolus vulgaris*	A recent introduction by the BoARD – less than 10 observation were recorded
13	Horse bean	*Vicia faba*	The same as faba bean – less than 10 observations were recorded under this name

The data were analysed using the statistical program, STATA. The average grain and straw yields converted from g/plot to kg/ha for each treatment for the nine crops are given in Table 3. The table also gives the number of observations included in the analysis for each crop and treatment. The average grain and straw yields as kg/ha for the seven cereal crops, based on the averages for each crop, are shown in Figure 1.

Table 3 *Average yields by treatment in kg/ha for 9 crops in Tigray, 2000-2006 inclusive*

	Average Yield (kg/ha)					
Crop type	**Check**		**Compost**		**Fertilizer**	
	Grain	**Straw**	**Grain**	**Straw**	**Grain**	**Straw**
Barley	1,115	2,478	2,349	4,456	1,861	3,739
	(n=56)	(n=52)	(n=57)	(n=55)	(n=36)	(n=35)
Durum wheat	1,228	2,342	2,494	3,823	1,692	3,413
	(n=73)	(n=67)	(n=61)	(n=57)	(n=48)	(n=45)
Finger millet	1,142	2,242	2,652	4,748	1,848	3,839
	(n=16)	(n=16)	(n=14)	(n=13)	(n=8)	(n=7)
Hanfets	858	2,235	1,341	3,396	1,199	2,237
	(n=31)	(n=31)	(n=31)	(n=31)	(n=29)	(n=29)
Maize	1,760	3,531	3,748	4,957	2,900	3,858
	(n=31)	(n=20)	(n=41)	(n=31)	(n=25)	(n=13)
Sorghum	1,338	2,446	2,497	3,662	2,480	4,433
	(n=14)	(n=13)	(n=11)	(n=10)	(n=5)	(n=5)
Teff	1,151	2,471	2,143	3,801	1,683	3,515
	(n=106)	(n=94)	(n=75)	(n=66)	(n=71)	(n=68)
Faba bean	1,378	2,121	2,857	4,158	2,696	3,783
	(n=20)	(n=17)	(n=23)	(n=24)	(n=3)	(n=3)
Field pea	1,527	1,201	1,964	1,625	0	0
	(n=9)	(n=9)	(n=9)	(n=9)		

'hanfets' is a mixture of barley and durum wheat (n = number of records for each treatment and crop)

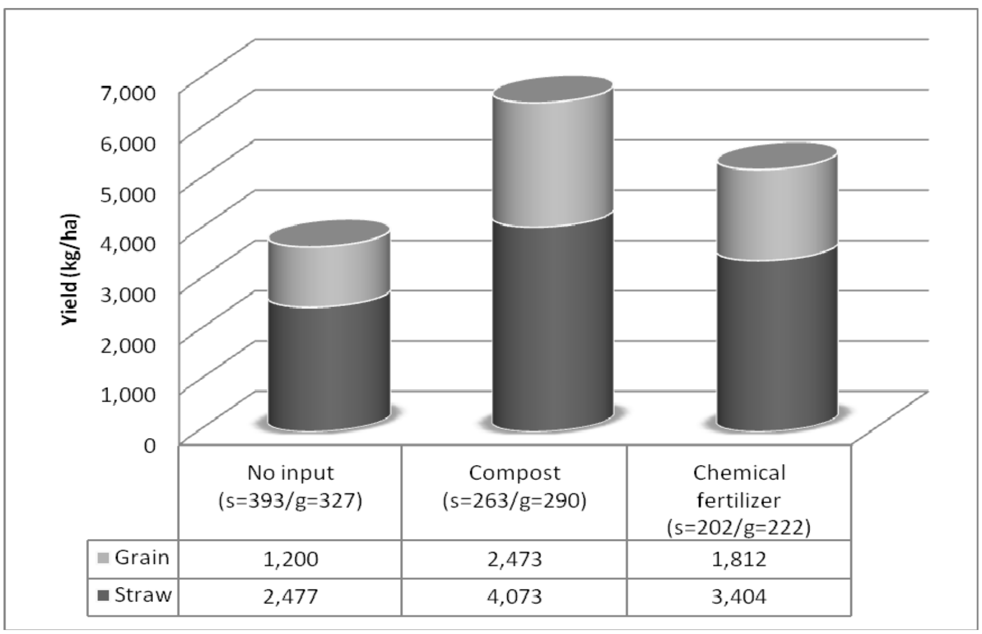


Figure 1 *Average grain and straw yields (kg/ha) for 7 cereal crops, based on the averages for each crop, Tigray, 2000-2006 inclusive (s=number of observations for straw yield g=number of observations for grain yield)*

The data for the 9 crops were subjected to linear regression analysis by treatment based on the values obtained from fields where compost was applied, chemical fertilizer (DAP and urea) was applied and no input (check) was applied. The null hypothesis used was that the treatments have no impact on the yields. The probability that this null hypothesis could explain the results was found to be less than 0.05. In other words, the confidence limit was found to be above 95 percent. The increase in grain yields in fields where chemical fertilizer was applied was significantly higher (95% confidence limit) than in the fields where no input (check) was applied, and the grain yields in fields where compost was applied were also significantly higher (95% confidence limit) than in the fields where chemical fertilizer was applied. The significance in the differences among the straw yields for each treatment was similar. The differences among treatments in the yields of each of the crops were also similarly significant.

Except for field pea, the compost generally doubled the grain yield when compared to each respective check (Table 3). The difference was significant (95% confidence limit). The application of compost also increased straw yield compared to the check, but not to the same extent as it increased grain yield (Figure 1).

The use of compost also gave higher yields than the use of chemical fertilizer, though differences in the yields from compost and from chemical fertilizer were not as great as the differences between the use of compost and the check. For sorghum and faba bean the yields from the use of compost and chemical fertilizer were similar. But the yield difference for all the other crops was greater with that from the compost treatment being always higher than that from the use of chemical fertilizer.

The proportion, expressed in percentages, of the grain in the total harvested yield (grain + straw) for each of the 9 crops is given in Table 4. For the cereal crops, the percentages of the grain in the harvest are given in Figure 2. The data are only indicative because, as noted earlier, the farmers usually leave long stubble up to 20 cm tall from their cereal crops in the field for domestic animals to graze on. However, for faba bean and field pea all the above ground biomass is harvested. The results show that compost not only increases the overall biomass yield, but also increases the proportion of the grain to straw in the yield. The most striking crop is field pea where the proportion of grain in the total yield exceeded 50% for both the check and the compost treatment, but the field pea 'check' was probably grown in fields that had received compost in previous years – see the discussion below. For all the other crops, the proportion of grain in the total harvested yield ranged from 28% for hanfets to 35% for sorghum in check fields, from 28% for hanfets to 43% for maize in fields treated with compost, and from 32% for finger millet and teff to 43% for maize in fields where chemical fertilizer had been applied.

In 1998, when the first set of data were collected from plots in the four original communities, except for maize, the grain yields of the cereals from the fields without any inputs (checks) were all below 1 tonne a hectare: 395-920 kg/ha for barley, 465-750 kg/ha for durum wheat, 760 kg/ha for finger millet, 590-630 kg/ha for hanfets, and 480-790 kg/ha for teff (Annex in Edwards, 2003). In the 7-year data set, only hanfets had an average grain yield below 1 tonne a hectare (858 kg/ha). The average check yields for all the other cereals ranged from 1115 kg/ha for barley to 1760 kg/ha for maize. The 4 original communities had been making and using compost for ten years, and all the others had been using compost for 3-5 years, and the higher average check yields were probably due to the residual effect of the use of compost in previous years.

Table 4 *Total biomass and percentage grain by crop in Tigray, 2000-2006 inclusive*

	% Grain in total biomass yield (kg/ha)					
	Check		**Compost**		**Fertilizer**	
Crop type	**% Grain**	**Total**	**% Grain**	**Total**	**% Grain**	**Total**
Barley	31	3,593	35	6,805	33	5,600
Durum wheat	34	3,570	39	6,317	33	5,105
Finger millet	34	3,384	36	7,400	32	5,687
Hanfets	28	3,093	28	4,737	35	3,436
Maize	33	5,291	43	8,705	43	6,758
Sorghum	35	3,784	41	6,159	36	6,913
Teff	32	3,622	36	5,944	32	5,198
Faba bean	39	3,499	41	7,015	42	6,479
Field pea	56	2,728	55	3,589	0	0
'hanfets' is a mixture of barley and durum wheat						

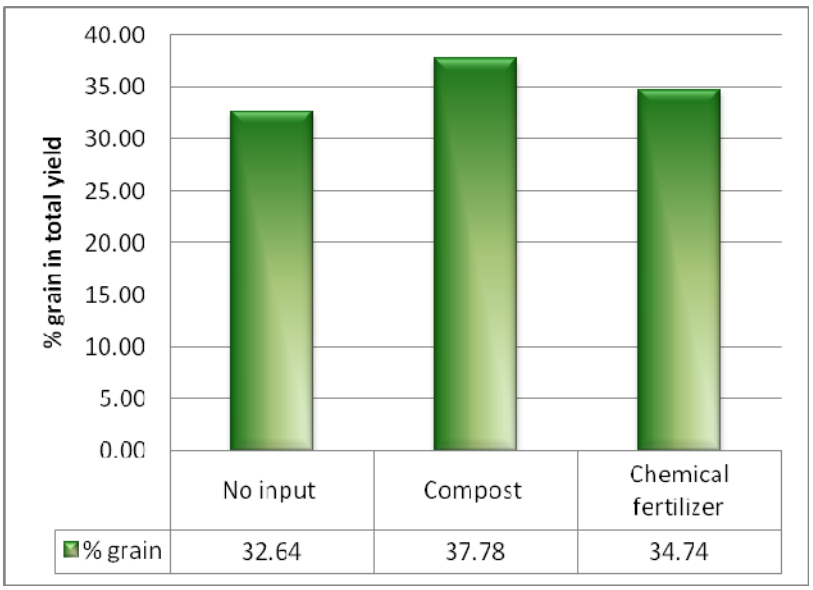


Figure 2 *Averages of cereal grain yields/crop/treatment as proportions of their respective grain + straw yields/crop/treatment, averaged over all the 7 cereal grains and expressed as percentages, Tigray, 2000-2006*

The impact of compost on restoring soil fertility is well illustrated by data for grain yields of the pulses, faba bean and field pea, shown in Figure 3 for Adi Abo Mossa. The difference between the yields for the check fields and fields that had received compost was very large in 1998, but in 2002 there was hardly any difference – for both crops and both treatments, the grain yields were over 2 tonnes a hectare. This similarity in yields is also seen for field pea in the 7-year data set in Table 3.

The residual effect of compost in maintaining soil fertility for two or more years was soon observed and appreciated by the farmers. They are thus able to rotate the application of compost on their cultivated land and do not have to make enough to apply to all their cultivated land each year.

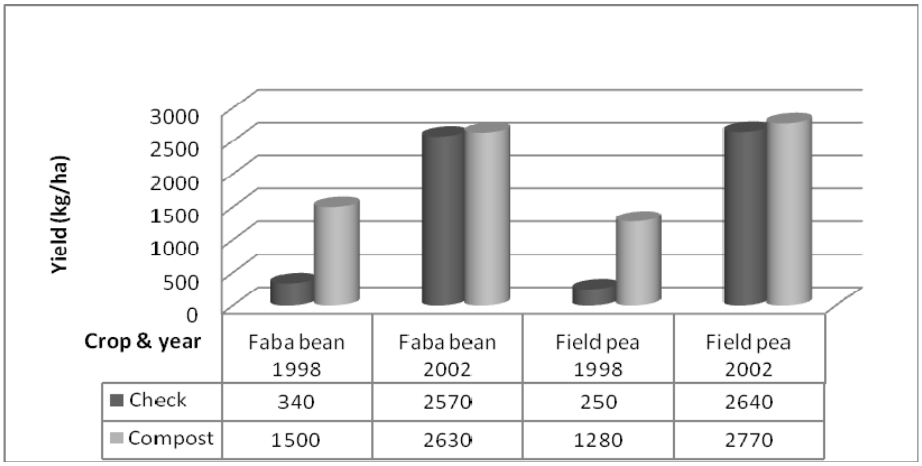


Figure3 *Yields (kg/ha) for faba bean and field pea from Adi Abo Mossa, 1998 and 2002*

The reduction of difficult weeds, such as Ethiopian wild oats *Avena vaviloviana*, and improved resistance to pests, such as teff shoot fly, has also been noted by the farmers. These impacts from the use of compost, including better resistance to crop diseases, have also been found with farmers practicing organic agriculture in France (Chaboussou, 1985).

One reason that compost has been able to significantly increase yields could be the fact that the farmers are still using their own varieties (also referred to as landraces), which have been selected by them in an organic environment where overall soil fertility is more important than just the amounts of the two major nutrients, N and P, supplied by urea and DAP. Dr Stephen Jones (personal communication) of the Washington State University and his colleagues have been breeding wheat for organic agriculture and they find that varieties that give high yields under organic conditions are different from those that give high yields with chemical fertilizer inputs.

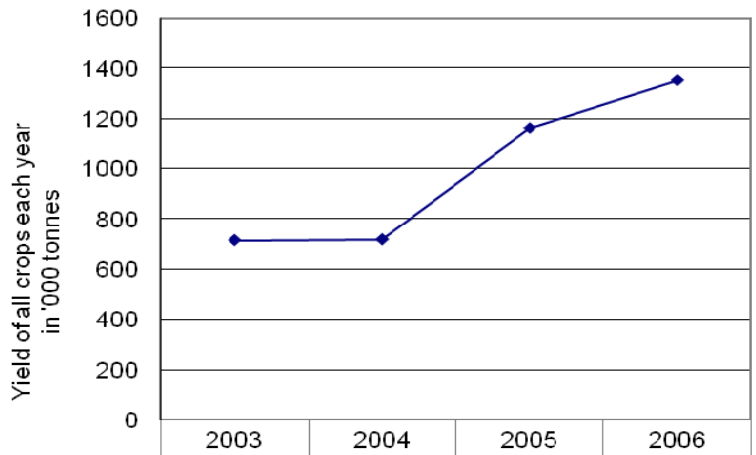
Other reasons that farmers have been ready to adopt making and using compost are that it enables them to avoid the financial risk of taking chemical fertilizer on credit, and that the compost is available when it is needed – chemical fertilizer is sometimes delivered late.

Conclusion

Since 1998, the Bureau of Agriculture and Rural Development of Tigray Region has adopted the making of compost as part of its extension package and by 2007 at least 25% of the farmers are making and using compost. A reflection of the success of this approach is that between 2003 and 2006 grain yield for the Region almost doubled from 714 to 1,354 thousand tonnes (Figure 4). Since 1998, there has also been a steady decrease in the use of chemical fertilizer from 13.7 to 8.2 thousand tonnes (Figure 5).

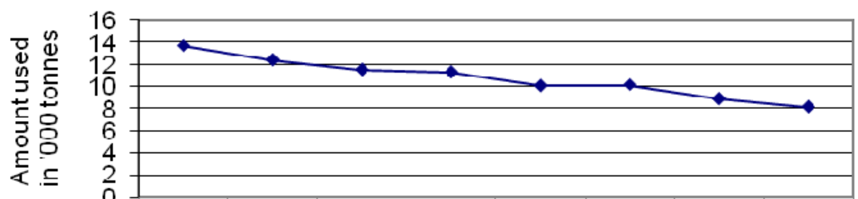
Making and using compost is also being promoted in other regions of the country, particularly through the "Community-based Participatory Watershed Development" project of the Ministry of Agriculture, and the Land Rehabilitation Project of the Environmental Protection Authority, which has been supported through three successive phases of the Country Cooperation Programme of UNDP.

Figure 4 *Total recorded crop production in Tigray, 2003-2006*



	2003	2004	2005	2006
Crop yield in '000 tonnes	713.95	716.96	1,162.20	1,353.79

Figure 5 *Total use of urea and DAP in Tigray, 1998-2005*



Year	1998	1999	2000	2001	2002	2003	2004	2005
Urea/DAP in '000 tonnes	13.71	12.43	11.54	11.32	10.09	10.17	8.90	8.17

There is also a need to involve plant breeders and farmers together in participatory plant breeding in order to explore and develop the potential of the farmers' varieties to give consistent high yields under an organic agriculture system, i.e. where compost is made and used regularly by the farmers.

Acknowledgements

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Overcoming the challenges of Parthenium hysterophorus weed through Ecological Agriculture in Southern Tigray

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1. Background

Weeds in general are a problem for agricultural production. Their negative impacts are as underestimated as crop pests are in tropical agriculture. In no other part of the world do weeds cause as much crop yield reductions and have as much an influence on human social activities (Holm, 1976; Akobundu, 1987). However, there are several weed species which are edible and provide an important source of leafy vegetables during the rainy season, especially for food insecure families.

Parthenium hysterophorus, native to the Gulf of Mexico (IPRNG, 1997), is one of the worst weeds because of its invasiveness and its negative impact on human and animal health, the economy and the environment. *Parthenium* has spread to N. America, Australia, Taiwan, Southern China, the Pacific Islands, and India (Navie et al 1996) as well as to East and South Africa (IPRNG, 1997). More recently, it has come into Ethiopia (Tamado, 2001).

The plant is a short-lived ephemeral herb, reaching 2m tall in good soils, usually 50 to 150cm tall, germinating after rain in any season, and flowering in 6 to 8 weeks. It grows on a wide range of soil types ranging from sands to heavy clay, but favours the latter, which is one of the most productive soils. It can grow in any area with a rainfall greater than 500mm/annum. Its small seeds last up to 20 years in the soil. Seed dormancy is induced by burial (IPRNG, 1997). It produces large quantities of seed, up to 150,000 per plant or more than 340 million seeds per hectare. It colonizes areas with poor ground cover such as wastelands, roadsides and overgrazed pastures because its seeds are light and easily dispersed by wind (IPRNG, 1997b), and also by vehicles, machinery, stock, flooding, in food-grain and in fodder (Tamado, 2001).

Parthenium is unpalatable to stock, and on suitable soils in the summer rainfall tropics and sub-tropics, will quickly dominate both native and planted pastures particularly where these are overgrazed. Once dominant, *Parthenium* continues to persist as pure stands unless managed. Therefore, it threatens biodiversity.

Some people suffer severe allergic reactions from its pollen; it can cause dermatitis, hay fever and asthma. It is toxic to cattle, and meat from livestock that eat it can be tainted (IPRNG, 1997b). *Parthenium* has a serious impact on the pastoral industry, costing farmers and grazers in Queensland, Australia, over USD 22 million a year in reduced production and increased management costs (IPRNG, 1997b).

Removing weeds takes up more of the tropical farmers' time and labour than any other crop production activities. Akobundu (1991) estimated that 50% of all labour input into crop production in sub-Sahara Africa is for weed control. Weeding is one of the reasons for having a large family size, which provide the needed labour for crop production. Weeding is mostly done by women and children, and gives them an additional burden, when their food stores are empty or almost empty. Crop yield loss from weeds has been estimated at 10% in the less-developed and 25% in the least-developed countries (Akobundu, 1987). In India yield decline due to *Parthenium* infestation has been estimated to be as high as 40% (Khosola and Sobti, 1981).

Nowadays *Parthenim* is becoming useful for many purposes such as green leaf manure, as a biopesticide and also as a raw material for making compost; in India *Parthenium* green leaf manure increased the height of rice (Sudhakar, 1984).

2. Current problem

Parthenium was introduced to India in 1955 through imported food grain (IPRNG, 1997b). It is a belief of Ethiopian farmers that *Parthenium* was introduced to Hararge[2], Jijiga and Dire Dawa by army vehicles during the Ethiopia-Somalia war of 1976-77, and to western Hararge with food-grain, livestock and road construction (Tamado, 2001). Farmers in Northern Ethiopia believe that it came with food-aid in the Great Ethiopian Drought of 1984/85. Some people, especially farmers, say that they saw it spread in a short time after the food-aid distribution. Before this it had only been seen in the eastern part of the country following the main roads from the ports of Assab and Djibouti, but now it is throughout the country, especially in the Rift Valley area, lowlands of northern Shewa and southern Wollo and the Raya-Mohoni of southern Tigray. From roadsides it spread to farmers' fields and grazing land.

Crop loss due to *Parthenium* infestation in sorghum was studied by Tamado (2001) in Eastern Ethiopia and found it to be 41 to 97 percent. Even though figures have not been obtained from agricultural land in Southern Tigray and Wollo, the farmers report high losses.

Regional Bureaus of Agriculture and Rural Development are trying to eradicate *Parthenium* through different methods and improve agricultural production. Since 1996, the Institute for Sustainable Development (ISD) in collaboration with the local agricultural experts of the Bureau of Agriculture and Rural Development (BoARD) of Tigray has been training smallholder farmers in the preparing and use of compost. However, farmers were initially advised not to include *Parthenium* in the composting biomass. Then, in 2005, the former Agriculture Main Department Head of the Tigray Region BoARD asked an ISD project officer to experiment and find out if *Parthenium* could be used to make compost without its seeds staying viable.

3. Parthenium eradication methods tried

In many places of the world attempts to control *Parthenium* infestation have been tried through eradication campaigns but the progress is slow. This is because it colonizes new lands faster than it can be controlled.

[2] Hararge and Jijiga refer to the old administration region. Now the study area referred by Tamado (2001) is between Somali, Harari and Oromiya regions, and Dire Dawa city administration.

Classical biological control, involving the use of insect pests or pathogens for problematic weeds such as Mealy Bug (*Ferris virgata*) can be used to control *Parthenium*. It feeds on the root and the affected plant starts drying due to wilting. Another insect, Lantana Bug (*Orthezia insignis*), is also effective in controlling it. The beetle (*Zygogramma bicolorata*) is another important insect to control *Parthenium*. It causes defoliation in the plant and finally destroys it. A leguminous weed, *Cassia sericea*, inhibits the growth of *Parthenium* by allelopathy (IPRNG, 1997b). But this does not easily fit into the broad category of weed control in the specific cropping patterns or systems of smallholder farmers (Tamado, 2001).

Chemical weed control is a relatively new introduction in controlling *Parthenium* but it is not economically feasible for most small-scale farmers (Tamado, 2001); moreover, the chemical can be dangerous for other living organisms, including people. *Parthenium* is easily killed with herbicides, but rapid regeneration from seed soon follows. The only successful way to control the plant with herbicides is to use residual pre-emergence compounds to prevent further seed production (IPRNG, 1997).

Weed eradication campaigns can only be achieved by initial destocking followed by reduced stocking rates to maintain grass competition (IPRNG, 1997). Pulling out the plant (Tamado, 2001) with its roots before flowering and burning it is one of the easiest ways of controlling *Parthenium* (IPRNG, 1997b).

In a few places, notably in India, *Parthenium* has been used to make compost (IPRNG, 1997b), and this is the approach described in this paper.

4. Materials and methods

The main objective of the study was to find out a means to reduce, even if not eradicate, *Parthenium* weed through using its biomass for making compost. Compost making from *Parthenium* has been tried in India but no body tried it in Ethiopia until the Tigray Region BoARD asked ISD to investigate this possibility. ISD saw this challenge as a good chance for getting biomass for making compost.

The study was conducted in 2006 summer season. The compost making and field trials were in a Farmers' Training Center of Selam Bikalsi tabia of Alamata Town of Southern Tigray, which is one of the tabias highly infested by *Parthenium* weed.

The making of compost from *Parthenium* weed was as follows. Four types of biomass were used for preparing compost from *Parthenium*. These were: 1. 100% green *Parthenium* without water being added; 2. 75% of equal amounts of green and dry *Parthenium* mixed and 25% of other plant materials, animal manure, urine and water; 3. 100% dry *Parthenium* without water being added, and 4. 50% dry and 50% green *Parthenium*, without water being added.

A germination test was carried out on the seeds picked from the compost prepared to find out if any of them were viable.

The field experiment was using maize of a local farmer's variety. There were four sub-plots for each type of compost prepared from *Parthenium*. The sizes of the sub-plots were 126.56 m^2.

Samples from compost prepared from Parthenium weed were collected. All were analysed for organic carbon, Total Nitrogen (N), Phosphorous (P), Potassium (K), Cation Exchangeable Capacity (CEC), pH and Exchangeable Cations (EC). The analysis was done by Water Works Design and Supervision Enterprise of the Ministry of Water Resources.

5. Results and discussion

Compost pits and their observation results

Table 1 gives the four types of compost preparation, dates and observations made when compost pits were opened. The compost prepared from 75% of equal amounts of green and dry *Parthenium* mixed and 25% of other composting materials was well decomposed, nothing was visible. As can be seen from table 1, the 100% green *Parthenium* without water being added did not decomposed instead it became compacted silage. The other pits were well decomposed with visible seed and stems not decomposed of the compost prepared from dry *Parthenium*, and 50% green and 50% dry mixed *Parthenium* respectively. The compost making with the two pits were without water being added.

Table 1 *Observed results of different mixtures in making compost using Parthenium*

Biomass used	Date made	Date opened	Observation
100% Green Parthenium without water being added	May 2006	October 2006	Dark colored compacted silage
75% green & dry Parthenium and 25% other composting materials	May 2006	October 2006	Well decomposed, good smelling, color & structure
100% dry Parthenium without water being added	May 2006	October 2006	Well decomposed; seeds visible.
50% green Parthenium and 50% dry Parthenium without water being added	May 2006	October 2006	Decomposed but not the stems of the Parthenium

Sources: Field observation report

Germination test of the *Parthenium* compost

Tamado (2001) showed that the seeds are initially dormant especially those buried in the soil. Except for the compost from the pit where dry Parthenium without water had been buried, there were no seeds visible. Therefore, the visible seeds were taken for a germination test but none of the seeds germinated in six months. May be the seeds died due to the heat and moisture inside the pit inspite of the fact that no water had been added to help the composting process: perhaps enough moisture was picked up from the soil for sufficient microbial action to generate heat to kill the seeds. But this requires a further study.

Laboratory results

Compost made with *Parthenium* was analyzed along with compost samples from other sites and biomass as composting materials. The results of the *Parthenium* compost analysis are given in Table 2.

The pH of all the *Parthenium* compost showed that they are more alkaline than other kinds of compost; the high Exchangeable Cations also explained the existence of more soluble salts in the compost. When compared with other compost prepared by farmers in the rural areas and from urban waste, the pH and EC are very much higher (see table 3).

The organic carbon, which is an indicator of organic matter, and total nitrogen of all the compost are at a very good status (see table 2). The compost prepared by mixing with other composting materials is lower i.e. 4.92% and 0.24% as compared with 7.87% and 0.43% when compost is prepared from *Parthenium* alone respectively. Organic Carbon is also higher when compared with other composts while total nitrogen is very much higher with the compost prepared from urban waste (see table 3).

***Table 2** Nutrient status of Parthenium compost different by their biomass used*

Type of compost (No. of observations)	pH H_2O (1:2.5)	EC (ms/cm) (1:2.5)	OC (%)	TN (%)	C:N	Available P(mg P_2O_5/kg soil)	Available K(mgK_2O/kg soil)
75% green & dry Parthenium mixed and 25% other composting materials, animal manure, urine and water.	7.71	1.76	4.92	0.24	21:1	342.20	6680.52
100% dry Parthenium without water	7.92	4.71	8.72	0.43	21:1	392.90	10218.40
50% green Parthenium and 50% dry Parthenium without water.	7.90	3.86	7.87	0.44	18:1	369.20	8481.27

The Available P and K are also higher. The available P from *Parthenium* is lower than the compost prepared by farmers while higher than the compost prepared from urban waste. But the available potassium of the compost prepared from *Parthenium* is very much higher than all types of compost other than *Parthenium* (see table 3).

As can be seen from the tables 2 and 3, the C:N ratio is also in the optimal range, the carbon content and total nitrogen are higher. Referring table 3, the C:N ratio of the compost prepared from urban waste is low, which is an indicator of low organic carbon content as compared with total nitrogen.

Table 3. Average nutrient contents of different types of composts

Type of compost (No. of observations)	pH H_2O (1:2.5)	EC (ms/cm) (1:2.5)	OC (%)	TN (%)	C:N	Available P(mg P_2O_5/kg soil)	Available K(mgK_2O/kg soil)
Farmer made compost (4)	7.51	1.26	6.48	0.33	20	483.5	4373.67
Parthenium compost (3)	7.84	3.44	7.17	0.37	20	368.1	8460.06
Urban waste compost (2)	7.64	0.75	4.80	0.69	7	309.0	3685.50

Results of field trials

The field experiment was conducted in 2007 cropping season in a Farmers' Training Center (FTC) near Alamata Town with a local variety of maize for the treatments with all types of *Parthenium* compost. The sowing date for the experiment was 02 August 2007 i.e. the same for all treatments.

Germination dates were different with one or two days depending on the compost used. The well decomposed compost had germinated 2 days (07 August 2007) before the compost from green *Parthenium* (09 Aug 2007), observed as silage; and three days before the other two (10 Aug 2007) compost.

The maturity dates were also different and may be based on the type of compost used. The sub-plot with compost prepared from 75% of equal amounts of green and dry *parthenium* mixed and 25% other composting materials matured first; the sub-plot with 50:50 green and dry *Parthenium* without water being added followed. Again the compost from only green *Parthenium* was the third. The sub-plot which was treated with compost from 100% dry *Parthenium* only matured last.

***Table 4** Local farmers' variety of Maize yield in Selam Bikalsi FTC, Alamata 2007*

Biomass description in the pits	Yield (kg) per 126.56m2 plot		Yield (kg) per hectare	
	Grain	Straw	Grain	Straw
100% Green Parthenium without water being added	25.5	89	2015	7052.5
75% of green & dry mixed Parthenium and 25% other composting materials, animal manure, urine and water	34.0	119	2687	9404.5
100% dry Parthenium without water being added	14.0	49	1107	3874.0
50% green Parthenium and 50% dry Parthenium without water being added	21.5	75	1685	5897.5

The result shows us that the yield of grain and straw are highest with the compost prepared from 75% green and dry mixed *Parthenium* and 25% of other composting materials. The assumption of the researchers ignoring the compost prepared from 100% green *Parthenium*, which became compacted silage, was wrong because the grain and straw yield from this is the second in the field experiment. The other composts from 50% each green and dry, and 100% green *Parthenium* are third and fourth respectively. The reported low summer rain fall forced surrounding farmers to shift to other short season crops.

6. Conclusion and Recommendations

Parthenium has been introduced to Alamata and Mehoni Weredas of Southern Tigray through contaminated food-aid during the 1984/85 Great Drought of Ethiopia. Now Parthenium infestation has been affecting animal feed and crop yield. This has led to a loss of crop yield.

The Institute for Sustainable Development and the Bureau of Agriculture and Rural Development of Tigray Region had been hesitant to recommend using *Parthenium* in compost for extension work before knowing the nutrient level of the compost. At the pragmatic level, the experiment has been successful in showing that compost can be prepared, particularly if animal manure and urine and some other biomass materials and soil are incorporated in its preparation. As compared with other types of compost made by farmers the organic carbon (an indicator of organic matter), total nitrogen and available potassium are at a very good status. At the same time it is offering a better opportunity to eradicate this weed through using it to make compost as a source of biomass and it improves soil fertility of poor soils.

Germination tests on the compost also showed that the *Parthenium* seeds did not remain viable.

From the farm trials with farmer variety of maize the yield applied with the compost produced by equal amount of dry and green *Parthenium* mixed with other biomass and starters showed the highest result.

From the research the following recommendations are forwarded. It needs further research with farmers and extension professionals to:

- Identify the best compost making process,
- Analyse the nutrient content of the plant,
- Carry out long-term tests on seed germination potential in all the compost types,

- Test for impacts on most important crops in lowlands, e.g. maize, sorghum, tef, finger millet.

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Sustainable Land Management: Identifying the Best Practices

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Introduction

In every where and especially in the developing countries land is a primary means of production, to the country economy, and generate a livelihood for large proportion of the population. Accordingly, land issues in developing countries in general, and in Ethiopia in particular is becoming a central focus and a concern of many scholars and policy makers.

The land question of 1960s in Ethiopia, were exploitation of peasants by a few land lords and the ruling aristocrats came to an end in 1975, which nationalized all land and provided usufruct right to the farming population. Similarly the EPRDF government that took power from the Derg, has also maintained the land holding system as it was.[3] But to avoid the previous limitations the current government has introduced certain modification on the problems related to efficiency, tenure insecurity, reducing farm size focusing on the agricultural productivity through provision of some agricultural packages. However, despite all these efforts the problem faced by the rural community and agriculturalists still persists, and current land policy is becoming a debatable issue.

Up to now the arguments are revolving around two main streams. While some tried to stick to the political and economic passion, support the present land holding system (public ownership) presuming that the existing land policy is a special precondition to maintain sustainable land management procedure and have rural social security.[4] The second groups are criticizers of the existing land policy stating: the present land holding system and its impact on economic, environment, social and political process remains negligible- instead it leads to unsustainable use of resources

Main focuses of this paper is to examine different land management practices, it is aimed at identifying the best sustainable land management procedures and technologies used mainly by smallholder farmers either in the high potential and/or food insecure areas but are increasingly becoming vulnerable to land degradation and food insecurity. This agenda (sustainable land management) is important to the nation in general and to region (Tigray) in particular as having sustainable land management practices is crucial so as to improve agricultural productivity of small land holder farmers, reducing of poverty; realizing of the Millennium Development Goal. Therefore, understanding/examining of how different land management practices tend to lead to different evolution or intensification processes as well as which factor (economic, social, environmental, etc) hase been most critical in enabling some communities and farmers to prosper is necessary. In this paper the term sustainable land management systems refers to striking the challenges, and maintaining an appropriate balance between land use and conservation that ensures increasing of income and better wellbeing of the rural community.

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[3]3 The December 1994 Constitution of the Federal Democratic Republic of Ethiopia Proclaimed that land is a common property of the nations, nationalities and people of Ethiopia and shall not be subject to sell or to other means of transfer.

4 If the current policy is changed in favor of private ownership farmers would be forced to resort to what is called distress sale (Abebe and Mansberger, 2003)

Main intuition of this paper is to come up with approaches that are regarded as important (message) to help the region, and the community so as to develop coherent sustainable land management procedures, policies and actions that contribute to efficient and socially desirable method, enhancing the positive and mitigating the negative effects of different methods of land use or management practices.

Objective of this study

Land is one of the important resources supporting every creature (human, and non-human), and has many functions. Particularly in Ethiopia larger percentage of the population (85%) are dependent on land, source of their livelihood. Thus, to provide the greatest sustainable benefits and insure efficient use of land, land and land related problems should be given due attention. Land related problems could occur either due to inappropriate utilization, administration or management procedures. Though all these are very much related main focus of this paper is on problems that affects sustainable land management with special emphasis in the highland of Ethiopia 'Tigray'.

From different reviews I referred and observations I made I have learned that there is no single type of problem or solution, there are different combinations of problems that result from diverse localized differences in terms of physical, climatic, ethnic, demographic, and economic factors. Since factors that affect sustainable land management are complex in nature understand the nature and causes of the nexus of problems that characterize the highlands as well as the ways in which successes have occurred is necessary, which is main objective of this paper. Specific objectives are:

- Discuss the link between the various development strategy and its implication on sustainable land management, with a particular emphasis to Tigray region.
- Examine the factor that contributes to the sustainable or unsustainable use of land- identifying the best practices

Problem

In Ethiopia almost in the last three or more decades several attempts has been made to address the problems related to Environment. Consequently a consensus has been reached and all government officials, non-government institutions and community representative have agreed up on protecting the natural losses (deforestation and soil degradation) through implementing of various environmental protection programs. Simultaneously the Tigrayan government has already undertaken various environmental protecting mechanisms. However, despite these efforts continuous loss of soil and other natural resources is still a major predicament. Thus, what are the major factors for the problem of soil degradation to remain as unsolved agenda is the main question of this paper?

I believe there relationship between human and the factors that influences human wellbeing, natural, social, political and economic parameters is so complex. As a result of this complex interaction, natural resources, and in this regard land is heavily affected. The factors that causes environmental degradation (soil erosion and deforestation) and its implication on productivity and livelihood is given by the following schematically links.

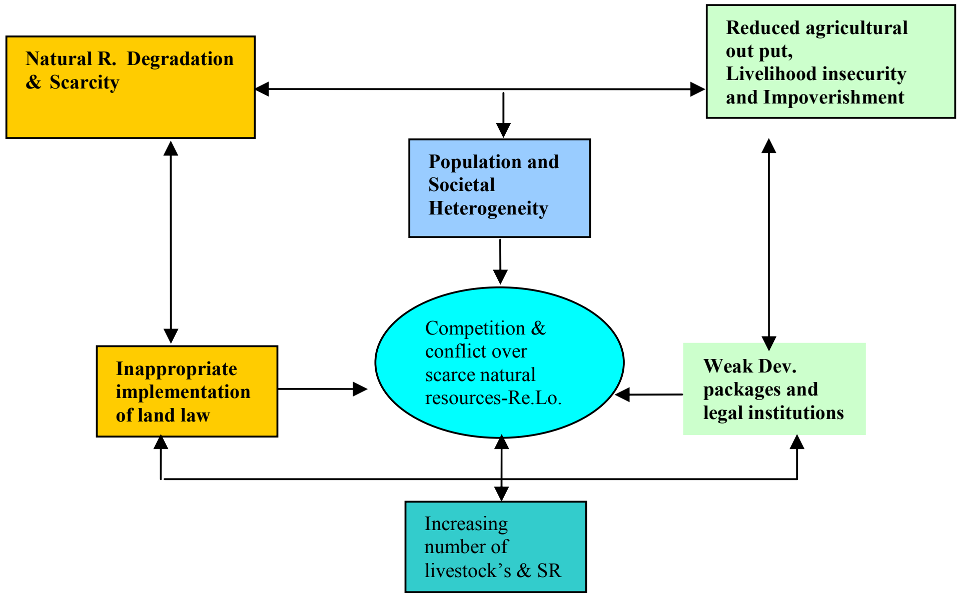

Figure 1 *Relationship between factors that affects resource use, resource degradation, and poverty (adopted from Tekelu, 2001)*

Methodology

To write this paper, both primary and secondary method has been used. Primary method includes observation (only some Weredas of Tigray), and discussion with key informants. This information from key informants has obtained from a focus group discussion conducted for other related research

Using secondary method, review of related theoretical works that shows conceptual links between land use and sustainable land management has been used. From the review and observation made I tried to check the region (Tigray) land management practice. Identifying the problems and best practices related to sustainable land management.

Apicultural Policies, Alternative Income Generating Activities, and Sustainable Land Management

To the Ethiopian economies agricultural is the dominant sector that continues to be the main livelihood for the larger portion of population, where 85 percent of the work force are engaged in agriculture as source of livelihood. This implies land is the only asset that could effectively put at a disposal of the majority of the population. Due to this fact the government of Ethiopia has given due attention to rural economies and specifically to agriculture sector. Accordingly specific development policy has been developed, which is known as Ethiopia's core policy for economic development, Agricultural Development Led Industrialisation (ADLI) launched in 1994/95 (Nega, 2003).

The main essence of this strategy is giving much emphasis to the agricultural sector, a backbone to the country's economy, with out neglecting other sectors. ADLI was designed with the aim of introducing agricultural innovations by using modern agricultural techniques and supply of basic agricultural inputs; such as fertilizer, better seed quality, pesticide and other technical assistance that enhances productivity. Simultaneously it is aimed at creating better living environment in urban areas through enhancing market outlets.

Its main objective is increasing the productivity of "smallholder farmers" through the diffusion of fertilizers and improved seeds, together with the establishment of credit schemes as well as the expansion of infrastructure - the road system, improvement of primary health care, and primary education.

All these initiatives has lead to achieve slight changes on the wellbeing of rural communities and reducing of poverty in the rural areas(stated in vrious reports compiled by government officials). Nevertheless, the achievements are far below the amount of resources utilized and efforts applied. The development strategy is trapped by various internal and external problems, which are complex in its nature, result in little progress. Of all natural (environment) threat, and population booms are the major once affected land fertility, worsen soil losses and reduce land productivity of Tigray region.[5] Though environmental related problem (soil degradation) is common in all over Ethiopia, it is sever in the northern highlands. For instance a study conducted by (Hurni 1993, cited in EPTD 2003) confirms this: Tigray region provides a recent example, that it is the most degraded state with seriously eroded and nutrient deficient arid lands. It is due to this fact the Tigrian government added the descriptor "conservation-based", to the national policy ADLI, gave particular emphasis to building value-adding and marketing chains

The environmental degradation could be because of the common and frequently stated problems such as excessive concentration of human and livestock population in ecologically marginal, dry and fragile soils that are used beyond capacity for sustained agricultural practices, over grazing and deforestation a result of much deeper underlying forces of socioeconomic nature such as poverty and total dependency on natural resources (UNCCD, 2003). However, one of the major reason which is given less weight is the complex relationship between implementation of the development programs and its effect. Sometimes negative trade-offs occur while implementing the development strategy-success in one side is complemented by failure on the other. For instance the paradoxes often occurred when the regional government is constructing roads is one that can be mentioned. Constructing of roads in Tigray is always complemented by environmental damages, soil and/or forest losses. While constructing the road, the areas (right and left) around the routs have been removed permanently from agricultural activities, often devoted for transportation.[6] During the construction of rural road project disturbances caused to the natural soil introduced erosion effects to the fertile soils including areas far away form the road alignment. Soil and/or forest losses are affecting the short and long run sustainable use of resources, and have socio-economic implications not only to these people who are residing in areas where the road construction projects are carried out but also hinders the region economic growth at large. This implies careless way of implementing/undertaking rural road projects led to have negative effects on environment, affects sustainability of the resource and retards economic growth of the region. Sustainability is a long term food self sufficiency, which requires agricultural systems that are more ecologically based and that don't destroy the natural resource.[7]

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[5] Due to rapid increasing of population land as a main source of agriculture getting scarcer, the system of productivity is primitive; and the natural treats like shortage of rain, heavy rain, off season rain, etc. are affecting the success of the development strategy, ADLI

[6][6] When the rural road is constructed all land plots around the area are often made to be unproductive. Plots of land are used for query and borrow material developments, land is used as a camp site, and land areas as an alternative road

[7] Definition compiled by Greenland 1994 cited in Mtiku et. al., (2006: 163)

Another development program, which is part of the development strategy (ADLI) causing a lot of damage to the environment is resettlement. The government of Ethiopia has introduced resettlement as means to minimizes the problem of land scarcity caused as a result of population boom and reducing excessive use of land, improve the wellbeing of the people.

A special arrangement was made to move people from high lands to low lands of Tigray around Humera. This has granted them with various opportunities, enable them to live better. However, since the new settlers are interested to owe large land as much as possible they are clearing the vegetation and the trees, damaging the protected land, This shows how less follow up and poor orientation forced them to do all the merciless acts to nature as they were doing in the high lands to earn their means, if a correction measure is not introduce it seems spreading the land degradation from the northern highland to the northern low land.

Even though resettlement is serving as a relief to the problem of overcrowding of people in small land size less follow up and in appropriate implementation of the program will affect the environment. Around the resettlement areas the removal of vegetation and cutting of wood lots is result in loss of specious. has an adverse impact on the bio-diversity conservation.

Clearing of vegetations and contraction of forest resources are the chef source of resentments to the local communities. From the informal discussion made with people around the resettlement areas I came to understand their differences on protecting the environment. The local residents in that area said: People from the highlands (settlers) have indiscriminately cut the trees to clear land for farming. "Clearing of vegetations and cutting of trees is going to affect our economic life."[8] Other factors are also contributing over time: need to have large land for cultivation, contraction of traditional sources of livelihood such as forest products, weak social integration and importation of unsustainable farming practices (around the settlement areas).

In fact this is becoming source of conflict between the settlers and the endogenous habitants in the Western and south western parts of Tigray. The likelihood of conflict tends to increase when people compute on the given resource that induces environmental degradation. The linkage between environmental insecurity and conflict are not one to one, environmental degradation and scarcity is likely to contribute to conflict under sets of conflict aggravating conditions ((Tekelu, 2004)

Moreover, building of dams and adoption of technologies to rise agricultural productivity and reducing of poverty is also another approach used to attain the objective of ADLI. However some of the technologies/mechanisms introduced to attain the target of ADLI has affected proper use of natural resources, land. The water conservation mechanism, 'Horoyo'is one of the best instances that can be listed here hardly contributed to the realization of the intended objective. Specifically in the northern part of Tigray, none of them are functioning well, rather become another factor for the land fragmentation problem to get worsen(Observation). Problems generated from implementing such type of development programs (has complementary effect) have led the majority farmers to operate farms too small to make sustainable and profitable use of technologies difficult.

Technical assistance programs are more likely to be successful in identifying and promoting profitable technologies if they take a farmer-centered, demand-led approach and provide farmers with a broad menu of options rather than a narrow package of technologies. Farmers

[8] Key informants

need information about the potential profitability, costs, and risks of alternative livelihood and land management options (Pender, 2006). In general, development policy and program interventions are likely to involve tradeoffs among the objectives of increasing agricultural productivity, increasing household income, and reducing land degradation

All these shows ADLI, which was envisaged to play a leading role to the growth of the country by transforming the economy from rural oriented sector to some what industrial, did not work as it is expected. Reducing poverty in rural Ethiopia by using the agricultural extension program alone without addressing problems relating to land policy is unlikely to succeed (Nega, 2003). I partially agree with Nega's paper that beyond the extension programs and other than the land policy focuses on improving of technology, changing the types of agricultural productivity(from crop to agronomy type), and feeding habit of the rural communities could have lead to better out come, increasing of productivity, improving wellbeing, and sustainable use of resource. Otherwise with the already existed incentives (supports), increasing of agricultural productivity, transformation form agriculture to industry as that of the classical economies presumed that agricultural labour could be shifted to the industrial sector without any reduction in total agricultural output.

Unlike the efforts put by the government and supports mad by various non-government and civic community organizations to increase agricultural productivity and livelihood of the rural communities the changes observed in the last one and half decades is not sufficient in a way to transform the rural communities of Tigray from being agrarian to other income sources. Still households have fewer resources (financial) to invest in new technologies or they may not have the opportunity to learn new technologies. Findings (Ersado, L. et. al., 2003), came out with confirms the absence of alternatives that improves land and labour market function and its implication on land degradation. "steps that improves land and labour market functions will likely increase adoptions, thus helping to enhance productivity and resource conservation" (p.22), indicates the nexus between labour market functions, improving new technologies and conservation.

What did the Previous Studies Reveal and Are There Best Practices?

In Ethiopia, specifically in Tigray region agricultural productivity, household income, and land degradation is affected by many factors. Due to this, only less than 10 per cent of this potential land has been cultivated which is estimated at about 7 million hectares in any one-crop season. Around 95 per cent of the cultivated land is under smallholder farming and the rest under state/commercial farms. The country has not been self sufficient in food and chronically dependent on food aid. Of various reasons responsible for food deficit, low/poor land productivity is the most crucial. The average yield for grain crops has remained around 11 quintals per hectare. This meager land productivity is not because of the poor soil fertility rather as a result of ill management of the limiting factor of production, i.e. land and also due to rapid increasing of population.(Gebreselassie, 2006). Effect of rapid increasing of population on land productivity and livelihood of the citizens is illustrated by Holden and Shiferaw (2000: 4) and their statement goes like this: "in a country with a fast growing population vulnerable to frequent famines, loss of food production potential is a concern not only for future generations but also for the present generation of Ethiopians .

This has attracted several scholars and motivate them to come up with different opinion, all tried to contribute to introducing or adoption of sustainable land management procedures . The first groups tried to blame to the land policy as a factor but the second groups pin point on the method of cultivation, type of crops produced, and knowledge of the household about land use and resource allocation as a min obstacle for the land management to be more of unsustainable type. To the first groups land privatization is considered as a better approach so as to have more tenure security, a system that provides the necessary incentives for farmers to manage their land more efficiently and invest in land improvement

Absences of land privatization constitute a serious constraint on economic and social development. On the one hand, insecure land tenure and dysfunctional land institutions discourage private investment and overall economic growth. On the other hand, skewed land ownership distribution and discrimination according to gender or ethnicity limit economic opportunities for disadvantaged groups and provide fertile conditions for social conflict which often erupt in violence (CSD 4).

Similarly a study conducted by Hoben (2000, p.7) reveals the disadvantage of having state ownership and his argument goes like this: "the current system does not guarantee security of tenure and undermines incentives, has detrimental effects on agricultural productivity and natural resource conservation... current land policy does not give farmers secure rights over the land they use, does not maintain equitable access to land over time, does not provide incentives for investment in improvements or conservation, and does not encourage farmers' entrepreneurial and experimental efforts to better their lot. From a policy perspective, it does not foster agricultural intensification, improved environmental management, accretion capital formation, or rural development….", his study recommends the necessity of changing the existing land holding system not only to improve the wellbeing of the rural community but also to protect the environment.

On the other hand these (government officials and academicians) who supports government ideology claims that if the current policy were changed in favor of private ownership it would encourage rural farmers to sell their land. Their argument indicates how the current policy is protecting the farmers from a possible loss of their prized and perhaps irretrievable asset which would occur if and when polices like full land ownership rights were conferred.

Other groups of studies that tried to highlight the advantage and disadvantage of implementing both; private versus social ownership. Study conducted by Holden and Shiferaw (2000), shows the divergence between private and state ownership: "the divergence between private and social paths of soil use in LDCs may be attributed to imperfect information, high transaction costs, imperfect insurance and capital markets, incomplete property rights, and misguided government policies."9

Generally, scholars from each group are giving different justification as a source of tenure security, maintaining land sustainability, improving livelihood of rural community, and reducing of poverty. However, despite the increasing concern about the present land holding system there is no nationally applicable idea (blue print) as to what an appropriate land versus environment policy should be.

Since this study is not a detail investigation of land tenure system and its implication on land sustainability I could not draw a conclusion in support/against the existing land tenure system of Ethiopia. However I believe directly or indirectly land use, administration, management, and other related factors influences land sustainability.

Moreover, absence of specific policies that address environmental related issues could be another factor for the continuous degradation of resources in the Ethiopian highlands. Problems related to environment are treated as homogenous to agricultural related problems

[9] Holden and Shiferaw (2000: 2)

and there is no specific designed blue print;_and policy instruments that efficiently internalize land degradation externalities. Land degradation, especially soil erosion and nutrient depletion are major problems in the high lands of Tigray. The proximate causes of land degradation are complex array of factors that affects sustainable land management and diverse agro ecological and economic condition of the region. These includes cultivation of steep slopes and erodible soils, low vegetation cover of the soil, burning of dung and crop residues, declining fallow periods, law and uncertain rainfall, and limited application of organic and/or inorganic fertilizer, fuel and animal feed, limited farmer knowledge of integrated soil and water management measures., lack f access to credit, and other factors.[10]

All these can be solved through implementation of appropriate sustainable land management approaches and policies. Government policies and programs can play a crucial role through creating convenient ground by drafting of policies, which are coercion type and encouraging of communities to participate in environmental protection activities willingly. The policy and programs includes macro economic and sectoral policies, land tenure policies, agricultural research and extension policies credit programs, infrastructural development programs.[11] There should be specific polices that could address environmental related problems Gebremedhin (2003). I share the same view as Gebremedhin, that to avoid the problem of land degradation special focus related to use, and management of resources is needed.[12]

Some of the previous conducted studies tried to emphasize on the environmental policy, argued not mainstreaming the land management problems, and absence complementary policy related to land management leads to worsen the manner of land utilization. A typical argument that could characterize this claim looks like the following. "Appropriate institutions and policy instruments that efficiently internalize land degradation externalities are urgently needed in many countries suffering from deterioration of their resource base." (Holden and Shiferaw, 2001)

Moreover, there are several debates about current policy farmer's mobility and environmental degradation. Since land policy in Ethiopia demands permanent residence in a farming community to be eligible for use right over a peace of land, the confinement view accuses the policy of having shackled farmers and forced them to be permanently stay in rural areas.[13] This has hindered farmers from looking to other alternatives income generating activities, limited them to subsistence agricultural producers with limited income, and slow transformation.

Even the government has already realized the problem of overcrowding of population in small land, land scarcity and land fragmentation and its effect on the livelihood of the community, and on the over all economic development of the state. It is due to this fact various development packages has been introduced and farmers are encouraged to adopt a development package, which is convenient to them. The package includes both, on farm and non-farm income generating activities and is expected to enhance farmers participation in various development programs, including on environment protection, synergy effect. Experience reveals though large number of farmers are not risk takers, some (risk takers) who involved in the package (both, on and off farm type) program are able to attain significant change in their livelihood.

[10] Gebremedhin, B. 2003:Xii
[11] Ibid.
[12] For instance leasing out forests for specific period (on short lease base, 1-3 year) so as to rehabilitate the already degraded resource could serve as a best overcoming mechanism to the problem of deforestation and land degradation.
[13] Gebreselassie, S. (2006)

Out come (result of adopting) reveal mixed effect: The first categories are these who managed to improve their income (increasing), and their resource use (protecting soil degradation and forestation). The second categories are these who adopt package and as a result mange to change their livelihood but increasing their income did not have any implication on their resource use. The third categories are these who adopt pckage but did not mange either to increase their income or improve their resource use.

The first groups are risk taker farmers who adopt mixed package (crop production using irrigation, input (fertilizer), and livestock reproduction). Consequently, their totlincome earned and their livelihood got improved, transform themselves from low income to middle income. At the same time increasing in income has encouraged them to increase their investment on land. This reveals how Increasing number of livestock's and/or increasing of their income is playing multiple role -to rise income of the household and at the same time to rehabilitate the environment.

Moreover, these who preferred package of agroforestry and horticulture are equally benefited, motivated to diversify their source of income, become market oriented producers, and efficient resource users. Unlike the past farmers who engaged in the production of fruits (agroforestry) have already realized the economic losses that occurs from erosion. This has encouraged them to improve the land quality though making continuous investment in conservation.

However, it does not mean that all packages are effective enough to improve land sustainability, these who adopt petty trading package. Since the income they got form off farm is higher than from farm they start to regard agriculture as secondary source of income (women and young people, preferred to rent out their land). This is consistent with the findings of (Holdent et. al., 2004:390). "improved access to non-farm income undermines incentive to conserve land, the over all effect is increased degradation in the form of erosion."

The third groups are these who adopt package but don't able to use the resource efficiently. To these groups package programs didn't contribute either to the improvement of their income or to the change (improvement of) of land conservation, they remain defaulters.

All these shows the concerns required while introducing any development packages, there should be a detail investigation that the package fits to the environmental condition, and skill of the individual. At the same time to avoid the unexpected threats a proper follow up and supervision is required during the implementation

Conclusion

The paper has tried to highlight on impact of implementing development programs, maintaining sustainable land management in Tigray, an attempt is made to identify the best practices Of the various development programs introduced some packages serving as a tool for achieving sustainable agricultural farming and improving the welfare of the farmers. A mechanism to reverse the process of environment and land degradation- improving income and maintaining sustainable use of resource, a synergy effect.

Particularly development packages related to Mixed farming and participation in agroforestry are proved to be very effective to improve individuals wellbeing and sustainable use of resource, land. These development strategies (packages) has encouraged farmers to spend much of their time on their land, and increase competition among themselves. This assures how effective government support and introduction of development programs according to the choice and priority need of farmers has allowed to the increasing of their income and the development of a conservation culture. Conservation of soil and forest has become a high profile activity of the farmers and has played a crucial role on the land resource management. Hence to achieve sustainable development any development programs should follow a holistic approaches and needs to a long term perspective with a strong focus on public education.

From the reviews and also based on my observations following win-win strategy is the best way of managing resource that guarantees sustainability resource utilization and environmental protection. Using of resources in ways that do not affect its long run economic, social, and environmental implication. This is is supposed to be realized by the ability to draw all stack holders: government, none-government and civil community organizations to participate in environment protection (effective and cost-less) through implementation of action oriented environmental protection and rehabilitation programs.

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Agro-Ecosystem Productivity in Developing Countries:

The Economics of Crop Biodiversity in the Highlands of Ethiopia

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Abstract

The paper investigates the value of biodiversity as it relates to the productive value of services provided by an ecosystem. It analyzes how the value of an ecosystem can be "greater than the sum of its parts." First, it proposes a general measure of the value of biodiversity. Second, this measure is decomposed into four components, reflecting the role of complementarity, scale, convexity and catalytic effects. This provides new information on the sources and determinants of biodiversity value. Third, the methodology is applied to analyze the productive value of diversity of an agroecosystem in the Highlands of Ethiopia. The analysis provides estimates of the value of diversity and its components. The value of diversity is estimated to be positive. The complementarity component is found to be large and statistically significant: it is the main source of biodiversity value in this agroecosystem of Ethiopia. However, the convexity component is negative, indicating that non-convexity contributes to reducing the value of biodiversity.

Keywords: Ecosystem services, biodiversity, productive value, Tigray Ethiopia, complementarity, convexity.

JEL *classification*: D6, Q2, Q5

1. Introduction

Food is a very important output of ecosystems around the world (Millenium Ecosystem Assessment, 2005). While agro-ecosystem services help support economic livelihood everywhere, these services are crucial in developing countries where the agricultural sector constitutes a large part of the economy. Farmers in developing countries often face poorly functioning markets and limited opportunities for technological progress. While this tends to reduce farmers' options, it means an enhanced reliance on nature's services. This stresses the economic importance of agro-ecosystem management in developing countries. Of special interest is the role of crop biodiversity and its effects on agro-ecosystem productivity. Biodiversity has been identified as an important component of ecological systems (e.g., Heal; Tilman and Downing; Tilman et al.; Wood and Lenné). This is particularly significant in developing countries: one quarter of undernourished people in the developing world live in so-called "biodiversity spots" that are rich in crop biodiversity (Cincotta and Engleman). The relevance of biodiversity in the provision of ecosystems services is highlighted by growing evidence that biodiversity loss can have adverse effects on the functioning and productivity of ecosystems (e.g., Loreau and Hector; Naeem et al.; Cork et al.; Hooper et al; Tilman and

Downing; Tilman et al.). Loss of biodiversity and the consequent reduction in ecosystem services (i.e., food production) are seen as a primary obstacle to the achievement of Millenium Development Goals. In the agro-ecological literature, explanations for the diversity-productivity relationships have included the species complementarity hypothesis and the scale hypothesis (Callaway and Walker; Loreau and Hector; Sala et al.; Tilman et al;).[xiii] Complementarity in an ecosystem arises when particular species perform better in the presence of others (either because they actively cooperate with each other or because niche partitioning allows them to make better use of available resources). The scale hypothesis reflects the fact that the functioning of an ecosystem can be affected by its size and its degree of fragmentation. In addition, these effects can be complex. For example, size, spatial density and spatial heterogeneity can interact in their impact ecosystem productivity (Bissonette and Storch; Giller et al.; Tilman and Kareiva).

To measure the effects of diversity on productivity, two approaches have appeared in the literature. One approach is based on ecological diversity indices, including the Margalef, the Shannon index and the Simpson index (e.g., Hill; Lande; May; Polasky and Solow; Simpson). These diversity metrics rely on species richness, dominance or abundance. They have been used extensively in the empirical analysis of biodiversity issues (e.g., Di Falco and Chavas; Heisey et al.; Meng et al.; Priestley and Bayles; Smale et al., 1998, 2002, 2003). Yet, the use of diversity indices raises several issues. First, different indices seems to deliver very different results and there is a debate on which diversity index is most appropriate (e.g., Routledge). At this point, it appears that no particular index is always superior. This point is made clear when the value of biodiversity is found to depend on the presence and nature of complementary among ecosystem services (e.g., Faith et al.; Justus and Sarkar; Loreau and Hector). Second, diversity indices do not identify the sources of diversity value. This is problematic to the extent that knowing the source and nature of diversity value is often important in evaluating alternative management strategies for diversity. Addressing these issues appears challenging. The other approach developed by Weitzman (1992, 1998) measures biodiversity through a diversity function based on a measure of dissimilarity. However, Brock and Xepapadeas have shown that a more diverse ecosystem can be much more valuable even when the increase in dissimilarity is almost zero. This reflects the complexity of ecosystems. It also suggests the need for further research on the characterization and valuation of biodiversity.

The objective of this paper is to develop a general analysis of the productive value of crop biodiversity, with an application to an agro-ecosystem in the region of Tigray, in the highlands of Ethiopia. Tigray is the northernmost of the nine ethnic regions of Ethiopia. As the rest of Ethiopia, Tigray has one of the highest rates of soil nutrient depletion in Sub-Saharan Africa (Grepperud, 1996; FAO, 2001). This coupled with harsh climatic conditions has contributed to harvest failure and famine. Indeed, during the last millennia, at least 25 severe drought periods were recorded, and crop production in most areas “never topped subsistence levels” (REST and Noragric, 1995 P. 137). Agriculture is the source of livelihood to an overwhelming majority of the population. It employees more than 80% of the labor force, and accounts for 45% of the GDP, and 85% of the export revenue (MoFED, 2007). Cereals are staple food in the region and Ethiopia is a recognized global center of crop diversity for several cereal crops, including barley and teff (Vavilov, 1949; Harlan, 1992). All these characteristics make this area a great case study of farmers’ reliance on ecosystem services and of the productive value of biodiversity.

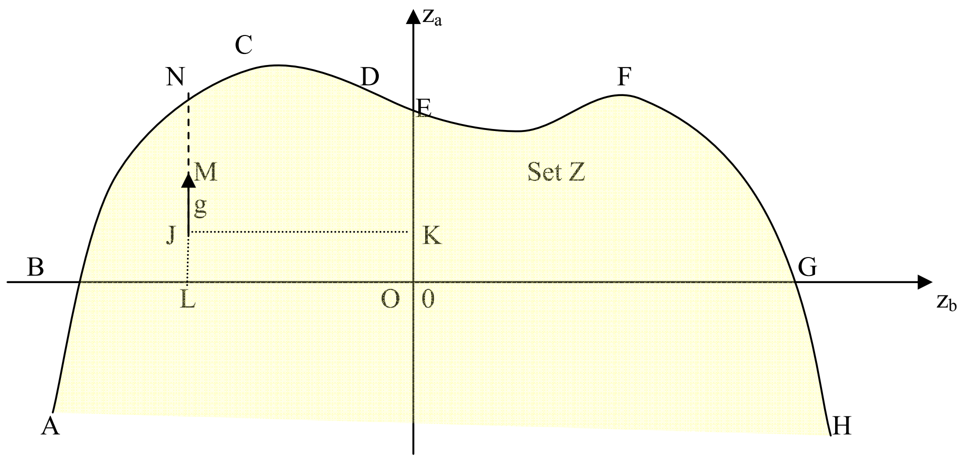
Our analysis develops a methodology to measure the productive value of biodiversity. The technology underlying ecosystem functioning is represented by a multi-output production function which is used to characterize the value of biodiversity. The methodology applies under general conditions, allowing for non-convexity, and lack of free-disposal in environmental goods. First, we propose a general measure of the value of biodiversity. While not relying on a fixed index, the proposed measure captures how the value of an ecosystem can be "greater than the sum of its parts." Second, we show that the value of diversity can be decomposed into four additive parts: one associated with complementarity, one with scale effects, one with convexity effects, and one with catalytic effects. This provides new information on the sources and determinants of biodiversity value. The analysis provides estimates of the value of diversity and its components. Applied to farm survey data from the Highlands of Ethiopia, the value of diversity is estimated to be positive. The complementarity component is found to be large and statistically significant. This provides evidence that complementarity provides the main source of biodiversity value in this agroecosystem of Ethiopia. However, the convexity component is negative. This shows that non-convexity contributes to reducing the value of biodiversity.

2. The Productive Value of an Ecosystem

Consider an ecological system as a production process involving a set of goods $z = (z_1, z_2, \ldots) \in R^{m+n}$. We use the netput notation where quantities are defined to be negative for inputs (with $z_i \leq 0$ when the i-th netput is an input) and positive for outputs (with $z_i \geq 0$ when the i-th netput is an output). The ecosystem involves two types of netputs: private goods $z_a = (z_1, \ldots, z_m) \in R^m$ and other goods z_b, with $z = (z_a, z_b)$. The goods $z_b = (z_{m+1}, \ldots, z_{m+n}) \in R^n$ can be non-market goods, i.e. goods without observable market prices. In this section n, it will be convenient to assume that z_b represents n environmental goods. The underlying production technology is denoted by the set $Z \subset R^{m+n}$, where $z \equiv (z_a, z_b) \in Z$ means that private goods z_a can be feasibly produced in the presence of environmental goods z_b. Throughout, we assume that the set Z is closed, and that it exhibits free disposal with respect to the private goods z_a (where free disposal in z_a means that, for any $z \equiv (z_a, z_b) \in Z$, $z_a' \leq z_a$ implies that $(z_a', z_b) \in Z$). However, we do <u>not</u> assume that the set Z is convex, or that it exhibits free disposal with respect to z_b. Thus, our analysis applies under a general technology characterizing the productivity of the ecological system: it allows for <u>non-convexity</u>; and it does not require that <u>the environmental goods z_b exhibit free-disposal</u>.

This is illustrated in Figure 1, where m = 1, n = 1, and the upper bound of the feasible set Z is given by the line ABCDEFGH. In the region EFG both z_a and z_b are considered as outputs. This would apply to a healthy ecosystem that allows for the production of valuable ecological services as well as private goods. In the region BCDE, the environmental good z_b is an input in the production of z_a. This corresponds to situations where the ecological system is used mainly to produce private goods (e.g., agriculture using the ecological system to produce food). Region GH corresponds to a case of environmental enhancement where the private good z_a is an input into the production of the environmental good z_b (e.g., protecting the ecological system that provides clean water for New York City). Finally, in the region AB, both z_a and z_b are inputs. This would correspond to unproductive ecological systems where the production of private goods becomes impossible (e.g., on Mount Everest). Note that the technology Z in Figure 1 is <u>not</u> convex (e.g., the region CDEF). And it does <u>not</u> exhibit free disposal in the environmental good z_b in the regions ABC and DEF.

Figure 1 *An illustration of the technology*



We are interested in providing a general representation of the frontier technology given by the boundary of Z. Such a representation is given by the shortage function proposed by Luenberger. Let $g \in R^m_+$ be a reference bundle of private goods satisfying $g \geq 0$, and $g \neq 0$. For a given g, the shortage function S(z, g) evaluated at point $z \equiv (z_a, z_b)$ is defined as

$$S(z, g) = \min_\alpha \{\alpha: (z_a - \alpha\ g, z_b) \in Z\}, \text{ if there is an } \alpha \text{ such that } (z_a - \alpha\ g, z_b) \in Z\}, = +\infty \text{ otherwise.} \quad (1)$$

The shortage function S(z, g) measures the number of units of the reference bundle g reflecting the distance between point $z \equiv (z_a, z_b)$ and the frontier technology. The general properties of the shortage functions are discussed in Luenberger and Chavas. In general, $z \in Z$ implies $S(z, g) \leq 0$. And under free disposal in z_a, $Z = \{z: S(z, g) \leq 0\}$, implying that $S(z, g) \leq 0$ provides a complete characterization of the technology. In this case, S(z, g) = 0 if and only if z is on the upper bound of the feasible set Z, with S(z, g) = 0 providing a multi-input multi-output functional representation of the underlying frontier technology. Finally, $S(z_a, z_b, g)$ would be non-decreasing in z_b if the technology exhibited free disposal in z_b. But it would be decreasing in z_b in regions where free disposal in z_b fails to hold.

The shortage function is illustrated in Figure 1. Consider evaluating it at point J, where the private good $z_a > 0$ is an output (represented by the distance OK in Figure 1) and the environmental good $z_b < 0$ is an input (where $|z_b|$ is given by the distance OL). Given the reference bundle g (represented by JM in Figure 1), the shortage function S(z, g) evaluated at point J is given by -JN/JM.

As a further illustration, consider the special case where g = (1, 0, …, 0). Then $S(z, g) = \min_\alpha \{\alpha: (z_1 - \alpha, z_2, \ldots, z_{m+n}) \in Z\} = z_1 - G(z_c)$ where $z_c = (z_2, \ldots, z_{m+n})$ and $G(z_c) = \max \{z_1: (z_1, z_c) \in Z\}$ is the largest possible z_1 that can be obtained given other netputs z_c. When z_1 is an output, $G(z_c)$ is a standard production function representing the underlying technology, where feasibility is given by $z_1 \leq G(z_c)$. In this case, under differentiability, $\partial S/\partial z_1 = 1$ and $\partial S/\partial z_c = -\partial G/\partial z_c$, implying that $-\partial S/\partial z_c$ can be interpreted as measuring the marginal product of z_c.

For a given $z \equiv (z_a, z_b)$, the shortage function S(z, g) in (1) provides a convenient basis for analyzing the productive value of the environmental goods z_b. To see that, consider a change in environmental goods from z_b^1 to z_b^2. Then, define

$$P(z_a, z_b^1, z_b^2, g) = S(z_a, z_b^1, g) - S(z_a, z_b^2, g). \quad (2)$$

Starting from the point $z \equiv (z_a, z_b^1)$, $P(z_a, z_b^1, z_b^2, g)$ in (2) measures the number of additional units of the reference bundle g that can be obtained from changing environmental goods from z_b^1 to z_b^2. To illustrate, consider the case where z_b are inputs (with $z_b < 0$) and (2) is evaluated under a technology exhibiting free disposal in z_b. As suggested by property 3, $S(z_a, z_b, g)$ would be non-decreasing in z_b. Then, with $z_b < 0$, any increase in the environmental inputs from $|z_b^1|$ to $|z_b^2|$ would mean a decrease in z_b, implying that $P(z_a, z_b^1, z_b^2, g) \geq 0$ in (2). In this case, increasing environmental input z_b can make it possible to produce more of the private goods z_a, with $P(z_a, z_b^1, z_b^2, g) \geq 0$ measuring the additional number of units of the private goods g that can be produced. Importantly, equation (2) applies under general economic conditions. It allows for a general technology underlying the productivity implications of an ecological system (e.g., it does not require the technology to be convex; and it does not require that the environmental goods satisfy free disposal). It applies when the environmental goods z_b are "non-market goods" (i.e., goods with no observable price). And it remains valid even in the presence of poorly functioning markets for the private goods z_a.

To note the role of free disposal for the environmental goods z_b, consider the case of an increase in the environmental input from point J in Figure 1. With $z_b < 0$, increasing the environmental input $|z_b|$ means a decrease in z_b from point J, implying an increase in the shortage function. This reflects the fact that free disposal in z_b does not hold in the region BC of Figure 1, and that the shortage function $S(z_a, z_b, g)$ is now decreasing in z_b in the neighborhood of point J. In this case, any increase in the environmental input $|z_b|$ implies that $P(z_a, z_b^1, z_b^2, g) < 0$ in (2). This illustrates that, without free disposal, increasing environmental input z_b can reduce the ability to produce the private goods z_a, with $P(z_a, z_b^1, z_b^2, g) < 0$ measuring the associated reduction in the number of units of g that can be produced.

In the case where the private goods z_a are market goods with prices $p \in R^m_{++}$, equation (2) can be modified to obtain the following monetary evaluation:

$$V(z_a, z_b^1, z_b^2, p, g) = P(z_a, z_b^1, z_b^2, g)\ (p\ g)$$

$$= [S(z_a, z_b^1, g) - S(z_a, z_b^2, g)]\ (p\ g). \quad (3)$$

Starting from the point $z \equiv (z_a, z_b^1)$, $V(z_a, z_b^1, z_b^2, p, g)$ in (3) gives a monetary value of the private goods that can be obtained when environmental goods change from z_b^1 to z_b^2. When the reference bundle g is chosen to have unit value (with $p\ g = 1$), combining (2) and (3) yields

$$V(z_a, z_b^1, z_b^2, p, g) = S(z_a, z_b^1, g) - S(z_a, z_b^2, g). \quad (4)$$

Equation (4) shows that changes in the shortage function can measure the value of changes in environmental goods from z_b^1 to z_b^2.[14] This provides some guidance for choosing the reference bundle g.

3. The Value of Biodiversity

Equations (2) and (3) provide measures of the productive value of an ecosystem. However, it is often of interest to know more about the source of this value. The concerns about biodiversity provide a good example. Indeed, biodiversity issues typically arise when it is believed that the value of an ecosystem is greater than the value of its parts. This suggests the need to evaluate the value of environmental goods both for their "total value" and for the "sum of their parts." To address this issue, let I_b denote the set of environmental goods in z_b, and consider a partition of the set $I_b = \{I_{b1}, I_{b2}, \ldots, I_{bK}\}$, with $2 \leq K \leq n$. Let $z_{bk} = \{z_j: i \in I_{bk}\}$ denote the environmental goods in the subset I_{bk}, $k = 1, \ldots, K$, with $z_b = (z_{b1}, \ldots, z_{bK})$.

To address diversity issues, for a given $z \equiv (z_a, z_b) \in Z$, consider K situations where $z^k \equiv (z_a{}^k, z_b{}^k) \neq 0$ for $k = 1, \ldots, K$, and where $\sum_{k=1}^{K} z^k = z$. Using the shortage function (1), we propose the following measure of diversity

$$D(z, g) = \sum_{k=1}^{K} S(z^k, g) - S(z, g), \quad (5)$$

where $z = \sum_{k=1}^{K} z^k$. Equation (5) compares two situations involving netputs z: one where the netputs z are involved in a single production process; and the other situation where there are K separate production processes, with z_k being the netputs used in the k-th production process. With $z = \sum_{k=1}^{K} z^k$, it follows that, in each situation, the same aggregate amounts of resources are used to produce the same aggregate netputs. In this context, equation (5) provides a measure of the number of units of the reference bundle g that can be saved by producing z jointly (compared to producing the same aggregate netputs z in K separate production processes). Intuitively, $D(z, g) > 0$ if there are productivity gains associated with a joint use of the netputs z. This reflects that $D(z, g) > 0$ corresponds to situations where "the whole is worth more than the sum of the parts." From (5), this would be associated with the subadditivity of the shortage function.

To help further motivate (5), consider the case where p g = 1. Then, use equation (2) to define $P_k \equiv S(z_a, 0, g)/K - S(z^k, g)$ as measuring the value of the environmental goods in z^k, k = 1, ..., K, where $\sum_{k=1}^{K} z_a{}^k = z_a$. Note that $S(z_a, 0, g)$ is divided by K to reflect the fact that the original ecosystem is being evaluated in the context of K separate systems. Then, the value of the "sum of the parts" across the K systems is

$$\sum_{k=1}^{K} P_k = S(z_a, 0, g) - \sum_{k=1}^{K} S(z^k, g),$$

$$= P(z_a, 0, z_b, g) - D(z, g),$$

using (2') and (5). It follows that $D(z, g) = P(z_a, 0, z_b, g) - \sum_{k=1}^{K} P_k$. This shows that the value of diversity $D(z, g)$ in (5) is indeed the difference between the total value of the environmental goods z_b, $P(z_a, 0, z_b, g)$, and the value of the "sum of its parts", $\sum_{k=1}^{K} P_k$.

As indicated in proposition 1, when the reference bundle g is chosen such that p g = 1, then $D(z, g)$ in (5) provides a monetary measure of the value of diversity. As such, equation (5) provides an absolute measure of diversity. However, it can be easily used to obtain a relative measure. In situations where the total value $P(z_a, 0, z_b, g)$ in (2') is non-zero, a relative measure of diversity can be written as

$$R_D(z, g) \equiv D(z, g)/P(z_a, 0, z_b, g)$$

$$= [\sum_{k=1}^{K} S(z^k, g) - S(z, g)]/[S(z_a, 0, g) - S(z_a, z_b, g)]. \quad (6)$$

where $z \equiv (z_a, z_b) = \sum_{k=1}^{K} z^k$. $R_D(z, g)$ in (6) measures the value of diversity as a proportion of the total value of z_b given in (2'). In situations where $z \equiv (z_a, z_b)$ is on the upper bound of the feasible set, then $S(z_a, z_b, g) = 0$ and equation (6) reduces to

$$R_D(z, g) = \sum_{k=1}^{K} S(z^k, g)/S(z_a, 0, g), \tag{6'}$$

showing that a ratio of shortage functions provides a simple relative measure of diversity.

Note that equation (5) defines diversity in the general context of the netputs z, which include both the private goods z_a and the environmental goods z_b. Given our interest on biodiversity, we want to focus our attention on diversity issues related only to environmental goods. In this context, it will be useful to define $z^k \equiv (z_a^k, z_b^k)$ in (5) in a more specific way. Consider choosing

$$z_a^k = z_a/K, \tag{7a}$$

and

$$z_i^k = z_i^+ \equiv \beta_k z_i \text{ if } i \in I_{bk}, \tag{7b}$$

$$= z_i^- \equiv z_i (1-\beta_k)/(K-1) \text{ if } i \in I_b \backslash I_{bk}, \tag{7c}$$

for some $\beta_k \in (1/K, 1]$, k = 1, …, K.[xiv] First, note that equations (7a)-(7c) always satisfy $z = \sum_{k=1}^{K} z^k$. This guarantees that the same aggregate netputs are involved in both situations. Second, equation (7a) divides the private goods z_a equally among the K production processes. This imposes "no diversity" in the use of the goods z_a across the K production processes. Third, equations (7b)-(7c) establish the patterns of specialization for the environmental goods z_b. The parameter β_k in b) represents the proportion of the original environmental netputs $\{z_i: i \in I_{bk}\}$ that are produced in the k-th process. And from (7c), $(1-\beta_k)/(K-1)$ represents the proportion of the original netputs $\{z_i: i \in I_b \backslash I_{bk}\}$ produced in the k-th process. When $\beta_k = 1$, this corresponds to the case of complete specialization where the k-th process relies exclusively on environmental netputs in the subset I_{bk} (with $z_{ik} = z_i$ if $i \in I_{bk}$) with $z_{ik} = 0$ for $i \in I_b \backslash I_{bk}$. If it applies for all k, each of the K process is associated with a complete loss of biodiversity in environmental goods z_b across elements of the partition $I_b = \{I_{b1}, I_{b2}, …, I_{bK}\}$. Alternatively, when $\beta_k \in (1/K, 1)$, this allows for partial specialization. Then, the k-th process is associated with a partial loss of biodiversity in environmental goods z_b. Thus, the parameter $\beta_k \in (1/K, 1]$ allows for varying amount of specialization in the environmental netputs in the k-th process. Alternatively stated, the β_k's allow for varying amount of loss of biodiversity among the K processes. In general, the degree of specialization in the k-th process increases with β_k. This means that the loss in biodiversity in the K processes also increases with the β_k's.

With $z^k \equiv (z_a^k, z_b^k)$ given in (7a)-(7c), equation (5) becomes

$$D(z, \beta, g) = \sum_{k=1}^{K} S(z^k, g) - S(z, g), \tag{8}$$

where $\beta = (\beta_1, …, \beta_K)$. Equation (8) provides a measure of the value of biodiversity. It measures the number of units of the reference bundle g that can be saved when the environmental goods z_b are part of a joint production process in the ecological system (compared to the case where the environmental goods z_b are part of K specialized production processes satisfying (7a)-(7c) and producing the same aggregate netputs z). This interpretation remains valid whether or not the private goods z_a face properly functioning markets. However as discussed above,_when the private goods z_a are market goods, then $D(z, \beta, g)$ can be given a monetary interpretation. In particular, when the reference bundle g is chosen to have unit value (with p g = 1), then $D(z, \beta, g)$ in (8) gives a monetary measure of the value of biodiversity.

4. A Decomposition

While equation (8) provides a basis to evaluate the value of biodiversity, it is of interest to identify the sources of this value. In this section, we develop a general decomposition of the benefits associated with biodiversity, thus providing new insights into its sources.

Without a loss of generality, let $S(z, g) \equiv S_v(z, g) + S_f(z, g)$. This decomposes the shortage function $S(z, g)$ into a "variable function" $S_v(z, g)$ and a "fixed function" $S_f(z, g)$. We assume that the variable shortage function $S_v(z, g)$ is continuous in z. The fixed shortage function $S_f(z, g)$ is defined as a step function with possible discontinuities around $z = 0$. The step function $S_f(z, g)$ satisfies $S_f(0, g) = 0$, and it is constant with respect to z as long as the set of non-zero netputs does not change. Thus, $S_f(z, g)$ (an hence $S(z, g)$) can exhibit jump-discontinuities in z when any netput z_i changes between zero and an arbitrarily small non-zero number. As further discussed below, the jump-discontinuities reflect the presence of catalysts (or repressors) when the presence of a small quantity of z_i generates a large increase (decrease) in ecosystem productivity. Thus, the fixed function $S_f(z, g)$ can capture "catalytic effects" when a small increase in some netputs from 0 has a large effect on productivity.

We start from the partition $I_b = \{I_{b1}, \dots, I_{bK}\}$, where I_{bk} denotes the environmental goods that the k-th ecological process specializes in, $k = 1, \dots, K$, with $2 \le K \le n$. We use the following notation. Let $z_a = \{z_i: i \in I_a\}$, $z_{bk} = \{z_i: i \in I_{bk}\}$, $z_b = (z_{b1}, \dots, z_{bK})$, $z_{b\backslash bk} = (z_{b1}, \dots, z_{b,k-1}, z_{b,k+1}, \dots, z_{bK})$, and $z_{b,i:j} = (z_{bi}, z_{b,i+1}, \dots, z_{b,j-1}, z_{bj})$ for $i < j$. From equations (7), it follows that $z^k = (z_a/K, \beta\, z_{bk}, (1-\beta)\, z_{b\backslash bk})$. Our main result is stated next. (See the proof in the Appendix).

<u>Proposition 1</u>: Given $S(z, g) \equiv S_v(z, g) + S_f(z, g)$, assume that $S_v(z, g)$ is continuously differentiable in z_b almost everywhere. Under equations (7), the value of biodiversity $D(z, \beta, g)$ in (8) evaluated at netputs $z = (z_a, z_b)$ can be decomposed as follows

$$D \equiv D_C + D_R + D_V + D_f, \tag{9}$$

where

$$D_C \equiv \sum_{k=1}^{K-1} \Big\{ \int_{z_{bk}^-}^{z_{bk}^+} \frac{\partial S_v}{\partial \gamma}(z_a/K, z^-_{b,1:k-1}, \gamma, z^-_{b,k+1:K}, g)\, d\gamma - \int_{z_{bk}^-}^{z_{bk}^+} \frac{\partial S_v}{\partial \gamma}(z_a/K, z^-_{b,1:k-1}, \gamma, z^+_{b,k+1:K}, g)\, d\gamma \Big\}, \tag{10a}$$

$$D_R \equiv K\, S(z/K, g) - S(z, g), \tag{10b}$$

$$D_V \equiv S(z_a/K, z^+_b, g) + (K-1)\, S(z_a/K, z^-_b, g) - K\, S(z/K, g), \tag{10c}$$

and

$$D_f \equiv \sum_{k=1}^{K} S_f(z_a/K, z^+_{bk}, z^-_{b\backslash bk}, g) - S_f(z_a/K, z^+_b, g) - (K-1)\, S_f(z_a/K, z^-_b, g), \tag{10d}$$

Proposition 1 gives a decomposition of the value of biodiversity $D(z, g)$ in (8) into four additive terms: D_C given in (10a), D_R given in (10b), D_V given in (10c), and D_f given in (10d).

The term D_C in (10a) depends on how $z_{b\backslash bk}$ affects the marginal shortage of z_{bk}, $k = 1, \dots, K$. It reflects the presence of complementarity among environmental netputs in z_b. To see that, consider the case where the shortage function is twice continuously differentiable in z_b. Then, equation (10a) can be written as

$$D_C \equiv -\sum_{k=1}^{K-1} \int_{z^-_{b,k+1:K}}^{z^+_{b,k+1:K}} \int_{z^-_{bk}}^{z^+_{bk}} \frac{\partial^2 S_v}{\partial \gamma_1 \partial \gamma_2}(z_a/K, z^-_{b,1:k-1}, \gamma_1, \gamma_2, g)\, d\gamma_1\, d\gamma_2. \tag{10a'}$$

Equation (10a') makes it clear that the sign of D_C depends on the sign of $\partial^2 S/\partial z_{bk}\partial z_{b\backslash bk}$, k = 1, …, K. As discussed above, the marginal shortage can be interpreted as the negative of the marginal product. In this context, define complementarity between z_{bk} and $z_{b\backslash bk}$ as any situation where the shortage function satisfies $\partial^2 S/\partial z_{bk}\partial z_{b\backslash bk} < 0$. Indeed, with $\partial S/\partial z_{bk}$ reflecting the negative of the marginal product of z_{bk}, complementarity (with $\partial^2 S/\partial z_{bk}\partial z_{b\backslash bk} < 0$) means that z_{bk} has positive effects on the marginal product of $z_{b\backslash bk}$, implying positive synergies between z_{bk} and $z_{b\backslash bk}$. Then, it is clear from (10a) that $D_C > 0$ if the shortage function exhibits complementarity between z_{bk} and $z_{b\backslash bk}$, k = 1, …, K.

Thus, proposition 1 establishes that complementarity among environmental netputs (as reflected by the term D_C) is one of the components of the value of biodiversity. This supports the arguments that complementarity is an important contributing factor to the value of biodiversity (e.g., Faith et al.; Justus and Sarkar; Loreau and Hector).

The interpretation of the decomposition given in (9) is discussed in Chavas. First, by definition, the technology Z exhibits increasing returns to scale (IRTS), constant returns to scale (CRTS) or decreasing returns to scale (DRTS) if $\alpha\, Z \subset Z$, $\alpha\, Z = Z$, or $\alpha\, Z \supset Z$, respectively, for all $\alpha > 1$. With $K \geq 2$, Chavas showed that $K\, S(z/K, g) \begin{Bmatrix} < \\ = \\ > \end{Bmatrix} S(z, g)$ under $\begin{Bmatrix} \text{decreasing returns to scale (DRTS)} \\ \text{constant returns to scale (CRTS)} \\ \text{increasing returns to scale (IRTS)} \end{Bmatrix}$. It follows that

$$D_R \begin{Bmatrix} < \\ = \\ > \end{Bmatrix} 0 \text{ under } \begin{Bmatrix} \text{DRTS} \\ \text{CRTS} \\ \text{IRTS} \end{Bmatrix}. \tag{10b'}$$

Equation (10b') implies that D_R vanishes under CRTS, but is positive (negative) under IRTS (DRTS). Thus, the term D_R can be interpreted as capturing scale effects generated as the netput vector z is produced in more specialized ways. Also, equation (10b') shows that $D_R \geq 0$ under non-decreasing returns to scale. Intuitively, more specialized processes involve smaller scales of operation. Under IRTS, such processes (associated with lower biodiversity) would appear less productive (their scale of operation is "too small"), implying that the scale effect contributes positively to the value of biodiversity ($D_R > 0$). Alternatively, under DRTS, the specialized processes would appear more productive (as the scale of operation of the integrated process is "too large"), implying a negative scale effect ($D_R < 0$).

Thus, proposition 1 establishes how the scale of ecosystem and the nature of returns to scale for the underlying process (as reflected by the term D_R) can affect the value of biodiversity. This supports the arguments that scale effects can play an important role in the evaluation of ecological functioning (e.g., Debinski and Holt; Bisonnette and Storch).

The term D_V in (10c) reflects the effect of convexity. To see that, note that shortage function S(z, g) is convex in z when the feasible set Z is convex (Luenberger; Chavas). It follows that, under the convexity of Z, the shortage function satisfies $\sum_{j=1}^{K} \theta_j\, S(z^j, g) \geq S(\sum_{j=1}^{K} \theta_j\, z^j, g)$ for $\theta_j \in [0, 1]$ satisfying $\sum_{j=1}^{K} \theta_j = 1$. Choosing $\theta_j = 1/K$, $z^1 = (z_a/K, z_b^+, g)$ and $z^j = (z_a/K, z_b^-, g)$ for j = 2, …, K, it follows from (10c) that $D_V \geq 0$. Thus, a convex technology is sufficient to imply that $D_V \geq 0$. Intuitively, a convex technology means diminishing marginal productivity, a standard characterization of resource scarcity. This suggests that the term D_V reflects the role of resource scarcity. In this context, proposition 1 shows that resource scarcity contributes positively to the value of biodiversity. Alternatively, our analysis indicates that $D_V < 0$ can arise only under a non-convex technology. The identification of such effect seems to be new in the literature. Its empirical relevance will be evaluated below.

Finally, the term D_f in (10d) reflects catalytic effects associated with discontinuous productivity effects. Indeed, in the absence of discontinuity of the shortage function S(z, g) around z = 0, then $S_f(z, g) = 0$ and thus $D_f = 0$ in equation (10d). When S_f can be non-zero, note that D_f can be positive, zero, or negative. Interestingly, we defined the fixed shortage function $S_f(z, g)$ to reflect possible discontinuities but only around z = 0. This means that $S_f(z, g)$ is a constant as along as the set of non-zero netputs does not change. Then, from equation (10d), $\beta \in (1/K, 1)$ implies $D_f = 0$. Alternatively, the catalytic component D_f can be non-zero only when some $\beta_k = 1$. It means that the catalytic effects are relevant in the value of biodiversity only when some $\beta_k = 1$, i.e., only under a complete loss of diversity in some environmental goods. In the context where $\beta_k = 1$ for all k, from equation (10d), D_f is positive if and only if $\sum_{k=1}^{K} S_f(z_a/K, z_{bk}, 0, g) > S_f(z_a/K, z_b, g) + (K\text{-}1)\, S_f(z_a/K, 0, g)$. Then, catalytic effects contribute to the value of biodiversity. This corresponds to situations where a complete loss of biodiversity generates a discontinuous and large decrease in the productivity of the specialized processes. Thus, in the presence of discontinuities related to catalytic netputs around $z_b = 0$, Proposition 1 shows how a complete loss of biodiversity can contribute positively to its value through D_f.

Proposition 1 provides useful information on conditions contributing to the value of biodiversity. It generates the following result.

<u>Proposition 2:</u> Sufficient conditions for a positive value of biodiversity are:

- there is complementarity between z_{bk} and $z_{b\backslash bk}$, k = 1, …, K, ($D_C > 0$),
- the technology exhibits non-decreasing returns to scale ($D_R \geq 0$),
- the technology Z is convex (with $D_V \geq 0$), and
- $D_f \geq 0$.

Thus, the value of biodiversity can arise from complementarity among environmental goods in z_b ($D_C > 0$), from increasing returns to scale ($D_R > 0$), from a convex technology ($D_V \geq 0$), and/or from catalytic effects (when $D_f \geq 0$). This identifies the role of complementarity as an important contributing factor to the value of biodiversity. However, it also shows that complementarity is in general neither necessary nor sufficient to generate a positive value for biodiversity. For example, under decreasing returns to scale (DRTS), equation (10b') implies that $D_R < 0$. This reflects the fact that, under DRTS, the smaller and more specialized processes require fewer resources to produce the same aggregate outputs. When this scale effect dominates the other components in (9), then D < 0, i.e. biodiversity would have a negative value even in the presence of complementarity. Alternatively, B_V can become negative under a non-convex technology. Again if this negative convexity effect dominates the other components in (9), then D < 0, and biodiversity would have a negative value even in the presence of complementarity. Finally, the catalytic effect D_f is present only under complete loss of biodiversity in environmental goods across at least some elements of the partition $I_b = \{I_{b1}, I_{b2}, \ldots, I_{bK}\}$. Scenarios where D_f is positive and large can arise when catalytic netputs associate a complete loss of biodiversity with a large decline in the productivity of the specialized processes. This illustrates the usefulness of the decomposition provided in Proposition 1. However, the relative importance of each component is likely to be specific to each ecosystem. This stresses the need for empirical analyses.

5. Empirical application

This section presents an empirical illustration of the methodology discussed above. Our empirical analysis focuses on an agroecosystem where inputs $x = (x_1, x_2, \ldots)$ are being used to produce outputs $y = (y_1, y_2, y_3, \ldots)$, with $z \equiv (y, -x) \in Z$. Choosing $g = (1, 0, \ldots, 0)$ and assuming that y_1 is an output satisfying free disposal, it follows that the production technology Z can be written as $Z = \{(y, -x): S(y_1, y_2, y_3, \ldots, -x, g) \leq 0, (y, -x) \in R^{m+n}\}$, where $S(y_1, y_2, y_3, \ldots, -x, g)$ is the shortage function defined in (1). Letting $S(y_1, y_2, y_3, \ldots, -x, g) \equiv y_1 - F(y_2, y_3, \ldots, x)$, the frontier technology is represented by the multi-output production function $y_1 = F(y_2, y_3, \ldots, x)$. An empirical application of our methodology then requires the specification and estimation of the production function $y_1 = F(y_2, y_3, \ldots, x)$.

First, we specify a parametric form for the production function: $F(y_2, y_3, \ldots, x) = f(y_2, y_3, \ldots, x, \beta)$, where β is a set of parameters to estimate. Second, we add an error term to generate the econometric model

$$y_1 = f(y_2, y_3, \ldots, x, \beta) + e, \tag{11}$$

where e is a random variable distributed with mean zero and finite variance. Equation (11) is an econometric model that can be used to generate a consistent estimate β^e of β. This gives a consistent estimate of the mean shortage function: $E[S(y_1, y_2, y_3, \ldots, -x, g)] = y_1 - f(y_2, y_3, \ldots, x, \beta^e)$. Using equations (5), (9) and (10), such estimate provides a basis to investigate empirically the value of biodiversity.

The estimation of equation (11) poses at least two econometric challenges. First, we would like $f(y_2, y_3, \ldots, x, \beta)$ to provide a flexible representation of the effects of outputs $(y_2, y_3, \ldots)$ on the productivity of the ecosystem. This is feasible when the number of outputs remains small. However, this becomes problematic if the number of outputs becomes large (e.g., more than 5). Indeed, a flexible representation of output effects with a large number of outputs requires a large number of parameters, implying the prospects of facing severe collinearity problems. In other words, the econometric estimation of (11) can become problematic if the number of outputs is large. Second, when applied to an agroecosystem, equation (11) involves netputs that are subject to direct management. This means that the choice of (y, x) generates the possibility of endogeneity issues. Indeed, if the netput decisions for (y, x) depend on information that is not available to econometrician, then they may become correlated to the error term e in (11), implying the presence of endogeneity bias. This bias implies that standard estimation methods (e.g., least squares) will provide biased and inconsistent parameter estimates. This suggests the need to address endogeneity issues explicitly by using appropriate estimation methods. This can be done by using instrumental variable estimation methods that provide consistent parameter estimate in the presence of endogeneity.

Our empirical analysis focuses on a situation with three outputs. Three is "large enough" to allow the investigation of the benefit of diversity across agroecological processes, yet "small enough" to avoid collinearity problems. In this context, with three outputs, we specify (11) to be quadratic function of outputs y. This provides a parsimonious specification allowing for a flexible representation of how each output affects the marginal product of other outputs. We also assume that inputs x enter (11) in log form.[xv] To address endogeneity issues, we adopt an instrumental variables estimation approach.

6. Site description and data

The dataset used in the analysis is from a farm survey conducted in 1999 and 2000 in the highlands (more than 1500 meters above sea level (masl)) of Tigray region of Ethiopia by researchers from Mekelle University, the International Food Policy Research Institute (IFPRI), and the International Livestock Research Institute (ILRI). The survey involved a stratified sampling of farm households, with the strata being chosen according to agricultural potential, market access, and population density (Pender et al. 2001). In the Tigray region, peasant associations (PAs) were stratified by distance to the *woreda* town (greater or less than 10 km). Three strata were defined, with 54 PAs randomly selected across the strata. PAs closer to towns were selected with a higher sampling fraction to assure adequate representation. From each of the remaining PAs, two villages were randomly selected, and from each village, five households were randomly selected. A total of 50 PAs, 100 villages, and 500 households were then surveyed. Usable data were available for 96 villages, or kushets. After controlling for outliers and observations with missing values for relevant variables, 292 household observations remained.

We screened the production of these households and identified teff, barley and wheat as the most widely grown crops. Cereal production is the most relevant agricultural production in the studied area. Ethiopia is a biodiversity "hotspot." It is, indeed, a recognized global center of genetic diversity for several cereal crops (Vavilov; Harlan). Farms are diversified thus different plots are allocated to different cereal crops. Thus our analysis of agro-biodiversity focuses on three outputs: teff, barley and wheat. The use of conventional inputs is minimal. Farmers rely mostly on labor and oxen power. Agroecological conditions can be challenging because of pervasive land degradation and erratic rainfall. This setting, therefore, provides a prime example to empirically investigate the contribution to production of biodiversity. Biodiversity's gains are indeed expected to be high when agroecological conditions are more difficult (Callaway and Walker).

Table 1 *Variable Description*

Outputs	Teff	Quantity produced in Kg
	Barley	Quantity produced in Kg
	Wheat	Quantity produced in Kg
Conventional inputs	Animal traction	Animal traction in oxen days
	Land	Land for cereals in M^2
	Labor	Labor in person days
	Fertilizer	Fertilizer use in Kg
Agroecological Conditions	Rainfall	Rainfall in mm/year
	Soil fertility	Share of land classified as high fertility
	Soil Erosion	Share of land affected by severe erosion and water logging
	Slope	share of land on steep slope
Location Dummies	South	Location dummy
	East	Location dummy
	West	Location dummy
Adoptions	Improved seeds	Adoption of improved seeds (Yes=1; No=0)
	Soil conservation	Share of land under reduced tillage

Table 2 *Descriptive Statistics*

	Mean	Standard deviation	Minimum	Maximum
Teff	151.007	207.685	0	1292
Barley	179.521	235.828	0	1363
Wheat	82.1179	142.365	0	777
Animal traction	28.825	19.8131	2	144
Land	6631.93	4694.81	612	43194
Labor	86.2286	53.1831	15	429
Fertilizer	18.8431	23.1647	0	150
Rainfall	648.909	120.912	420.4	893.55
Soil fertility	0.092857	0.290752	0	1
Soil Erosion	0.442857	0.497613	0	1
Slope	0.088525	0.219294	0	1
South	0.264286	0.441742	0	1
East	0.275	0.447314	0	1
West	0.128571	0.335324	0	1
Improved seeds	0.107143	0.309849	0	1
Soil conservation	0.10861	0.263086	0	1

7. Econometric Results

Using farm-level data from the Ethiopian survey, equation (11) was specified and estimated by instrumental variable method. The analysis covers three outputs: y_1 = teff, y_2 = barley and y_3 = wheat. The inputs x include animal traction, land, labor, fertilizer and rainfall. A number of additional variables were added to capture the heterogeneity in agro-climatic conditions across observations in the sample. They include soil fertility, soil erosion, slope, location, improved seeds, and the presence of soil conservation practices. Equation (11) was specified to be quadratic in outputs (y_2, y_3), linear in the logarithm of land, labor and animal traction, and linear in other variables. The quadratic output terms allow for flexible patterns of marginal productivity, including the effect of an output on the marginal product of other outputs.

To address the issue of endogeneity, we rely on instrumental variable (IV) estimation. We identified a set of suitable instruments following both theory and existing literature (Pender et al.). In the absence of serial correlation in the error term, lagged variables for output, farm agroecological heterogeneity, land share under conservation measure and distance from input supplier are suitable instruments. To assess the validity of these instruments, both Hausman test and regression residuals tests for endogeneity were applied. We found that outputs variables (barley and wheat), their interaction and soil conservation measure to be endogenous. The C test statistic for endogeneity is reported at the bottom of table 3: it provides strong evidence of endogeneity for these variables. The Sargan-Hansen test using the over-identifying restrictions was used to investigate whether the orthogonality conditions between the instruments and the error term are satisfied. We failed to reject the null hypothesis. Therefore the choice of instruments seems appropriate. A number of specification tests were conducted (they are reported at the bottom of table 3). The null hypothesis of homoscedasticity was tested against the alternative hypotheses of *i)* general heteroscedasticity, and *ii)* multiplicative heteroscedasticity. Tests results confirmed the presence of heteroscedasticity and that multiplicative heteroscedasticity was present. To obtain efficiency gains, we therefore implemented a weighted estimation method using weights obtained from the consistent estimate of the error variance. The estimation results are reported in Table 3 for both IV and OLS estimation. The empirical estimates appear qualitatively robust.

Table 3 *Shortage function estimation*

	Coefficients	Standard Errors	Coefficients	Standard Errors
	OLS		IV	
Constant	-293.39***	66.74	-291.94***	71.75
Barley	-0.42***	0.08	-0.461**	0.2
Barley^2	0.00028***	8.30E-05	0.0002	0.0002
Wheat	-0.273***	0.109437	-0.46	0.3
Wheat^2	6.83E-06	0.000151	-0.000137	0.00023
Barley*wheat	0.00033***	0.0001	0.00117**	0.0006
Animal traction	60.18***	15.68	67.8***	17.98
Land	16.85**	8.3	19.64**	8.99
Labor	87.3***	15.19	84.26***	16.85
Fertilizer	1.11***	0.436	0.85*	0.5
Rainfall	0.11	0.157	0.0361	0.176
Soil fertility	14.42	25.02	22.08	29.61
Soil erosion	-13.2	14.6	-9.97	16.33
Slope	-37.09	30.59	-49.8	32.7
South	-23.1	20.1	-27.86	20.97
East	-63.7	19.9	-72.62***	28.167
West	59.09*	25.97	40.5*	29.98
Improved seeds	-15.4	23.08	6.68	37.14
Soil conservation	59.7*	34.2	126.08**	62.03

N= 310; Hansen J test: Chi-square test statistic 3.56 (with 2 degrees of freedom), P-value = 0.168. C test for endogeneity of barley, wheat, barley squared, wheat squared, barley*wheat, soil conservation: 17.31 (P-value=0.008). Breusch Pagan Test for heteroscedasticity: chi-square test statistic 193.92 (with 18 degrees of freedom), P-value < 0.001. Significance levels are denoted by one asterisk (*) at the 10 percent level, two asterisks (**) at the 5 percent level, three asterisks (***) at the 1 percent level. Robust standard errors have been used.

We also investigated whether the production function f(·) in (11) exhibited discontinuities at y = 0. This was done by introducing dummy variables equal to 1 if y_i = 0 and zero otherwise, and testing their statistical significance. Using a Wald test and a 10 percent significance level, we failed to reject the null hypothesis that these dummy variables have a significant effect on productivity. Thus, we did not find statistical evidence that the production function f(·) was discontinuous at y = 0. This means that we did not find statistical evidence of significant "catalytic effects". On that basis, our analysis proceeds assuming that the production function f(·) in (11) is continuous everywhere.

Table 3 reports the estimation results. The conventional inputs (animal traction, land, labor and fertilizer) are all positive and statistically significant. The estimated coefficients for outputs show statistical significance. The coefficient of the linear term for barley is negative and statistically significant at the 5 percent level. And the interaction term (barley × wheat) is positive and statistically significant at the 5 percent level. This indicates the presence of positive interaction effects across crops. Such positive interaction effects on productivity give a hint about the presence of complementarity in the agro-ecosystem. Such effects and their implications for the value of diversity are further evaluated below. In Table 3, while the coefficients related to agroecological conditions are consistent with expectation, none of them is statistically significant at the 10 percent level. A negative and strongly significant coefficient was estimated for "East". This is consistent with evidence that the eastern part of the region has the worst conditions for agricultural production (Gebremedhin et al.).

The use of improved seeds seems not relevant. Indeed, the estimated coefficient is not statistically significant. The share of land under reduced tillage is found to have an important impact on productivity. The estimated coefficient, indeed, is positive and statistically significant. This result indicates that soil conservation measures can be a win-win strategy in such agricultural system.

8. Implications

The estimated production function (reported in Table 3) provides a basis for investigating the productivity of the agroecosystem. Of special interests are the implications for the value of diversity D given in (8) and its components given in (9) and (10): scale effect D_R, complementarity effect D_C, and convexity effect D_V.[xvi] In this context, based on the estimated production function, bootstrapping is used to simulate the distribution of D and its components. This provides a basis for assessing both the magnitude of the diversity measures and their statistical significance. The simulation results are presented in Tables 4, 5 and 6.

Table 4 *Simulated Measure of Diversity D and its Decomposition (complementarity effect DC, scale effect DR, and convexity effect DV).**

Diversity	$D = D_C + D_R + D_V$	D_C	D_R	D_V	$D_C + D_V$
Diversity measure	3.966	14.257	2.203	-12.594	1.663
Standard error	(80.316)	(7.937)	(77.359)	(4.136)	(6.805)
P-value for testing $D_.$ = 0	0.480	0.036	0.491	0.001	0.405

* Evaluated at a farm size equal to 1.3 times the sample mean, and at a degree of specialization β = 0.8.

Table 5 *Simulated Effects of the degree of specialization β on complementarity DC and convexity DV.**

Measure of diversity	D_C		D_V		$D_C + D_V$	
Degree of specialization β	Diversity measure	Standard error	Diversity measure	Standard error	Diversity measure	Standard error
β = 0.4	0.291**	0.162	-0.257***	0.084	0.034	0.139
β = 0.6	4.655**	2.592	-4.112***	1.350	0.543	2.222
β = 0.8	14.257**	7.937	-12.594***	4.136	1.663	6.805
β = 1	29.097**	16.198	-25.703***	8.441	3.394	13.888

* Evaluated at a farm size equal to 1.3 times the sample mean.
Significance levels are denoted by one asterisk (*) at the 10 % level, two asterisks (**) at the 5 % level, three asterisks (***) at the 1 percent level.

Table 6 *Simulated Effects of farm size on complementarity D_C and convexity D_V.**

Measure of diversity	D_C		D_V		$D_C + D_V$	
Farm size (proportion of sample mean)	Diversity measure	Standard error	Diversity measure	Standard error	Diversity measure	Standard error
0.5	4.304**	2.396	-3.802***	1.249	0.502	2.054
0.7	8.436**	4.696	-7.452***	2.447	0.984	4.027
1	17.217**	9.584	-15.209***	4.995	2.008	8.218
1.3	29.097**	16.198	-25.702***	8.441	3.394	13.888
1.5	38.738**	21.565	-34.219***	11.238	4.518	18.490

* Evaluated at a degree of specialization β = 1.

Significance levels are denoted by one asterisk (*) at the 10 % level, two asterisks (**) at the 5 % level, three asterisks (***) at the 1 percent level.

Table 4 shows the diversity measure D and its components: complementarity D_C, scale D_R and convexity D_V, evaluated for a farm being 1.3 times the sample mean and facing a degree of specialization β equal to 0.8.[xvii] Table 4 shows that both convexity effect and complementarity effect are statistically significant. The complementarity effect D_C is found to be positive and significant at the 5 percent level. This provides evidence that each crop tends to have a positive effect on the marginal productivity of other crops. Comparing D_C = 14.257 with an average teff production of 151, the productivity benefit associated with complementarity amounts to a 9.3 percent boost in productivity. This documents that the complementarity component of diversity provides significant productivity benefits to the functioning of the agro-ecosystem.

The scale component D_R in Table 4 is positive (2.20) but not statistically significant. As shown in equation (10b'), D_R = 0 under constant returns to scale (CRTS). This indicates that the scenario evaluated in Table 4 corresponds to a situation where CRTS cannot be rejected. We also conducted the analysis reported in Table 4 under different farm sizes. We did find some evidence that D_R became positive and statistically significant for very small farm sizes. This indicates the presence of increasing returns to scale (IRTS) for very small farm sizes, where $D_R > 0$ under IRTS means that scale effects can contribute positively to the value of diversity. However, such evaluations involved simulating farm sizes that were at the lower bound of the ones observed in the sample. This means that the statistical evidence in favor of IRTS has to be interpreted with caution: it is always dangerous to try to extrapolate outside of the sample information. We found that, within the range of most farm sizes observed in the sample, D_R was not statistically different from zero (as in the case reported in Table 4). This means that, for most farms, the technology of the agro-ecosystem seems to exhibit CRTS (in which case $D_R = 0$), except possibly for very small farms (where IRTS may arise, with $D_R > 0$).[xviii] In other words, for most farms, the evidence against CRTS is weak, implying that the scale effect D_R does not appear to be an important part of the value of diversity in our agroecosystem.

Table 4 shows that the convexity effect D_V is negative: -12.59. And it is statistically significant at the 1 percent level. As discussed above, D_V is expected to be positive under convex technology (i.e. a technology exhibiting decreasing marginal returns). This provide evidence that our agro-ecosystem does not exhibit decreasing marginal returns, and that its underlying technology is <u>not convex</u>. Moreover, this non-convexity means that the convexity component D_V provides an incentive to specialize. Comparing $D_V = -12.59$ with an average teff production of 151, the productivity loss associated with (non)convexity amounts to a 8.33 percent decline in productivity. Besides being statistically significant, this also appears to be economically important. In other words, our empirical analysis indicates that non-convexity in the technology of the agro-ecosystem provides disincentives to diversify and contributes to reducing the value of diversity.

When putting all components together, Table 4 shows that the value of diversity D remains positive: D = 3.97. This amounts to a 2.6 percent contribution to productivity. This reflects the fact that the complementarity component ($D_C = 14.24$) is large enough to dominate the negative convexity component ($D_V = - 12.59$). Even if we ignore the (non-significant) scale component D_R, note that $D_C + D_V = 1.663$ is positive and contributes to a 1.1 percent boost in productivity. However, neither D nor ($D_C + D_V$) is statistically different from zero at the 5 percent significance level. This means that the evidence of significant overall value of diversity in our agro-ecosystem is weak. The reason is that, even in the presence of significant complementarity benefits, such benefits are cancelled out by opposite effects from the (non) convexity component.

Table 5 presents simulation results evaluating the effects of the degree of specialization β on the complementarity component D_C and the convexity component D_V. It shows that both D_C and D_V are small under mild specialization (e.g., $\beta = 0.4$). However, their magnitude increases rapidly with β. For example, under complete specialization ($\beta = 1$), D_C rises to 29.10 while D_V becomes –25.70. This amounts to a 19.2 percent increase and a 16.6 fall in productivity, respectively. These magnitudes indicate large and significant impacts of each component on agro system productivity. In all cases, the magnitude of the complementarity component dominates the magnitude of the (non) convexity component. This means that their combined effect ($D_C + D_V$) is always positive. However, these two effects tend to cancel each other, implying that their combined effect tends to be small and is no longer statistically significant. Thus, the evidence of non-significant overall value of diversity reported in Table 4 remains valid under alternative diversification schemes.

Table 6 presents simulation results evaluating the effects of farm size on the complementarity component D_C and the convexity component D_V. It shows that, although they remain statistically significant, both D_C and D_V tend to be small on small farms. However, their magnitude increases rapidly with farm size. For example, for farm size equaled to 1.5 times the sample mean, D_C rises to 38.74 while D_V becomes -34.22. These magnitudes indicate large and significant impacts of each component on larger farms. This provides evidence that, in absolute value, both the complementarity component and the (non)convexity component increase with farm size. In all cases, the magnitude of the complementarity component dominates the magnitude of the (non)convexity component. This means that their combined effect ($D_C + D_V$) is always positive. Again, these two effects tend to cancel each other, implying that their combined effect is no longer statistically significant. This indicates that the evidence of non-significant overall value of diversity reported in Table 4 remains valid for a wide range of farm sizes.

9. Concluding Remarks

We have presented an analysis of the value of crop biodiversity in an agro-ecosystem, with an application to food production in the Highlands of Ethiopia. To this end, a conceptual framework was developed to assess the productive value of biodiversity. The analysis applies under general conditions, allowing for non-convexities. We relied on Luenberger's shortage function to provide a measure of the productive value of biodiversity. When positive, this value reflects the fact that an ecosystem is worth more than the "sum of its parts." We showed that this value can be decomposed into four additive components, reflecting complementarity effects, scale effects, convexity effects, and catalytic effects. This provides new and useful information on its sources and determinants.

The empirical analysis involved specifying and estimating the shortage function as a representation of the underlying technology. Relying on an instrumental variables estimator, the estimates were used to evaluate the productive value of biodiversity and its components. Results show that the value of crop diversity is positive. The complementarity effect was found to positive and significant at the 5 percent level. In the context of the Ethiopian agroecosystem, this provides evidence that each crop tends to stimulate the marginal productivity of other crops. The complementarity effect is estimated to generate a 9.3 percent increase in productivity. Thus, our analysis shows that complementarity provides a positive and significant contribution to the productive value of crop diversity in the Ethiopian agroecosystem. We also found evidence that the convexity component of diversity value is negative and statistically significant. This corresponds to a technology that is not convex, i.e. where marginal products of outputs are not diminishing. This means that the convexity component provides an incentive to specialize. In general, the (negative) convexity component is dominated by the (positive) complementarity component, generating a positive overall value of diversity. However, as these two terms tend to cancel each other, our estimate of the overall value of diversity is not statistically significant.

Our empirical analysis did not find statistical evidence that either the scale effect or the catalytic effect played a significant role in the value of biodiversity. The lack of evidence of a scale effect means that farm size does not have a large impact on the functioning of the agroecosystem in Ethiopia. However, our empirical results did suggest that both complementarity effects and convexity effects may increase with farm size. While our investigation focused on the productive value of agro-biodiversity, we should note that this value is only a part of the total value of an ecosystem. This indicates the need to place the analysis in the broader context of ecological-economic interactions. This would include the value of biodiversity to consumers. Under uncertainty, this means examining the role of risk preferences and their implications for the design and implementation of risk management schemes. And in a dynamic context, this would include addressing the issue of how new information that becomes available over time is used in ecosystem management. Finally, while our analysis of an Ethiopian agroecosystem illustrated the usefulness of our approach to biodiversity valuation, we should keep in mind that our empirical findings may not apply to alternative ecosystems. There is a need for additional empirical investigations of the productivity implications of ecosystem functioning. These appear to be good topics for future research.

Appendix

Proof of Proposition 1:

Let $z_{b,i:j} = (z_{bi}, z_{b,i+1}, \ldots, z_{b,j-1}, z_{bj})$ for i < j. Given $S(z, g) = S_v(z, g) + S_f(z, g)$, and using (5) and (7), the value of diversity is

$$D \equiv \sum_{k=1}^{K} S(z_a/K, z^+_{bk}, z^-_{b\backslash bk}, g) - S(z, g),$$

$$= \sum_{k=1}^{K-1} S_v(z_a/K, z^-_{b,1:k-1}, z^+_{bk}, z^-_{b,k+1:K}, g) + S_v(z_a/K, z^-_{b,1:K-1}, z^+_{bK}, g)$$

$$+ \sum_{k=1}^{K} S_f(z_a/K, z^+_{bk}, z^-_{b\backslash bk}, g) - S(z, g), \qquad \text{(A1)}$$

Note that

$$\sum_{k=1}^{K-1} S_v(z_a/K, z^-_{b,1:k-1}, z^+_{bk}, z^+_{b,k+1:K}, g) =$$

$$\sum_{k=1}^{K-1} S_v(z_a/K, z^-_{b,1:k-1}, z^-_{bk}, z^+_{b,k+1:K}, g) + S_v(z_a/K, z^+_{b}, g) - S_v(z_a/K, z^-_{b,1:K-1}, z^+_{bK}, g). \qquad \text{(A2)}$$

Also,

$$\sum_{k=1}^{K-1} S_v(z_a/K, z^-_{b,1:k-1}, z^-_{bk}, z^-_{b,k+1:K}, g) = (K-1)\, S_v(z_a/K, z^-_{b}, g). \qquad \text{(A3)}$$

Adding (A2) and (A3) to (A1) gives

$$D = \sum_{k=1}^{K-1} S_v(z_a/K, z^-_{b,1:k-1}, z^+_{bk}, z^-_{b,k+1:K}, g) + S_v(z_a/K, z^-_{b,1:K-1}, z^+_{bK}, g)$$

$$+ \sum_{k=1}^{K} S_f(z_a/K, z^+_{bk}, z^-_{b\backslash bk}, g) - S(z, g)$$

$$+ \sum_{k=1}^{K-1} S_v(z_a/K, z^-_{b,1:k-1}, z^-_{bk}, z^+_{b,k+1:K}, g) + S_v(z_a/K, z^+_{b}, g) - S_v(z_a/K, z^-_{b,1:K-1}, z^+_{bK}, g)$$

$$- \sum_{k=1}^{K-1} S_v(z_a/K, z^-_{b,1:k-1}, z^+_{bk}, z^+_{b,k+1:K}, g)$$

$$+ (K-1)\, S_v(z_a/K, z^-_{b}, g) - \sum_{k=1}^{K-1} S_v(z_a/K, z^-_{b,1:k-1}, z^-_{bk}, z^-_{b,k+1:K}, g).$$

This can be alternatively written as

$$D = \sum_{k=1}^{K-1} S_v(z_a/K, z^-_{b,1:k-1}, z^+_{bk}, z^-_{b,k+1:K}, g) - \sum_{k=1}^{K-1} S_v(z_a/K, z^-_{b,1:k-1}, z^-_{bk}, z^-_{b,k+1:K}, g)$$

$$- \sum_{k=1}^{K-1} S_v(z_a/K, z^-_{b,1:k-1}, z^+_{bk}, z^+_{b,k+1:K}, g) + \sum_{k=1}^{K-1} S_v(z_a/K, z^-_{b,1:k-1}, z^-_{bk}, z^+_{b,k+1:K}, g)$$

$$- S(z, g) + K\, S(z/K, g)$$

$$- K\, S(z/K, g) + S_v(z_a/K, z^+_{b}, g) + (K-1)\, S_v(z_a/K, z^-_{b}, g)$$

$$+ \sum_{k=1}^{K} S_f(z_a/K, z^+_{bk}, z^-_{b\backslash bk}, g). \qquad \text{(A4)}$$

Assuming that $S_v(z, \cdot)$ is continuous everywhere and continuously differentiable almost everywhere on R^{m+n}, and using $S_v(z, g) = S(z, g) - S_f(z, g)$, this yields

$$S = \sum_{k=1}^{K-1} \{ \int_{z^-_{bk}}^{z^+_{bk}} \frac{\partial S_v}{\partial \gamma} (z_a/K, z^-_{b,1:k-1}, \gamma, z^-_{b,k+1:K}, g)\, d\gamma$$

$$- \int_{z^-_{bk}}^{z^+_{bk}} \frac{\partial S_v}{\partial \gamma} (z_a/K, z^-_{b,1:k-1}, \gamma, z^+_{b,k+1:K}, g)\, d\gamma \}$$

$$+ K\, S(z/K, g) - S(z, g)$$

$$+ S(z_a/K, z^+_{b}, g) + (K-1)\, S(z_a/K, z^-_{b}, g) - K\, S(z/K, g)$$

$$+ \sum_{k=1}^{K} S_f(z_a/K, z^+_{bk}, z^-_{b\backslash bk}, g) - S_f(z_a/K, z^+_{b}, g) - (K-1)\, S_f(z_a/K, z^-_{b}, g), \qquad \text{(A5)}$$

which gives equations (9)-(10). R

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Footnotes

1 Another hypothesis is the "sampling effect" stating that increasing diversity improves the chances that specific species would be adapted to particular ecological condition (Tilman et al.).

2 While equation (3′) provides <u>absolute measures</u> of changes in environmental goods, relative measures can be easily obtained. To see that, consider the case where $z_b^1 = 0$ and $z_b^2 = z_b$. Then, equation (2) becomes

$P(z_a, 0, z_b, g) = S(z_a, 0, g) - S(z_a, z_b, g)$,

which measures the <u>total value</u> of the environmental goods z_b when p g = 1. In situations where $P(z_a, 0, z_b, g) \neq 0$, a <u>relative measure</u> of changes in environmental goods from z_b^1 to z_b^2 can be written as

$$R_1(z_a, z_b^1, z_b^2, g) \equiv P(z_a, z_b^1, z_b^2, g)/P(z_a, 0, z_b^2, g)$$
$$= [S(z_a, z_b^1, g) - S(z_a, z_b^2, g)]/[S(z_a, 0, g) - S(z_a, z_b^2, g)].$$

$R_1(z_a, z_b^1, z_b, g)$ measures the value of the change from z_b^1 to z_b^2 as a proportion of the total value of z_b^2. Finally, note that, in situations where (z_a, z_b^2) is on the upper bound of the feasible set, then $S(z_a, z_b^2, g) = 0$ and $R_1(.)$ reduces to

$R_1(z_a, z_b^1, z_b^2, g) = S(z_a, z_b^1, g)/S(z_a, 0, g)$,

showing that a ratio of shortage functions provides a simple relative measure of environmental changes.

3 This extends the analysis presented by Chavas and Kim, and Chavas. By allowing the β_k's to vary, our approach can capture heterogeneous patterns of specialization.

4 Alternative specifications were also estimated. In general, they provided results that were qualitatively similar to the ones reported below.

5 Given the lack of statistical evidence about catalytic effects, the estimated model implicitly assumes that $D_f = 0$.

6 Alternative degrees of specialization were also explored. See below.

7 We also conducted the analysis assuming constant returns to scale (CRTS). This was done by defining all inputs and outputs on a per-hectare basis. As shown in (10b′), this implied $D_R = 0$. The estimates of the value diversity and its components were similar to the ones reported in the paper. This is consistent with the test results reported in Table 4 showing no strong evidence against the hypothesis $D_R = 0$.

Sustainable biodiversity conservation for improved land management in Ethiopia: Five decade analysis

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Abstract

The Ethiopian region is characterised by a wide range of agro-climatic conditions, which accounted for the enormous resources of agro-biodiversity that exist in the country. The most important of these resources is the immense genetic diversity of the various crop plants in the country. Of these, one of the most on farm genetically diverse crops is sorghum. Since the advent of formal breeding in particular after green revolution, genetic diversity of most crops has been threatened worldwide. In order to assess on farm genetic erosion (GE), various research methodologies were employed. These were focused group interviews with 360 farmers, on farm monitoring and participation with 120 farmers, key informant interviews with 60 farmers and development agents, and semi-structured interviews with 250 farmers. Besides, diversity fairs were done with over 1200 farmers. Notwithstanding the complexity of assessing GE, it was assessed by various methods; namely, by temporal method (comparing 1960 and 2000 collections), area method, and semi-structured interview method at individual, community or *wereda* level and causes of varietal loss from other various perspectives. Farmers perceived GE as the reduced importance of the variety as indicated by lower proportion in the varietal portfolio. The five most important factors for varietal loss at individual farmers' level were reduced benefit from the varieties, drought, *Khat* expansion, reduced land size and introduction of other food crops respectively. GE was not affected by wealth groups and ecological regions. Farmers do not make simple replacement as a strategic mechanism for genetic resources management. GE at regional level was quantified by temporal and spatial method. There was a complementation not rivalry between Farmer Varieties (FVs) and Improved Varieties (IVs). The whole process of GE is explained by three models, namely: Bioecogeographic enhanced genetic erosion model, Farmer induced genetic erosion model and Farmer-cum-bioecogeographic genetic erosion model. As aforementioned, sorghum genetic erosion behaviour is completely different from other food crops such as tetraploid wheat. The prediction in the late seventies that complete erosion of FVs by IVs by the end of the eighties, the principle of GE that competition between IVs and FVs, favours the former and results in the replacement of the latter is not valid in the context of sorghum in Ethiopia. Hence, maintenance of the on farm genetic diversity of sorghum is a reality but GE is rhetoric.

Key Words: area method; Ethiopia; genetic erosion; genetic erosion modalities; on farm genetic diversity; spatial method; sorghum

Introduction

Biodiversity, at the world summit on sustainable development held in Johannesburg in South Africa in 2002, is outlined as one of the five major areas for progress in achieving a sustainable future for humanity. The United Nations Convention on Biological Diversity (UNEP 1992) defines biodiversity as '*the variability among living organisms from all sources,* *including terrestrial, marine and the ecological complexes of which they are part*.' Agro-biodiversity encompasses the variety and variability of plants, animals, microorganisms at genetic, species and ecosystem level that are necessary to sustain key functions in the agro-ecosystem, its structure and processes for, and in support of, food production and food security (FAO, 1999). Agro-biodiversity has spatial, temporal, and scale dimensions especially at agro-ecosystem levels. These agro-ecosystems are determined by three sets of factors, namely the genetic resources, the physical environment and human management practices.

The Ethiopian region is characterised by a wide range of agro-climatic conditions, which account for the enormous resources of agro-biodiversity that exist in the country (Worede, 1992). The most important of these resources is the immense genetic diversity of the various crop plants in the country.

Doggett (1988) suggested that sorghum is domesticated and originated in North-East quadrant of Africa, most likely in the Ethiopian-Sudan border. The presence of wild sorghums and their cultivated forms and their ecotype differentiation of sorghum into different races (Mekbib, 2007c) and their presence in different parts of the country supports that Ethiopia is the primary centre of origin and hence the centre of diversity for sorghum.

The Ethiopian Institute of Biodiversity Conservation and Research holds ca 60,000 accessions of some 104 species (IBCR 2000). Sorghum collections have been made at various times by different organizations in the country and collected closer to 8000 accessions (PGRC/E 1986). Of these collections, considerable number is from eastern Ethiopia. These accessions represented a wide array of diversity and the major sorghum areas in the country. However, the collection is not exhaustive and does not cover the whole country and systematic collection and updating is lacking.

It is Harlan and Martini (1936) as cited in by Brush (1999) who have recognised for the first time the problem of genetic erosion. A recent notion of genetic erosion is well discussed by Hammer and Laghetti (2005). Genetic Erosion (GE) implies that the normal addition and disappearance of genetic variability in a population is altered so that the net change in diversity is negative (Brush 2000). Conventionally, GE is the loss of genetic diversity including the loss of individual genes and the loss of gene complexes such as those manifested in locally adapted landraces (FAO 1998). According to Maxted and Hawkes (1997), the loss of genetic diversity is of primary importance for utilization, because mankind relies upon the use of genetic rather than its taxonomic boundaries. In addition, the genetic diversity of a given species expands further than its taxonomic boundaries. GE is detrimental to the short-term viability of individuals and populations, the evolutionary potential of populations and species, and the direct use of genetic resources (Brown et al. 1997).

The FAO (1996) global plan of action recommends monitoring and developing an early warning system for the loss of plant genetic resources for food and agriculture (PGRFA). The on farm monitoring of GE in sorghum in the context of Ethiopia is deemed necessary for five major reasons: (i) over years there have been changes in cropping systems to adjust to the prevalent complex, fragile, risk and diverse sorghum production environments, (ii) the change of the socio-economic environment has an implication on the cropping condition thereby on the on-farm genetic resources management, (iii) the change of climatic conditions for the sorghum growing environments might have changed the type of varieties used to be grown and (iv) the impact of biotic stresses, and (iv) formal sorghum research in Ethiopia was started in 1960s with the establishment of Haramaya University. Since then, many varieties have been released for production which might result in the replacement of farmers' varieties. After four decades, it becomes imperative to check whether farmers are maintaining the *de facto* on farm genetic diversity or they have replaced them by improved varieties.

In view of the above, the objectives of this study were to assess: (i) farmers' perception of genetic erosion, (ii) the reasons and levels of genetic erosion (iii) the varieties and areas affected by genetic erosion, and (iv) the modalities shaping the process of on farm genetic erosion.

Materials and methods

Eastern Ethiopia (Fig 1) is selected for the following reasons: (i) sorghum is the first food crop in the region in area, production and importance, (ii) the region is one of the micro-centre of diversity for sorghum, and hence ideal sites for studying on farm GE, (iii) the production of sorghum in the diverse ecologies (altitude, rainfall, soil type, landscape etc.,) helps to assess the impact of environmental factors on GE, (iv) the diverse social, cultural and economic conditions prevalent in the region helps to tap the Indigenous Technical Knowledge (ITK) associated with the crop and (v) there are diverse cropping systems; namely, mono-cropping, intercropping associated with pulses and other cereals, alley-cropping with different perennial crops which need a *de facto* genetic diversity to fit into these various cropping systems.

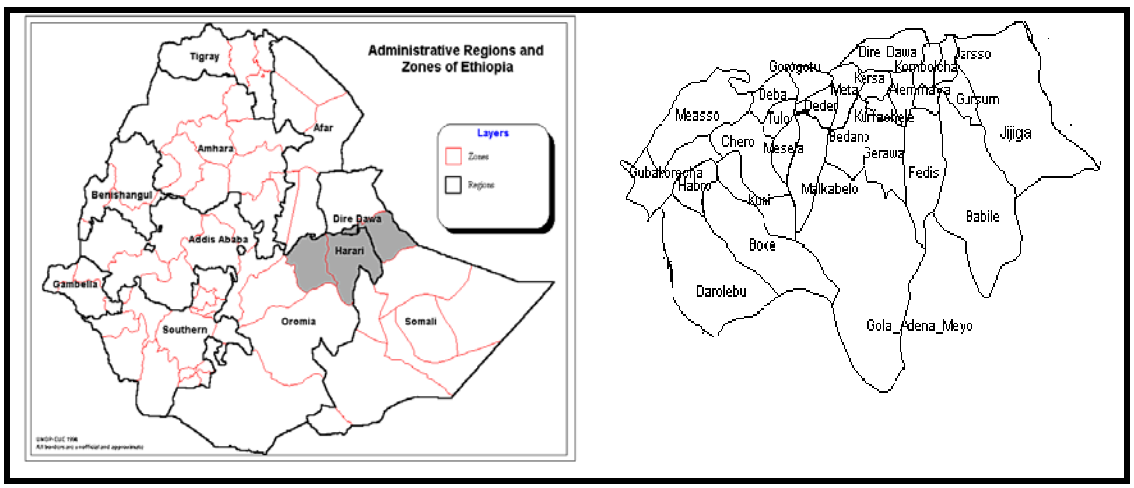

Figure 1 *The position and map of the study site in Ethiopia and detail wereda map of eastern Ethiopia*

In order to assess farmers' management of on farm GE, survey research was undertaken. These were, focused group interviews (informal discussion to explore on-farm genetic erosion subtopics in depth by interviewing a small, carefully selected group, homogenous in social composition) with 360 farmers; direct on-farm participatory monitoring (assessment of genetic resources management with participation of the farmer directly on-farm and in the house) with 120 farmers; key informant interviews (interviews with special sorghum knowledge holders in farming community) with 60 farmers (farmers seconded by the farming community for their rich indigenous technical knowledge on sorghum production, management and utilization) and development agents, and semi-structured interviews (a survey done with a structured questionnaire with individual farmers for quantifying and comparing data on on-farm sorghum genetic erosion) with 250 farmers.

Diversity fairs (on-farm exhibition, description and characterisation of sorghum diversity on a panicle or whole plant or seed level) were one of the tools employed for assessing and inventorying on farm GE. This was done around physiological maturity of the crop. An average of 50 farmers participated in the 24 of the diversity fairs i.e., a total of 1200 farmers. Both women and men brought all the varieties grown in their field to the fair and discussed prevalence, distribution and importance of each variety.

Participatory collection of germplasm was done in the year 2000 for comparative estimation of GE with that of 1960. Geographical information of the 1960 collection sites were used as bases to synchronise with 2000 collections. Both focused group and key informant interviews were made and the folk species and varieties grown in the region were listed (Mekbib 2006a). Most of them were collected in the course of diversity fair held in the various farming communities across the three sorghum growing ecologies. Besides, additional collections were made in the course of on farm monitoring for quantification of number of varieties and assess the eco-geographical factors affecting GE. In all the directly monitored farms, a participatory zigzag sampling in the diagonal direction of the plot was made with 120 directly on farm-monitored farmers. All encountered varieties were counted. For varieties in the field that were not encountered in the course of monitoring, the farmers were consulted.

The age of the participating farmers ranged from 18 to 80 with a mean age of 42 years and farming experience of 20 years. As aforementioned, more than 2000 farmers participated in the study; of which 1400 were male and 600 female. Male headed one wife household type (92%) was the dominant one in the region. The participated farmers ethnically comprised *Oromo*, *Amhara* and *Somali* in decreasing order.

Quantification of Genetic Erosion. Genetic integrity and erosion were calculated as indicated by Hammer et al. (1996). GI (Genetic Integrity) = ratio of the number of collected accessions per crop per area where FVs were presented in 1960 and 2000 i.e., $C_{2000}/C_{1960} \times 100$. Information about the 1960s collections was obtained from the Ethiopian Institute for Biodiversity and Conservation. Then, GE was calculated as GE=100%-GI. Using the indicated formula number of collection made in the 1960s was compared with that of the collection made in this study, in the year 2000. Comparison of collection was made both in number and in name because of the similarity in the area of collection. Comparison by name is used for the first time in this study. Besides comparison of collections, survey methods such as on farm monitoring, semi-structured interview and focused grouped discussion were also used in assessing on farm GE.

In order to assess the long term trend on sorghum and maize area and production nationally 42 years crop acreage data was used. The data used was obtained from Central Statistical Authority of Ethiopia and FAO agricultural statistical data base.

Collected data were subjected for descriptive statistics, analysis of variance, log-linear regression, and trend analysis using STATISTICA, SPSS ver. 10 and MINITAB Ver. 14 statistical software.

Results and discussion

Farmers' perception of GE

Farmers' perceived GE as varietal loss. It is the loss of variety on farm (reduced role or benefit of the variety) owing to biological, economic, ecological and socio-cultural reasons. Sometimes farmers do not grow variety when it is 'tired off', not performing very well for yield and resistance against various biotic and abiotic stresses. It does not equate the conventional sense of GE. Sometimes, it might not either refer that the net change (alteration of varietal addition and disappearance) in diversity is negative as indicated by Brush (2000).

There can still be a loss even if the net change in diversity is positive, the number of varieties can be the same but the type of varieties can change i.e., there can be loss in type but not in number (reduced population size).

GE can happen at single alleles, allele complexes, FVs, whole populations, ecotypes or even species level. However, in view of the established varietal mixture growing culture and moderate out crossing rate, it is difficult to presuppose that GE has happened at single allele or allelic complexes. In eastern Ethiopia, sorghum is not as high in the state of genetic vulnerability at a gene level because farmers usually practice varietal mixtures per season. Reduction of GE at the level of gene loss is also enhanced by the level of sorghum out crossing rate up to 50% (with a mean of 5%, depending on the various factors) (House 1992; Arriola et al. 1995; Yao et al. 2004).

In this study GE is shown at variety level. GE as aforementioned is revealed by the low proportions in the varietal composition thereby reduced acreage allocation to the same. However, it was understood that what is reduced or lost at individual level was not happening at the community level, *wereda* or regional level. Even, farmers who have stopped growing that variety will tell you where or with whom you can find that variety in the same community. In this region it is really difficult to say a variety is lost completely. In the course of on farm monitoring, it was found out that a farmer will tell you that he has lost the variety but when you go the field, you will find the variety. When you ask the farmer that did not you say that you have lost the variety? He will say that yes, this is just '*tokuuma*' (in Oromiffa language, one of the Ethiopian languages), means *'very few plants'*. Hence, farmers attached less or 'insignificant' population to the loss of varieties. It might not refer to the complete absence of the varieties in their fields. Hence, in view of the above it is difficult to say that there is a varietal loss in absolute sense in the centre of diversity. But we can simply concede to what farmers define as varietal loss or reduced varietal importance.

It has been found out that in Ethiopia in sorghum GE is not simple, automatic and discrete activity of the farmers in the management of varietal portfolio. This is also shared by Bellon et al. (1997) and Brush et al. (1981), that there is no support for a 'simple replacement theory' in the centre of genetic diversity.

Major reasons for GE

The main cause of GE in crops as reported by almost all countries were the replacement of FVs by IVs (FAO 1998). But in Ethiopia for sorghum, the dominant causes for GE were not IVs. On the contrary, the IVs have resulted in widening the genetic base. The five most important factors for varietal loss for sorghum in the region as indicated (Table 1) were: reduced benefit from the varieties, drought, *Khat* expansion, reduced land size and introduction of other food crops respectively.

Reduced benefits of the varieties can be due to low yield, susceptibility to pest and diseases, *Striga* etc. Drought has been affecting recurrently farmers' sorghum production. In some years drought becomes serious and wipes out the whole sorghum production which might result into the loss of varieties. In other years, drought occurs at various stages but the most important one is the terminal stress, which results in reduced seed production (Mekbib 2006b). *Khat* (*Chata edulis* Forsk) is a mild drug crop which is primarily originated in Ethiopia. It is expanding at an alarming rate in the region and is taking over the land that used to be for sorghum. Farmers were aggressively shifting into *Khat* production from sorghum and coffee (*Coffea arabica* L.) because of higher income farmers' are earning from *Khat*. Nationally, *Khat* is also one of the most economically important crops for export earning. In the year, 1999/2000, *Khat* worth closer to 500 million USD was exported to many countries (The Reporter 2000). Much of the *Khat* production and export is from the study region, eastern Ethiopia. The estimation for the year 2005 is less than that of 2000. The value for domestic market is expected to be higher than that of the export one.

The reduced sorghum land size due to introduction of other crops on GE are discussed in detail in the 3a and 3b parts of the manuscript.

Besides, regardless of wealth groups and ecological regions, there was no variation for the loss of varieties. As shown in Table 2, there was a proportional difference in the various wealth groups with respect to the level of GE as average farmers are those with dynamic cropping systems where there is continuous influx and outflux of varieties. However, if you see within each wealth groups across various ecologies, the proportional differences was very small (rich: 4 vs 3.3 vs 3.3; Average: 21.3 vs 28.7 vs 16.7; and Poor: 10.7 vs 9.3 vs 2.7). Intermediate altitudes and average farmers domains have more dynamic biological, ecological, social, and economical conditions which enhanced proportionally higher GE. On the contrary, there was a variation among farmers and ecological regions for the absence of GE (Table 2).

***Table 1** Factors affecting genetic erosion on farm*

Factors	%(N=250)
Reduced benefit derived from the varieties	51.7
Drought	41.4
Expansion of *Khat*	9.7
Reduction in land size	9.2
Introduction of other food crops (maize, horticultural crops)	8.5
Lodging problem	3.7
Destruction of habitat and farmland	3.1
Change in land use pattern	3.0
Better sorghum varieties came	2.5
Reduction in the number of sorghum farmers	1.8
Bird damage	1.8
Change in economic status of the farmers	1.2
Late maturity of the varieties	1.2

***Table 2.** Proportion of genetic erosion in various wealth groups and ecological regions*

Genetic erosion	Ecological region	Wealth rank			Total
		Rich	Average	Poor	
Yes (NS)	Highland	4	21.3	10.7	36.0
	Intermediate	3.3	28.7	9.3	41.3
	Lowland	3.3	16.7	2.7	22.7
	TOTAL	10.7	66.7	22.7	100
No*	Highland	1.0	35.4	11.5	47.9
	Intermediate	4.2	27.1	5.2	36.5
	Lowland	1.0	14.6	0	15.6
	TOTAL	6.3	77.1	16.7	100

*Significant difference (at 5%) in the proportion of farmers experiencing no genetic erosion by wealth and ecology. NS=Non-significant difference. Phi and Cramer's v values were not significant.

Commonly, the advancing pressure on land and labor increases the importance of 'yield' as selection criterion for farmers, lead to the intensified crop production, the adoption of improved varieties with higher yield potentials and use of more inputs and the planting of fewer varieties on a farm (Lipton and Longhurst 1989). This was not seriously observed in the study area. Besides, as opposed to the idea of de Boef et al. (1993), in eastern Ethiopia, the vast reservoir of local knowledge on varieties and their maintenance is not threatened, simultaneously with genetic diversity of plants, through the widespread adoption of modern varieties. Hence, farmer varieties did not tend to be left to the more marginal, risk-prone habitats and ethnological niches for which the improved varieties were not suitable.

Quantifying GE

GE is a protracted process in the areas where farmers are growing many number and type of varieties. Actually, it is easier to assess the loss of a variety in modern agriculture based on IVs in countries of non-centre of diversity than in country of the centres of diversity such as Ethiopia. Besides, GE demands time series data, and hence it is very difficult to quantify the same in the centre of diversity.

On top of the complexity of the process, GE concept is constrained by the cut off value. For instance, what proportions of farmers have to grow these varieties in order to say that the variety is genetically eroded? What should be the minimum area a variety has to be planted in order to say that the variety is at the brink of loss? Similarly, the most common means of assessing GE in farm level crop diversity is by counting named varieties but this is different from actual GE because sometimes variety names (Mekbib 2006a) might not necessarily correspond to genetic content either geographically or over time.

Notwithstanding the complexity of assessing genetic erosion, I have indicated below the assessment of varietal loss (genetic erosion) by various methods: these are; (i) varietal loss assessment by semi-structured interview at individual, community or *wereda* level, (ii) temporal comparison of 1960 and 2000 collections by number and name, and (iii) area (spatial) method to quantify GE from various perspectives are described. Finally, (iv) the impact of sorghum IVs and other food crops on GE of sorghum is also discussed. It is hoped that this gives the first ever comprehensive and multi-faceted analysis of GE .

1. GE at individual farmer level

- Farmers' in general stated that they have not lost all their varieties. If it is not on their farm, they have indicated that it will be found with other farms' in the village. They do also believe that the area they use to allocate for sorghum has tremendously reduced due to a change in farming system which resulted for farmers to produce horticultural crops, food legumes, Khat and maize. Actually this pressed them not to grow all varieties but to focus on some varieties. Farmers' prioritise varieties and reduce the number of varieties grown on farm to respond for reduction in land size. Some varieties like Fendisha, Muyra, and Wegere, have been avoided by some of the farmers from their farm for certain reasons. This has resulted in the ecotypic differentiation (Mekbib, 2007c) of varieties and also in growing specific varieties per farmers' village. However, varieties lost in one farmer will be gained by the other farmer in the same community or different community. Or variety lost in a farmer might be found either within that FA (Farmers' Association) or wereda. Hence, it is important to determine the level at which GE is happening. As indicated in Table (3), both loss and maintenance occurred in various weredas and FAs.
- The decision for GE was not collective; it rested upon the individual farmer. The change of varietal portfolio is a continuous and dynamic process at the individual farmers' level. Hence, the varieties lost by an individual farmer will still be grown by the other farmer. This partly indicated the heterogeneity in socio-economic and bio-physical environments in the farming systems in the centre of diversity. This is the most common scenario in the centre of crop diversity and has been observed in cassava (Sambatti et al. 2001), potato (Brush et al. 1981; Zimmerer and Douches 1991), maize (Hernandez et al. 1993) and rice (Bellon et al. 1997). The criteria used by farmers varied. On the contrary, for commercial uniform growing of varieties in

modern crop production, varietal loss can happen over the region for instance due to disease epidemics and it happens commonly on bread wheat varieties in Ethiopia.

- The synthesis of example for loss of sorghum varieties across weredas and overall the region is indicated (Table 3). The year 1984 was selected for three major reasons; namely, 1. Ethiopia was hit by severe drought and drought was one of the prime factors for GE. 2. There were various restructuring in rural areas in particular, villagisation and formation of farmer's co-operatives of socialist orientation system. 3. Formal sorghum research was incepted in 1960 hence the duration, four decades, is enough to assess the impact of modern varieties on GE.

Even if the varieties indicated were lost by certain proportion of individual farmers, they are still grown by many other farmers (Table 3). The reason why the answer 'No' was given, except for *Tomis* variety in *Hirna wereda*, was due to the fact that the varieties indicated lost by certain proportion of individual farmers, were still grown by many farmers at FA and *wereda* level. In addition, the focused group discussion held in various sites with farmers' manifested that that there was no as such significant variation with the types of sorghum varieties they grew before 1960, 1970-84 and after 1985 except that they had to focus on some of the varieties and adjust the varietal portfolios according to the prevalent growing environments.

Table 3 *Varieties lost and their reasons after 1984 (for the period of 1984-2000) at individual (across the region), FA and wereda level.*

Varieties	Reason for loss after 1984 at individual farmers level		Overall (%) (N=250)	FA* level	*Wereda*** level
Fendihsa	• Late maturity • Lodging • Pest and disease • Reduction in land size	• Drought susceptibility • Expansion of maize • Decrease in soil fertility • Expansion of *Khat*	18.4	No	No
Muyra	• Pest attack • Lodging problem • Late maturity • Drought	• Other better FVs came • Very much consumed as *Eshet* (green), thus lost (no enough seed) • Maize expansion • Not easily threshed	20.4	No	No
Daslee	• Decrease in yield performance • Early maturity and bird damage • Reduced land size	• Drought and pest • Stem breakage at the node	2.8	No	No
Gebabe	• Late maturity • Many nodal tillers	• Drought susceptible • Maize expansion	6.4	No	No
Bullo	• Panicle attacked by pests • Maize expansion through extension	• Pest susceptible • Drought susceptible	6.0	No	No
Wegere	• Pest and disease susceptible • Weevil attacks when hanged over the roof	• Maize extension package expansion • Weevil susceptible	8.4	No	No

Table 3 Continued

Abdelota	• Other better sorghum FVs came • Pest susceptible	• It is sweet and is eaten by the farmers for its sweet stalk before it matures and thus reduced harvest and less seed	4.4	No	No
Worabi	• Drought • Decline in yield performance	• Other better sorghum FVs came	2.4	No	No
Tomis	• Pest • Yield reduction	• Less storability	3.2	No	Yes-only in *Hirna Wereda*

Wereda** (an administrative structure within the regional state comprising Farmers Association); Farmers Association* (FA) is lowest administrative structure delimited based on geographical settlement pattern and locations and it is the main power centre to run various activities at grass root level.

2. GE by temporal method (time method): GE estimation by comparative quantitative method for collection of 1960 and 2000.

What has been described earlier is the semi-structured survey method for assessment of GE at individual farmers' level. The other method to assess GE is comparative quantitative method which is the comparison of amount of collections of two milestone dates. Estimation of Genetic integrity and erosion was calculated both by number as suggested by Hammer et al. (1996). Quantifying the same using the names of varieties is the method suggested for the first time in this study. This was possible as the 1960 collections passport data has included local varietal names.

GI (Genetic Integrity) = ratio of the number of collected accessions per crop per site where landraces were presented in 1960 and 2000, C_{2000}/C_{1960}x 100. Accordingly, GI by number and name were 167% and 238% (Table 4 and 5) respectively.

GE was calculated as GE=100%-GI. GE by number and name were –67% and –138% respectively. Hence, there was no loss in both of the cases and these agreed with the findings of Hernanadez (1993) who disproved GE of maize in Mexico in the centre of diversity. However, when we use the new way of doing GI and GE, i.e., by name basis, twelve varieties which used to be grown in the 1960 were not grown now even if the total number of varietal names in 2000 was still greater than that of 1960. On the contrary, there were many new varieties added in 2000 as compared to that of 1960.

Table 4 *Genetic integrity and erosion based on the number of FVs*

Parameter	Amount
Total number collected in 1960	379
Total number collected in 2000	635
Genetic integrity	167
Genetic erosion	-67%

Table 5 *Genetic integrity and erosion based on the name of the FVs*

Parameter	Amount
Total names*collected in 1960	36
Total names** collected in 2000	86
Genetic integrity	238
Genetic erosion	-138%

*8 names of the 1960 collections were not clear by name but are added in the total count.

**More than 86 names are identified but only samples of 86 were present.

Why insignificant GE as quantified by temporal methods?

1. The farmer-to-farmer seed network in the region has enhanced over the years the movement of varieties that was not accessed before, and it might result in the surfacing out of some of the diversities that were not captured in the time of classical collections in the 1960s.
2. Farmers as individuals might have reduced the population in the varietal portfolios. However, at the community, *wereda* and regional level the net diversity is positive.
3. Farmers as described in the various part of the text are knowledgeable on the importance, management and control of on farm genetic resources hence a variety has never been found to be 'useless', though it might have reduced importance.
4. The process of acquiring a new variety is easy while the reverse process is not the same. There is no as such simple rejection of a variety.

In view of the above, there is not any significant GE. This is both by number and names of folk varieties and species. One thing to be noted here is that whatever is the discrepancy in collection, almost all of the collection in number and name is maintained on farm by the farmers for the last four decades or so. These varieties are still under production though there can be some changes in the varietal performances over the years. At least the maintenance of these varieties on production indicates the importance farmers attach to their FVs.

In conclusion, maintenance of the varieties for 40 years is a reality but GE is rhetoric.

3. GE by spatial method (area method)

a. Comparison of sorghum production area of 1974 and 2000: Individual farmers level

Sorghum is one of the oldest crops grown in Ethiopia for hundreds of years (Mekbib, 2007d). As time goes, there have been changes in the agricultural systems, for the reason of climate, biotic and abiotic stresses, socio-economic demands and varietal performance. Accordingly, individual farmers adjusted allocation of the farm size depending on the prevalent circumstances. This was shown by on farm monitoring of 250 farmers who have been growing sorghum for the last three decades (Fig 2). The net sorghum area has reduced for the period of 26 years, between 1974 and 2000. The mean area for sorghum in the 1974 and 2000 were 9.72 *timmad* and 6.47 *timmad* respectively (1ha=8*timmad* or 1 *timmad*=0.125ha). Hence, there was 30% reduction of sorghum area. A part of the land that used to be for sorghum was used for various crops, namely, potato, horticultural crops, legumes, wheat, barley, coffee, and *Khat*.

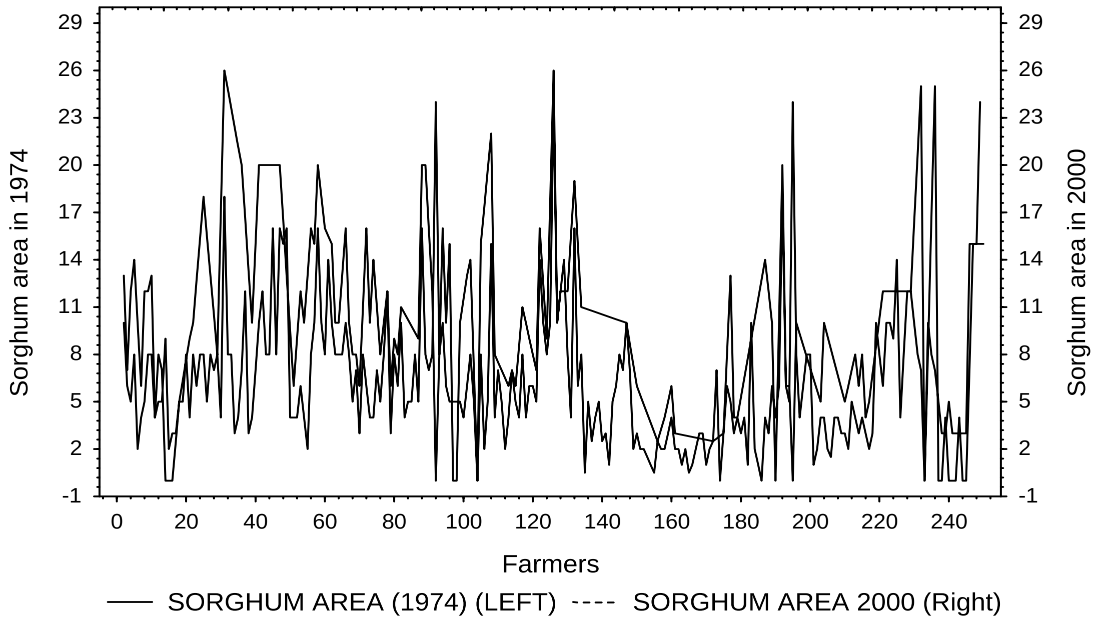

Figure 2 *Comparison of farmer allocation of area for sorghum for the year 1974 and 2000.*

b. Impact of other food crops on GE of sorghum

Both sorghum and maize (*Zea mays* L.) are C_4 plants which compete for similar ecological niches. Commonly throughout the world sorghum is grown in the dry land areas. Despite this global scenario, in Ethiopia, sorghum ecological spectrum is far wider than the international ecological domain. In view of this, in Ethiopia , sorghum grows from humid and dry lowlands to cool and high rainfall areas.

It is believed that maize, common bean (*P. vulgaris* L.) and potato (*Solanum tuberosum* L.) were introduced to Ethiopia in the 16th century by the Portuguese. Historically, Emperor Menelik-II introduced maize to the eastern Ethiopia at the beginning of 19th century. Hence, maize production in eastern Ethiopia was not more than 100 years old. Since its introduction, it has been expanding in both area and production over the years. Currently maize is the second important crop in Ethiopia in area coverage. Besides, by virtue of the physiological similarity of the two crops, maize has been competing, as of its introduction, for the areas that were growing sorghum. If we see the trend in area for the whole country (Fig 3), maize area has increased by 21.21% while sorghum area declined by -2.23%. Maize has taken most of the area that used to be for that of sorghum and for other indigenous crops.

In the perspectives of eastern Ethiopia, twelve *weredas* were the major maize production areas (Fig 4). As indicated in Fig (5), in these *weredas* maize has taken the place of sorghum production over the years. A continuous expansion of maize in these areas is due to the longer period of sorghum growing, the bird problem, less cold tolerance of some sorghum varieties vis-à-vis maize and comparative higher yield of maize. On one hand, maize is replacing sorghum here in Ethiopia; and, on the other hand, sorghum is replacing maize in Mexico, a reverse scenario. The rise of sorghum in Mexico has been spectacular that it has been called ‘ *the country's second Green Revolution'* as a result of this Mexico has become the sixth largest sorghum producing country in the world. The drought resistance of sorghum compared with maize and wheat has been the single most important reason for sorghum expansion in Mexico (NAS 1996).

Pertaining to other cereals, i.e., small cereals such as *tef* (*Eragrostis tef* (Zucc.) Trotter) and bread wheat (*Triticum aestivum* L.), though not at alarming rate, are partly taking over the area of sorghum. *Tef* and wheat were mono-cropped except in some areas where they were intercropped and under sown with sorghum. For example in Eastern Hararghe: *Tef* was expanding in *Gursum* and *Bedeno*: and Wheat in *Kersa, Gorogutu, Melkabello, Bedeno*, and *Gerawa weredas*. The expansion of small cereals is due to higher demand in the market and shorter growing duration (double cropping possible); *Striga* and bird problem on sorghum. Farmers in *Hirna* area increasingly shifting from sorghum into *tef* and other small cereals for the reason of drought, long maturity and market reasons. Compared with *Khat*, food legumes and small cereals were not threatening sorghum as such and were at the right platform of crop diversification and they could also be grown as bonus crops with sorghum (Mekbib 1997; Mekbib 2006b).

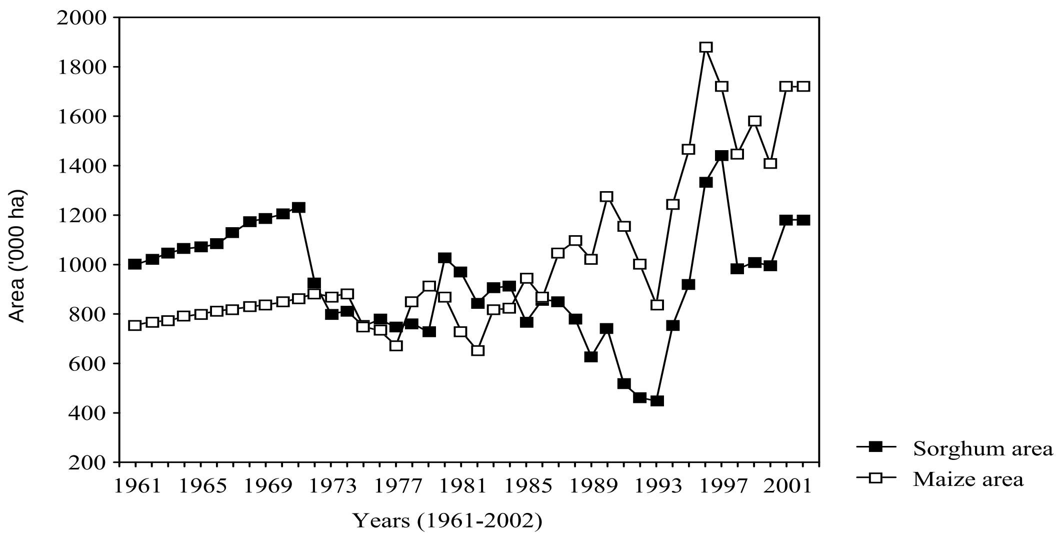

Figure 3. *Long term trend of sorghum and maize production area in Ethiopia. NB: the area allocated for improved varieties of sorghum was only 6.312 ha out of 1,253,620 ha which was less than 1% (Mekbib, 2007a,b; CSA, 2005).*

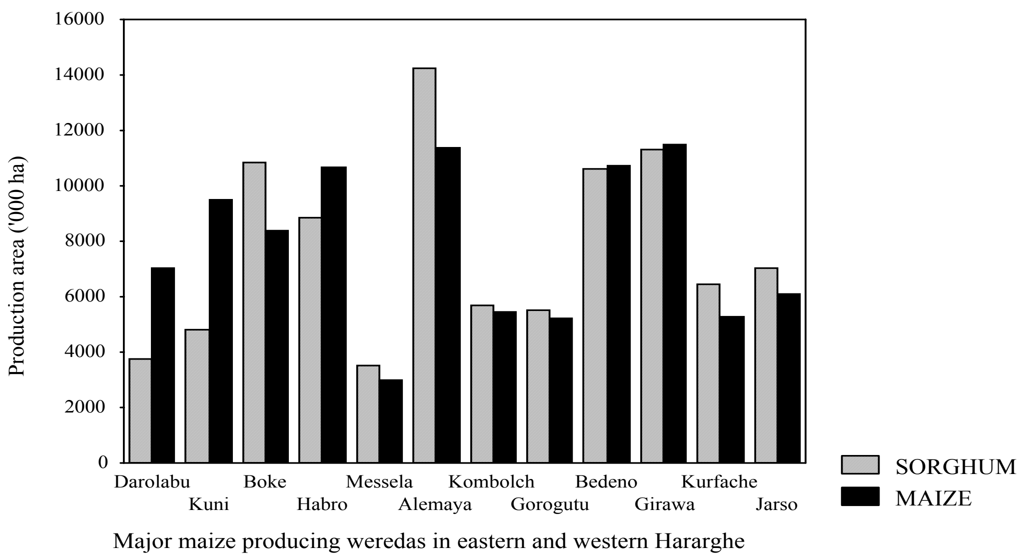

Figure 4 *Area of maize and sorghum production in eastern and western Hararghe weredas identified for sorghum production threatened by maize. Data source: Bureau of Agriculture for western and eastern Hararghe.*

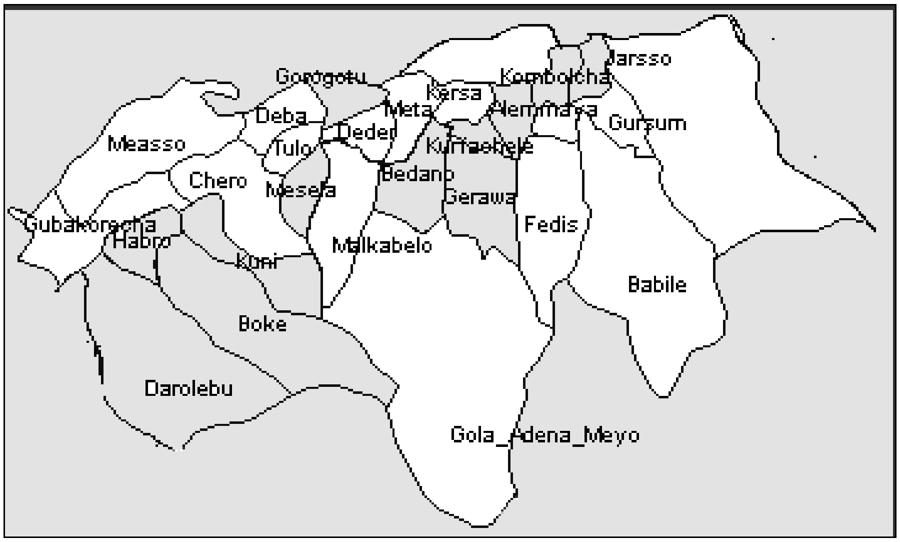

Figure 5 *Shaded weredas indicate sorghum production threatened by maize. In particular the cold tolerant sorghums are threatened by maize in Gerawa, Kurfachelle, Bedeno, Gorogutu, Messela, Alemaya, Kombolcha and Jarso. Bedeno, Girawa, Jarso, Melkabello, Messela, and Deder weredas are where high altitude sorghum production areas have been partly replaced by maize.*

4. Genetic erosion as affected by modern sorghum varieties: no infra-specific competition but complementation exists between FVs and IVs in eastern Ethiopia.

In eastern Ethiopia, IVs of sorghum are important only in the lowlands. The number of farmers who have adopted IVs in the intermediate and highlands is almost nil. Hence, the data below referred to the lowland farmers. Of 250 farmers interviewed with semi-structured interview (SSI) questionnaire and 120 farmers in the on farm monitoring; only 12% of farmers have grown improved varieties (Mekbib, 2006b). Adoption of IVs is inversely proportional to the amount of diversity. This is witnessed in eastern Ethiopia in the lowlands, which had comparatively lower diversity vis-à-vis highland and intermediate altitude areas. Gebrekidan (1981) has indicated that Ethiopia has a narrow genetic base for lowland sorghum. It is one of the many reasons for adoption of IVs by farmers in the lowlands than those in the highlands. Farmers' justification for adopting both FVs and IVs are indicated (Mekbib 2006b). As shown previously, none of the farmers who have adopted IVs, both in SSI and on farm monitoring, have completely replaced the FVs. The IVs are increasingly becoming the components of the varietal mixture. Replacement of FVs by IVs could not happen as the rationale for adoption of IVs and FVs were different. Hence, in the context of eastern Ethiopia IVs of sorghum are not the reasons for GE of FVs. On the contrary, they have made some contributions for the genetic enrichment of the existing on farm genetic diversity.

In general, for yield, seed quality, taste, biomass, feed, fuel wood and construction value attributes are ranked higher for FVs while for early maturity and drought resistance IVs were ranked higher (Mekbib 2006b). There were also some FVs that appear to be associated with better drought resistance attributes.

On the contrary, improved crop and pest management measures don't push to the cultivation of IVs in the region. Actually, the sorghum farming in eastern Ethiopia is a natural crop farming in which farm labour is the input in most of the times. The current sorghum extension package program in the region used FVs and other improved farm management practices. The FVs have been ratified by the regional bureau of agriculture as better ones vis-à-vis the available IVs. The most amazing scenario of adoption is that there is no simple replacement of FVs by IVs. The commonest process is addition not substitution.

The reasons for maintaining their varieties while adopting improved ones were:

1. Farmers knew that the IVs did not meet all the requirements (Mekbib 2006b)
2. Poor seed quality and lower multipurpose value of IVs forced farmers to retain their own varieties (Mekbib 2006b; Mekbib 2007a,b)
3. The IVs are normally used as 'emergence variety' in the course of failure of the first (normal) planting. Hence to capture the crop season the IVs are planted , which were early and drought resistant (Mekbib 2006b).
4. Analysis of yields of IVs and FVs cultivated in this region showed that FVs were actually quite competitive and high yielder than IVs (Mekbib 2006b).
5. The relative pest and disease resistance capacity of FVs vis-à-vis IVs was also one of the factors for the maintenance of FVs while adopting IVs (Mekbib 2006b; Mekbib, 2007b)

In sum, the prediction in the late seventies that complete erosion of FVs by IVs by the end of the eighties (Brush 1995); and Frankel's (1970) and Harlan (1975) principle of GE that competition between IVs and FVs, favours the former and results in the replacement of the latter is not valid in the context of sorghum in eastern Ethiopia. In view of these facts, there were not any infra-specific competition between FVs and IVs rather there is infra-specific complementation between IVs and FVs of sorghum.

The Modalities for GE

The concept of GE appears to be simple and deceptive. The process of conservation and replacement is normally an outcome of the interactions between socio-economic and biophysical environmental factors and the action of both natural and conscious selection (Brush 2000). To explain the process shaping GE scenario on farm, three modalities have been suggested. Actually Brush (2000) indicated that GE of crop populations is an ecological concept that draws implicitly on models of ecology and population biology, but this concept has not been theoretically elaborated or empirically tested for crops. Hence, attempts were made here to use the ecological models and farmer management model, and their interaction to explain the GE scenario in eastern Ethiopia. The models indicated below are the function of both human and ecological concept but it is not only ecological concept *per se*. The Meta-population and Niche model suggested by Brush (1999) are not comprehensive to explain the whole scenario of the GE on farm.

Hence three new models are suggested below to expound the scenario:

1. Bioecogeographic induced genetic erosion model: this model embodies the natural factors, namely, biological, ecological and geographical factors of GE. Drought, bird, late maturity, pest and disease, and *striga* are some of the bioecogeographic factors indicated by the farmers (Table 1 and 3) responsible for GE on sorghum in the region.

This model generally takes into account the natural ecological model-the niche model proposed by Brush (1999) refers much to that of interspecies interaction that is only a part of this model and it explains merely the crop introduction and enhancement aspect. Intra-specific competition is not indicated by the model though it was suggested to be scaled down for inter-varietal competition. Inter-varietal competition that lead to a balance or unbalance in the specific niches is niche theory for GE but this is not sufficed. The assumptions of the classical models are easily violated in farming systems in the centre of diversity, so that we should expect co-existence rather than the competitive exclusion to prevail. Hence, the niche model is incomplete to explain the GE scenario.

The other model-the meta-population model-is the island biogeography concept, which refers to reduction of area and fragmentation of populations, threaten species' survival and biological diversity (Brush 1999). This also explains only that of the land size as a factor for genetic erosion model. Both the niche and meta-population theory are the part of bioecogeographic enhanced GE model. In the Meta-population model, particular populations may not be so important as long as their alleles and agro-morphological characteristics are present in other linked populations. This is a good notion included in the model but it is not easy to verify.

In general, both the models did not include the human aspect and the interaction of human and natural aspect, and the models suggested here better explain the on farm GE scenario.

2. Farmer induced genetic erosion model: refers to the human factors (Table 1 and 3) in varietal selection, changing in the composition of varietal portfolio, change in food habits and preferences, change in the marketing value of varieties, change in production objectives (feed, food, fuelwood etc.,) and other socio-economic factors. On top of this, the change in household size dictated the farm enterprise, for example, livestock or crop or mixed which in turn affects the maintenance of genetic diversity on farm. Besides, the presence of various ethnic groups in the region such as *Oromo, Amhara, Somali, Harare,* and *Argoba* warranted the selection of certain varieties suiting to the specific ethnic needs. The range of variations on the type and number of varieties across individual farmers and communities is partly explained by the variation among socio-economic and cultural variations for GE. This is the human induced aspect of the GE model. Hence, GE is not exhaustively demand or supply driven. In some cases, it is the former, in others it is the latter, and in still others, it is both.

3. ***Farmer-cum-bioecogeographic induced genetic erosion model:*** This is the blend of human and natural factors. Factors such as reduced benefits from the varieties, introduction, and expansion of other crops (for example *Khat* and maize), reduction in number of farmers, destruction of habitat and farmlands includes both natural and human factors (Table 1 and 3). For example, reduced benefits, which might be due to low yield, can arise from pest or disease infestation or poor selection of varieties. Similarly, the expansion of *Khat* in the region is due to adaptation of the crop and farmers' interest for increased income from *Khat*. Similarly, the reasons for maize expansion were its biological competitiveness and maize selection by the farmers for multipurpose benefits. Hence, expansion and introduction of other crops can be due to natural factors or human factors. The relative contribution of both factors for GE might vary based on the actual scenario of socio-economic and crop growing environments.

Summary and conclusion

GE is one of the most fascinating issues in plant genetic resources management study, however, it is not easy to ratify. In this study, very first attempt has been made to use various comprehensive methods in order to assess on farm GE. The area (spatial) method partly indicated the possible presence of GE. However, the area method is also constrained by the lack of evidence for its direct association with GE. However, in the other methods there can be GE at individual farmer level, but at regional level the net genetic erosion was relatively nil.

In order to corroborate area method for GE, comparative evaluation of varieties conserved *ex situ* and *in situ* (on farm) needs to be made at molecular and isozyme level. The 1960 and

2000 collections contain many similar varieties from the same sites. Farmers have witnessed that there was a change of varietal performance but not significant loss of varieties over years. Hence, farmers' assertion has to be supported by empirical evidences

The region is endowed with various valuable varieties for increased popularisation and utilization thereby to reduce GE. This needs to be considered by follow up projects in order to support the farmers in the region. Biodiversity is not an end in itself, it is the way for food security, environment and health and enhancement is one way to empower farmers' achievements, increased utilization of on farm genetic diversity and reduce GE.

The region is partly characterised by seed insecurity (Mekbib 2007b). This can be ameliorated by establishing community seed banks at FA level which can be used for both alleviation of seed insecurity, minimization of GE and improving on farm genetic resource management and utilization.

Very limited studies in the country were present on the study of the wild progenitors of sorghum. Most of the reports are limited to indicate the presence of the progenitors only. Hence, comparative introgression study of the wild, cultivated and their crosses is imperative as a part of the genetic resource management of the *Genus*.

The complementary role played by both farmer and formal sorghum genetic resource conservation for sustainable utilization is tremendous. In order to benefit from their complementarities, integrated genetic resource management, and utilization for reducing GE has to be implemented.

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Organic Farming Technologies and Agricultural Productivity:

The case of Semi-Arid Ethiopia

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Abstract

Organic farming practices, in as far as they rely on local or farm renewable resources, present desirable options for enhancing agricultural productivity for resource-constrained farmers in developing countries. In this paper we use plot-level data from semi-arid area of Ethiopia to investigate the impact of organic farming practices on crop productivity, with a particular focus on conservation tillage. Specifically we seek to investigate whether conservation tillage results in more or less productivity gains than chemical fertilizer. Our results reveal a clear superiority of organic farming practices over chemical fertilizers in enhancing crop productivity. Thus our results underscore the importance of encouraging resource-constrained farmers in developing countries to adopt organic farming practices, especially since they enable farmers to reduce production costs, provide environmental benefits, and as our results confirm, enhance crop productivity.

Keywords: Conservation tillage, Chemical fertilizer, Crop productivity, Matched observations, Ethiopia

JEL Classification: C21; Q12; Q15; Q16; Q24

Introduction

Agriculture accounts for about 30% of Africa's gross domestic product (GDP) and 75% of total employment (World Bank, 2007). However, nearly half of the area of Africa, which is home to more than 14% of the low-income countries in the world, is either arid or semi-arid, and over 90 percent of agricultural production is rain-fed (Fisher *et al*., 2004; WDI, 2005). This implies that erratic rainfall patterns present serious challenges to food production in these areas (Fisher *et al*., 2004), and this will be further worsened by climate change which is expected to increase rainfall variability in many African countries that are already at least partly semi-arid and arid.

These challenges are also of concern in Ethiopia where the agriculture sector, though it remains the most important sector for poverty reduction, has been undermined by lack of adequate nutrient supply, the depletion of soil organic matter and soil erosion (Grepperud, 1996). In an effort to overcome these challenges, the government and non-governmental organizations have consistently promoted inorganic fertilizer as a yield augmenting technology. Despite this, inorganic fertilizer adoption rates remain very low (Byerlee et al., 2007) and in some cases there has been evidence suggesting dis-adoption of fertilizer

(EEA/EEPRI, 2006), possibly due to escalating prices and production and consumption risks (Kassie et al., 2008b; Dercon and Christiaensen, 2007).

The key to tackling these challenges lie not only in the adoption of farming technologies that enhance water retention capacities of soils in these areas, but also in the adoption of farming technologies that rely mainly on local or farm renewable resources, thereby reducing production costs and risks. Sustainable agricultural production practices are a good example of such technologies. Sustainable agricultural production systems are agricultural systems that; conserve resources such as land and water, are environmentally non-degrading, technically appropriate, and economically and socially acceptable (FAO, 2008). In practice, sustainable agriculture uses less external off-farm inputs (e.g. purchased fertilizers) and more of locally available natural resources (Lee, 2005). Conservation agriculture is an example of a sustainable agricultural practice that seeks to achieve sustainable agriculture through minimal soil disturbance (i.e. zero- or minimum-tillage farming), permanent soil cover and crop rotations. The potential benefits from conservation or reduced tillage lie in not only conserving but also in enhancing the natural resources (e.g. increasing soil organic matter) without sacrificing yield levels; making it possible for fields to act as a sink for carbon-dioxide; increasing the soils' water retention capacities and reducing soil erosion; and reducing the production costs through reducing time and labor requirements as well as costs associated with mechanized farming e.g. costs of fossil fuels (FAO, 2008). It is due to its ability to address such a broad set of farming constraints that makes conservation tillage a widely adopted component of sustainable farming (Lee, 2005).

Moreover, the water retention characteristics of conservation tillage (Twarog, 2006) make it especially appealing in water-deficient farming areas such as our study area. In addition to reducing natural risks, conservation tillage enables poor farmers to avoid the financial risk of taking chemical fertilizer on credit, and also overcomes the prevailing problem of late delivery of chemical fertilizer. Consequently since 1998 Ethiopia included conservation tillage as part of extension packages to reverse extensive land degradation (Sasakawa Africa Association, 2008).

While encouraging adoption of reduced tillage is important, an equally if not even more important aspect is whether or not it enhances productivity. How does it compare to external inputs such as chemical fertilizers, in terms of its impact on crop productivity? These are important questions that farmers presumably consider when deciding to adopt a given technology. Whether reduced tillage increases yields might be influenced by agro-ecology. For example research has shown that in Ethiopia, the economic returns to soil and water conservation investments as well as their impacts on productivity are greater in lower rainfall areas than in more humid areas (Sutcliffe, 1993; Benin, 2006; Kassie and Holden, 2006; Kassie et al., 2008a).

In this paper we examine the productivity gains associated with adoption of sustainable agricultural production practices, with a particular focus on the adoption of reduced tillage (hereafter conservation tillage). We go a step further to investigate how these productivity gains compare with the productivity gains associated with adoption of chemical fertilizer. To achieve this and at the same time ensure robustness we pursue an estimation strategy that employs both semi-parametric and parametric econometric methods, permitting us to (1) explore how household and plot characteristics influence decisions to adopt either conservation tillage or chemical fertiliser, (2) assess and compare the impact of these technologies on crop productivity, and (3) explore determinants of crop production in general. The semi-parametric method we use is the Propensity Score Matching Method (PSM) while the parametric methods are pooled OLS and random effects estimators which allow us to treat each plot observation within a given household as a variable unit thereby controlling for unobserved effects. The parametric analysis is based on observations that found matches in the PSM; this is to ensure a comparable sample. Our results reveal a clear superiority of organic farming practices over chemical fertilizers in enhancing crop productivity. Our results also demonstrate the significance of both plot and household characteristics on crop productivity and technology adoption decisions.

The rest of the paper is organized as follows. The next section presents the econometric framework and estimation strategy we pursue followed by a description of the dataset in section three. The empirical results are presented in section four. Finally, section five concludes the paper and draws some policy implications of the study.

Econometric framework and estimation strategy

We use semi-parametric and parametric techniques to overcome the econometric problems mentioned below and ensure robustness. The semi-parametric method we use is the propensity score matching while the parametric analysis uses a switching regression framework. The parametric analysis is based on matched observations from the propensity score matching (PSM) process.

Semi-parametric analysis

The propensity score matching method (PSM) is used here to address the 'selection on observables' problem, that is, it might be the case that adoption of conservation tillage and/or chemical fertilizer is non-random. This is especially the case here since we have observational rather than experimental data. Farmers are not randomly assigned to the two groups (adopters and non-adopters) but make the adoption choices themselves, or they might be systematically selected by development agencies based on their propensity to participate in the adoption of technologies. Furthermore, farmers or development agencies are likely to select plots non-randomly based on their quality attributes (often unobservable). If this is the case, there is a risk that the non-random selection process may lead to differences between adopters and non-adopters that can be mistaken for effects of adoption. Failure to account for this potential selection bias could lead to inconsistent estimates of the impact of technology adoption.

The rationale behind the PSM is that one group of people participates in a programme or treatment (adopting a given technology in this case) while another group does not, and the objective is to assess the effectiveness of the treatment by comparing the average outcomes. A matching process based on observed characteristics is used to compare adopters and non-adopters. Comparisons are therefore between plots with and without technology adoption but with characteristics that are similar and relevant to the technology choice. This reduces the potential for bias from comparing non-comparable observations, although there still may be selection bias caused by differences in unobservables. The PSM method is a semi-parametric method used to estimate the average treatment effect of a binary treatment on a continuous scalar outcome (Rosenbaum and Rubin, 1983). We take adoption as the treatment variable, while crop productivity is the outcome of interest. Adopters constitute the treatment group, while non-adopters form the control group.

In order to estimate the average treatment effect of technology adoption on crop productivity among adopters, we would ideally want to estimate the following:

$$ATT = E[y_{hp1} \mid d_{hp} = 1] - E[y_{hp0} \mid d_{hp} = 1] \quad , \qquad (1)$$

where ATT is the average effect of the treatment on the treated households or plots, $d_{hp} = 1$ when the technology has been adopted by household h on plot p and $d_{hp} = 0$ when no adoption has taken place. $y_{hp0} | d_{hp} = 1$ is the level of crop productivity that would have been observed had the plot *not* been subjected to the technology under analysis, while $y_{hp1} | d_{hp} = 1$ is the level of productivity actually observed among adopters. The challenge is that $y_{hp0} | d_{hp} = 1$ cannot be observed i.e. we do not observe the outcome of plots with conservation tillage or chemical fertilizer had they not had these technologies. This creates a need for the creation of a counterfactual of what can be observed by matching treatment and control groups.

Matching on every covariate is difficult to implement when the set of covariates is large. To overcome the curse of dimensionality, propensity scores ($p(x_{hp})$) – the conditional probabilities that plot p receives conservation tillage or chemical fertilizer treatment conditional on x_{hp} – are used to reduce this dimensionality problem. Here x_{hp} is the set of household and plot covariates that influence the decision to adopt a particular technology. The model matches treated units to control units with similar values of x_{hp}. The equation to be estimated is thus:

$$ATT = E[y_{hp1} | d_{hp} = 1, p(x_{hp})] - E[y_{hp0} | d_{hp} = 0, p(x_{hp})] \quad . \tag{2}$$

The PSM relies on the key assumption that conditional on x_{hp}, the outcomes must be independent of the targeting dummy d_{hp} (the conditional independence assumption, or CIA). Rosenbaum and Rubin (1983) show that if matching on covariates is valid, so is matching on the propensity score. This allows matching on a single index rather than on the multidimensional x_{hp} vector.

We perform the matching process in two-steps. In the first step, we use a probit model to estimate the propensity scores and in the second stage, we use nearest neighbor matching based on propensity scores estimates to calculate the ATT. The nearest-neighbour matching matches each treated unit to the n control units that have the closest propensity scores. Compared to other weighted matching methods such as kernel matching, the nearest neighbor matching method allows us to identify the specific matched observations that entered the calculation of the ATT which we then use for parametric regressions.

Parametric analysis

Besides non-randomness of selection into technology adoption, the other econometric issue is that using a pooled sample of adopters and non-adopters (dummy regression model where a binary indicator is used to assess the effect of conservation tillage or chemical fertilizer on productivity) may be inappropriate. This is because pooled model estimation assumes that the set of covariates has the same impact on adopters as non-adopters (i.e. common slope coefficients for both groups). This implies that conservation tillage and chemical fertilizer adoption have only an intercept shift effect, which is always the same irrespective of the values taken by other covariates that determine yield. However, for our sample a Chow test of equality of coefficients for adopters and non-adopters of conservation tillage and chemical fertilizer rejected equality of the non-intercept coefficients at 1%

significance level.[15] This supports the idea of using a regression approach that differentiates coefficients for adopters and non-adopters.

To deal with this problem we employ a switching regression framework which is such that the parametric regression equation to be estimated using multiple plots per household is:

$$\begin{cases} y_{hp1} = x_{hp}\beta_1 + u_h + e_{hp1} \text{ if } d_{\text{hp}} = 1 \\ y_{hp0} = x_{hp}\beta_0 + u_h + e_{hp0} \text{ if } d_{\text{hp}} = 0 \end{cases}, \tag{3}$$

where y_{hp} is value of crop production per hectare (hereafter gross crop revenue)[16]obtained by household h on plot p, depending on its technology adoption status (d_{hp}); u_h captures unobserved household characteristics that affect crop production, such as farm management ability, average land fertility; e_{hp} is a random variable that summarizes the effects of plot-specific unobserved components on productivity, such as unobserved variation in plot quality and plot-specific production shocks (e.g. microclimate such as variation in rainfall, frost, floods, weeds, pests and diseases infestations); x_{hp} includes both plot-specific and household-specific observed explanatory variables and β is a vector of parameters to be estimated.

To obtain consistent estimates of the effects of conservation tillage and chemical fertilizer we need to control for unobserved heterogeneity (u_h) that may be correlated with observed explanatory variables. One way to address this issue is to exploit the panel nature of our data (repeated cross sectional plot observations per household), and use household specific fixed effects. The main shortcoming of fixed effects in our case is that we have many households with only a single plot. At least two observations per household are needed to apply fixed effects. These households therefore do not play a role in a fixed effects analysis. Random effects and pooled OLS models are consistent only under the assumption that unobserved heterogeneity is uncorrelated with the explanatory variables. As an alternative, we use the modified random effects model framework proposed by Mundlak (1978), whereby we include on the right hand-side of each equation the mean value of plot-varying explanatory variables[17]. Mundlak's approach relies on the assumption that unobserved effects are linearly correlated with explanatory variables such that:

$$u_h = \bar{x}\gamma + \eta_h,\ \eta_h \sim \text{iid}(0, \sigma_\eta^2), \tag{4}$$

where $\bar{x}$ is the mean of plot-varying explanatory variables within each household (cluster mean), γ is the corresponding vector coefficients and η is a random error unrelated to the $\bar{x}'s$. We include average plot characteristics, such as average plot fertility, soil depth, slope and conventional inputs, as we believe they have an impact on production and technology adoption decisions.

The selection process in the parametric switching regression model can be addressed using the inverse Mills ratio derived from the probit criterion equation, which addresses the problem of selection on unobservables. However, the criterion models turned out to be

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15 χ^2(35) = 100.81 (p-level = 0.000), χ^2 (35) = 161.20 (p = 0.000), and χ^2 (35) = 64.49 (p = 0.000) for models comparing only reduced tillage versus chemical fertilizer adoption plots, reduced tillage versus all other plots, and chemical fertilizer versus all other plots, respectively. Although not reported, similar results were found without the Mundlak approach.

16 To compute the value of production, we used average crop prices based upon the community and household level surveys.

17 We did not use Mundlak's approach for the model that compares only reduced tillage versus chemical fertilizer impact on crop production value per hectare because the control group (plots with chemical fertilizer) has insufficient observations.

insignificant (i.e. the overall model significance test statistics (Wald χ^2) is insignificant). This is perhaps not surprising since we use matched samples obtained from nearest neighbor propensity score matching. As a result we did not use the inverse Mills ratio derived from such insignificant model instead we assumed that addressing selection on observables using propensity score matching, we may also reduce problems with selection on unobservables. Kassie et al. (2008a), in estimating the impact stone bunds on productivity, found that the problem of selection on unobservables can be addressed by addressing selection on observables using propensity score matching. However, if selection and endogeneity bias are due to plot invariant unobserved factors such as household heterogeneity, the selection process and endogeneity bias can be addressed using the panel nature of our data and Mundlak's approach (Wooldridge, 2002). In addition, our rich plot and household characteristics dataset (see Table 1A in the appendix) can assist reducing both household and plot unobserved effects. In terms of plot characteristics, the dataset includes plot slope, position on slope, plot size, soil fertility, soil depth, soil color, soil textures, plot distance from homestead, and input use by plot. Including observed plot characteristics and inputs could also address selection due to idiosyncratic errors, such as plot heterogeneity, —as is likely—observable plot characteristics were positively correlated with unobservable ones (Fafchamps 1993; Levinsohn and Petrin 2003; Assunção and Braido 2004). Including input use also help control for plot heterogeneity because farmers typically responded to shocks (positive or negative) by changing input use (Ibid).

Controlling for the above econometric problems and incorporating equation (4) into (3), the expected yield difference between adoption and non-adoption of conservation tillage or chemical fertilizer becomes:

$$E(y_{hp1} \mid x_{hp}, u_h, d_{hp} = 1) - E(y_{hp0} \mid x_{hp}, u_h, d_{hp} = 1) = x_{hp}(\beta_1 - \beta_0) + \overline{x}(\gamma_1 - \gamma_0). \quad (5)$$

The second term on the left-hand side of (5) is the expected value of y if a plot had not received conservation tillage or chemical fertilizer treatment. This is the counterfactual outcome, which will be approximated by non-conservation tillage and non-fertilized plot observations after taking into account the selection process. This is our parameter of interest in the parametric regression analysis. Equation 5 will also be estimated without including the second term of the right hand side equation (i.e. without the Mundlak approach) for comparison purposes and to generate a greater degree of confidence in the robustness of the econometric results. It is important to note that the parametric analysis is based on observations that fall within common support from the propensity score matching process i.e. matched observations.

The data and descriptive statistics

The data used in this study are from a farm survey conducted in 1999 and 2000 in the Tigray region of Ethiopia. The dataset includes 500 farm households, 100 villages, 50 *kebeles* and 1067 plots located above 1500 meters[18]. To compare the productivity impact of conservation tillage with that of chemical fertilizer we dropped plot observations with neither technology (586 observations). Similarly, plots that received a combination of fertilizer and conservation tillage inputs are also dropped from the analysis (27 observations) in order to investigate their pure impact on productivity.

[18] For more details on study areas, sampling techniques and criterions used to select sample areas please see Pender and Gebremedhin (2006).

Table 1A in appendix 1 presents the descriptive statistics for the sub-samples of plots after matching. The sub-samples in the analysis include: plots that have adopted conservation tillage (column 1 of Table 1A) and the rest of plot observations (non-conservation tillage adopters) (column 3 of Table 1A); plots that have adopted chemical fertilizer (column 4 of Table 1A) and the rest of plot observations (non-chemical fertilizer adopters) (column 5 of Table 1A); and only those have adopted only conservation tillage (column 1 of Table 1A) and chemical fertilized (column 2 of Table 1A).

About 13% and 34% of the sample plots had conservation tillage and chemical fertilizer, respectively. Fertilizer use averages about 40 kilograms per hectare. The mean plot altitude, which is associated closely with temperature and rainfall, ranged 2146-2207 meters above sea level. Similarly, the mean population density ranged 124 to 153 persons per square kilometer.

In addition to these variables, plot characteristics, household endowments and indicators of access to infrastructure are included in the empirical model. The choice of these variables is guided by economic theory and previous empirical research. Given missing and/or imperfect markets in Ethiopia, households' initial resource endowments and characteristics are expected to play a role in investment and production decisions and thus included in the analysis (Holden *et al*., 2001; Pender and Kerr, 1998).

The empirical results

In this section we present and discuss the empirical results, starting with results from semi-parametric analysis followed by results from parametric estimations.

Results from semi-parametric analysis

As the foregoing discussion on the econometric strategy shows, the use of the PSM method allows us an opportunity to explore how the plot and households' characteristics influence the households' decisions to adopt either conservation tillage or chemical fertiliser as well as how the adoption subsequently impacts crop productivity. In addition we use the PSM to compare conservation tillage with chemical fertiliser adoption decisions; what determines the decision to adopt conservation tillage instead of chemical fertiliser and how do the productivity impacts of the two technologies compare?

Table 1 below presents probit results of the decisions to adopt (1) conservation tillage (column 1), (2) chemical fertiliser (column 2) as well as (3) conservation tillage instead of chemical fertilizers (column 3). At this stage our main interest is to analyse factors affecting adoption of sustainable farming practices (conservation tillage) over chemical fertlizers. Accordingly the ensuing discussion of the results focuses on factors that influence the household's decision to adopt conservation tillage instead of chemical fertilizers i.e. the discussion is based on results reported in column (3).

***Table 1** Conservation tillage and chemical fertilizer adoption decisions*

	(1)		(2)		(3)	
	Conservation tillage		Chemical fertilizer		Conservation tillage vs. Chemical fertilizer	
Variable	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Socioeconomic characteristics						
Gender	-0.31	0.19	0.06	0.16	-0.22	0.25
Age	0.04	0.21	0.12	0.15	-0.24	0.26
Family size	-0.11***	0.03	0.01	0.02	-0.14***	0.05
Education low	-0.09	0.24	0.40**	0.16	-0.39	0.29
Education high	-0.19	0.28	0.01	0.17	-0.33	0.34
Extension contact	0.29*	0.16	0.12	0.11	0.33*	0.20
Oxen	-0.25***	0.07	0.08	0.05	-0.40***	0.12
Livestock	0.02***	0.00	-0.00	0.00	0.03***	0.01
Farm size	0.35***	0.10	-0.10	0.08	0.51***	0.13
Population density	-0.00	0.00	0.00***	0.00	-0.002	0.001
Altitude	0.00	0.00	-0.00***	0.00	0.000	0.00
Market distance	0.03	0.03	-0.11***	0.02	0.11***	0.04
Plot characteristics						
Plot distance	0.20	0.16	-0.58***	0.16	0.65***	0.23
Rented	0.06	0.19	-0.45***	0.14	0.31	0.27
Soil and water conservation	-0.22	0.23	0.02	0.15	-0.05	0.27
Stone covered	0.27*	0.14	-0.08	0.11	0.32*	0.18
Deep soils	-0.07	0.17	-0.03	0.12	0.14	0.21
Moderately deep soils	0.16	0.17	0.04	0.12	0.23	0.21
Brown soils	0.60**	0.27	0.14	0.18	0.49	0.31
Gray soils	0.54**	0.27	-0.16	0.18	0.62**	0.31
Red soils	0.44*	0.26	0.13	0.17	0.42	0.29
Loam soils	0.10	0.24	0.15	0.17	-0.12	0.27
Clay soils	-0.23	0.25	0.27	0.17	-0.50*	0.28
Sandy soils	-0.58*	0.34	0.35*	0.20	-1.07**	0.44
Moderate erosion	0.03	0.14	0.06	0.10	-0.07	0.18
Severe erosion	0.01	0.25	-0.24	0.20	0.15	0.35
Moderate slope	-0.07	0.17	-0.00	0.13	-0.16	0.24
Steep slope	-0.33	0.26	0.04	0.20	-0.39	0.34
Middle slope	-0.45**	0.22	0.11	0.18	-0.19	0.29
Bottom slope	-0.34	0.22	0.22	0.18	-0.35	0.28
No slope	-0.23	0.21	0.38**	0.17	-0.31	0.28
Constant	-1.49	1.01	-0.38	0.76	-0.35	1.37
Pseudo R-squared	0.20		0.10		0.30	
Model chi-square	142.23***		133.54***		121.87***	
Log likelihood	-286.21		-590.09		-178.66	
Number of observations	1039		1039		453	

Note: * significant at 10%; ** significant at 5%; *** significant at 1%

The results suggest that both socioeconomic and plot characteristics are significant in conditioning the households' decisions to adopt any technology. In addition there is heterogeneity with regards to factors influencing the choice to adopt conservation tillage or chemical fertilizer.

It has been argued that one of the advantages of adopting conservation tillage is that it helps households save on labor or relaxes labor shortage (Lee, 2005). Our results support this contention; specifically we find that the probability of adopting conservation tillage instead of chemical fertilizers decreases with family size. Family size is a crude proxy of household's assured labor in this analysis. This underscores the importance of labor availability in technology adoption, consistent with findings by Caviglia and Kahn (2001) and Shiferaw and Holden (1998). The results could also be implying that compared to adoption of conservation tillage, adoption of chemical fertilizer is labor intensive as farmers might have to travel long distance to obtain this input.

Access to agricultural extension services, indicated by whether or not the household has contact with an extension worker, impacts the decision to practice conservation tillage over using chemical fertilizers positively. This is intuitive given that access to information on new technologies is crucial in creating awareness and attitudes towards technology adoption (Place and Dewees, 1999). Contact with extension services allows farmers to have access to information on new innovations and advisory inputs on establishment and management of technologies. In most cases, extension workers establish demonstration plots where farmers have the possibility of learning and experimenting with new farm technologies. Consequently, access to extension is thus often used as an indicator of access to information (Adesina et al., 2000; Honlonkou, 2004). These results might be indicating that the decision to include conservation tillage as part of extension packages has been successful in encouraging conservation tillage adoption.

The fact that we find evidence that livestock ownership and farm size increase the likelihood of adopting conservation tillage over chemical fertilizer suggests that poverty significantly limits technology adoption. Wealth intuitively affects adoption decisions since wealthier farmers have greater access to resources and may be better able to take risks. It must be acknowledged, however, that the wealth measures we use might be confounded with other factors related to adoption. For instance farm size, though measuring farmers' wealth, could also suggest for economies of scale in production using conservation tillage. All the same, these results suggest that policies that alleviate poverty among farmers will impact the adoption of sustainable agricultural practices positively. The negative impact of oxen ownership, on the other hand, on the decision to adopt conservation tillage over chemical fertilizer might be capturing the fact that in the local setting crop residues are used as feed for oxen and intuitively this disadvantages the adoption of conservation tillage, which has crop residues as its component. Alternatively this result implies that conservation tillage can relax household's oxen constraints.

The further away the household is from the input markets, the more likely they are to adopt conservation tillage over adopting chemical fertilizers. Distance from input markets increases the transaction costs associated with the use of external inputs such as inorganic fertilizers, and this intuitively stimulates the adoption of practices that rely on locally or farm-derived renewable farm resources. This applies to the significance of the distance from the homestead to the plot in negatively affecting the use of chemical fertilizers as compared to conservation tillage. The distance captures the transaction costs households incur in carrying purchased fertilizers from their residences to the plots as well as in carrying crop residues from their plots to residences to use them as livestock feed.

With regards to the impact of plot characteristics on adoption decisions; households are less likely to adopt conservation tillage over chemical fertilizers on clay and sandy soils while the likelihood of adoption is higher on gray soils as well as on plots that are covered, to a certain extent, in stone. These results imply that for sustainable agricultural practices to be successful they must address site-specific characteristics as these condition the need for adoption as well as the type of the technology adopted.

The estimated propensity scores are used to generate samples of matched observations using the nearest neighbour matching method. We start by matching plots that have adopted conservation tillage to control plots, which is basically the rest of the observations (hereafter

Model 1). The results are then used to calculate the impact of the conservation tillage on crop productivity. Second, we match plots that have been fertilised to control plots, which is basically the rest of the observations and use the results to calculate the impact of the chemical fertilizers on crop productivity (hereafter Model 2). Lastly we match plots that have adopted conservation tillage to plots that have been fertilised; here fertilized plots constitute the control group (hereafter Model 3). This allows us to compare the productivity impacts of the two technologies. The PSM results are presented in Table 2 below. ATT is the average treatment effect on the treated. The results are reported for gross crop revenue per hectare.

Table 2 *Productivity impacts estimated by PSM*

	Model 1	Model 2	Model 3
ATT	744.55***	448.74***	768.24**
Std. Error	364.32	169.12	392.27
Number of observations			
Treated	113	340	113
Control	80	211	57

Note: ** significant at 5%; *** significant at 1%.

The results indicate that, based on both household and plot characteristics, both conservation tillage and chemical fertilizers enhance productivity. However, interestingly, comparing the impact of conservation tillage with that of chemical fertilizer suggests that conservation tillage leads to significantly higher productivity gains than chemical fertilizers. The results are comparable to when net crop revenue are used i.e. when the monetary cost of fertilizer has been deducted, although the impact of chemical fertilizer turned out to be statistically insignificant (results are not reported but available upon request).

Results from parametric analysis

All regression models except for the control group (chemical fertilizer adoption) in model 3 are estimated using random effects methods with and without Mundlak's approach[19]. The dependent variable in all cases is the gross crop revenue per hectare in logarithmic form. Our parameter of interest as indicated in equation (5) is to estimate the ATT (mean gross crop revenue per hectare difference) of conservation tillage and chemical fertilizer adoption. In the interest of space we focus the discussion of the results on the ATT. The detailed results are presented in Tables 2A, 2B, and 2C in the appendix 2. Table 2A reports the factors that determine agricultural productivity of plots that are subjected to conservation tillage as well as factors determining the productivity of plots that are not subjected to conservation tillage (Model 1). Table 2B presents the factors that determine agricultural productivity of plots that are fertilized together with factors that determine the productivity of non-fertilized plots (Model 2). Finally, column (1) of Table 2C shows the factors that determine agricultural productivity of plots that are subjected to conservation tillage while column (2) reports factors affecting the productivity of chemical fertilized plots (Model 3).

In brief the results underscore the significance of plot and household characteristics as well as conventional agricultural inputs (seeds, labour and oxen)[20] in influencing crop productivity. More importantly the results suggest that the effectiveness of these factors in

[19] The control group (fertilizer adoption) has no sufficient observations to run random effects but pooled OLS. However, the same conclusion is reached when both treatment (conservation tillage plots) and control groups are run using pooled OLS. Similarly, the Mundlak approach is not applied in model 3 because of few observations.

[20] Traditionally, farm households retain their own seeds from previous harvests for planting. Seed use is therefore a pre-determined variable. Improved seeds were used only on 3% of all sample plots. We assume labor and oxen use are fixed in the short term since households usually depend on family resources.

influencing crop productivity varies depending on the technology that has been adopted on a given plot. Thus understanding how these factors interact with specific technology is crucial for policy makers as this will enable them to formulate more effective and appropriate polices.

The switching regression estimates from Tables 2A, 2B, and 2C, are used to investigate the predicted gross crop revenue gap between conservation tillage and chemical fertilized plots as well as the revenue gap between plots that have these technologies and those that do not.

Consistent with results from semi-parametric analysis, parametric results indicate that while both conservation tillage and chemical fertilizer enhance productivity, conservation tillage leads to significantly higher productivity gains than chemical fertilizers (Table 3). Again these results are robust to both gross and net crop revenue per hectare but Model 2 where impact of fertilizer is negative and significant.[21]

Table 3 *Productivity impacts from parametric regression analysis*

Model types	Predicted mean gross crop revenue per hectare from			Predicted mean gross crop revenue difference (standard errors)
	Conservation tillage	Withoutconservation tillage /chemical fertilizer	Chemical fertilizer	
Model 1				
With Mundlak	2028.360	1419.472		608.892(258.159)**
Without Mundlak	1952.656	1416.285		536.371(235.633)**
Model 2				
With Mundlak		1320.182	1696.55	376.369(105.214)***
Without Mundlak		1283.297	1667.345	384.048(97.0942)***
Model 3				
Without Mundlak	1952.656		1339.506	536.371(235.633)**

Note: ** significant at 5%; *** significant at 1%.

In sum, the empirical results show that adoption of organic technologies such as conservation tillage could create a win-win situation for resource-constrained farmers in developing countries i.e. they can result in reduction in production costs, environmental benefits and at the same, as the results demonstrate, they can lead to increased yields. Thus promotion of organic farming techniques could go a long way in ensuring increased yields in Sub-Saharan Africa.

Conclusions and policy implications

Inadequate nutrient supply, depletion of soil organic matter and soil erosion continue to present serious challenges to crop production in semi-arid Ethiopia. This is further compounded by increased population pressure which is not accompanied by technological and/or efficiency progress. Efforts by the government to promote the adoption of chemical fertilizers have been frustrated by escalating fertilizer prices and production and consumption risks associated with fertilizer adoption. This means that sustainable agricultural production practices such as conservation tillage; in as far as they rely on local or farm renewable resources, present good options for resource-constrained farmer to improve productivity of their plots.

In this paper we use plot-level data from semi-arid Ethiopia to examine the productivity gains associated with adoption of sustainable agricultural production practices, with a

[21] These results (not reported) are also robust after controlling for crop types.

particular focus on the adoption of conservation tillage. In addition we compare the productivity impacts of conservation tillage with the productivity impacts of chemical fertilizers. In so doing we employ both semi-parametric and parametric econometric methods which permit us to (1) explore how household and plot characteristics influence decisions to adopt either conservation tillage or chemical fertiliser, (2) assess the impact of these technologies on crop productivity, and (3) explore determinants of crop production in general. Our results, though indicating that both conservation tillage and chemical fertilizer enhance productivity, reveal a clear superiority of conservation tillage over chemical fertilizers in enhancing crop productivity.

The results thus suggest that the promotion of organic farming techniques could go a long way in ensuring increased yields in sub-Saharan Africa. There is a need for governments and non-governmental organizations in developing countries to shift their focus from chemical fertilizer to considering organic farming technologies as yield augmenting technologies. Organic farming technologies not only increase yields but could also provide multiple benefits whereby farmers are also able to reduce production costs, provide environmental benefits, and can reduce crop failure risk due to moisture stress and financial risks associated with taking chemical fertilizer on credit.

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Appendices

Appendix 1

***Table 1A** Descriptive statistics (means)*

Variable	Description	Column 1	Column 2	Column 3	Column 4	Column 5
Production						
Gross crop revenue	Gross crop value production (ETB/ha)	2094.19	1365.87	1421.37	1925.61	1598.72
Net crop revenue*	Net crop production value (ETB/ha)	2094.19	1129.97	1283.56	1641.15	1598.72
Inputs						
Seed	Seed use on the plot, kg/ha	182.00	117.07	93.75	171.39	145.21
Labor	Labor use on the plot, days/ha	42.27	75.36	58.30	85.59	73.34
Oxen use	Oxen use on the plot, days/ha	14.39	30.04	28.19	34.18	28.61
Socioeconomic characteristics						
Gender	Sex of household head (1=male;0=female)	0.82	0.79	0.84	0.92	0.90
Age	Household head age	48.34	49.07	48.11	49.30	49.52
Family size	Number of household members	5.48	5.93	5.77	6.24	6.01
Illiterate	Head illiterate (1= yes;0=otherwise)	0.90	0.84	0.88	0.82	0.88
Education low	Head had up to grade one and two (1=yes;0=otherwise)	0.06	0.05	0.07	0.10	0.08
Education high	Head has above grade 3 (1=yes;0=otherwise)	0.04	0.11	0.06	0.07	0.05
Extension contact	Extension contact	0.18	0.25	0.19	0.22	0.24

Table 1A Continued

Oxen	Number of oxen owned by household	1.19	1.25	1.27		1.49	1.47		
Livestock	Livestock number other than oxen, in tropical livestock units	15.11	11.90		15.40		10.22	10.54	
Farm size	Total land holdings, hectares	1.85	1.18		1.31		1.02	0.97	
Population density	Village population density , person/km2	124.39	153.75		132.27		152.99		151.95
Altitude	Village altitude, in meters	2145.51	2150.07		2086.13		2168.34		176.14
Market distance	Residence distance to markets, walking hrs	3.54	3.02		3.96		2.26	2.50	
Plot characteristics									
Plot distance	Distance from the residence to plot, walking hrs	0.37	0.30		0.34		0.22	0.246	
Rented	Plot rented in (1= yes;0=otherwise)	0.11	0.12		0.08		0.09		0.11
Soil and water conservation	Soil and water conservation structures on the plot (1= yes; 0= otherwise)	0.06	0.05		0.03	0.09		0.09	
Stone covered	Plot covered in stone (1=yes;0=otherwise)	0.38	0.32		0.32		0.19	0.16	
Deep soils	Deep soil depth (1=yes;0=otherwise)	0.34	0.37		0.36		0.39		0.43
Moderately deep soils	Moderately deep soils (1=yes;0=otherwise)	0.49	0.51		0.49		0.38	0.33	
Shallow soils	Shallow soil depth (1=yes;0=otherwise)	0.18	0.12		0.16		0.23	0.24	
Black soils	Black soils (1=yes; 0=otherwise)	0.10	0.19		0.12		0.20	0.20	
Brown soils	Brown soils (1=yes; 0=otherwise)	0.21	0.23		0.20		0.41		0.14
Gray soils	Gray soils (1=yes; 0=otherwise)	0.35	0.20		0.29		0.20		0.24
Red soils	Red soils (1=yes; 0=otherwise)	0.34	0.46		0.39		0.46		0.42
Loam soil	Loam soil plots (1=yes;0=otherwise)	0.60	0.34		0.51		0.34	0.33	

Table 1A Conintued

Clay soil	Clay soil plots (1=yes;0=otherwise)	0.23	0.35	0.27	0.35		0.32		__
Sandy soil	Sandy soil plots (1=yes;0=otherwise)	0.04	0.07	0.06		0.13		0.16	__
Silt soil	Silt soil plots (1=yes;0=otherwise)	0.12	0.21	0.17		0.19	0.19		__
No erosion	Plots with no erosion problem (1=yes;0=otherwise)	0.63	0.60	0.66		0.67		0.66	__
Moderate erosion	Moderately eroded plots (1=yes;0=otherwise)	0.27	0.28	0.24		0.29		0.30	__
Severe erosion	Severely eroded plots (1= yes;0=otherwise)	0.10	0.12	0.10		0.04		0.04	__
Flat slope	Plot is of flat slope (1=yes; 0= steep slope)	0.57	0.51	0.57		0.69		0.65	__
Moderate slope	Plot is of moderate slope (1=yes; 0= steep slope)	0.34	0.37	0.33		0.25		0.28	__
Steep slope	Plot is of steep slope (1=yes; 0= steep slope)	0.10	0.12	0.10		0.07	0.07		__
Top slope	Top slope position (1=yes;0=otherwise)	0.18	0.18	0.16		0.08	0.09		__
Middle slope	Middle slope position (1=yes;0=otherwise)	0.20	0.23	0.23		0.18		0.24	__
Bottom slope	Bottom slope position (1=yes;0=otherwise)	0.24	0.16	0.20		0.21		0.23	__
No slope	Not on slope position (1=yes;0=otherwise)	0.39	0.44	0.41		0.54	0.44		__
Total observations		113	57	90		340	211		

*Fertilizer cost deducted from value of crop production

Column 1 = Refers to mean of variables from matched sample with conservation tillage (CT).

Column 2 = Refers to mean of variables from matched sample with chemical fertilizer (where only CT & Chemical fertilizer considered as treatment & control group, respectively)

Column 3 = Refers to mean of variables from matched sample without conservation tillage (where CT & rest of plot observations considered as treatment & control group, respectively)

Column 4 = Refers to mean of variables from matched sample with chemical fertilizer (where chemical fertilizer & rest of plot observations considered as treatment & control group, respectively)

Column 5 = Refers to mean of variables from matched sample without chemical fertilizer (where chemical fertilizer & rest of plot observations considered as treatment & control group, respectively)

Appendix 2

***Table 2A** Productivity analysis using switching regression: conservation tillage adopters vs. non-adopters (Model 1)*

	Using Mundlak's approach				Without Mundlak's approach			
	Conservation tillage adopters		Conservation tillage non-adopters		Conservation tillage adopters		Conservation tillage non-adopters	
Variable	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Socioeconomic characteristics								
Gender	-0.081	0.39	0.47	1.48	-0.27	0.34	0.33	1.15
Age	-0.10	0.41	-0.24	1.51	-0.42	0.49	-0.80	1.29
Family size	0.10	0.08	0.14	0.26	0.00	0.08	0.16	0.21
Education low	0.04	0.33	-0.21	1.97	-0.10	0.43	-0.241	1.54
Education high	-1.60***	0.46	-0.99	1.92	-0.35	0.55	-1.09	1.57
Population density	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Altitude	0.000	0.00	0.00	0.00	0.00	0.00	-0.00**	0.00
Extension contact	-0.40	0.32	-0.24	1.22	-0.00	0.35	0.26	1.01
Farm size	-0.0	0.04	-0.10	0.65	-0.03	0.08	0.30	0.41
Oxen	-0.26	0.19	0.10	0.67	-0.11	0.19	-0.45	0.51
Livestock	0.02*	0.01	-0.01	0.04	0.02*	0.01	0.012	0.03
Market distance	0.03	0.06	-0.16	0.23	-0.00	0.05	-0.05	0.16
Inputs								
Ln(Seed)	0.61***	0.16	1.34***	0.16	0.34***	0.11	1.21***	0.13
Ln(Labour)	0.08	0.09	-0.38***	0.13	0.06	0.09	-0.27**	0.11
Ln(Oxen days)	-0.137	0.16	1.63***	0.30	0.05	0.16	1.31***	0.24
Plot characteristics								
Plot distance from residence	0.339*	0.19	2.11*	1.23	0.09	0.16	1.65*	0.90
Rented in plots	-0.640	0.40	-0.35	0.33	-0.66*	0.36	-0.30	0.28
Soil and water conservation	0.611	0.43	0.931	1.95	0.39	0.34	1.13	1.09
Stone covered plot	0.04	0.25	-1.52	1.49	0.02	0.16	-1.03	0.77
Deep soil plots	0.54**	0.23	-0.38	1.20	0.38	0.27	0.60	0.65
Medium soil plots	-0.01	0.25	-1.95	1.23	0.06	0.31	-0.75	0.66
Brown soil plots	-0.17	0.32	0.01	1.63	-0.23	0.30	-0.49	0.94
Gray soil plots	-0.42	0.34	0.32	1.79	-0.30	0.27	-1.02	1.05
Red soil plots	-0.97***	0.37	0.90	2.03	-0.62**	0.26	-0.37	1.06
Loam soil plots	0.50*	0.27	-0.33	1.24	0.186	0.28	0.545	0.68
Clay soil plots	-0.06	0.31	1.28	1.74	-0.316	0.29	1.95**	0.88
Sandy soil plots	0.64*	0.37	-0.53	3.88	0.212	0.34	0.856	2.27
Moderately eroded plots	0.14	0.18	0.07	1.34	-0.05	0.18	-0.44	0.71
Severely eroded plots	-0.50**	0.22	-0.94	2.40	-0.42*	0.22	0.79	1.36
Gently slope plot	0.16	0.24	-0.17	1.71	-0.09	0.27	-1.48**	0.71
Steep slope plot	0.54	0.34	-0.79	2.08	0.15	0.39	-1.67	1.20
Middle slope position	1.01***	0.3	-0.91	2.14	0.54**	0.25	1.01	1.19
Bottom slope position	0.67***	0.21	-1.85	1.91	0.46*	0.27	-0.08	1.01
Not on slope position	1.67***	0.24	-1.05	2.5	0.84***	0.32	-0.95	1.05
Constant	5.42**	2.15	8.99	8.07	6.69***	2.01	7.50	5.47
R-squared	0.71		0.48		0.41		0.29	
Model chi-square	1070.28		414.03		269.90		521.13	
Number of observations	113		90		113		90	

Note: * significant at 10%; ** significant at 5%; *** significant at 1%

***Table 2B** Productivity analysis using switching regression: fertilizer adopters vs. non-adopters (Model 2)*

	Using Mundlak's approach				Without Mundlak's approach			
	Fertilizer adopters		Non-Fertilizer adopters		Fertilizer adopters		Non-Fertilizer adopters	
Variable	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Socioeconomic characteristics								
Gender	0.43**	0.20	0.69***	0.23	0.32*	0.19	0.59***	0.23
Age	-0.23	0.17	-0.19	0.21	-0.27	0.16	-0.32	0.21
Family size	0.02	0.03	-0.05	0.03	0.03	0.03	-0.06	0.04
Education low	-0.08	0.16	-0.03	0.29	-0.13	0.16	0.05	0.28
Education high	-0.25	0.21	-0.25	0.27	-0.27	0.20	-0.12	0.31
Population density	0.00	0.00	-0.00	0.00	-0.00	0.00	-0.00	0.00
Altitude	-0.00***	0.00	-0.00***	0.00	-0.00**	0.00	-0.00**	0.00
Extension contact	0.03	0.12	0.29*	0.16	-0.03	0.12	0.17	0.15
Farm size	-0.15	0.10	-0.12	0.15	-0.11	0.10	-0.08	0.15
Oxen	-0.02	0.09	-0.02	0.08	-0.06	0.08	-0.02	0.08
Livestock	0.00	0.01	0.01	0.01	0.01	0.01	0.01*	0.01
Market distance	-0.06**	0.03	0.00	0.05	-0.06**	0.03	-0.03	0.04
Inputs								
Ln(Seed)	0.31***	0.06	0.29***	0.10	0.34***	0.05	0.23***	0.06
Ln(Labor)	0.37***	0.09	0.02	0.12	0.28***	0.07	0.04	0.08
Ln(Oxen days)	-0.04	0.11	0.07	0.24	0.05	0.09	0.20	0.15
Plot characteristics								
Plot distance	-0.24	0.18	-0.24	0.26	-0.26	0.16	-0.17	0.25
Rented in plots	0.09	0.14	-0.27	0.19	0.18	0.12	-0.10	0.17
Soil and water conservation	-0.01	0.17	0.28	0.27	0.10	0.14	0.11	0.17
Stone covered plot	-0.01	0.12	-0.04	0.21	-0.03	0.10	-0.16	0.17
Deep soil plots	-0.22**	0.10	-0.05	0.19	-0.26***	0.08	-0.17	0.15
Medium soil plots	-.53***	0.11	0.21	-0.09	-0.50***	0.10	-0.13	0.18
Brown soil plots	-0.08	0.18	-0.36	0.38	0.08	0.15	0.10	0.28
Gray soil plots	-0.15	0.15	-0.26	0.40	-0.05	0.13	0.15	0.29
Red soil plots	-0.11	0.16	-0.14	0.40	0.01	0.13	0.13	0.28
Loam soil	0.07	0.16	0.66*	0.34	-0.01	0.15	0.14	0.27
Clay soil	0.06	0.15	0.28	0.39	0.05	0.14	0.09	0.28
Sandy soil	0.23	0.23	0.22	0.37	0.08	0.17	0.05	0.25
Moderately eroded	0.12	0.10	0.05	0.21	0.09	0.08	-0.00	0.14
Severely eroded plots	-0.29*	0.17	0.41	0.46	-0.33**	0.13	0.07	0.36
Gently slope plot	-0.03	0.15	-0.21	0.21	-0.02	0.11	-0.31**	0.14
Steep slope plot	0.07	0.19	-0.38	0.39	0.13	0.19	-0.76**	0.34
Middle slope position	0.16	0.22	0.08	0.31	0.08	0.19	-0.03	0.20
Bottom slope position	0.30*	0.18	0.10	0.34	0.23	0.17	-0.22	0.25
Not on slope position	0.21	0.21	0.12	0.38	0.07	0.18	-0.20	0.24
Constant	7.23***	0.96	7.77***	1.33	7.03***	0.79	7.96***	1.10
R-squared	0.47		0.41		0.40		0.31	
Model chi-square	410.95***		196.57***		289.90***		99.34***	
Number of observations	340		211		340		211	

Note: * significant at 10%; ** significant at 5%; *** significant at 1%

***Table 2C** Productivity analysis using switching regression: conservation tillage vs. chemical fertilizer adopters (Model 3)*

	(1) Conservation tillage		(2) Chemical Fertilizer	
Variable	Coeff.	Std. Error	Coeff.	Std. Error
Socioeconomic characteristics				
Gender	-0.27	0.34	-0.03	0.43
Age	-0.42	0.49	-0.14	0.43
Family size	0.00	0.08	0.07	0.08
Education low	-0.09	0.43	-0.11	0.42
Education high	-0.35	0.55	-0.73	0.45
Population density	0.00	0.00	0.00	0.00
Altitude	0.00	0.00	-0.00	0.00
Extension contact	-0.00	0.35	-0.13	0.33
Farm size	-0.03	0.08	-0.07	0.34
Oxen	-0.11	0.19	0.03	0.17
Livestock	0.02*	0.01	0.01	0.01
Market distance	-0.00	0.05	-0.07	0.08
Inputs				
Ln(Seed)	0.34***	0.11	0.25*	0.12
Ln(Labour)	0.06	0.09	0.31*	0.18
Ln(Oxen days)	0.05	0.16	0.32	0.31
Plot characteristics				
Plot distance from residence	0.08	0.16	-0.08	0.48
Rented in plots	-0.66*	0.36	0.14	0.42
Soil and water conservation plots	0.39	0.34	-0.09	0.54
Stone covered plot	0.02	0.16	-0.42	0.41
Deep soil plots	0.38	0.27	-0.55	0.46
Medium soil plots	0.05	0.31	-0.66	0.46
Brown soil plots	-0.23	0.30	0.71	0.57
Gray soil plots	-0.30	0.27	0.18	0.53
Red soil plots	-0.62**	0.26	0.46	0.55
Loam soil plots	0.19	0.28	-0.02	0.64
Clay soil plots	-0.32	0.29	-0.34	0.54
Sandy soil plots	0.21	0.34	-0.42	0.71
Moderately eroded plots	-0.05	0.18	0.41	0.34
Severely eroded plots	-0.42*	0.22	-0.02	0.50
Gently slope plot	-0.09	0.27	-0.19	0.37
Steep slope plot	0.15	0.39	-0.59	0.56
Middle slope position	0.54**	0.25	0.03	0.59
Bottom slope position	0.46*	0.27	-0.51	0.60
Not on slope position	0.84***	0.32	-0.74	0.54
Constant	6.69***	2.01	6.43**	3.00
R-squared	0.41		0.78	
Model chi-square	269.90***		2.32**	
Number of observations	113		57	

Note: * significant at 10%; ** significant at 5%; *** significant at 1%

Greening Ethiopia for Food Security1

Sue Edwards,
Institute for Sustainable Development, Addis Ababa, Ethiopia

A remarkable project reversing the ecological and social damages of the neglect of smallholder farmers for over 100 years that have locked the country in poverty

The world's largest single study of its kind now shows that composting increases yields two to three-fold and outperforms chemical fertilizers by more than 30 percent

Challenges

Ethiopia is a land-locked country in the 'Horn of Africa' to the northeast of Africa. Its topography is very diverse, encompassing mountains over 4 000 m above sea level, high plateaus, deep gorges cut by rivers and arid lowlands including the Dallol Depression, which is 110 m below sea level in the Afar desert [1].

The South Westerly Monsoon is one of the country's three moisture-bearing wind systems. Originating from the South Atlantic, it brings the greatest amount of moisture during the main rainy season (May/June–September/October). The small rains (February-April/May) originate from the Indian Ocean and bring rain to the southern and eastern highland areas. The third rainfall system also originates from the Indian Ocean. It brings rain to the southern half of the country any time between October and January, and March to May [2]. The mean annual rainfall is highest (above 2 700 mm) in the south-western highlands, gradually decreasing to below 100 mm in the eastern lowlands of the Afar. The mean annual temperature ranges from a high of 35 °C in the Afar to 10 °C or lower in the highlands above 2 500 m [1]. From November to January in the highlands above 1 500 m, diurnal temperatures can range between below freezing at night bringing frost to over 25 °C during the day [2].

Based on an extrapolation of the 1994 population and housing census the total population of Ethiopia in the year 2002 was 67.22 million, of which 56.9 million (84.7%) were rural. By 2007, it was estimated to have exceeded 77 million and could reach 94.5 million by 2015 [3]. The population is very young with 50 percent under 25 years old. More than 49 percent of the country's population lives in the highlands above 2 200 m altitude; 11 percent lives below 1 400 m and 40 percent in between 1 400 and 2 200 m altitude. Human and animal pressure is high in the highlands. About 85 percent of the human population lives in the 45 percent of country that constitute the highlands and 75 percent of the animal population lives with the people above 1 400 m altitude [4, 5].

By 2005, school enrolment rose to 11.4 million making the gross enrolment ratio 79.8 percent (70.9% female and 87.3% male). There has also been a rapid expansion of private education – schools, colleges and universities – in the larger urban centres, and a large number of urban dwellers attend informal education. [6]

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1 Chapter 11 of the book "Food Futures Now", launched in London Houses of Parliament, 22 April 2008 and published by Third World Network, Penang, and Institute of Science in Society, London.

To improve agricultural production, education has focused on producing better qualified Development Agents and trained farmers. By 2005 over 23 thousand Development Agents had graduated from 3-year diploma programmes and 5,493 Farmers Training Centers had been completed. These are designed to teach farmers modern agricultural technologies to solve problems of production and improve productivity. [6]

The country faces a number of environmental challenges resulting directly or indirectly from human activities, exacerbated by rapid population growth and the consequent increase in the exploitation of natural resources. The challenges mostly revolve around land degradation due to the removal of self governance by local communities of smallholder farmers starting around the second half of the nineteenth century. This left the farmers only able to exercise some control over their land when it was growing a crop and the traditional systems of land management were undermined. The most visible physical impacts have been gully formation eating away the soil with vegetation recovery prevented by free-range grazing and the unregulated felling of trees for firewood and other purposes. The central control of local farming communities continued under the military government (1974-1991) and did nothing to restore farmers' confidence to control their own affairs and invest in their land. The exploitation of natural resources includes burning dung as fuel instead of using it as a soil conditioner. Losses to crop production from burning dung and soil erosion are estimated at over 600 000 tonnes annually, or twice the average yearly requests for food aid [5].

These negative trends are now being reversed through the present government's emphasis on the decentralization of power down to the wereda, the lowest level of official government intervention, and their constituent tabias in Tigray (kebeles in the rest of the country). Each wereda is also the seat for a member of parliament sitting in the Federal House of Representatives – the Parliament. The day-to-day affairs of the local communities are run by the elected officials of the tabia.

Until recently, environmental pollution from chemicals was only a problem in a few areas where there was misguided application in state run farms (particularly growing cotton), or for the manufacture of industrial products. However, agricultural production is also threatened by outbreaks of migratory pests, particularly Quelea birds, army worm, desert locust, pachnoda beetle and the endemic Wollo bush cricket. Hence, Ethiopia has accumulated one of the largest stockpiles of obsolete pesticides in the continent, estimated to be over 3 000 tonnes in 2006, but smallholder farmers producing rain-fed crops were not using pesticides on a regular basis. [7]

Opportunities

Despite the categorizing of Ethiopia as one of the least developed countries in the world [8], traditional agricultural production is highly diverse and is the main source of food for the population. The high diversity in crop species and genetic diversity within crops is a reflection of the environmental and cultural diversity of Ethiopia and the antiquity of crop cultivation in the country. Two of the main staple crops, the cereal teff (*Eragrostis tef*) and the root crop enset (*Ensete ventricosa*) are endemic and many of the crops that are known to have their centres of origin in the fertile crescent of south-west Asia, for example durum wheat (*Triticum durum*), now have their highest genetic diversity in Ethiopia. Ethiopia is one of the eight major centres for crop diversity in the world [9].

Other important crops with high genetic diversity in Ethiopia include the cereals—barley (*Hordeum vulgare*), finger millet (*Eleusine coracana*) and sorghum (*Sorghum bicolour*); pulses—faba bean (*Vicia faba*), field pea (*Pisum sativum* including the endemic var. *abyssinicum*), chick pea (*Cicer arietinum*) and grass pea (*Lathyrus sativus*); oil crops—linseed (*Linum sativum*), niger seed (*Guizotia abyssinca*), safflower (*Carthamus tinctorius*) and sesame (*Sesamum indicum*); and root crops—anchote (*Coccinia abyssinica*), 'Oromo or Wollaita dinich' (*Plectranthus edulis*), and yams (*Dioscorea* spp.). Over 100 plant species used as crops in Ethiopia have been identified. [10]

Agriculture accounts for more than 75 percent of total exports, over 85 percent of employment; and about 45 percent of the GDP (gross domestic product). Coffee alone makes up more than 87 percent of the total agricultural exports. Hides and skins are the next most important export items as raw, processed or manufactured goods. [5]

The Government has stated that Ethiopia's development has to be based on its capacity to produce agricultural products to ensure food security for its population, provide the raw materials for agro-industrial development and earn foreign exchange. This is set out in "Ethiopia: Building on Progress — A Plan for Accelerated and Sustained Development to End Poverty (PASDEP) (2005/06-2009/10) [6].

Problems of chemical inputs

In 1995, a revised version of the Green Revolution, called the Sasakawa Global 2000 (SG-2000) programme [11] was started by the Ministry of Agriculture to boost food crop production through a focused campaign to get smallholder farmers to use chemical fertilizer along with, when possible, high yielding varieties (HYVs) and pesticides. However, it mostly promoted the adoption of fertilizer through credit schemes and subsidized prices. Maize was the only crop where HYVs were regularly promoted. Prior to 1995, Ethiopia had one of the lowest per capita uses of fertilizer in the world [12]. Under SG-2000, farmers were allowed to select the crops they wanted to grow with fertilizer and use the best of their own local varieties rather than buy seed of HYVs. It is only since 2003 that more widely adapted 'improved seeds' have been promoted and taken up by smallholder farmers. However, there are also efforts to promote the conservation and enhancement of farmers' varieties (often called landraces) using organic principles [13].

From 1998, the subsidy on chemical fertilizer (Urea and DAP) was withdrawn but the price had more than doubled by 2007. Access to credit for purchasing fertilizer has continued to be made available to farmers up to the present (2007). By 2001, around 5 percent of the smallholder farmers of the country, particularly those growing maize, had become accustomed to using fertilizer. But that year, the price dropped out of the bottom of the maize market and the farm gate price in some areas fell to the equivalent of US$ 1.50 per 100 kg of maize [13].

In 2002, many farmers were heavily in debt and withdrew from the fertilizer schemes. Many parts of the country were also hit by a much reduced rainy season with the rains stopping early, or by drought. The result was that yields declined, or crops failed completely and the government requested food aid for more than 14 million people, nearly a quarter of the total population in 2002 [14].

Since 2002, the use of pesticides has changed rapidly as farmers have been encouraged to diversify into vegetable production where they have been able to harvest rainwater and/or get access to ground water through shallow hand-dug wells. Since 2003, there has also been exponential growth of the labour and input-intensive floriculture and vegetable industry for cut flowers and vegetables for export. This industry is now implementing integrated pest management and training pesticides handlers and its workers. However, there is very little awareness among smallholder farmers and their development agents of the adverse effects of pesticides to human health and the environment. For example, in a survey of pesticide use in the Rift Valley of Ethiopia, a farmer was spraying his tomatoes with pesticide while his 8-year old daughter stood less than 2 metres away. Both had bare feet. Pesticides in local shops are stored next to food items and containers are usually re-used, even to contain drinking water! [7].

Greening Ethiopia

The Environmental Policy of Ethiopia, issued in 1997, has incorporated a basic principle similar to one adopted in organic agriculture: "Ensure that essential ecological processes and life support systems are sustained, biological diversity is preserved and renewable natural resources are used in such a way that their regenerative and productive capabilities are maintained, and, where possible, enhanced...; where this capacity is already impaired to seek through appropriate interventions a restoration of that capability." [15]

Key elements of the policy cover soil husbandry and sustainable agriculture, and provide the framework for the development of more specific policies, strategies and regulations for organic agriculture. These include promoting the use of appropriate organic matter and nutrient management for improving soil structure and microbiology; maintaining the traditional integration of crop and animal husbandry in the highlands, and enhancing the role of pastoralists in the lowlands; promoting water conservation; focusing agricultural research and extension on farming and land use systems as a whole, with attention to peculiarities of local conditions and the central role of smallholder farmers; promoting agroforestry/farm forestry; ensuring that potential costs of soil degradation through erosion and pollution are taken into account; maintaining the emphasis in crop breeding on composites and multi-lines to increase adaptability to environmental changes and to better resist pests and diseases; using biological and cultural methods, resistant or tolerant varieties or breeds, and integrated pest and disease management in preference to chemical controls; and applying the precautionary principle in making decisions [15].

This enabling policy context dovetails with a unique experiment in sustainable development and ecological land management conducted with farmers in Tigray and the birth of an organic agriculture movement in the country as a whole.

Proof of concept

"Is there sufficient biomass in Ethiopia to make adequate quantities of compost?" This is the question most often raised whenever there is any suggestion that Ethiopia could use organic principles to increase crop yields.

In 1995, Dr Tewolde Berhan Gebre Egziabher, founder of the Institute for Sustainable Development (ISD), was asked by some government officials to design a project that could help farmers trying to eke out an existence on the highly degraded land of the highlands. The aim was to help the farmers use an ecological approach with a minimum of external inputs to improve the productivity of their land and rehabilitate their environments. The project started in 1996 as a partnership with the Bureau of Agriculture and Rural Development (BoARD) of Tigray, and is still continuing to be run by the BoARD. The other partners in the project are Mekele University, the local communities and their local administration. The project focused on the following activity areas [16]:

Helping local communities restore local control and effective management of their natural resources through the development and enforcement of their own by-laws.

Improving biological and physical water and soil conservation in crop land including the control and rehabilitation of gullies;

Controlling, preferably stopping, free-range grazing to allow more grass, herbs and trees to grow;

Restoring soil fertility through making and using compost, and helping farmers avoid debt paid for chemical fertilizer;

Including grasses and fast growing legumes in areas treated for soil and water conservation. The most successful has been the small multipurpose indigenous tree, *Sesbania sesban* planted for animal forage and compost biomass on the bunds between fields, and in the rehabilitated gullies along with grasses, particularly elephant grass. There has also been a rapid re-establishment of indigenous plants, particularly shrubs and trees, in the gullies and on hillsides protected from grazing animals.

Project activities in four communities were established in 1996/97 and 1997/98. Since 2000, there has been a rapid up-scaling of the project so that by 2006, ISD was following up the project activities in 57 local communities in 12 of the 53 weredas (districts) in Tigray. Much effort has been made to include households headed by women in the project because these are generally among the poorest of the poor in their villages [16].

Since 2000, the BoARD has been promoting the land rehabilitation 'package'—compost, trench bunding for soil and water conservation with planting multipurpose trees and grasses—in over 90 communities within 25 weredas (administrative districts) in the drier more degraded areas of the Region. It was estimated in 2007 that about 25 percent of the farming population in Tigray are using this package, particularly making and using compost.

From the beginning, the project has been funded by the Third World Network (TWN), an international NGO network with its head office in Penang, Malaysia. In 2006, TWN published the experiences of the Tigray Project under the title: "*The Tigray Experience: a success story in sustainable agriculture*" [16]. This included some of the data from monitoring the impact of compost and chemical fertilizer on crop yields in farmers' fields.

Starting from 2005, the Swedish Society for Nature Conservation (SSNC) has also provided funding to ISD for its work to promote sustainable agriculture in Tigray, Amhara and Oromiya Regions. This included the publishing of a poster on the making of compost to support the compost manual in Tigrinya (the local language of Tigray) published in 2002 [17], and distributed to all 53 weredas of the Tigray Region. In 2007, an Amharic version of the compost manual and poster was prepared to be published as part of the UNDP-funded Land Rehabilitation Project in the Federal Environmental Protection Authority (EPA).

In 2006, the FAO Natural Resources Department provided funding to help collect additional yield data from plots in farmers' fields during the 2006 harvesting season, and pay for the entry and statistical analysis of the data. The final data base included plot yields from 974 farmers' fields and 13 crops taken over the years 2000 to 2006 inclusive [18]. The results were presented at the FAO International Conference on "*Organic Agriculture and Food Security*" held 2-5 May 2007 in FAO, Rome [19]

This is now the single largest study of its kind in the world comparing yields from the application of compost and chemical fertilizer in farmers' fields. The results show without any doubt that compost can replace chemical fertilizers and increase yields by more than 30 percent on average.

Comparing yields

An important feature of the Tigray Project is that it is largely the farmers supported by local wereda-based experts from the BoARD who have led the project. They choose which crops to treat with compost and which with chemical fertilizer.

The method used to collect the yield data was based on the crop sampling system developed by FAO to estimate a country's potential harvest and identify threats to local food security. Three one-metre square plots were harvested from each field to reflect the range of conditions of the crop. The harvested crop was then threshed and the grain and straw were weighed separately. For comparison, all yields have been converted into kg/ha in the following table.

The fields for taking the yield samples are selected with the farmers and chosen to represent the most widely grown crops. There are three treatments: 'check' means a field which has received neither compost nor chemical fertilizer, although it may have received compost in one or more previous years. 'Compost' is for fields treated with mature compost; the rates of application range from around 5 t/ha in poorly endowed areas, such as the dry Eastern Zone of the Region, to around 15 t/ha in the moister Southern Zone. 'Fertilizer' is for fields treated with the chemicals DAP (diammonium phosphate) and urea. The recommended rates are 100 kg/ha of DAP and 50 kg/ha of urea.

The original data were collected community by community and included 13 crops, but here they have been compiled for the four most widely grown cereals and the most important pulse, viz. barley, wheat, maize, teff, and faba bean. The results of a one-way analysis of variance (ANOVA) are given in Table 1, which also shows the 95 percent confidence intervals for the mean.

As can be seen, there are large differences between the means of every crop with respect to treatments. Compost gives the highest yields for all crops; typically double those of the 'check', and better than those from chemical fertilizer by an average of 30.1 percent (from 17.8 percent for faba bean to 47.4 percent for wheat).

Pairwise comparisons (not shown) of treatments for all crops are highly significant (at the 0.1 percent level or better), except for compost versus fertilizer in faba beans, where there are too few observations for treatment with fertilizer. This is hardly surprising as faba bean is a pulse capable of fixing its own nitrogen. Traditionally farmers improve soil fertility for growing faba bean by applying animal manure and ash, but not chemical fertilizer, to the soil.

The analysis reported here is an independent confirmation of the highly significant impacts of the use of compost on crop yields reported from a linear regression analysis of the same data presented at the FAO International Conference on *Organic Agriculture and Food Security* [19]

The farmers' experience

Farmers who have learnt how to make and use compost based on the method recommended by ISD are not interested in continuing to use chemical fertilizer, i.e. they have willingly withdrawn from the use of chemical fertilizer without any loss in production.

In 1998, when the first set of data were collected from plots in the four original communities, except for maize, the grain yields of the cereals from the fields without any inputs (checks) were all below 1 t/ha: 395-920 kg/ha for barley, 465-750 kg/ha for durum wheat, and 480-790 kg/ha for teff [20]. In the 7-year data set for the four widely grown cereal crops the average check yields ranged from 1116 kg/ha for barley to 1642 kg/ha for maize. The four original communities had been making and using compost for ten years, and all the others had been using compost for 3-5 years.

The residual effect of compost in maintaining soil fertility for two or more years was soon observed and appreciated by the farmers. They are thus able to rotate the application of compost on their fields and do not have to make enough to apply to all their cultivated land each year.

The following observations are among the other positive impacts of the use of compost and environmental rehabilitation noted by the farmers, development agents, and ISD staff.

- The reduction of difficult weeds, such as Ethiopian wild oats *Avena vaviloviana*, and improved resistance to pests, such as teff shoot fly. These impacts from the use of compost, including better resistance to crop diseases, have also been found with farmers practicing organic agriculture in France [21].

***Table 1** Average yield (kg/ha) of main crops for all locations*

Barley				Individual 95% Confidence Intervals for Mean based on Pooled StDev													
Treatment	**N**	**Mean**	**St Dev**	**1000**	**1200**	**1400**	**1600**	**1800**	**2000**	**2200**	**2400**	**2600**	**2800**	**3000**	**3200**	**3400**	**3600**
Check	**165**	**1116**	**742**		X												
Compost	**171**	**2349**	**956**								X						
Chemical fertilizer	**108**	**1861**	**811**					X									
Total N	**444**																
Wheat (durum)				Individual 95% Confidence Intervals for Mean based on Pooled StDev													
Treatment	**N**	**Mean**	**St Dev**	**1000**	**1200**	**1400**	**1600**	**1800**	**2000**	**2200**	**2400**	**2600**	**2800**	**3000**	**3200**	**3400**	**3600**
Check	**219**	**1228**	**682**		X												
Compost	**183**	**2494**	**1455**								X						
Chemical fertilizer	**144**	**1692**	**852**				X										
Total N	**546**																
Maize				Individual 95% Confidence Intervals for Mean based on Pooled StDev													
Treatment	**N**	**Mean**	**St Dev**	**1000**	**1200**	**1400**	**1600**	**1800**	**2000**	**2200**	**2400**	**2600**	**2800**	**3000**	**3200**	**3400**	**3600**
Check	**87**	**1642**	**1301**				X										
Compost	**117**	**3552**	**2024**													X	
Chemical fertilizer	**69**	**2736**	**1344**										X				
Total N	**273**																

Teff				Individual 95% Confidence Intervals for Mean based on Pooled StDev													
Treatment	**N**	**Mean**	**St Dev**	**1000**	**1200**	**1400**	**1600**	**1800**	**2000**	**2200**	**2400**	**2600**	**2800**	**3000**	**3200**	**3400**	**3600**
Check	**312**	**1151**	**986**	X													
Compost	**222**	**2264**	**1836**							X							
Chemical fertilizer	**207**	**1701**	**1119**				X										
Total N	**741**																
Faba bean				Individual 95% Confidence Intervals for Mean based on Pooled StDev													
Treatment	**N**	**Mean**	**St Dev**	**1000**	**1200**	**1400**	**1600**	**1800**	**2000**	**2200**	**2400**	**2600**	**2800**	**3000**	**3200**	**3400**	**3600**
Check	**60**	**1379**	**1034**		X												
Compost	**72**	**3176**	**2929**											X			
Chemical fertilizer	**9**	**2696**	**1226**									X					
Total N	**141**																

N = number of fields sampled

- Farmers who make and use compost are able to avoid the financial risk of taking chemical fertilizer on credit, and the compost is available when it is needed – chemical fertilizer is sometimes delivered too late for the farmers to use. The most visible impact of farmers not having to take fertilizer on credit is that they often invest in improving their homes and compounds, for example, replacing thatching with more water-proof corrugated iron sheets, and/or diversifying their production base with beehives.
- Fields treated with compost are able to retain more moisture than untreated fields or those given chemical fertilizer so that when there are dry gaps in the rainy season and/or the rains stop early, the crops on these fields continue to grow. This was seen dramatically in 2002 when the main rains were very poor and stopped early. The crops in the fields treated with compost were still green when those in non-treated fields and especially those with chemical fertilizer had withered and died. Even if the farmers were not able to get an adequate grain yield that year, these better grown crops provided much needed forage for their domestic animals.
- The women say that food made from grain harvested from fields that have had compost applied have better flavour and provide a more satisfying and sustaining meal for their families than grain from crops where the fields had chemical fertilizer applied.
- Once farmers appreciate the improved productivity of their fields treated with compost, they usually start to re-establish the diversity of crops, particularly cereals and pulses, familiar to them before their land became highly degraded. One farmer successfully searched far and wide for 'Demehai', a variety of easily de-hulled barley that is used to make a snack of roasted grain, to reintroduce it to his farm once he had become food secure through the use of compost. He was able to buy just one jug, *c* 1 litre, of seed which he then carefully multiplied. Now all visitors to his house are offered this traditional roasted grain snack with a cup of coffee.
- Farmers also become innovative in trying out new crops and crop combinations. For example, one farmer in Adi Nifas now regularly plants vegetables, particularly tomato and chilli pepper in his teff field. These do not interfere with the teff, maturing after the grain is harvested and bringing the farmer additional income. Many other farmers have now adopted this and other innovative forms of inter-cropping.
- Many farmers have also started to plant fruit trees, both around their homesteads and in rehabilitated gullies. Women farmers are particularly adept at taking care of these fruit trees, such as citron (*Citrus medica*) and papaya, and they are now also starting to grow mulberry and castor (*Ricinus communis*) to raise silkworms because there is an emerging market for the silk. ISD, with financial support from SSNC, assisted the local agricultural experts of Tahtai Maichew Wereda near Axum establish a fruit tree nursery to meet the escalating demand for fruit tree seedlings from the farmers.
- In Adi Nifas, where the main gullies and hillside were treated with check dams at the start of the project, the streams from the hillside used to dry up quickly in the dry season. Now these streams hold water all year round and the resulting small river has made it possible for several farmers downstream to develop irrigated vegetable production, particularly of onions, after they have harvested their grain crops. These farmers are able to regularly get two

crops a year from their land and their land, which used to be considered as being among the worst in that area, is seen as totally rehabilitated and productive.

These results also show that the use of compost to restore soil fertility can go a long way towards combating poverty and ensuring food security for smallholder farmers who typically cultivate less than one hectare of land. For various reasons, it is not easy to get an accurate account of household food security directly from farmers, but farming families who have been able to abandon using chemical fertilizer are often seen to have healthier and better clothed children who go to school and better fed animals. Through indirect discussions, it appears that most of these farming families have at least sufficient food grains stored in their houses to feed their families for the whole year, and some have larger stores. The following anecdote illustrates this situation. A farmer who generally looked poorly dressed had his house threatened by a flood. He had to call his neighbours to help him and his family move their stored grain to a safe place because he had been able to accumulate enough to maintain his family for about three years!

In 2003, the administration of Tahtai Maichew Wereda, about 25 km west of Axum in northern Tigray asked ISD, the federal Environmental Protection Authority and the BoARD of Tigray to help it expand the 'Sustainable Agriculture/Development Project' to all tabias in the Wereda, i.e. to over 20,000 households. The project was launched in July 2004 at a workshop involving around 200 women and men farmers, the local administration, all 50 local experts and key representatives from the Regional offices in Mekelle, the Regional capital. The local experts led the workshop along with one or two farmers, who gave testimony of the successes of the Tigray Project. There was also an experience-sharing session of problems and how they were solved, or how these still remained as challenges. A pre-workshop day was set-aside for the local experts to have an in-depth discussion on what constitutes 'sustainable rural development'. The second workshop, a year later, had a similar number of farmers and more participation of policy makers from the Regional Government. This confirmed that the expansion of the project's activities was going ahead well, but there were some farmers who said that they could not use controlled grazing because they lacked the family members to assist them.

An emerging challenge is the involvement of the local justice system, the 'social courts', to help uphold and enrich local by-laws to back up improvements to land and its management by the local communities.

The experience with the farmers in Tigray in producing and using compost shows that the aim for Ethiopia to have a substantial number of farmers producing organically can be realized. It also shows that the introduction of ecologically sound organic principles can have very quick positive impacts on the productivity and well-being of smallholder farmers because they do not have to go through a conversion period of reduced yields as they go into using compost. Most farmers, particularly those in marginal areas, are not able to afford external inputs, so for them an organic production management system offers a real and affordable means to break out of poverty and obtain food security.

Organic production for Ethiopia

Spurred by growth of organic coffee production and the successes of the Tigray Project, the Ethiopian government stated its interest to increase the capacity of farmers to use organic methods of crop production and identified a task force to draw up appropriate legislation to define how organic products are produced and certified. The first product of this task force was a proclamation to establish an *Ethiopian Organic Agriculture System*, which was approved by the Parliament on 8 March 2006 [22].

Improving agricultural production, particularly of the smallholder farmers but also at a commercial scale in the lowlands where water for irrigation is easily available, is seen as the key for Ethiopia to eliminate extreme poverty, become food secure and drive industrialization and export-oriented development. Originally set out in the Government's programme for Agriculture Development-Led Industrialization and the Rural Development Policies, Strategies and Methods of 2000 [23], this approach has been developed in detail for the 5-year (2005-2010) development plan set out in PASDEP [6]. Although organic agriculture production is not specifically mentioned in PASDEP, many of the components for a viable organic sector are given; for example, the need to improve local marketing infrastructure, identify and develop products for niche markets, and also to develop agricultural products to diversify the economic base of the country. All these developments should include strategies that prevent further degradation of the environment and provide maximum employment opportunities both on farm and in the development of value-added chains for marketable products [6].

The international trade in organic products is an expanding market that Ethiopia is geographically well situated to exploit, not just in the developed economies of Europe, North America and Japan, but also in the Arabian Peninsula and Near East.

Coffee was the first certified organic product exported from Ethiopia. Starting in 1995, the world market price for coffee started to decrease dramatically and it was quickly realised that producers could improve their returns through organic production supported by fair trade. Organic fair trade coffee is increasing its market share by about threefold each year with most of it being exported to the USA. Through these quality certificates, a minimum of 20 per cent is added on top of the local price for farmers. This has changed the livelihood of the farmers and their communities: additional schools have been built as well as health centres and several clean water delivery points. By 2007, the Oromia Coffee Union, the first and now the largest in the country, was buying coffee from 115 cooperatives. When it started, these were the first organic certified cooperatives in Africa, selling more than 4,000 tonnes of organic coffee obtained from 80,000 ha of organic certified land. [24]

By 2007, there were four international organic inspection and certification bodies working in Ethiopia, all with local Ethiopian experts. The certified organic products being exported are all high value products: coffee, honey, sesame, pulses, teff, pineapple, bananas, linseed, spices and herbs from farmers' fields, and incense and myrrh collected from the wild [24].

There is also an expanding awareness of the importance of producing healthy fruits and vegetables for the educated middle-class and expatriate market in Addis Ababa.

For example, Genesis Farm, started in 2001, now produces high quality organically grown vegetables on an area of 40 ha. The vegetable farm has 302 permanent workers and 52 daily labourers. The farm also has a dairy herd of 110 cows and 50,000 chickens, not totally organic by European standards, but much healthier than most other animal production enterprises of a similar size in Ethiopia. [24] There is a high demand for the products of the farm which supplies to hotels and supermarkets in Addis Ababa, as well as having its own shop on the farm. What is very interesting to note is that the prices of the products in the shop on the farm are generally the same or even somewhat cheaper than their equivalents from non-organic production units around Addis Ababa.

An Organic Movement for Ethiopia

A 2-day workshop to stimulate awareness and the need for an organic agriculture movement in Ethiopia was held in Addis Ababa in May 2007. The collaborating institutions in the organization of the workshop were Agro Eco of the Netherlands, the Dir Foundation of the Netherlands and Ethiopia, and the Safe Environment Association (SEA) and Institute for Sustainable Development (ISD) of Ethiopia. Responsibility for raising the funds and organizing the logistics of the workshop were given to ISD. [24]

Although the plan was to invite up to 45 participants, interest in the workshop grew rapidly, particularly from mid-May, so that there were 76 people present on the first day, including 9 journalists, and over 60 on the second day of the workshop. Participants included representatives of the major stakeholder groups in the country – government offices, non-governmental and civil society organizations (NGOs and CBOs), agricultural research, certifiers, exporters, and farming cooperatives – as well as representatives from Grolink of Sweden, Agro Eco of the Netherlands, and the Horn of Africa-Regional Environmental Network and Centre (HoA-REN/C) based in Ethiopia.

Both exporters and local growers' groups, principally youth and women practicing organic urban agriculture, put up displays of their produce. These ranged from high quality vegetables, and even eggs, through samples of honey and wax, aromatic plants, spices, coffee and sesame to field crops. Particularly interesting was a display from the Institute of Biodiversity Conservation of samples of farmers' varieties (landraces) of Ethiopia's traditional crops. [25]

At the end of the workshop, a task force was identified to establish an Organic Agriculture Movement for Ethiopia. A small company called Aco Ersha (meaning 'agriculture as our mother did it'), set up by an agronomist and a plant protection specialist, both trained in organic agriculture in Europe and Israel, offered to host the secretarial functions needed to launch the organic agriculture movement and on 27 November 2007, the Ethiopian Association for Organic Agriculture (EAOA) obtained its legal recognition.

The 7-member Board of EAOA includes representatives from producers (farmers and cooperatives), organic certifiers, NGOs and organic businesses. The first task of Aco Ersha in the name of EAOA has been to encourage and coordinate Ethiopian producers and exporters to attend the largest organic agriculture exhibition in

Europe, Biofach in Nuremberg at the end of February 2008. There will be 24 organizations from Ethiopia attending Biofach making this the second largest country display representation from Africa. ISD will be represented because the horticultural expert in ISD is also a Board member of EAOA.

Locally, the EAOA will lobby the Ethiopian Government to complete and produce the laws needed to define organic production systems and products in the Ethiopian context, and establish a local certification authority.

ISD, itself, is now starting to develop projects and programmes to bring the smallholder farmers of Ethiopia more firmly into the whole organic agriculture system by focusing on the widely grown field crops of the country, particularly the cereals barley and durum wheat, and the pulses chickpea, fenugreek and lentils. [26]

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Houshold Tree Planting in Tigray: Tree Species, Purposes and Determinants

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Abstract

Trees have multiple roles in rural livelihoods and provide significant economic and ecological benefits for poor farmers. For example, by providing the household with wood products that can be converted into cash or used as firewood, planting trees increases household incomes. Planting trees also decreases soil degradation.

In the current study we empirical analyze the determinants of household tree planting using a unique data set covering cross-section of 200 households from the Tigray province, northern Ethiopia. We investigates two attributes of household tree growing, i.e., a household's decision to grow trees and the extent of tree growing, in an econometrically consistent framework. We used logistic model to determine most important purpose(s) for which households plant trees. Our findings suggest that both household characteristics, characteristics of the household head and village level factors determine household tree planting.

Key words: Tree planting/growing; tree species; tree attributes/purposes; Tigray; Ethiopia.

JEL *classification*: Q2; Q23; Q28

1. Introduction

Trees have multiple roles in rural livelihoods and provide significant economic and ecological benefits for poor farmers. For example, by providing the household with wood products that can be converted into cash or used as firewood (Thacher et al., 1997), planting trees increases household incomes. Planting trees also decreases soil degradation. Some studies have suggested that *Eucalyptus* trees, which are relatively fast growing, are particularly profitable in northern Ethiopian context. They found rates of return to farmers' investments in *Eucalyptus* to be often above 20 percent (Jagger and Pender, 2003). The economic benefits are greatest specially when community wastelands-which are of low quality and have few productive uses-are used for private tree planting. Similarly, the environmental benefits are substantial particularly when the trees are planted on degraded land.

Moreover, planting trees is currently been seen as an alternative livelihood strategy in areas of the country that are plagued by drought, including much of Tigray, soils are very poor, and rainfall is inadequate and where fertilizers and improved seeds focused agricultural extension intervention are deemed to be less successful. In fact, on top of planting trees, there are many other ample opportunities to increase agricultural production and household incomes in these dry land areas, while at the same time practicing sustainable use of natural resources. Some of these strategies that are particularly profitable constitute soil and water conservation measures, small livestock production, development of non-farm activities, and improved management of community resources. (Pender et al., 2006)

Tree planting also has significant linkages to activities such as honey and beeswax production. These are two key by-products of planting trees that can be produced with relatively low-input, low-cost technologies. Note that these two (by-) products are often referred to as non-timber forest products (NTFP) in the standard literature. Tremendous opportunities also exist to increase a family's income particularly if rural households can get these products to market. Ethiopia ranks fourth in the world in beeswax exports, and tenth in honey. And tree planting could substantially enhance the production of these NTFP and the country's role in the export market. Therefore, it would of interest understanding the behavioral factors underlying household tree planting.

The purpose of the current study is to analyze the determinants of household tree planting using a unique data set covering 200 households. More specifically, the objectives of the study are twofold: first, we investigate the determinants of household's decision to plant trees and the extent of tree growing. Second, we identify the most important attributes/purposes for which the trees are grown. Key questions are: what factor(s) enhance the likelihood of involvement in tree planting? What are the most important attributes/purposes for which households grow trees? We tackle the question of most important attributes/purposes for which households grow trees by considering 3400 (i.e., 200×17) observations on tree species grown and the purpose(s) meant for that came from these same households. Our goal in here is to determine as to which purpose(s) enhance the likelihood of involvement in tree growing on a species-by-species binary choice fashion. Finally, we draw lessons/implications for policy from the stories that the data tell about.

The paper is organized as follows we begin in the next section with tree planting and tree resources in Tigray, the theory model is presented in section 3.. In section 4, we outline an empirical model, and then section 5 results and discussions. We conclude by drawing some policy implications.

2. Tree Planting and Tree Resources in Tigray

Planting trees has been an indigenous practice for generations. Experiences of adapting or transplanting self germinated seedlings from the bush (forest) to the backyard were there for centuries. Self germinated seedlings of the species weyra (*Olea europaea*), tsihdi (*Junipers procera*) and tahses (*Dodonia viscosa*) were the ones which were adapted to the backyard (Gebreegziabher, 1998) . The adapting process involved finding and uprooting of the seedlings from the bush and planting it at the backyard . However, afforestation efforts by government in Tigray began in 1970. Between 1970 and 1974 nearly 1,500 ha were planted and terraced at 11 sites (Hunting, 1976), an insignificant area considering ongoing levels of degradation. A survey in 2000/01 showed that there are about 9 woodlots or plantation sites per *tabia*[1], most of which were established in the post 1991 period. The average size or area of the woodlots varied between 5 and 18.5 hectares (Gebremedhin et al., 2003; Jagger et al., 2003).

Three distinctions are now made regarding tree resources (forests) in the country at large and Tigray in particular. These are *private (individual)* tree holdings, *community* woodlots, and *state* forests. The *private* tree holdings include trees privately grown around homesteads and cultivated land for various purposes that fall under the category technically referred to as agro forestry. It also includes indigenous trees grown or managed for various purposes. The diversity of tree species grown by private households[2] can be aggregated into indigenous trees, *Eucalyptus* species, other exotic species (e.g., *Shinus molle*, *Acacia decurrens*, etc), cash crop trees (coffee, etc), fruit trees (lemon, orange, papaya), and multi-purpose trees (i.e., leguminous and for fodder almost entirely *Sesbania* species). The proportion of tree growing farmers by agro-ecology and type of trees is provided in Table 1. Indigenous trees and *Eucalyptus* are the two most important. Overwhelmingly farmers in the lowlands plant indigenous rather than Eucalyptus species, while the opposite happen to be the case for the midland and highland regions. Clearly, government nurseries constitute major sources of seed/seedlings in all regions and for all species, with the exception of cash crop and fruit trees (Table 2).

***Table 1** Distribution of tree growing farmers (households) by agro-ecology and tree type, Tigray in 2000 (in %)*

Tree type	Agro-ecology			
	Lowland (East)	Lowland (West)	Midland	Highland
Indigenous	74	69	70	58
Eucalyptus	13	14	65	89
Other exotics	6	31	11	11
Cash crop trees	8	0	7	6
Fruit trees	6	0	7	6
Multi-purpose trees	6	0	2	0
No trees	19	22	7	6

Source: WBISPP (2002)

***Table 2** Distribution of tree growing farmers (households) by seed (seedlings) sources and tree type, Tigray in 2000 (in %)*

Tree type	Seed (seedling) source							
	Gov't nursery	Other farmer	Own nursery	Market	NGO	School	Church	Community plantation
Indigenous	60	6	17	8	3	1	2	0
Eucalyptus	72	4	9	12	0	1	1	1
Other exotic	85	0	12	3	0	0	0	0
Cash crop	28	26	16	4	0	0	0	0
Fruit trees	8	0	12	29	0	0	0	0
Multi-purpose	91	0	0	5	0	0	0	0
All trees	66	6	12	11	1	0	1	1

Source: WBISPP (2002)

1 Tabia is the name for the Local County or lowest administrative unit which constitutes about 1000 to 1500 housholds.

2 Three distinctions can be made regarding property rights and tree resources in Tigray: private or household tree holdings, community woodlots, and state forests (Gebreegziabher, 2007). The private or household tree holdings include trees privately grown around homesteads and cultivated land for various purposes that often fall under the category technically referred to as agro-forestry.

Arguably, property rights here are vested in the individual farm household, except for the policy restrictions. Article No. 10.1 of the current land policy of the region (TNRC, 1995) also gives the ownership of trees found on the cultivated land to the user or the farmer to whom the holding belongs. It restricts cutting of economically important indigenous trees such as *Boswellia papyrifera*, *Acacia senegal*, *Ficus vasta*, *Diospyros mespiliformis*, *Faidherbia albida (Acacia albida)*, *Ficus sycomorus*, and *Podocarpus gracilor* found on cultivated land. However, the holder (farmer) is free to make use of sell or rent the yield, berries or exudes of such trees found on her land. Nevertheless, despite the aforementioned merits, there appear to be ambiguities in two important respects of tree tenure rights: Firstly, a farmer is required to get permits from the local *baitos* for cutting trees grown by one self, in the event of a need to cut the trees. Secondly, it prohibits the planting of Eucalyptus trees on cultivated fields.

The *community* woodlots are area enclosures and community plantations where the rights are vested in the respective community. The story of community woodlots in Ethiopia goes to the period between 1975 and 1990 when area enclosures and community plantations were initiated primarily for ecological regeneration as part of the environmental reclamation program. However, these proved unsuccessful presumably not only because they were top-down oriented but because they were largely ecological oriented and lacked economic linkages with the respective communities (Hoben, 1995). Cognizant of the previous failures, *community* woodlots in Tigray after 1991 were initiated through a better participatory process with both ecological and economic objectives (Gebremedhin *et al.*, 2003). These *community* woodlots are more or less regulated by the respective communities with some form of local bylaws. These bylaws most often emphasize input contributions and protection against human and livestock interference. The critical challenges in these *community* woodlots appear to be the use restrictions. With few exceptions, uses such as cutting trees (branches), shrubs, collecting fuel wood, etc are not allowed in most woodlots. The benefits received currently by the community constitute mainly of cut grasses. The *community* woodlots hence collective action might be viewed as viable resource management arrangements in areas with intermediate population density and more remote markets. However, it turns out that a further step is needed for *community* woodlots to incorporate utilization and benefit distribution issues in their bylaws which in itself, in turn, call for another institutional arrangement to handle those issues.

State forests constitute natural high forests preserved for biodiversity conservation and other purposes in which the property rights are vested in the state. It could be either national forest priority area (NFPAs) or regional forest priority areas (RFPAs). Cross-boundary forest areas also fall within the category of *state* forests. The first priority within the context of these high forests is protection and conservation. Of the 58 most important high forest areas classified or designated as national forest priority areas (NFPAs), two are found in Tigray (EFAP, 1994). However, the development and utilization of these two high forests in Tigray has been constrained by the lack of implementation of management plans. In addition, as these areas were delineated without the consent of the local communities that lived with the forest perhaps for decades, integrating and involving the local communities in management and benefit sharing poses another challenge.

3. Theoretical Model

There are two approaches to analyzing the tree growing (planting) decision of households: one is to choose investments that maximize net expected returns (Patel et al., 1995), the other analyzes the behavioral factors that underlie the tree growing decision (Thacher et al., 1997). The former views tree planting as an investment to be undertaken if tree planting yields higher net expected returns compared to major crops such as maize and coffee, or if it enhances the output of agricultural crops so that costs of tree planting are more than covered. Under the behavioral approach, an individual farm household is assumed to be involved in tree planting so long as the utility attained from planting or investing in trees is larger than what would be attained otherwise.

Let t=1 if a household decides to plant trees, and 0 otherwise. Then, the utility function for the ith household's decision can be specified as $U(\mathbf{z}_i^t,\mathbf{h}_i)$ (Chambers and Foster, 1983), where $\mathbf{z}_i^t$ is a vector of attributes related to tree planting and $\mathbf{h}_i$ is a vector of household i's specific socio-economic characteristics.

Given that behavior is consistent with a well-defined utility function, the utility associated with not planting trees can be written as:

$$U_i^0=V(\mathbf{z}_i^0,\mathbf{h}_i) + \eta(\mathbf{z}_i^0,\mathbf{h}_i,e_i^0), \qquad (1)$$

where V and η are real valued functions with V the certain component of utility and η the random component, and e_i^0 is a vector of unobserved variables containing all unmeasured attributes and characteristics. Similarly the utility from planting trees can be written as:

$$U_i^1=V(\mathbf{z}_i^1,\mathbf{h}_i) + \eta(\mathbf{z}_i^1,\mathbf{h}_i,e_i^1), \qquad (2)$$

where e_i^1 is a vector representing unmeasured attributes or characteristics relating to the planting decision. Utility maximization condition implies that the household will plant trees when:

$$V(\mathbf{z}_i^1,\mathbf{h}_i) + \eta(\mathbf{z}_i^1,\mathbf{h}_i,e_i^1) > V(\mathbf{z}_i^0,\mathbf{h}_i) + \eta(\mathbf{z}_i^0,\mathbf{h}_i,e_i^0). \qquad (3)$$

Among the household variables influencing the tree planting decision are income, labor, area cultivated and number of cattle. Income and labor availability are expected to increase a household's probability of investing in trees. Land holding is expected to have a positive influence on the number of trees planted, because greater land availability would be expected to permit tree planting without the sacrifice of agricultural production necessary to meet food and income needs of the household. We distinguish between land area cultivated and homestead area. Cattle may be either a substitute or a complement to tree planting.

Regarding tree attributes, one can envisage trees having multiple roles for rural livelihoods. One attribute could be that they provide households with wood products that can be used as firewood or converted into cash (Thacher et al., 1997). Moreover, trees provide wood for various local uses, such as housing construction, fencing, farm tools (implements), furniture, and household utensils. Trees also provide products such as fodder, berries for food and serve as bee forage. In addition to fulfilling such material needs, trees have an important ecological function in agricultural systems, maintaining and enhancing the physical environment needed to sustain crop production (Filius, 1982). Farm households will also plant tree species on the basis of specific attributes such as fast growth, ability to protect against winds, and so on.

4. Empirical Model and Data

4.1 Household tree planting determinants

Consider a random sample of *n* observations, and distinguish between the household's decision whether or not to be involved in tree planting (growing) and the extent of tree planting (growing). Let Y_{1i} and Y_{2i} respectively denote the household's decision whether or not to involve in tree planting and the extent of tree planting by a household, and let Y_{1i}^* and Y_{2i}^* be the corresponding latent variables underlying tree planting measures. The Heckman selection model equations for household *i* are specified as (Verbeek, 2004):

$$Y_{1i}^* = X_{1i}\beta_1+u_{1i}, \qquad (4a)$$
$$Y_{2i}^* = X_{2i}\beta_2+u_{2i} \qquad (i=1, \ldots,n), \qquad (4b)$$

where X_{ji} is a $1\times K_j$ vector of exogenous regressors, β_j is a $K_j\times 1$ vector of parameters, and

$u_1 \sim N(0,1)$, $u_2 \sim N(0, \sigma)$, and $corr(u_1, u_2)=\rho$.

Note that Y_{2i}^* is not observed for households not involved in tree planting. As in Heckman (1979), equation (4a) is the selection equation and equation (4b) is the regression equation. The first equation is of binary choice type specified to describe whether or not i^{th} household is involved in tree planting. Then, we have the following observation rule:

$$Y_{2i} = Y_{2i}^*, Y_{1i}=1 \text{ if } Y_{1i}^* > 0 \qquad (5)$$
$$Y_{2i} \text{ not observed}, Y_{1i}=0 \text{ if } Y_{1i}^* \leq 0. \qquad (6)$$

where Y_{2i} is household *i*'s actual number of trees grown. The binary variable Y_{1i} simply indicates growing or not growing trees.

The Heckman selection model is preferred over standard models, because it corrects for selection bias and it enables us to discern whether or not the same factors underlie the decision to plant trees and the extent of tree planting.

4.2 Tree species and purposes

We specified logistic regression model to determine/ identify the most important attribute(s)/purpose(s) of household tree growing as :

$$prob(y_i = 1) = \frac{e^{x'\beta_i}}{1+e^{x'\beta_i}} \qquad (7)$$

where x is a vector of explanatory variables (i.e., in our case elicited purposes why for households plant/ grow a particular tree species) and β_i vector parameters to be estimated.

Note that this is viewed in the context of which attributes/factors are more important or enhance the likelihood of households involvement in planting a particular tree species.

Table 3 *Summary statistics of variables used in regression (n=200)*

Variable	Mean	Std. Dev.	Min	Max
Family size	5	2	1	12
Adult males	1	1	0	5
Adult females	1	1	1	4
Household income (Eth Birr/month)	140.01	94.23	9.94	647.08
Number of cattle	4	3	0	14
Land area (hectares)	2.54	2.98	0	19
Age of household head	48	13	23	85
Education of head (year of schooling)	0.92	1.47	0	7
Sex of head				
Male (in percent)	21.0			
Female (in percent)	79.0			
Involvement in tree planting				
Households involved (in percent)	86.5			
Households not involved (in percent)	13.5			
Total Number of trees (all trees)	74	172	0	1834

4.3 Data and sampling design

Our data are from a survey of 200 households conducted in 2000 in Tigray, northern Ethiopia. Two-stage sampling was used to select the sample households. First 50 *tabias* – the smallest administrative unit in the region – were randomly selected from a total of 600 available *tabias*, and then a random sample of 200 households was selected from these *tabias*. Both quantitative and qualitative data were collected on the household's production (collection) and consumption of various biomass fuel types, and tree planting; demographic characteristics of the household include age, sex and literacy level/education of the household head and household size. Family resource endowments include total land holding, cultivated area, livestock holdings, and tree growing. Data on tree planting (growing) covered number of trees grown by species, age of trees, purpose(s) for which the trees were grown. Also obtained from the survey were village level factors, including agro-ecological conditions or altitude range and distance traveled (time spent) to collect different fuels.

In rural settings, it is not uncommon to find diversity of tree species grown by farm households. In our dataset, we found a total of 112 tree species grown by sample households, of which seventeen species dominated, hence, were included in the analysis. Twelve of them are indigenous, while the remainder are exotic species. The detail scientific and vernacular or local names of these seventeen tree species has been provided in Table A.1 in the Appendix.

5. Results and Discussion

5.1 Household tree planting determinants

In here we explore what factor(s) enhance the likelihood of involvement in tree planting as well as the extent of tree growing? The Heckman selection model estimates of the determinants of household tree planting decision and the extent of tree growing are presented in Table 4.

Most of the variables considered were found to be highly significant and positive in both the selection and regression equations. From the selection equation results (Table 4), number of adult males was negative and significantly influenced the household's decision to grow trees, whereas number female adults was found to have highly significant and positive effect. Land area cultivated was important and highly significantly influenced tree growing decision with expected positive sign, indicating that households with relatively more land are more likely to be involved in tree planting compared to households with relatively less land. However, both household income and number of cattle turned out to have no significant effect on households' tree planting decisions. Other household characteristics such age, sex and education of head also highly significantly and positively influenced household's tree planting decision. All the location factors/variables considered also turned out to be positively and highly significantly related to household's tree planting decision, implying that the likelihood of the household deciding to plant trees increases as one moves up to the middle and upper highlands, relative to the lowlands.

Table 4 *Heckman selection model results of determinants of tree planting (dependent variable total number of tree planted) and of the decision to plant trees*

Explanatory Variable	Estimation results	
	Coefficient[a]	t-statistic
Regression equation		
Adult males	-0.139*	-1.66
Adult females	0.438***	3.65
Land size (hectares)	0.509***	2.81
Number of cattle	0.002	0.07
Household income (Birr/month)	0.000	0.69
Age of head	0.054***	8.86
Education of head	0.169***	2.99
Sex of head	0.767***	3.46
Middle highland	0.671***	3.77
Upper highland	1.070***	4.81
Constant	-5.199***	-18.80
Selection equation		
Adult males	-0.027*	-1.66
Adult females	0.084***	3.71
Land size (hectare)	0.098***	2.84
Number of cattle	0.000	0.07
Household income (Eth Birr/month)	0.000	0.69
Age of head	0.010***	10.02
Education of head	0.032***	3.03
Sex of head	0.147***	3.52
Middle highland	0.129***	3.86
Upper highland	0.206***	4.99
Statistic		
ρ	1	1.45e-12[b]
σ	0.192	0.010[b]
λ	0.192	0.010[b]
N	200	
Log likelihood	28.676	
Wald Chi2(10)	4633.75	
Prob>chi2	0.000	
LR test of indep. eqns. (rho=0): chi2(1) = 105.47 Prob>chi2 = 0.000		

a ***, and * indicate statistically significant at 1%, and 10% level (or better), respectively.
b standard error rather than t-statistic.

With respect to the extent or amount of tree planting, number of adult males still negatively and significantly influenced the number of trees grown by a household, albeit at lower level of significance. This suggests that households with relatively more number of adult males will grow less trees than households with less number of adult males. As it was the case on household's tree planting decision, number of adult females also turned out to have highly significant and positive effect on extent of tree growing of household, probably because planting wood trees is essentially female activity. Cultivated land area was found to have highly significant effect on number of trees grown by household, still with expected positive sign. Number of cattle was found to have no significant effect on extent of tree growing of households, as was the case in households' tree planting decisions. Probably because the livelihood role of trees is dominant and, hence, wealth has no significant relationship with tree planting. As was the case in households'tree planting decisions, household income was also found to have no significant effect on extent of tree planting,. All the location factors/variables, i.e, both middle and upper highland, highly significantly and positively influenced the extent of tree planting. It implies that households located in middle and upper highlands plant more trees compared to those in the lowlands. Such results depict the diverse nature of the agro-ecological specificity of the activities like tree planting.

Concerning the goodness of fit, likelihood ratio, LR test (see bottom row of Table 4), suggests that we can not reject the alternative hypothesis that roe is different from zero, implying that the two equations are not independent (or cannot be estimated independently) and Heckman selection model was the right procedure. Which justifies that we used an econometrically consistent framework estimating the two attributes of household tree growing, i.e., a household's decision to grow trees and the extent of tree growing.

Model results or findings are interesting in the sense it turns out that the same factors underlie the two aspects of tree planting, i.e., household's tree planting decision and the extent of tree growing.

5.2 Tree species and purposes

To identify the most important purposes for which the trees are grown, logistic regression of the purposes of tree growing was run on species-by-species basis for seventeen tree species considered in the study. Results are presented in Table 5. Detail description of the tree species considered in the study is presented in Appendix Table A.1.

***Table 5** Logistic regression results (standard error in parenthesis) of purpose(s) of tree growing by tree species*

Explanatory variable	Tree Species [a]								
	1	2	3	4	5	6	7	8	9
Market (=1; 0 otherwise)					8.1435*** (1.0383)				
Fuel wood (=1; 0 otherwise)	2.509*** (0.6088)	5.617*** (0.8493)	0.7825 (0.6017)	4.9099*** (1.1538)	3.0873*** (0.3531)	2.5777*** (0.7005)	0.5265 (0.4995)	0.7770 (0.7577)	2.2216** (1.1106)
Soil conservation (=1; 0 otherwise)		6.0752*** (1.8819)							6.5616*** (1.7336)
House construction (=1; 0 otherwise)	0.9385 (0.6204)	-1.0487 (0.7158)	-1.0402* (0.6168)	0.0013 (0.8280)		1.0509* (0.6093)	0.1821 (0.5467)	0.4685 (0.8792)	
Fodder (=1; 0 otherwise)		-2.4681* (1.4359)	-.5296905 (0.6747)			-0.7551 (0.7723)	0.2926 (0.4382)	0.5823 (0.5490)	
Farm implements (=1; 0 otherwise)	0.1824 (0.6842)	-1.1973 (0.8018)	5.0122*** (0.7697)		1.3227*** (0.3757)	-0.2241 (0.6204)	2.5371*** (0.4981)	1.6172** (0.7833)	-1.1293 (1.2710)
Fencing (=1; 0 otherwise)	-0.1987 (1.0894)					2.7766*** (0.5599)	2.5448*** (0.5063)	1.2955 (0.9325)	4.4802*** (1.2804)
Shade (=1; 0 otherwise)	1.6841** (0.7258)					-0.5651 (1.1321)	1.5809*** (0.6007)	3.0937*** (0.7422)	
House utensils (=1; 0 otherwise)			4.30455* (2.4107)						
Constant	-6.502*** (0.4299)	-7.4846*** (0.7273)	-7.0763*** (0.5844)	-8.1092*** (1.0002)	-5.0525*** (0.2147)	-6.4383*** (0.4161)	-5.9285*** (0.3229)	-7.0936*** (0.5674)	-8.4936*** (1.0957)
Pseudo R2	0.2309***	0.4288***	0.4337***	0.3177***	0.6220***	0.3149***	0.3054***	0.2773***	0.4653***

Table 5 Continued

Explanatory variable	Tree Species [a]							
	10	11	12	13	14	15	16	17
Market (=1; 0 otherwise)								
Fuel wood (=1; 0 otherwise)	0.3424	-1.4118	-0.5995	-0.5185	0.3513	0.1502	0.2407	0.3474
	(0.6358)	(0.9446)	(0.8753)	(0.8766)	(0.5775)	(0.7043)	(0.7376)	(1.5188)
Soil conservation (=1; 0 otherwise)								
House construction (=1; 0 otherwise)	2.6366***			3.9677***	2.3410***	1.3455	4.5209***	
	(0.6258)			(0.9699)	(0.5900)	(0.8682)	(0.9053)	
Fodder (=1; 0 otherwise)	0.4754	1.9922***	1.0175		1.1579*			4.3008***
	(0.8216)	(0.7933)	(0.9115)		(0.6716)			(1.5203)
Farm implements (=1; 0 otherwise)	-0. 0374	-0.3825	1.5089*		1.3195***			
	(0.6882)	(0.9022)	(0.8069)		(0.5449)			
Fencing (=1; 0 otherwise)	2.1288***		0.0934	2.8722***	-0.3735			
	(0.6350)		(1.3857	(0.8692)	(1.1188)			
Shade (=1; 0 otherwise)		5.6361***	5.0952***		1.6509**	5.7470***		
		(0.6632)	(0.8953)		(0.6936)	(0.7085)		
House utensils (=1; 0 otherwise)	3.1627							
	(2.0021)							
Constant	-6.1666***	-6.7786***	-7.5603***	-7.4513***	-6.0954***	-7.1475***	-7.4274***	-3.1143***
	(0.3674)	(0.5138)	(0.7255)	(0.7098)	(0.3521)	(0.5924)	(0.7076)	(1.3027)
Pseudo R2	0.2234***	0.3937***	0.4224***	0.3383***	0.2202***	0.4711***	0.3117***	0.4847***

[a] ***, **, and * indicate statistically significant at 1%, 5% and 10% level (or better), respectively.

The purposes fuelwood and shade were found to be the most important in the case of the species *Acacia ethbaica*. The purposes fuelwood and soil conservation were found to be most important in the case of *Euclea shimperi* whereas farm implements was found to be the most important purpose in the case of *Olea europaea*. Although at a lower level of significance, making household utensils was found to be another important purpose for which *Olea europaea* is grown. Fuelwood was found to be the most important purpose in the case of *Rhus natalensis* whereas market, fuelwood and farm implements were found to be most the important purposes in the case of *Eucalyptus* spp.

Fuelwood and fencing were found to be the most important purposes in the case of *Acacia lihay*. In addition, however at a lower level of significance, house construction was found to be another important purpose of growing *Acacia lihay*. Farm implements, fencing and shade were found to be the most important purposes in the case of *Acacia seyal* whereas farm implements and shade were found to be the most important purposes in the case of *Balanites aegiptica*. Soil conservation, fencing and fuelwood where found to be the most important purposes in the case of *Mytenus senegalensis* whereas house construction and fencing were found to be the most important ones in the case of *Faidherbia albida*. Fodder and shade were the most important purposes in the case of *Azadricha indica* whereas shade was the only most important purpose in case of *Acacia saligna*. Moreover, however with low level of significance farm implements was found to be another important purpose in the case of *Acacia saligna*.

House construction and fencing were found to be the most important purposes in the case of *Euphorbia candelabrum* where as house construction, farm implements, and shade were found to be the most important purposes in the case of the species *Croton macrostachys*. Shade was found to be the most important purpose in the case of *Shinus molle* house construction was the only most important purpose in the case of *Juniperus procera* and fodder in the case of *Ficus species*.

Generally, results depict the multiple role of trees in rural livelihoods and the multiplicity of purposes involved in household tree planting. Most of the trees considered were found to involve diversity of purposes.

6. Conclusions

This paper analyses the determinants of household tree planting using datasets from sample cross-sections of 200 households in the highlands of Tigray, northern Ethiopia. Key questions were: What factor(s) enhance the likelihood of involvement in tree planting as well as the extent of tree growing? What are the most important purposes for which households' plant trees? The following lessons or conclusions could be drawn.

As regards to factors underlying the households' decisions to plant trees and the extent of tree planting, both household characteristics, characteristics of the household head and village level factors were found to be the most important determinants. Our findings reveal a clear pattern, that exactly the same factors do underlie the two aspects of tree growing. Moreover, our findings also point to intra-household patterns of resource endowments or allocation such as male versus female labor availability in the household's decision to grow trees as well as the extent of tree growing.

Generally, results depict the multiple role of trees in rural livelihoods and the multiplicity of purposes involved in household tree planting. Most of the trees considered were found to involve diversity of purposes.

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Appendix A.

1 Description of Tree Species considered in the study

Tree Species	Scientific name	Local name	Key
1	Acacia ethbaica	Seraw	Indigenous
2	Euclea shimperi	Kliow	Indigenous
3	Olia europaea	Awlie	Indigenous
4	Rhus natalensis	Tetaelo	Indigenous
5	Eucalyptus spp	Kelanitos	Exotic
6	Acacia lihay	Lihay	Indigenous
7	Acacia seyal/ abyssinica	Cha'a	Indigenous
8	Balanites aegiptica	Mekie/Bedano	Indigenous
9	Mytenus senegalensis	Argudi	Indigenous
10	Faidherbia albida (Acacia albida)	Momona	Indigenous
11	Azadricha indica	Neem	Exotic
12	Acacia saligna	Akacha	Exotic
13	Euphorbia candelabrum	Kolankul	Indigenous
14	Croton macrostachys	Tambukh	Indigenous
15	Shinus molle	Tikur berbre	Exotic
16	Juniperus procera	Tsihdi	Indigenous
17	Ficus spp	Shibakha	Exotic

Conservation and Production Potential of Afforestation Activities in Tigray

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Abstract

The environmental degradation of Ethiopia and Tigray has been documented and described in detail by several studies. The complex problems of land degradation are partly addressed with the various efforts in afforestation. The current efforts in afforestation concentrate around private woodlots, area closure, community plantations and hillside distributions. The private woodlots show a high level of biomass gain and survival of seedling however do not cover a substantial land area. The area closures have a good social mobilization impact, economic gains and good success in environmental rehabilitation, however the biomass gains and actual productivity volume is not substantial. The community plantations cover a substantial land mass and show good biomass gains, however do not have a good seedling survival rate. Hill side distribution interventions, though promising also have some room for improvement. Overall, the interventions combined still fall short in meeting the demand for forest products, especially fuel wood demands. Thus there is need for improved extension services supported by research on mainly fast growing indigenous species with potentials to produce fuel wood, fodder and/or timber.

Background

Tigray, the northernmost region of Ethiopia, as the rest of the country faces environmental degradation (e.g. Tekeste and Smith 1989, Zenebe 1996). The long history of human settlement is an indicator of the extent of continued pressure on forest resources in the region (HTS 1975). The recurrent drought and poor crop production associated with increased land degradation, which can be seen from the rock outcrops and deep gullies, are clear indicators of the magnitude of the ecological disasters in the region. Land degradation in Tigray expresses itself in the high rates of soil erosion, reduction of the food production potentials, and loss in biodiversity of both fauna and flora (Tekeste and Smith 1989). Land degradation reduced biological productivity as a result of changes in the climatic and human use and management regimes (Valentin 1992). The vegetation cover of Tigray was estimated at only 0.3% in 1994 (SAERT 1994, cited in Anon 1994). HTS (1975) twenty eight years ago, estimated erosion rates to be 17 to 33 metric tons ha^{-1} $year^{-1}$ in the region. Hurni (1990) estimated average soil loss in the region by sheet and rill erosion to be 12 metric tons per ha per year. This value excludes soil lost through gullies and rivers. With increased pressure and intensive agricultural practices, which outweigh the efforts of environmental protection (REST, 1994 cited in MUC 1996), a higher rate of erosion is expected. Consequently 50% of the highlands are significantly eroded, 25% seriously eroded, and 4% are economical un-utilizable (FAO 2003).

The forest cover of Ethiopia is at present estimated to be 4.6 million hectares (ha), amounting to about 4% of the total area of the country (Million 2001). Ethiopia has on average lost 40,000 ha of forest per year from 1990 to 2000 G.C. (Ibid). In 1992 in Ethiopia the energy demand was 45 million m^3, while the supply was only 12.5 million m^3. This gave a deficit of 32.5 million m^3. The projected demand, with the increasing human population for the year 2014 was 89 million m^3 (EFAP, 1994). However, in 2003 the energy demand already reached 87 million m^3 (FAO 2003). In Tigray we find a similar pattern, in 1994 737,717m^3 wood products were produced, where as the demand was 4,402,439m^3, out of which 4,313,700m^3 of the demand was for fuel (TFAP 1996). In 2017 demand is predicted to reach 9,551.4 thousands m^3, while supply at the same time will decline from 737,717m^3 to 563, 517m^3 with the demand and supply gap widening from 3, 664, 722 to 8, 951, 883m^3 if no interventions are made (Ibid). With intervention the demand supply gap can become 8, 144, 753m^3. A difference of 807,130 m3 of wood being produced (Ibid). The Woody Biomass Inventory and Strategic Planning Project concluded in 2000 estimated the annual fuel wood demand of Tigray to be 3,027,851 million m^3, while the estimated annual sustainable supply is only 1,461,528 million m^3 with a resulting deficit of 2,566,323 (WBISSP, 2004 in Mengesteab, 2006).

To circumvent these problems, communities have started to establish area closures in degraded areas, establish wood lots and distribute hillsides with the hope of preventing further degradation and promoting re-vegetation. The main objective of establishing such systems is to improve the overall ecological conditions of degraded areas, so that they can provide better socio-economic benefits to the local communities.

What is then being done?

Although there is still a need for research, a lot of attempt has been made to tackle the problem based on experiences and lessons from other areas in the world. These efforts in Tigray have been focusing on community woodlots, area closures, private woodlots, and hillside distributions (Mengisteab, 2006; Zemichael, 2006; Hagos, 2008). Based on Jagger and Pender (2000) there are an estimated 334,000 hectares of wasteland in the highlands of Tigray in need of management to be brought towards productivity. Although Tigray is well known for its degraded landscape, it is also known for its concerted efforts in taking these problems firsthand through soil and water conservation, area closure and reforestation efforts (Fitsum *et al*, 1999). Any land use system is unsustainable if it leads to irreversible biophysical changes in the ability of the land to produce equally well in a future cycle of similar land use, or if the costs of reversing the changes are prohibitive (Mitiku *et al.,* 2006).

Community woodlots have been planted in Ethiopia and Tigray since the time of the Derg (Jagger and Pender, 2000). Over one million tree seedlings were annually produced in the years 1984 to 1987E.C in Tigray. The survival rate of tree seedlings in the region is about 55%. (TBoARD 2005). But compared to the number of seedlings planted every year and the extent of new vegetation cover due to reforestation the survival rate seems to be even lower. Tesfay (1996) found that survival rates just four months after planting were as low as 2% in some sites, but overall were lower than 40%. The BoANRD (2005, in Zemichael 2006) reported that, between 1992 and 2004 a total of 177.2 million seedlings were planted in communal plantations, out of which 46.8% have survived. According to Berhanu (2000 in Zemichael, 2006) collective action is an appropriate tool for fighting land degradation; however its effectiveness can be limited by three reasons. The first is the tragedy of the commons, i.e. the problems in management and avoiding free riding. The second is the lack of clear benefit sharing agreements. The third is the planting and popularisation of inappropriate or unwanted species by the extension services.

Area closures have resulted in many degraded forests, woodlands and bare lands being set aside and closed from grazing and wood harvesting for rehabilitation. CHADHOKAR (1992) argues that although there are many difficulties to be faced with this method, it has very high potential as it is easy and does not require a lot of resources for implementation. Establishing enclosures is considered advantageous since it is a quick, cheap and a lenient method for the rehabilitation of degraded lands (Bendz, 1986).

In the Tigray Region there was a plan of establishing 128,000 ha of closed areas until the year 2001. Until 1996 about 143,000 ha of land were already closed (TFAP 1996). As closing more land has been continuing, a lot more degraded land is now being rehabilitated. One can find closed areas ranging from 1 to 25 years of age. In the closed areas profuse natural regeneration has been observed (Kindeya 1997). As a result of this strategy, vegetation is now in a better condition than it was a few years ago. The emergence of enclosure as an alternative strategy is a relatively convenient management option to counteract degradation of the environment, while at the same time providing economic benefits for the local community (Demel Teketay, 2004).The success is well appreciated by the farmers involved. In a survey in Central Tigray, the people preferred to be more involved in the closed area systems rather than in community plantation - reforestation programs (MUC 1996). This is due to the relatively lower success rate achieved in community plantations and smaller labour input required for keeping the closed areas. This is definitely having a positive impact on the ecology and biodiversity conservation of the dry land environment of northern Ethiopia (Kindeya 1997, Medhanie 1997). In this regard, it has become a common phenomenon to observe increase of plant as well as wild animal diversity with time after the establishment of enclosures. In areas where they have been established, particularly in the Northern parts of the country, enclosures are among the green spots with considerable species diversity (Emiru, 2007; Kidane, 2002; Tesfaye, 2002; Tefera *et al*., 2005; Mastewal *et al*., 2007).

The economical significance of area closures has been well studied (e.g. Gebremedhin *et al*., 2000; Tarakegn, 2001; Jagger and Pender, 2003; Kindeya, 2003; Aerts *et al*., 2004; Descheemaker *et al*., 2005; Tefera *et al*., 2005). Moreover, a study conducted by Tefera *et al*., (2005) verified that enclosures have gained the enthusiasm of rural community since they bring back past memories of the vegetation of an area to the minds of the people and, hence, have a good cultural value. Furthermore, trees are vital assets to farmers in that they are sources of income during bad times. Apart from the ecological benefits of these areas, one can easily see that neither wood stocking, nor the non- timber products that can be obtained are substantial. Though in the degraded state it was in the land had not produced anything substantive, it has stopped being used and has the potential to produce more. So far the villagers benefit from it only in terms of environmental aspects and the small amounts of grass they cut and carry. These lands need to be studied, and better methods that will achieve higher biomass production need to be implemented.

Private woodlots are plantations on privately owned land around homesteads and farms. Since the removal of the Derg regime from political power in 1991, one of the major shifts in Ethiopia's forest policy has been the encouragement of private tree planting. The challenges of collective tree planting make private tree planting a potential institutional option that may serve the dual purpose of conservation as well as a source of renewable fuel wood more efficiently than community tree planting, particularly on partitioned hillsides and commons (Bruce, Hoben and Rahmato 1994 cited in Jagger and Pender 2000). The TBoANRD (2005, in Zemichael 2006) reports that, between 1992 and 2004 a total of 293.5 million seedlings were planted in communal plantations, out of which 61.6% have survived.

Hillside distribution is the practice of dividing up degraded hills to individuals, with special emphasis on the landless. Among some of the efforts against land degradation and landlessness, a scheme has been devised aiming at distributing hillsides to individual farmers for forest production (TBoARD, 1998 cited in Mitiku and Kindeya, 2001). Priority to own the hillsides is given to landless farmers. Regulation by the TBoARD indicate that the proportion of plants that should be grown in the hillsides were initially designed to be 50% serving fire wood/construction trees, 25% fodder and 25% serving fruit values. This practice of allocating hillsides for private management in the region has been put in action for about a decade. The practice was initiated by local communities and accepted as a regional strategy to respond to the economic and ecologic demands of the region.

Biomass productivity of these options

The overall biomass produced in Tigray was assessed by the Woody Biomass Inventory and Strategic Planning Project in 2000. The overall biomass productivity under the situations then is presented in the tables below.

Table 1 *Woody biomass supply and mean annual consumption in Tigray National Regional State*

Zone	Percent of the Region	Woody biomass supply,2000		Fuel wood consumption		Proportional figure with respect to percent of region	
		Total Yield (MAI*) tons	Total Yield (MAI) m³	Total dry weight (tons)	Total dry weight (m³)	Woody biomass (MAI) m³	Fuel wood (MAI) m³
Southern	27	93,017	155,028	482,667	804,446	5,741.78	29,794.30
N. western	16	244,117	406,861	290,789	484,649	25,428.81	30,290.56
Central	33	134,789	224,648	615,280	1,025,467	6,807.52	31,074.76
Western	6	333,878	555,464	112,919	188,199	92,577.33	31,366.50
Eastern	16	70,878	118,129	284,291	473,818	7,383.06	29,613.63
Mekelle	2	238	397	30,764	51,274	198.50	25,637.00
Region's total	**100**	**876,917**	**1,460,527**	**1,816,710**	**3,027,853**		

* MAI is the mean annual increment
Source: (WBISPP, 2004 in Mengisteab, 2006)

As the table 1 shows, the mean annual increment of biomass and the fuel wood consumption in the different zones of the region. As can be seen the table above, proportional to the % land cover of the region Mekelle zone produces the least amount of woody biomass while it still consumes a substantial proportion of the woody biomass produced in the region **although alternative energy sources ought to be available in it**. The highest volume of woody biomass is produced in the western zone, and the highest consumption also happens in the western zone **despite the fact that the population density in this zone is the lowest in the region**. All zones except for the western zone, do not produce enough woody biomass for the existing fuel needs.

In a recent study Mengistab (2006) published the actual woody biomass produced in two watersheds in Kilte Awlaelo Woreda in the different areas of intervention. His study showed that there is more woody biomass being produced in community and private woodlots than in area closures (Table 2).

Table 2 *Biomass productio in two watersheds in Kilete Awlaelo Woreda, Tigray*

	Land use	Gemad watershed				Hawza watershed			
		Total area	Per hectare	MAI		Total area	Per hectare	MAI	
				Total	Per hectare			Total	Per hectare
1	Area closure	1339.1	7.5	38.13	0.213	22.10	1.840	7.650	0.1500
2	Free grazing	2905.7	1.9	82.52	0.054	2.14	0.007	0.061	0.0002
3	Controlled grazing	750.0	1.5	21.30	0.043	0.42	0.001	0.011	0.0003
4	Homestead and private woodlots	668.4	1.3	167.10	3.500	139.30	3.400	34.800	3.0000
5	Church forest	2357.6	7.6	66.96	0.220	777.94	19.450	22.090	0.5524
6	Community plantations	13397.2	62.2	3349.30	15.500	100.10	6.670	25.000	4.2000
Total		**21,418.0**		**3,725.31**		**942.00**		**89.612**	**7.9029**

Source: Mengistab (2006 pp 55)

As can be seen in table 2, in both watershed areas the community plantations cover a substantial area, and also produce a substantial amount of woody biomass. The biomass produced in the church forests can be used as an indicator of the potential for production, if complete rehabilitation and proper succession can be obtained without any management interventions. The next largest biomass production is found with the homestead plantations, though they do not cover a substantial area. The area closure in its current state is not producing any substantial biomass, it should however be noted that the land under area closure is initially highly degraded and with very poor potential for high productivity without rehabilitation.

Divers efforts to fight the problem of land degradation in the existing divers environment is mandatory, thus the data presented above is only to show the productivity of these sites and not say that one method and only that needs to be used.

The rehabilitation of area closures is substantial in terms of fauna and flora biodiversity (Emiru, 2002; Sarah 2003; Mastewal 2006); and soil enrichment and hydrological inputs (Descheemaecker 2006). As we saw in table 2 however the biomass production from these sites is poor. On the other had Wisbourg *et al* (2000) found that the area closure managment and future directions are poorly planned. In the same study farmes expressed disapointmet in the increasing woody vegetation dominance in the area closure and the grass production from these sites declined. With poor biomass production and poor grass production, the needs of the farming community are not being met adequately. Therefore there is an urgent need for interventions in management of the area closures in line with the needs and demands of the local communities once the rehabilitation of the sites has been achieved.

The biomass productivity of hillside private plantations as compared to private area closures and communal plantations was assessed by Hagos (2008), the results of which are presented in table 3.

***Table 3** Biomass produced in private hillside plantations, area closures and communal plantations (Hagos, 2006 pp. 59)*

No	Study site	Biomass richness of the site (tone/ha)		MAI	
		Total (tones)	Tone ha^{-1}	Total (tones)	Tone ha^{-1}
1	Denguar hillside plantation	524.60	12.0	65.57	1.50
2	Zalawoini hillside plantation	427.50	9.1	61.07	1.30
3	Denguar area closure	111.34	2.9	15.90	0.40
4	Zalawoini private closure	164.30	2.7	10.20	0.16
Total		**1227.7**	**-**	**152.74**	**-**

As can be seen in table 3, the biomass produced per hectare and the mean annual increment per hectare is higher in the private hillside plantations. As compared to results in table 2, private and communal plantations in sites with higher productivity have higher mean annual increments, however overall the results are promising. However, the initial investment and waiting period coupled with the poor extension services provided present a potential for complications and reluctance expressed by the farming community especially the landless youth.

Possible intervention points

Through discussions with the local communities Wisbourg *et al* (2000) found that the demands and needs of local communites vary from place to place and from person to person. In line with this the expectations and contributions of the community also varies. This shows the need for a detailed community based participatory planning on the future of the area closure. The possiblie options for the area clousres in the short and long term need to be outlined:

1. Short term fodder and/or fuelwood and/or honey forage production using diverse fast growing indigenous pioneer species, with intensive management
2. Long term timber and/or fodder and/or fuelwood and/or honey forage production using diverse fast and slow growing pioneer and secondary species with intensive management
3. Long term land use change to other land management options, with strict land management and conservation interventions

Conclusion and recommendation

In conclusion, the land degradation problem that Ethiopia faces is complex and multi-faceted. This being the fact, the only way to solve this problem is when all aspects of the land resource are managed properly and sustainably, with substantial efforts being made to meet the day to day needs of the local communities.

In line with this the efforts being undertaken in Tigray are impressive and substantial, though they fall short of meeting even the basic fuelwood needs of the communities. The overall low survival rates of seedlings planted in the community plantations, the low biomass production of all land use categories, especially that of area closures shows that the efforts underway need to be strengthened through research and management of these natural resource bases that we have.

More intensified management options need to be laid down and with the full participation of the local communities the management of these communal resources worked out.

Research on the different indigenous and exotic fast growing tree species options that can be used for fodder, fuel and timber needs to be undertaken to support the intensive management needed.

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Implications of Land titling on Tenure Security and Long - term Land investment:

Case of Kilte Awela'elo woreda, Tigray, Ethiopia

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Abstract

Controversies abound on issues and impacts of policies of land tenure in Ethiopia because of limited research in the area and enormous political weight given. The current land tenure system is cited by many as a major impediment to the adoption of sustainable and long-term land improvement practices. In view of this, we decided to undertake an assessment on "the implications of land certification (titling)" implemented during 1998 – 2000 in Tigray, with regard to enhancement of tenure security and long-term land investment practices on small holders' holdings.

The study followed a three stage sampling: woreda selection purposively, Tabia/Kushet randomly and household selection based on ownership of land but randomly from list of land registery. The study was based on structured and semi-structured interviews. The formal questionnaires were administered to 135 randomly selected households from two Tabias. Semi-structured interviews were carried out with key informants and groups discussion. SPSS software (T.-test and Chi-square test) and Binary logit regression analysis was employed as a statistical model.

The findings revealed: 96.3% of study households surveyed confirmed that they were holding use right certificate of their entire holding and 87.5% of them responded that they feel sense of ownership and the current system is satisfactory; believing, they have life long use right and can inherit their holdings to their descendants. Such improvement in status of security of households as compared to previous studies may confirm the developed sense of ownership because of title of land and absence of major land redistributive actions in the area relatively for a decade or so. However, the constraint of male-based titling has been reflected and the need for paired titling and transparent land transfers as there are still unsettled cases in the study area.

The research also found that, land investment practices of long-term nature were underway before and after certification in the study tabias ; however, the variety, quantity, quality and number of farmers involved in, had significant mean difference especially on fruit tree and shallow wells investment (an overall growth observed by 34.1%, after titling). Moreover, before land certification, the attributes of long-term investments were more of the traditional types promoted through mobilizing communities as compared to the latter being largely of private initiative tending towards income generating and observable shift of interventions towards water based technologies. Furthermore, we found statistical significant mean differences between the two periods in number of farmers involved on investments of fruit trees and shallow wells (being significant after land titling) at the level of significance less than 1%). However, that of tree investment showed inconclusive results as was also similar in other studies. Therefore, land certification institution largely contributed, as farmers have felt, to relative security and transferability of land rights in providing incentives for long-term land investment decisions.

Key Terms: Tenure security, long-term land investment, Land certification, Perception, Tigray.

1. Introduction

Background Information

Agriculture is the main stay of the Ethiopian economy. It accounts for 44% of the GDP, contributes nearly 90% of the country's export earnings and 85% of the population earns a living from this sector (MOFED, 2000). Despite the contribution of agriculture to the economy, food production in Ethiopia in the last three decades has never been sufficient to enable the rural population to be food secure (PSNP, 2004).

In Ethiopia/Tigray, land is still the main source of livelihood and investment, for majority of the population. However, studies have indicated that degradation; land fragmentation, tenure insecurity, landlessness etc. have been cause of food insecurity in Ethiopia and the region a well. Of all the factors, land degradation is increasing as a result of poor practices and weak sense of ownership due to the absence of secured land use right. Land tenure systems affect rural farmers not only in the ability to produce for subsistence and for the markets but also their social and economic status, in any way of their incentive to work hard and use land in a sustainable way (Desalegn, 1994). Tenure rights are subjects of hot debate in the theoretical and policy analysis on how to foster economic, social, and environmental goals (Deininger and Binswanger 2001). Moreover, the land holding system in Ethiopia and the region is not purely an economic affair. It is much intertwined with people's culture and identity, and land related issues usually generate intense emotional reactions particularly in rural areas (EEPRI, 2002).

In many circumstances, a variety of measures increasing security and productivity of land users are available without the need of major legislative changes, which include the introduction of simple system of land rights: boundary definition, titling, support for the resolution of disputes etc. at community/individual level (Toulmin and Quan, 2000) in eds. of DFID 2000. A sensible approach expected from governments is thus to facilitate the development of transparent systems for the land rights, by capitalizing where possible locally available and acceptable practices. In accordance to this, Tigray Regional Government has issued the region's land law which includes provisions both ensuring ownership and limiting inheritance of land, as well as to preclude further fragmentation of land into smaller than economically viable pieces and to ensure that most needy descendants obtain parents' land (Mituku et. al. 2005, Land Proclamation of Tigray Government No 87/2006). For this purpose the regional government has implemented the rural land certification policy measure between 1998 and 2000.

Statement of the problem

Land issue in Africa is much more complex, due to various socio-cultural, institutional, economic, and environmental factors associated to the definition of land tenure security or insecurity than just the presence or absence of private property rights (Adams et.al., 2001).

In the past Ethiopian context, the state-interventions on land were more of redistributive than geared towards one of introducing formal title or individualization (Atakilte, 2001). Moreover, in 2003, a study on the status of land tenure security and land-related investment was undertaken in most regions of Ethiopia, including Tigray. Such study noted that in Ethiopia land tenure appears to be quite insecure and the rights to transfer land permanently or for longer time were severely restricted (Binswanger, 2003). Accordingly, for the benefit of appropriate formulation and implementation of land policy in Ethiopia/Tigray, there is a need for more empirical studies to assess the effectiveness and nature of different land tenure arrangements in solving land tenure constraints in relation to the inherent conditions of regions or farming systems. Hence, this research work has focused on studying the implication of land certification policy institution on farmers' perception of tenure security on the land they own and their subsequent actions on long-term investments on their holding.

Objectives and Key Research Hypothesis

Overall objective (purpose) of the study

This research was intended to identify and record the changes in perception of farmers on tenure security and their land investment behavior as a result of the land certification institution issued in the region in 1998-2000. Hence, based on the outcomes of the study; lessons, perspectives and critical areas requiring improvement on the institution are identified and recommended for further implementation in the region or country.

Key research hypothesis:

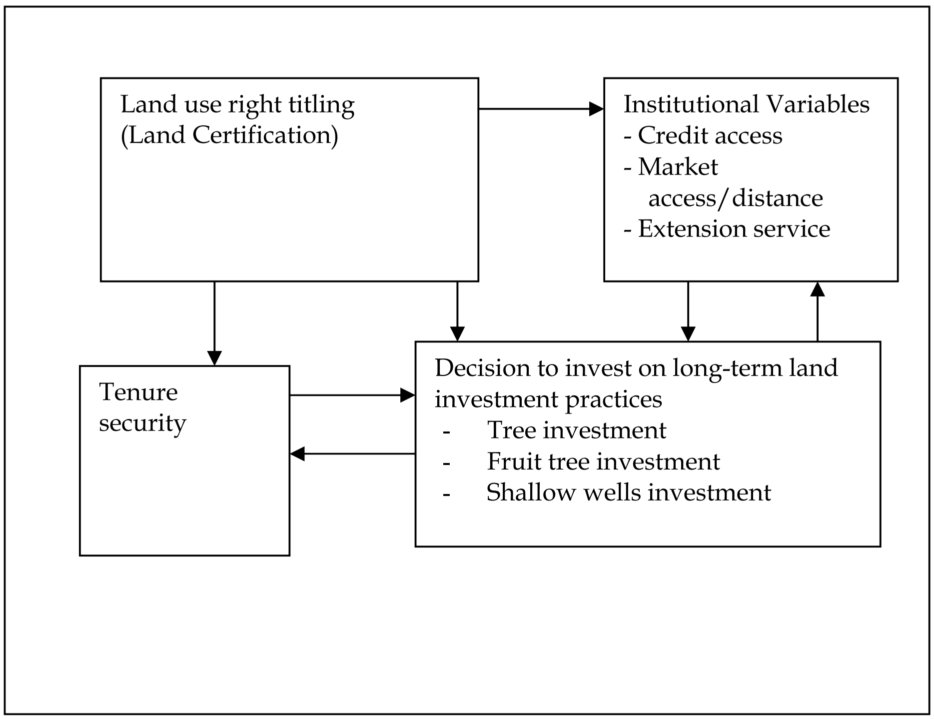
Land certification policy has served its purpose in enhancing ownership security of small farmers and initiating them to undertake long-term investments on their holdings.

2. Theoretical framework

Land investment decisions are determined by many factors operating at different magnitude. Demographic and socio-economic factors such as population density, access to markets, tenure arrangements and the level of credit finance support systems influence land management. Farm-level decision making must be considered as most important in any attempt to understand why land users act the way they act. Land investment practices require support from local and state structures through public expenditure and institutions, among which secure land right titling could be one major issue. Dessalegn, (1995 cited in Taye (1999), stated about relationship between land tenure system and sustainable land use that "land tenure arrangements influence farmers' land management practices and investment plans". Similarly, Dawn and Reya (1998 cited in Taye, 1999) conformed that "improved ownership security can promote long-term land improvement efforts and ownership security of land users".

At least three relationships are assumed by this study that relates tenure security through land titling: decision and enhancement in land investment, regulated transferability of land and role of credit, extension services and market access on land investment. Tenure insecurity increases farmers' uncertainty on their ability to use their land in the times to come, in the absence of secured use right titling. Investments in trees, fruit trees and shallow wells are largely made to accrue sustainable income generation and increase land value. Consequently, as use right land titling is served in the study area several years ago, it is expected that it has initiated long-term land investment types mentioned. Thus, such relationships and interactions of major institutional and socio-economic factors determining land investment as influenced by tenure security are illustrated using the following figure1. Such figure has been articulated and synthesized based on the theoretical formulation of related study of the conventional land management practices by Kebede (2005) for Ofla Woreda, Southern Tigray, and assumptions and analysis made during the study of this particular community in the study area (see figure 1 elow).

Figure 1 *Simple Schematic synthesis of theoretical framework of land titling and interactions of major factors of Long-term land Investment at Kilte Aw'laelo woreda, Tigray*



Definition of Variables and Working Hypothesis

After having appropriate analytical tools, it demands for selection, definition and description of the independent variables with their respective symbols and measurements.

The Dependent Variables of the Model: The dependent variable for the logistic regressions has dichotomous nature, taking the value 1 with a probability of (Yes), when invested a given land investment practice during the years 1992-1997 or 2000-2005 independently, or the value 0 when a given farmer did not invested (No). Tree, Fruit tree and Shallow wells construction, land investment practices to be analyzed using the binary logit model independently: Y_T =1 if a given farmer had invested on forest trees, otherwise 0; Y_{FT} = 1 if a given farmer, had invested on fruit trees, otherwise 0; Y_{SW} = 1 if a given farmer, had invested on shallow wells, otherwise 0

The Independent Variables of the study: The independent variables that were expected to influence farmers' investment decision can be diverse. 9 most hypothesized explanatory variables were considered for this study as detailed in the results and discussion section, and some of them are also indicated in the theoretical frame work analysis.

3. Data collection and methodology of analysis

Woreda, tabia and kushets selection (see Annex tables 1-2 for information of study area)

Multistage sampling was employed in this study. First two tabias with three kushets each were selected randomly, as land certification was entirely covered in the woreda. Secondly, one study kushet was randomly selected from each tabia. Third, as household heads owning land were the focus of the study; was used the list presented by the woreda Land Use and Administration desk land register as a sampling frame and 135 case household heads were selected using simple random sampling methods. Cases from each kushet were selected based on proportion to size.

Method of Data Collection

Household interview: households having own land, acquired through redistribution or inheritance were included for the interview in November 2006, using structured survey questionnaires. Field level investment, size and type of investment given from the interviewee were cross checked at random on sample basis. **Focus group discussion at tabia level: t**o check some of the responses of sample households and tabia level information were collected through group discussion by using open ended checklists. **Interview with relevant sectors at various levels:** outstanding constraints of current tenure system, constraints in the transfer of land, practicality and interpretation of the various land proclamation decrees, expected improvements required at policy levels, etc.

Data analysis and interpretation

In order to attain the objectives of the research, both quantitative and qualitative analysis were made using SPSS software. Data obtained from the sample households were compared and contrasted. Data on focus group discussions, views and opinions of professionals, officials and stakeholders involved in matters pertaining to land administration/ management gathered at woreda and regional levels were supplemented to strengthen the analysis.

Descriptive statistics such as percentage and frequency of occurrence were employed to assess farmers' perception on the attributes of each land investment practices. In order to compare the influence of the explanatory variables on land investment, descriptive statistics such as mean, standard deviation, frequency of occurrences, cross-tabulation and percentage were computed independently for each practice for before and after land certification. In addition, T-test and Chi-square were used to see the significances of continuous and discrete variables. Moreover, the logit model was employed for each investment variety based on Gujarati (1988) and Hosmer and Lemeshow (1989) which is mathematically described as indicated below:

$$Z_{(i)} = \beta_{\circ} + \sum \beta_i \chi_i + \cup_i \, ;$$

Where β_o is the constant. β_i, = i =1,2,…n are the coefficients of the independent variables to be estimated. X_i is a vector of independent variables; U_i is the error term with zero mean and constant variance. The dependent variable in this case is dummy (Y_i), which takes a value of:

Y_T = 1 if a given farmer had invested forest trees, otherwise 0; Y_{FT} = 1 if a given farmer, had invested fruit trees otherwise 0; and Y_{SW}=1 if a given farmer, had invested shallow wells otherwise 0.

Hence, the above Logit Model was employed to estimate the effect of the hypothesized explanatory variables on the three land investment practices. The values of the logit coefficients were interpreted by: dividing by a factor of 4 which gives an approximation of the linear probability coefficients to transform to have contextual meaning, as interpretation of the coefficient with the logistic regression model is not as straight forward as the linear probability (LP) model where coefficients estimate the change in probability to adopt (Maddala, 1983).

4. Results and Discussion

This chapter presents results of the study and discusses the findings by giving due emphasis on the research objectives. The chapter is divided into three sections: section one presents the socio-economic characteristics of survey households in reference to investment of tree, fruit tree and shallow wells and resource endowment of case households. Section two presents the general perception of case farmers on tenure security and senses of ownership of the current tenure system in the study area. And section three is a comparative description of the long-term land investment of households before and after land certification implementation in the study area.

Socioeconomic characteristics of the sampled households

Households characteristics

Family size, age and active labor forces

Family size of the respondents ranged from one person to ten persons with an average of about 6 persons per household. The numbers of children ranged from zero to seven with an average of about 2.4 and on average households have 2.7 economically active persons. This implies that farm households have a large number of children who are less than fifteen years.

T-test was conducted to assess if the mean difference between investing and not investing of tree, fruit tree and shallow wells with respect to family sizes has significance. The result showed that the mean difference for family size between investing and non-investing was significant for tree (T= 2.5, p<1 %) and fruit tree (T=2.58, p<1 %). EEPRI (2002) had similar result on tree planting practices implying that large sized household tends towards intensification in order to feed their family members.

Age of the household head was one of the demographic characteristics hypothesized to influence land investment. However, the survey result disclosed that the differences in mean age between investing and non-investing for tree, fruit tree and shallow wells were statistically not significant. An independent sample T-test conducted showed that the difference in mean number of active labor between fruit tree and shallow well investors and non- investors is found to be statistically significant, (T=3.44) and (T=3.27) at less than 5% probability level, respectively. The existence of significant mean difference between the two groups with respect to economically active labor force may be due to the requirement of frequent and extra labor force in managing, guarding of fruit trees and in the initial construction of shallow wells.

Education and Sex of sample household heads

When we assess this factor we observed that those investing farmers were not largely literate, contrary to our expectation. This could be due to the possible differences in resource endowments (land, oxen, labor) accumulated for long time in the older household heads; as compared to the young household heads that could be relatively educated but with scarce resources particularly land.

Similarly, disaggregating of sample household heads by sex with respect to investment types did not show statistically significant difference between investing and not investing of trees and shallow wells. However, with respect to investment on fruit trees, there is significant difference (at 10% level of significance) between male and female headed households. The possible explanation for this could be related to the intensive labor requirement of fruit trees production usually tailored management of horticultural crops on irrigating guarding and cultivation.

Household resource endowments

Cultivable land holding of sampled households

The average holding sizes of most sample households (58%) fall between 0.51 and 1.0 hectare, thus the average holding was 0.75ha. and 91.04 percent of the households' own below one hectare. Thus land variable was hypothesized to influence land investment practices. As depicted on Table 1, the average cultivated land holding of tree investors was about 0.74 and that of non-investors is 0.75 ha. An independent sample T-test was conducted to compare the mean difference between investors and non- investors of tree with respect to land holding size. However, this difference is found to be statistically insignificant. This finding resembles to the study conducted by EEPRI (2002) in Tigray and other regions. When we take fruit tree, the average holding size of fruit tree investors category is relatively larger about 0.81 ha than that of non- investing category about (0.68 ha), and according to the independent sample T- test, the difference in mean land holding between the two category is found to be statistically significant at less than 1% probability level (T=3.01). Probably this could be due to the requirement of larger inter-space for some of the fruit trees such as Orange, Mango, Guava etc. and enough space to invest on other related intermediate benefiting high value crops and supportive water source structures.

Similar to the tree investors, average land size of shallow well investors was relatively the same sized at about 0.77 ha and not investing 0.75 ha, which is statistically insignificant.

Oxen ownership

The majority of the sample households covered by the survey own animals of different kinds. As this study was concerned mainly on land related investment, it focused on the ownership of oxen than on total livestock numbers.

42.2 % of households owned one ox; 34.9 % 2 oxen and 20.7 percent do not own an ox while about 2.2 percent of the households own more than two oxen. The average oxen ownership of both study tabias was about 2.2, and thus, 79.3% of surveyed households owned oxen. This study has been relatively consistent with earlier study in Tigray by the World Bank, indicated 75% owning oxen (Binswanger, 2003).

The average ox holding of tree investors and no-investors was about similar: 1.21 and 1.15 respectively. An independent sample T- test was conducted to compare the mean difference in oxen ownership between investing and non-investors of tree. The result shows that there was no statistical significant difference between the two categories.

The average oxen owned by fruit tree investors was relatively higher (1.3) than that of non-investors (0.96) and the difference was statistically significant at less than 5% probability level (T=2.58). Likewise, the average oxen holding of shallow well investors were relatively higher (1.38) than that of non-investing (0.9). The T-test result also showed that there is statistically significant mean difference between the two groups with respect to oxen holdings at less than 1% probability level (T=3.7). The probable reason for both could be due to the requirement of oxen to plow for the frequent tillage practices that involve the household in continuous production of fruits as the inter-spaces are cultivated with other annual high value crops and the need for shallow wells to sustain income of farmers from horticultural crops.

Access to Agricultural Extension, Credit and market Services

Among the modern rural institutions, credit and extension play key roles in facilitating development. In the discussions following we shall see the association among accesses to credit, agricultural extension services, market, and investment of tree, fruit trees and shallow wells.

Access to credit services

The availability of credit for resource poor farmers is quite critical to finance the agricultural development activities including land investment practices. The major sources of credit in the study area have been a local micro-finance called Dedebit Credit and Saving Institution (DECSI), and farmers' service cooperatives. Furthermore, farmers obtain credit from informal sources, relatives and local money lenders. In the study area, it was found out that among the total respondents 75.6% of them have used credit services offered for general purposes like seed, fertilizer and livestock purchases. But the proportion of farmers who used for long-term land related investment was only 8.9% (for water pumps, treadle pumps and other water hauling materials). Hence, most of the credit services were focused on short-term inputs and livestock purchases than on long-term land investment related interventions.

In the study area, of the total sample households who used credit about 22.2% of them were investors of trees, though, the served credit was not mostly used for that purpose. Pearson chi-square test was conducted to compare the percentage scores of investing and non-investing groups with respect to use of credit, and the chi-square analysis depicted that, there was statistical significant difference at less than 10% probability level between the two groups with respect to general credit services and investment on trees. This is to mean that having access to general credit services increase probability to invest on trees. This could be due to the fact that tree plantation demands capital outlay, as the investment matures at longer period and households seek credit services in sustaining their livelihoods until they harvest their investment and accrue benefits from.

Fruit tree is among the widely introduced land investment interventions during recent years in the study area and farmers might be encouraged to adopt fruit trees and vegetables due to the expansion of water harvesting structures such as shallow wells and water lifting technologies. Access to credit was one of the institutional variables hypothesized to influence investment of fruit trees; among the sample farmers: 58.5% fruit tree producers were using credit service.

When we analyze the respondents by disaggregating in to investors and non-investors of fruit, we found that 48.1% of the total samples who secured general credit were investing on fruit. When we independently compare the percentage of investing and non-investing of fruit trees with respect to adoption of fruit investment and credit services, the chi-square analysis showed the existence of statistical significant differences between the two groups at less than 1% probability level (χ^2= 14.56). This implies that farmers, who have adopted fruit investment, have a higher probability of using credit services. Cash constraints, hence, could be partly, limiting in the household's decision to invest in fruit trees as they are expensive and not easily accessible and requiring other complimentary inputs (chemicals, water sources and water lifting technologies etc.), when compared with seedlings of forest trees that are easily available locally or at low price and grown under rain fed conditions. Moreover, as the produce price in the market is more paying considering a unit of quantity supplied and growing together with other plant community and giving additional income by providing continuous harvest/income once established.

Shallow wells investment for small-scale irrigation at private level is one of the locally available land investment practices with expanding rate in the recent times in the study area. From the sampled households 54.1% who use general credit were investors of shallow wells. The chi-square analysis test showed similar statistical significant difference in percentage between investors and non-investors of shallow wells with respect to credit offered at less than 1% probability levels of significance (χ^2=10.44). From practical point of view most farmers with sustainable private water sources (mainly shallow wells) for irrigation purpose are producing various marketable horticultural and other high value crops in the study area. Thus, such investment required credit service as it demands water hauling materials, though; the service for construction of shallow wells or durable inputs was rare, despite farmers insisted for.

Access to agricultural extension services

Agricultural extension systems in the study area, offers various activities including training, visits, field days, skill and market information training, etc.

When we compare the percentage of investing and non-investing in relation to extension access of the sampled population who had invested in trees, fruit trees and shallow wells about: 24.4%, 58.5%, 54.1% had access respectively, while 75.6%, 41.5%, and 45.9% of the non-investing had no access in the same order. The chi-square test shows statistical significant difference in percentage between investors and non-investors of tree and fruit trees in their access to extension at less than 5% probability level but the difference was not significant for shallow well investing farmers.

This result implies that farmers with access to agricultural extension services have a higher probability of initiating tree and fruit trees land investment practices than farmers who did not have regular access to such services. However, the chi-square test for shallow wells was statistically insignificant. Probably such contradictory result might have resulted in that the extension services on trees and fruit trees investment are more of input to promote trees, and fruit trees and other high value crops production than standing alone structures.

Access to main markets

With regard to the effect of distance to market on promoting land investment interventions, 54.4% of the households stated that they were affected by market distance among other factors, while 45.6% were not. When we examine this factor as related to the distance of Tabias from main market centers: 52.6% and 47.4% of respondents replied that they were affected by market distance in Abraha Atsebaha and Maikuiha respectively. This result deviates from our actual expectation that farmers at Maikuiha should have complaint on distance to market contrary to what was found in the survey as they are relatively far from main markets. This may be due to the reason that market demanding products of land investment (fruits, vegetables et.c) are currently more matured at Abraha Atsebaha than Maikuiha.

The analysis made on distances to the nearest, *Woreda* market shows statistically significant mean difference between tree investing and not investing sample households at (T=2.17) at less than 5% level of significance. There is also statistically significant mean difference between fruit tree investing and non-investing with respect to distance to *Woreda* market from dwelling tabias (T=-2.7) at 1% level of significance. Similarly, shallow well investors and non-investors showed significant statistical mean difference with regard to distance to main woreda market (T= -4.7) at less than1% level of significance.

Hence, it is found that market access has a significant effect on the probability of undertaking long-term land investment intervention types under consideration.

Farmers' Perception on current Land Tenure and Use right titling

The issue of form of land ownership is among the strongly contested aspect of agricultural policies. Being the most important institution, land tenure has important implications for agricultural development in general and land investment in particular (Atakilte, 2001, Berhanu, 2002 and Deininger, 2003). Land tenure arrangements in rural Ethiopia have undergone frequent changes since the 1974 revolution, where re-distribution of land was a widespread practice in the 1970s to 1990 (Desalegn, 1994). In 1991 the current government overthrew the ***Derge (military)*** regime, and in 1995 a new constitution has been enacted. In this constitution farmers have been given the right to use their land indefinitely, but selling or mortgaging of land is still prohibited (Yigremew, 2001).

According to the opponents of state/public ownership of land, having only use right may inhibit farmers to put their efforts on long-term land management practices or investments like tree, fruit tree planting, and water harvesting structures which have direct implication on land productivity and household livelihoods. As security of holding is affected by tenure arrangement, looking into the relation between tenure arrangement and land investment seems quite imperative. In the study area farmers have four major ways of accessing land; namely, land received from the Tabias during land re-distribution, inherited or gifted from family, sharecropping and fixed rental arrangements. However, the survey results indicated that most of the respondents' farm plots were obtained from land re-distribution during the early days of the current government.

In order to get essential information and insight into farmers' decisions of long-term land investment practices, looking at their perception on their private holding is of absolute importance. Hence, this section is aimed at examining current farmers' perception of land tenure security and the contribution of land certification (use right titling) institution which is theoretically supposed to be determinant for adoption of land investment interventions and their sustained use over time as outlined in the framework analysis section 2. For this purpose, some qualitative and to some extent quantitative land tenure security perception evaluation indications have been used. General questions were posed to assess farmers' perception of security to their landholdings (Table 1). The statements have been grouped into three main categories of indications as outlined below.

Overall perceptions of tenure security

We explored the following issues related to sense of ownership and feeling of security: households' response towards certification of use right; feeling of farmers on current land tenure system and sense of ownership; expectation of farmers on future land redistribution; and land loss after certification for any reasons.

Accordingly, the majority of households surveyed (96.3%) conformed that they were holding use right certificate of their entire holding, while small minority (3.7%) were not certified due to un materialized land transfer procedures of family holdings. Subsequently, after confirmation of titling, households were asked whether the current land tenure system is satisfactory and if they have a real sense of ownership. Most households (81%) responded that they have sense of ownership and the current system is satisfactory; as opposed to 19% of the households that feel moderate/low insecurity (Table 1 below).

Table 1 *Farmers' perceptions on current tenure system as assessed using main indicatives in the study area, 2006 (N=135)*

	Indicatives on perceptions of farmers on current land tenure security				
Household heads response	Certified of use right (%)	Positive overall perception (%)	Expect future land redistribution (%)	Title named by both husband and wife (%)	Decision of both spouses on land investment (%)
Yes	96.3	81	30.4	21.6	79
No	3.7	19	69.6	59.7	0
Not Applicable	0	0	0	18.7	21

Notes: Not applicable represents: the respondent was male headed or female headed only
Source: survey result, 2006

This finding is differing from those previous studies by World Bank in 2003, that stated about 61% felt security of their holding in Tigray, but this survey result was in line with that of (Fitsum, 2003). Such improvement in status of security of households confirms the relative reliability of the current system and could be an indication of developed sense of ownership related to the difference in the length of time living with the title of land and the absence of major land redistribution actions in the area for more than one and half decade. Those not quite sure of the current tenure system (19%) gave their reasons to inability of obtaining additional land or their holding being small sized.

Moreover, when households were asked about their expectation of holding to remain with them in the future: out of those who responded the prevailing system is satisfactory, about 87.5% believe that they have life long use right and are able to inherit to their descendants. The remaining 12.5 % believe that they are currently having use rights, but are not sure about the future. This finding was again far improved from the previous study by EEPRI (2002) that found out that 3.5% and 78.5% of the cases replied their holding will stay more than 20 years and 1- 5 years respectively, in a study that included Tigray region.

Furthermore, a cross checking question was posed to ascertain their feeling of future holding security, in that whether they expect future land redistribution: 30.4% (Table 1) forwarded that they suspect land redistribution in the future, despite the regions' declaration that stopped further land redistribution with exceptions of settlement and irrigation areas. However, about 70% of the households do not fear future land redistributions, as opposed to 27% that did not expect future land redistributions in the study by Binswanger (2003); and a study by Hagos and Holden, 2002, that indicated almost half of households surveyed in 1998 feared future land redistribution. The most important issue here is the experiences of households of past land redistribution actions of governments (Tekie, 1999). The major land redistributions: during the Rist period, after 1976 during the ***Derg*** regime which have been frequent, and the 1990 last land redistribution by Tigray People Liberation Front (TPLF) in Tigray, can be cited to name some.

Typical reasons forwarded by those threatened by future land redistribution (of those 30.4%): 50.4% responded government may reconsider land redistribution due to the growing number of landless family heads and 49.6%, said their holding may be reduced as they have relatively above average holding size and few number of household members. Thus, there seem to be improved sense of security as compared with past studies above in this section. With regard to land loss after certification for any reasons, 6.7% households had lost land after certification for road construction, grazing land, etc. at the early days of certification, and were not compensated for the loss. However, even those who lost were not expecting similar actions in the future as confirmed by their responses due to strengthening of ownership holdings with time.

Women and tenure security

We further explored the issue of women's access to land and their sense of ownership and the difference in position of male and female spouses on land related investment decisions. As stated earlier female-headed households constituted about 17% of the sample households and the land titling was given by their name provided that they are heading the family. However, in the case of couple households, the title was given to the male spouses. Of the total sample (Table 1), 21.6% of spouses had land titled to both spouses (marriage contracted after land certification), in 60.4% of the cases titles were given to male spouses and 18% of respondents were male headed whose wives had died.

With regard to the women's feeling of security, it was found that 55.2% believe that the law supports them to share use rights equally and feel can share equally in case of divorce. 21.2% have land by their title and the rest do not have clear opinion. However, the problem of male-based titling has been cross checked using focus group discussions at the Tabia and Kushet levels involving women, youth, farmers, leaders and social courts and elected members particularly in the cases of land transfer when the husband dies or when marriage contract is terminated. All groups in both Tabias insisted for the need of paired titling.

Despite, the constraints and gaps stated in instituting the land titling, 79.1% of the coupled respondents conformed that they discuss and decide together on most investments undertaken on land (Table 1) and the remaining were without wife or husband.

Roles of land titling on land dispute resolution and land transfer

Furthermore, we explored contribution of land certification on land related dispute resolution; land transfer and temporary land market transaction and on family labor engagement on land.

High levels of population growth with limited opportunities for non-agricultural employment and the resulting competition for land and threat of landlessness are obvious reasons to give rise to serious land conflicts and accompanying social tensions and violence, both across and within communities and within households (Binswanger, 2003). Thus, in addition to using local institutions as much as possible and giving legal validity to informal resolution of conflicts, knowledge of the law and the institutional responsibilities by those who might be affected by conflict is essential.

In this respect the land certification policy implemented in Tigray a couple of years ago has played a vital role in minimizing land related conflicts and landholders have developed confidence of their ownership. Hence, about 94.8% of the case farmers surveyed (Table 1) had responded that land certification has reduced land related disputes in their tabias, and expressed that "land related conflict has become almost a history" in their localities. Moreover, with regard to any challenges faced by households in relation to land with local authorities, 94.8% of the respondents replied they did not face any problem, as opposed to past studies that reflected 23% had conflict with local authorities revolving around land administration in Ethiopia including Tigray in the periods 1991–1998 (Deinninger and Binswanger, 2001).

Farmers were asked as to what types of rights are provided by land certification; multiple responses were forwarded. Thus 88.9% and 86.7% of the cases said they can rent/share crop and could inherit their holdings to their descendants respectively. These responses were given by most of the respondents, as they understood their right and are at their disposal, though not necessarily practiced by each household head in their locality. With respect to land selling, the majority (97 %) of the cases confirmed that they will not sell their land whatever reasons and challenges are faced, even if a chance was given to do so, contrary to the 3% that wanted to sell if allowed. And almost all farmers knew that land can not be sold as it belongs to the government/public. This finding was showing improvement in terms of relative tenure security status from the study made by EEPRI (2002) indicated conformation of 70% that did not want to sell their land at any circumstances, despite available frustrations or motivations for free rural land privatization. Most of them stated that when faced critical challenges, they usually rent their holding temporarily.

Furthermore, the study cases were assessed whether the land ownership title is rendering them as collateral or guarantee them in securing them cash/in kind credit from formal or informal creditors. However, most of the farmers (more than 81 %) replied that they were not able to get such services from any formal or informal source.

Accordingly, formal land market transactions do not seem effected by the establishment of secure land use rights in land in the study area. This has been in line with the view of (Migot-Adholla, 1994) that asserted 'land private property rights and market transaction may not be effective as expected to be even when they are legally backstopped and centrally registered under low levels of economic development'. Similarly, Toulmmin and Quan (in DFID, 2000) argued that ‘the growth of land markets does not require the existence of formalized property rights’. Moreover, land titling is neither a necessary, nor a sufficient condition for the activation of land market as the contrasted experience of Kenya (where land market is inactive despite titling) and Rwanda (where the land market is quite active despite the illegal character of most land transactions (Gebrehiwot et. al, 2002). The rationale behind these instances is that the supply of land to the market is usually limited because of social security considerations and land markets can not be viewed independently from broader: social, institutional and economic frameworks (Binswanger, 2003); and land is considered as symbolic reasons by most communities of Sub-Saharan Africa countries, as small farmers are unable to enter the land market because of limited access to formal credit facilities. Hence, in similar analogy, it can be observed that land titling alone cannot be a guarantee for the emergence of free land markets under conditions exhibiting low levels of agricultural technology development and traditional nature of the farming communities in Tigray region.

However, from the regulated land transaction point of view, the implementation of land certification policy in the study areas has increased the motivation and understanding of small holders to inherit, rent in/out, contract for share cropping and leasing their holding, as they feel secure due to the provision of land certificates (Table 1). Thus 88.9% of the cases have confirmed that if they wish: can rent, share crop and lease their land being part of their bundle of use rights. The opinions of study households’ were also assessed on the role played by the policy implementation, in connection to the contribution of land certification policy on improving family labour engagement on land to assess further implication. Thus 74.8% of the total responses confirmed that their labour-land attachment has improved because of increased sense of ownership. The confirmation has been further elaborated by farmers in that they were using more labour demanding water harvesting technologies/structures, planting high value crops, fruits, etc., since titling. Such confirmation of farmers agrees with that of World Bank's (1990) World Development Report that stated that; "the more small farmers are secure on their holdings and feel sense of ownership over small family run farms, the larger will be the labour input resulting land productivity" (DFID eds., 2000).

In order to understand the association between farmers' perceived security status of their holdings and undertaken land investment practices, the chi-square test was observed and depicted that there is no statistically significance difference in percentage between investing and not- investing of trees (Table 2). This implies that tenure security alone is not important precondition in trees investment, as indicated and reasoned out in previous sections. However, with regard to farmers' investment decision on fruit trees and shallow wells with respect to perceived feeling of tenure security, there is statistically significant (χ^2 =2.8) and (χ^2 =3.2) at (less than10% level of significance) difference between investing and not investing farmers respectively, as depicted on (Table 2).

Table 2 *Distribution of households by tenure security in the study area 2006 (N= 135)*

I=Investing, NI= Not investing; NS= Non Significant *Significant at less than 10% significance level Source: Survey result, 2006

Description		Tree investing			Fruit tree investing			Shallow wells investing		
		I %	NI %	χ^2	I %	NI %	χ^2	I %	NI %	χ^2
Tenure security	Yes	20.0	60.8	0.03 NS(.86)	49.6	31.1	2.8 (.087)*	46.7	34.1	3.2 (.075)*
	No	4.4	14.8		8.9	10.4		7.4	11.9	

The rationale behind the statistics is predicted to be the sensitiveness of farmers towards security of investing fruit trees and shallow wells to accrue sustainable supply of income/benefits for longer years once established, as compared to trees which have one/two time benefits. Also as indicated earlier, cited by different studies, farmers used to plant trees as a mechanism of establishing tenure security than probably planting being secured. This finding supports the argument of some researchers in that "basic use rights are apparently sufficient in initiating farmers to make land- specific investments" (Brasselle, et. al., 2002) cited in (Fitsum, 2003).

Effect of land certification in consolidating long-term land investment

The research found that though land investment practices of long-term nature were underway both before and after certification by farmers in the study tabias; the type, quantity, quality and number of farmers involved in were varying between the two periods. Almost half of the cases (about 49%) were not investing on their private plots before land certification from self-initiative

Moreover, the quality, size, number of plots covered, number of households involved in, and the varieties of long-term land investment were quite different, when we consider the time line data of seven and six selected years calculated from the interview, for the years before and after land certification.

Accordingly, in the years before land certification, the attributes of long-term investments were more of the conventional Soil and Water Conservation (SWC) types and very long known ones in Tigray, and promoted through mobilizing communities after the down fall of the *Derg* regime. The common investment types (conventional ones) include: terraces, tree planting, manure and composing to a limited extent, as depicted on the comparison Table 3 below. The selection of the seven years before certification followed preceding land redistribution of 1990 in the region by TPLF, considering that such years could be relatively stable period after redistribution and before starting the process of registration/certification in the region.

On the other hand, same households were interviewed on the situations of long-term land investment practices after land certification policy implementation. Types, quantity, quality and number of interventions each household is involved in, and in terms of interventions' contribution towards land development and prospects of income generation to households in the study tabias have been assessed. Thus 85.2% of the cases were involved on different types of interventions after land titling, contrary to 51% before the policy implementation indicating a growth of about 34.1% after titling. The number of farmers involved in land investment interventions was increasing at progressive level when we observe the six consecutive year data after land titling (2000 – 2005), a growth of farmers involved in land investment by more than two fold both in quantity and percentage was observed.

Moreover, besides the difference in number of farmers, types and qualities of investment after land titling; there is quite traceable increment in magnitude of income generating investment types comparing both events, which can be seen from the comparison on frequency of households and combination of varieties of investment Table 3 below for comparative purpose.

Table 3 *Comparison on frequency of interventions each household involved in and range of investments before and after land certification (N=135)*

Land investment enhancing interventions and Technologies	Frequency of households involved on investment types	
	Before titling	After titling
Terraces/bunds construction	37	27
Gully/check dams construction	13	6
Manure/compost application	12	12
Irrigation pump purchase	0	5
Treadle pump " "	0	22
Family drip sets " "	0	4
Shallow wells construction "	4	65
Tree planting	20	33
Fruit trees planting	4	67
Others	3	72

Source: Survey result 2006

Thus the frequency of households who practiced combinations of long-term land investment for both periods indicate: more growth in involvement of households on new investment types and significant shift towards income generating types of investment after land titling, as observed in the comparison Table 3 above. Those who have not invested after land certification, were asked for their reasons and as the responses include lack of financial capacity (4.4%), lack of labor (8.9%) and the remaining about (0.7%) could not invested due to other various unspecified reasons. Similarly, the number of plots covered after land titling were commonly 2, as compared before in one plot as observed during field observation. Moreover, the plots involved after certification were even at distant places from settlement area, as opposed to before the institution that were more around homesteads, which has been also identified by the EEPRI study (2002) that indicated that most study households planted fruit trees around home yards.

From such data, it can be understood that land titling has contributed towards improvement in investment endeavors and landowners were developing confidence with time as has been conformed during Tabia based discussions and of the study households presented on the number of households involved for fruit trees and shallow wells types of investment for both periods. This has been in line with the view of Tekie (1999), that stated “the more investment a household has made on land, the more secured it would like the tenure system would be”.

In the case of tree investment the numbers of households involved in were highly significant after titling at the level of significance less than 1%, but before titling tree investment was significant at less than 10% level of significance though, inconclusive behavior of farmers towards tree investment versus tenure security were also illustrated by some researchers in the past. However, with regard to fruit trees and shallow wells investment, there was significant mean difference between the two periods in number of farmers involved on investment indicating high involvement of households after titling of land, at the level of significance less than 1%. Such findings of fruit trees and shallow wells investments, agree with the study conclusions of Feder (1998) in Thailand that stated titled lands were characterized by higher investment demand and input intensity resulting high yield as compared to non-titled ones. Migot-Adholla et.al. (1994), and (Taslim et. al.1992) have also reported that more individualized land rights were associated with greater land improvement activities; and that parcels with the right to bequeath land, rather than transfer it freely, had received more drainage or liming than parcels with no right of transfer in any way.

Thus, there are quite clear and observable differences and shift of intervention types from traditional conservation measures to more economically sound water development and utilization based technologies; which are believed to be the implication and relative contribution of the land certification institution on tenure security and land investment consolidation. Hence, one could see the contribution of secure and relatively transferable land rights; and the absence of major land redistributions in the past one and half decades in the study area or region might have contributed to increased holding tenure security, and incentives for long-term investment decisions. Accordingly, this indicates that tenure security being one of the key goals to public land policies can be achieved under different modalities of land ownership. And instead of an often ideological instance in favour of full private ownership rights, long term secure and transferable rights may convey many of similar benefits to owners, and may be preferable where full ownership rights would be politically controversial or too costly (Binswanger, 2003). Therefore, relatively better definitions of land rights to reduce uncertainty seem to have resulted significant contribution to enhance the functioning of long-term land investment in the area.

However, the contributions of other government policy actions such as the focus given on water harvesting could have their own share that needs empirical evidences, which has been beyond the scope of this study to indicate quantified information.

5. Conclusion and Recommendation

Conclusion

We found 96.3% of study households were holding use right certificate of their entire holding and 87.5% of them feel sense of ownership and feel that the current system is satisfactory. They asserted to have life long use right and can inherit their holdings to descendants. This seems to confirm the relative sense of ownership related to titling of land and the contribution of absence of major land redistributive actions in the area. Hence, it indicated the need to strengthen the implementation of the institution and the need in minimizing remaining risks/obstacles that trigger insecurity of smallholders in the region and enhance long-term land investment practices.

The constraint of male-based ownership titling has been identified in relation to land transfer when the husband dies or when marriage contract is terminated. The need for paired titling and transparent land ownership has been insisted, and thus demanding an action as there are prolonged processes during land transfers and still unsettled cases in the study areas.

The land certification policy implemented in Tigray a couple of years ago has played a vital role in minimizing land related conflicts and landholders have developed confidence of their ownership. Hence, 94.8% of the case farmers had witnessed that land certification has reduced land related disputes, expressing 'land related conflicts becoming a history' in their localities.

The majority (97 %) of the cases confirmed that they will not sell their land, whatever reasons and challenges are faced. Most of them stated that when faced critical challenges, they usually rent their holdings temporarily, contrary to those promoting "market based land ownership" or fear of the government on land concentration through selling land, if privatized.

With regard to farmers investing on fruit trees and shallow wells as related to feeling of tenure security currently, there is statistically significant mean deference between investing and not investing at probability level less than 10%. However, there was no statistically significance mean difference in percentage between investing and not-investing of trees, as the cases of tree investment was inconclusive in similar other studies as well.

The research found that though, land investment practices of long-term nature were underway before (by 69 farmers) and after certification (by 115 farmers) in the study tabias; the variety, quantity, quality and number of farmers involved in were significantly different and indicated an overall growth by 34.1% after tilting and the types of investments increased highly.

The comparison on status of investment for both periods also showed significant mean difference in number of farmers involved in particular after land certification on fruit trees and shallow wells investment. Likewise, the trend of investing farmers was shifting towards: income generating, more paying and benefit maximizing varieties of land investment; and to water related development/ technologies.

The results of the regression models for the three types of investments depicted that:

Farmers' long-term land investment decision on trees and fruit trees was significantly influenced by access to credit, availability of active labor at household level and size of landholding after land titling, at varying significance levels.

Farmers' probability of investment in shallow wells for irrigation was significantly influenced by market distance, availability of active labor force and availability of credit service after land certification respectively, again at varying levels.

Therefore, all these are assumed to be due to the relative contribution of land certification on land investment consolidation and the link between tenure security and sufficiency of basic use rights. Thus, farmers have felt relative security and transferability of land rights in providing incentives for long-term land investment decisions.

Recommendation

The need for a transparent land use right institution is crucially vital and Tigray region has traveled some distance in this aspect so far, by taking the first initiative in implementing land use right titling of all the regions in the nation. In light of these endeavors and recognizing currently prevailing land tenure situations in Tigray region, the following recommendations are made by this study for further fine-tuning and reconsiderations on some of the basic improvements:

1. Tenure decrees that promote and encourage long-term land investment such as through long duration leasing/land contractual transfers have to be strongly engraved and transformed into practical applications without violating use right of respective owners.
2. The right to use land permanently should be based on evaluating the contributions of land users on: long-term investment/improvement efforts and towards its proper maintenance than ownership per se. This issue is stated in the land use law of the nation and the region as well, but substantive actions are yet to remain.
3. Our analysis of tenure security and long-term land investment practices, as related to land certification policy suggests that there is room to increase land productivity/value. Hence, land investment by improving the engagement of the farm labor on land and enhancing access to: The supply of credit that serve the purpose of long-term land investment interventions is one of the critical area that require due attention at strategy level, as previous experiences indicate almost non-existent (only about 8.9%) credit service for durable inputs.
    - The service of agricultural extension on water utilization and high value crops management (fruit trees, vegetables, spices and others) was at its lower level and seriously complained by case households as compared to SWC/health out reach packages that seem better; thus it demands to take for serious and timely measures to execute on scheduled basis.
    - The marketing linkages and post harvest management capacity development component is nearly missing, despite vast efforts of income generating land investment practices by farmers in the area that need sustained measures and to consider at program/project level.
4. 6.7% of the case households had lost land after certification for road construction, grazing land, etc. at the early days of certification, and were not compensate. Such types of actions are against the land law of the region and require corrective measures, otherwise could be source of tenure insecurity, if left unattended in the future.
5. The male-based land titling has been identified as constraint in the process of land transfer when the husband dies or when marriage contract is terminated. All groups in

both Tabias insisted the need for paired titling and transparent land ownership status, as experiences indicated lengthy process of materializing land transfer and title based dissatisfaction of women. Hence, this could be one of the issues to look into, future land policy amendments of the region, and the case from Amhara region may serve as a source of experiences.

6. Community based: grazing lands, forestry/ area enclosures and common water source areas are under frequent intrusion to cultivation or private use illegally in the study area as they are not titled; hence, requiring viable community and government actions to minimize such resource miss use.
7. Land transfer mechanism of died or without attendants (without descendants) is idle for longer time due to lengthy transfer process, despite huge number of existing landless households living under scarce means of livelihoods that demand timely actions in putting them into owner operated and be productive assets.
8. As this research was critically limited due to time, financial resource and its scope in covering wider area, we recommend further research to examine the contributions of land titling and the extent to which socio-economics and other policy factors influence the intensity of land investment decision of farmers in a wider perspective.

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Appendices

Annex Tables

Annex Table 1 *Basic background information of Kilte Aw'laelo woreda (district)*

No	Basic background information of the study Woreda	16 Tabias		Total
		Male	Female	
1	Population	58553 (49%)	60941 (51%)	119493
2	Number of Household Heads	16197 (67.8%)	7702 (32.2%)	23899
3	Livestock - cattle - Small ruminants - Pack animals Bee Colony -Modern -Traditional - Poultry			59236 46418 13036 9872 5914 42733
4	Land management/investment total area (ha)-------- - Cultivated - Grazing land - Closed area - Forested - Other		-	80,000 21089.5 4796 6698 3844 43572.5
5	Introduced Irrigation infrastructures/Technologies - Constructed shallow wells - " Ponds - " Water tanks - Installed water pumps - " Treadle pumps - " Family drip sets			 1712 2337 351
6	Education facilities-Elementary schools - Junior - Access schools - High schools			22 15 6 4
7	Health facilities –Nucleus Health centers - Health post - Clinics - Hospital			2 8 3 1
9	Social organizations and institutions Public Associations - Farmers' service cooperatives - Credit and saving institution			 3 16 6

Source: WoARD report, 2005

Annex Table 2 *Basic background information of the study Tabias*

No	Basic background information of the study Tabias	Study Tabia	
		Maiquiha	Abraha Atsebaha
1	Population - Male	3590	2254
	- Female	3737	2667
	- Total	7327	4921
2	Land ownership - (HH) Total	1602	911
	Land holders (HH)	1058	750
	Landless (HH)	544	161
	Total - Male	1150	648
	- Female	452	263
3	Livestock resources		
	- Cattle	3394	2625
	- Small ruminants	1303	2219
	- Pack animals	383	943
	- Bee Colony	-	-
	- Poultry	1735	1901
4	Land management/investment (ha) Area	5240	7221
	- Cultivated	1361	1500
	- Grazing land	79	206
	- Closed area	900	2125
	- Forested	209	360
	- Mountain sharing	-	30
	- Gully area sharing	-	5
	- Unusable land	3238	-
5	Introduced Irrigation infrastructures/Techno.		
	- Constructed shallow wells	59	484
	- " Ponds	459	273
	- " Water tanks	111	32
	- Installed water pumps	5	23
	- " Treadle pumps	30	246
	- " Family drip sets	2	4
6	Education facilities-Elementary schools	2	2
	- Junior	1	1
7	Health facilities – Health center	1	-
	- Health post	-	1
	- Clinics	3	-
8	Water and sanitation facilities		
	- Water supply schemes	15	14
9	Social organizations and institutions		
	- Farmer Associations	1	1
	- Women Associations	1	1
	- Youth Associations	1	1
	- Farmers' service cooperatives	1	1
	- Credit and saving institution	1	-

Source: Respective tabia extension offices

Impacts of Low-cost Land Certification on Investment and Productivity

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Abstract

New land reforms are again high on the policy agenda and low-cost, pro-poor reforms are being tested in poor countries. This article assesses the investment and productivity impacts of the recent low-cost land certification implemented in the Tigray region of Ethiopia, using a unique household and farm-plot level panel data set, with data from before and up to eight years after the reform. Econometric methods were used to test and control for endogeneity of certification and for unobserved household heterogeneity. Significant positive impacts were found, including effects on the maintenance of soil conservation structures, investment in trees, and land productivity.

JEL code: Q15

***Key words*:** low-cost land certification, land productivity, household panel data, soil conservation, tree planting, unobserved heterogeneity.

Introduction

A new wave of land reforms has hit Africa, typically aiming to provide more private and secure property rights to land. Formalization of land rights are being promoted by the Commission for Legal Empowerment of the Poor, The World Bank, UN organizations, and many donor countries. Yet it is questionable whether these reforms will succeed in promoting poverty reduction and economic growth, given past experiences and the difficulties of designing and implementing pro-poor land reforms. Past land titling programs have tended to benefit the wealthy and powerful at the expense of the poor and marginalized, owing to poor implementation, the high cost of obtaining titles in complex and often corrupt and inefficient bureaucracies, and limited or no formal recognition of customary land rights (Besley and Burgess 2000; Cotula, Toulmin, and Hesse 2004; Deininger 2003).

According to theory, tenure security is expected to enhance investment and vice versa (Besley 1995; Sjaastad and Bromley 1997). Therefore, if land certification can enhance tenure security it may enhance investment. In turn, tenure security may reduce conflicts over land, which may enhance the positive effects of tenure security on land productivity (Deininger and Castagnini 2006). In addition, property rights may contribute to better access to credit if land can be used as collateral and can contribute to land market development such that land will be reallocated to more efficient producers, which may stimulate investment on the land.

There are very few studies of the impacts of the new pro-poor and low-cost land reforms that have been implemented in some countries in recent years. One exception is Deininger et al. (2007) which assessed the early impacts of low-cost land registration and certification using a large cross-section data set from Ethiopia, a pilot country when it comes to such reforms. The cost of registration and certification was estimated to be about 1USD per farm plot or 3.5USD per household (Deininger et al. 2007) as compared to about 150 USD per household with the conventional titling upon demand that has been used in Madagascar (Jacoby and Minten 2006). The low-cost approach is affordable on a broad scale because of the use of simple technology, staff with limited training, and high local participation.[xix] Yet one may question whether this low-cost approach also means low quality and minimal impacts. The Ethiopian experience has demonstrated that it is a scalable approach as more than 20 million plots and 6 million households have received certificates within a period of seven years (Deininger et al. 2007).

This article assesses the investment and productivity impacts of the Ethiopian low-cost land certification using a unique and detailed data set with household and plot panel data from 1998, 2001, and 2006. The data provides a balanced household panel covering 16 representative communities in 11 districts in the Tigray region, where certification was implemented first in Ethiopia. With the last survey round, eight years after the reform, we were able to assess some of the longer-term impacts of certification. Alternative methods were used to test and correct for endogeneity of certificates. The rich household-plot panel data allowed us to control for time-invariant unobservable village, household, and plot heterogeneity in the land productivity analysis by using household fixed effects. The findings of significant and positive investment and productivity effects of certification have important land policy implications, as this is the first comprehensive impact assessment of the investment impacts of the low-cost, participatory, broad-based, high-speed land certification approach, which Ethiopia was one of the first countries to implement. The main reason for such positive impacts of certification is that certification has reduced tenure insecurity which was high due to the past policy with state ownership of land, providing households restricted user rights to land only, and frequent land redistributions that undermined investment incentives.

The article proceeds as follows. The first section provides an overview of the relevant literature and presents the hypotheses to be tested. The next section gives an overview of the land tenure history of Ethiopia, with an emphasis on the recent tenure reforms. A brief presentation of the data and descriptive statistics follows, before the estimated models are outlined. A comprehensive analysis of investment and productivity impacts is then presented, followed by the conclusion.

Literature Review and Hypotheses

The links between tenure security, credit markets, and investments are well established in neoclassical economic theory (Besley 1995; Haavelmo 1960; Jorgenson 1967). Investments may be enhanced through improving tenure security, facilitation of the use of land as collateral, and gains-from-trade effects (Besley 1995; Feder 1988). Reverse causality between investment and tenure security makes it important to take into account the fact that land rights and tenure security are endogenous (Brasselle et al. 2002; Place and Otsuka 2001; Sjaastad and Bromley 1997). Tenure-insecure people possibly enhance their tenure security through investment and this may be particularly important for visible investments, such as investment in trees (Deininger and Jin, 2006).

Although significant investment impacts from land titles have been reported in Latin America (Alston, Libecap, and Schneider 1995; Deininger and Chamorro 2004; Lanjouw and Levy 2002; Lopez 1997) and Asia (Do and Iyer 2002; Feder 1988), studies of such interventions in Africa have found insignificant or no investment effects (Atwood 1990; Carter and Wiebe 1990; Migot-Adholla 1993, Migot-Adholla, Place, and Oluoch-Kosura 1994; Place and Migot-Adholla 1998). No empirical evidence was found of land titling enhancing credit markets, land markets, and investment in Kenya (Migot-Adholla, Place, and Oluoch-Kosura 1994; Pinckney and Kimuyu 1994; Place and Migot-Adholla 1998).

Holden and Yohannes (2002) found no evidence of tenure insecurity having a negative effect on investment in trees in southern Ethiopia, whereas poverty had a significant negative impact on such investments. Therefore, tenure security may be neither a necessary nor a sufficient condition for investment. Poor rural households face capital market constraints, as revealed by studies of their discount rates and returns to capital (Holden, Shiferaw, and Wik 1998).

On the other hand, Deininger and Jin (2006) found that transfer rights to land as well as tenure security were investment-enhancing, based on a 2001 survey of the four major regions in Ethiopia. In addition, recent evidence from a broad cross-sectional survey in Ethiopia indicated that the recent land certification may have enhanced investment (Deininger et al. 2007). Both these studies use household-level cross-section data. The latter study did not analyze the effects on different types of investments.

Based on this brief review of the theory and relevant literature, the objective of this paper is to assess the investment and productivity impacts of the low-cost land certification program that was implemented in the Tigray region of Ethiopia, which was the first region in Africa to undergo a large distribution of non-freehold land certificates. Specifically, the impacts on investment in and maintenance of soil conservation structures, tree planting, and land productivity are estimated. The following hypotheses are tested:

H1: Having a certificate for a farm plot enhances investments on the plot in terms of the building of new conservation structures, the improvement/maintenance of existing conservation structures, and the planting of trees.

H2: Restrictions on tree planting in the land proclamations (especially on eucalyptus) have prevented investment in trees. Therefore, land certification has not stimulated this type of investment and there will be no difference between plots with and without a certificate.

H3: Land certification has enhanced land productivity.

The Land Tenure System and Recent Land Reform in Ethiopia

Civil war and border conflicts have had severe negative impacts on development in Ethiopia and land has played a central role in these conflicts. Emperor Haile Selassie lost power to the military Derg regime in 1974, which subsequently made all land state property. User rights to land were allocated to communities and to households within communities based on family size, leading to a very egalitarian land distribution. The reform was followed up with reasonably frequent land redistributions to maintain the egalitarian land distribution throughout the 1980s (Holden and Yohannes 2002; Rahmato 1984). After a long civil war in northern Ethiopia, the military government was overthrown and a new government was formed in 1991. Eritrea achieved independence and a more market-friendly policy was introduced in Ethiopia. As land legislation was based partly at the federal and partly at the regional level, this created variations both in the legislation and in how it was implemented across regions, which has provided interesting opportunities for research.

The Tigray region commenced the land registration and certification process in 1998–99 and was the first region to do so. It utilized simple traditional methods in implementation, including students with short-duration training, and strong local participation. The Amhara region started a land registration and certification process in 2003 with some donor support and used and tested more modern equipment, while the Oromia region and Southern Nations Nationalities and Peoples (SNNP) region started in 2004, and the process was still ongoing in these regions in 2007.

The Ethiopian land certificates provide only limited rights in the form of perpetual user rights, rights to bequeath, rights to obtain compensation for investment on the land in the case of loss of the land, and rights to lease out the land for a limited period. Nevertheless, in a country with high and increasing land scarcity and a historical land policy that promoted tenure insecurity, the land certificates represented a substantial improvement (Alemu 1999; Holden and Yohannes 2002). Land sales and mortgaging of land remain illegal and restrict capital markets development.

The new land laws and regulations impose obligations on certificate holders and penalties for violations. The basis for the land certificate to provide tenure security is that the land is properly conserved according to the earlier and most recent land proclamations and regulations (TRLAUP 2006; TLR 2007). There are restrictions on planting trees on arable land for food security reasons, making the effects of certification on tree planting uncertain. Another complicating aspect of analyzing the investment effects of certification relates to the widespread public interventions in soil and water conservation in Tigray. Special care has to be taken to distinguish between private and public investments at the farm-plot level. Public investments in conservation may crowd in or crowd out private investments in conservation (Hagos and Holden 2006; Holden, Barrett, and Hagos 2006). We have controlled for public investments in conservation at the farm-plot level when assessing the private investment impacts of certification. Public investments in conservation were introduced through a watershed approach, treating whole watersheds using a top to bottom approach by mobilizing people through compulsory participation, collective action, and provision of food-for-work incentives. Therefore, the presence of such public investments on plots is exogenous to households but may depend on the location and characteristics of plots.

The private investment effects of the low-cost certification approach used in Tigray may be low not only because of the low-cost approach itself, which may have affected the quality of the implementation, but also because of the restrictions on the land rights provided by the certificates and public investments. Furthermore, the effects are likely to depend on the initial conditions before the reform, the trust of the rural people in the state and its local responsible organs and representatives, the local legal knowledge, and interpretations of the law. Severe poverty affects households' levels of education, access to information, ability to understand the law, and participation in implementation. In addition, severe resource constraints may affect the local institutions' capacity to implement the land reform and the quality of the process.

The Tigray Region in Northern Ethiopia

Tigray is located in northern Ethiopia and has a semi-arid climate. Pastoralism dominates in the arid lowlands, while most of the population lives in the highlands above 1500 meters above sea level, where rain-fed agriculture (integrated crop and livestock production) provides the main source of livelihood. Droughts are frequent, whereas irrigation is developed only in a few locations, making food insecurity a major issue and policy challenge.

The region was affected severely by the civil war during the Derg regime (1974–1991) when a large share of the region's population was engaged in the struggle against the government. The new government that was victorious in 1991 originated from the Tigray region, which has contributed to the recent developments in the region. Most rural households in Tigray are net buyers of food owing to the small farm sizes, adverse agro-ecological conditions, poor market access, and limited technology. The population density in the highlands varies from 40 to 750 persons/km^2 (Hagos and Holden 2003; Hagos, Pender, and Gebreselassie 2002). Public programs have been established to conserve the natural resources, provide safety nets, and enhance food security through food-for-work programs, which have targeted soil and water conservation and irrigation development. Stone terraces and soil bunds are the dominant types of conservation structures on arable land and have been established through public as well as private efforts. Stone terraces are more important on steeper slopes and can last for a long time, although some maintenance is required every year to keep them in good shape. Soil bunds are less durable but can last for several years depending on their size, the slope, and vegetation cover.

Data and Descriptive Statistics

We used a unique balanced household and plot-level panel data set covering the five main zones of the Tigray region in northern Ethiopia. Sixteen communities were strategically sampled from 11 districts to represent the major variation in agro-ecological factors, market access, population density, and access to irrigation. Within each community, there was a random sample of 25 households. The first survey round took place in 1998, just before the land registration and certification program was introduced, and was followed up with survey rounds in 2001 and 2006. We were able to distinguish public and private investments in soil conservation at the plot level but we were not able to match plots over time.

Descriptive Analysis

The baseline survey in 1998 revealed that 51% of the sample households feared losing their land owing to future land redistributions, indicating a high level of tenure insecurity based on the land policy where land redistributions within communities have been an important element. It was typically households with more than average land in the communities that feared such land redistributions because they were likely to be among the losers. The other half of the population was rather expecting to gain land in the next redistribution and, therefore, many of them hoped for a new redistribution (Hagos and Holden 2003).

The survey in 2006 included questions to households about their perceptions of the effects of the land certification. Based on these questions, 84% of the households stated that they perceived the risk of being evicted from their land to have been reduced due to the land certification and 78% of the households stated that certification has increased the probability that they will get compensation in the case of land takings. This provides a basis for the hypothesis that land certification has strengthened tenure security and may explain, at least partially, why land certification has eventually contributed to increased investment and land productivity. Two-thirds of the households also perceived that border disputes had been reduced after certification.

Land quality and basic household characteristics may not be the same for plots with and without a certificate. A two-step approach was used to deal with this problem: 1) using non-parametric matching on observable plot characteristics to identify a sample that satisfies common support; and 2) using parametric regressions on the sample of plots that satisfied the common support requirement (Ho et al. 2007). The matched data of plots that were used in the productivity analysis included the plots planted with cereal crops with and without a certificate that satisfied the common support requirement but excluding rented in plots. This caused the number of plot observations to be reduced from 2718 to 2380. The propensity score was constructed based on observable plot characteristics without including the endogenous investment variables through which the land certification may have affected productivity. This kind of data preprocessing reduces model dependence in the following parametric analysis (Ho et al. 2007).

An overview of the variables used in the regression analyses is provided in Table 1, while table 2 compares the means of plots with and without a certificate in 2001 and 2006 for key investment and land productivity variables. Only plots that satisfied the common support requirement were included.

***Table 1** Variable Descriptions for Plot Panel Data (1998, 2001, 2006)*

Variable	Description	Obs	Mean	Std. Dev.
Certificate	Dummy for certificate	2380	0.64	
Certpr1	IV estimator for certificate	2380	0.69	0.42
Cererror1	Error for IV estimator	2380	-0.05	0.29
Certpr2	Household observed characteristics estimator for certificate	2362	0.72	0.42
Cererror2	Error for observed household characteristics estimator for certificate	2362	-0.07	0.31
Certpr3	Household fixed effects estimator for certificate	2380	0.61	0.45
Cererror3	Error for household fixed effects estimator for certificate	2380	0.04	0.14
Stone terrace	Dummy for Stone terrace	2380	0.47	0.50
Soil bund	Dummy for Soil bund	2380	0.16	0.37
Maintenance of SWC	Maintenance or improvement of soil conservation structure, 1=improved, 0=no change, and –1= worsened	1414	0.38	0.67
Eucalyptus trees	Number of eucalyptys trees	1123	6.10	39.49
Indigenous trees	Number of indigenous trees	1108	13.68	118.55
Young trees	Number of young trees, 2-5 years old	1096	5.20	33.60
Tree seedlings	Number of tree seedlings, 0-2 years old	1100	8.29	34.81
Log of yield value	Log of total output value per tsimdi[xx]	2380	7.02	0.95
Homestead plot	Dummy for homestead plot	2380	0.31	
Homestead plot 06	Dummy for homestead plot in 2006	2380	0.04	
Plot size	Plot size in tsimdi	2380	1.18	1.07
Public investment	Dummy for public investment in soil conservation on the plot	2380	0.37	
Shallow soil	Soil depth: Shallow	2380	0.40	
Medium deep soil	Soil depth: Medium	2380	0.36	
Deep soil	Soil depth: Deep	2380	0.24	
Flat slope	Slope: Flat, valley bottom	2380	0.69	
Low hill	Slope: Low hill	2380	0.23	
Mid hill	Slope: Mid hill	2380	0.06	
Steep hill	Slope: Steep hill	2380	0.02	
Soil type Cambisol	Soil type: Baekel=Cambisol	2380	0.28	
Soil type Vertisol	Soil type: Walka=Vertisol	2380	0.27	
Soil type Regosol	Soil type: Hutsa= Regosol	2380	0.24	
Soil type Luvisol	Soil type: Mekayih= Luvisol	2380	0.21	
Distance to plot	Distance to plot from home, minutes walk	2380	24.18	29.47
Sex of hh head	Sex of hh head, 1=female, 0=male	2360	0.15	
Age of hh head	Age of household head	2360	52.86	15.01
Education of hh head	Education of household head (years)	2360	0.42	0.74
Female labor force	Log of adult female labor force per tsimdi	2360	0.89	0.50
Male labor force	Log of adult male labor force per tsimdi	2360	0.85	0.60
Oxen per farm size	Log of oxen number per tsimdi	2360	0.56	0.56
Other livestock per farm size	Log of tropical livestock units per tsimdi	2360	1.01	0.75
Farm size	Size of own farm holding, tsimdi	2379	4.68	4.09
Year	Year, Gregorian calendar	2380	2002.03	3.18

Table 2 indicates that stone terraces are more likely to be found on plots with a certificate (54%) than on plots without a certificate (48%), whereas the opposite appears to be the case for soil bunds (25% vs. 15%). There was no significant difference in the mean maintenance status of plots[xxi] with and without a certificate. The numbers of eucalyptus trees, indigenous trees, young trees, and tree seedlings were significantly higher on plots with a certificate than on plots without. This may indicate that households are less inclined to harvest and more inclined to plant trees on plots with a certificate. The mean value of output per ha was significantly higher on plots with a certificate than on plots without a certificate. The yield distribution for plots with and without a certificate is presented in figure 1. A two-sample Kolmogorov–Smirnov test for equality of distribution functions was highly significant (P=0.004), indicating that the distributions were different.

Table 2 *Descriptive Statistics for Key Investment and Productivity Variables*

	Certificate			No certificate			
Variable	Mean	St.Error	N	Mean	St.Error	N	t-test
Stone terrace	0.54	0.01	1531	0.48	0.03	253	>*
Soil bund	0.15	0.01	1531	0.25	0.03	253	<***
Maintenance of SWC	0.38	0.02	1223	0.36	0.05	191	n.s.
Eucalyptus trees	5.05	1.26	924	1.37	0.71	168	>***
Indigenous trees	15.78	4.20	939	1.99	0.59	169	>***
Young trees	5.97	1.19	928	0.95	0.40	168	>***
Tree seedlings	9.08	1.18	933	3.86	2.01	167	>**
Log of yield value	7.13	0.02	1531	7.01	0.05	253	>**

Note: The table compares plots with and without certificate in 2001 and 2006**. >** means that plots with certificate have significantly higher value, * indicates p<0.10, ** indicates p<0.05, *** indicates p<0.01.

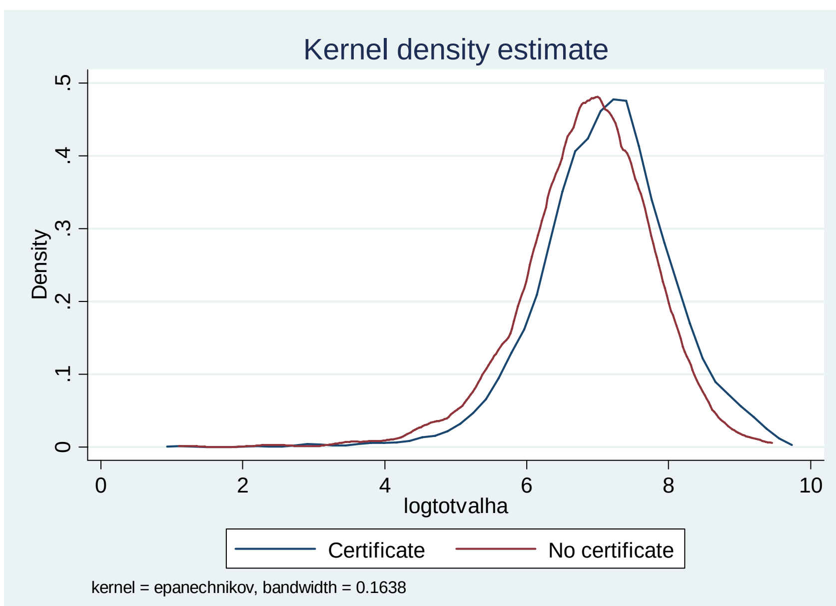

Figure 1 *Kernel density graph of log of plot level land productivity per ha for plots with and without land certificate (matched sample)*

Specific Estimators and Econometric Model Specifications

Correlation between the certificate variable and the error term of the outcome equation may be the result of potential endogeneity of land certificates. An empirical investigation of the process of registration and certification revealed the following reasons why some households did not have land certificates: a) administrative failures caused incomplete registration and certification in some communities; b) some households may have been left out of the registration because they were absent at the time; c) some households did not receive the certificates because the administration ran out of certificates and failed to obtain additional ones; d) some households did not collect their certificates because they may not have considered them to be important at that time; e) some households have lost their certificates after they received them or, if there was a change in the head of the household, the new head of the household failed to take over the old certificate or obtain a new one. The administrative failures appear to have affected households and communities quite randomly and are not likely to create any endogeneity bias. However, reasons b), d), and e) above may potentially create bias.

Three alternative models for determining which households had a certificate were formulated as follows:

(1) $C_{hpt} = \alpha_{10} + \alpha_{11}Q_{hpt} + \alpha_{12}D_v + \alpha_{16}\tau_{hpt} + u_{1hpt}$,

(2) $C_{hpt} = \alpha_{20} + \alpha_{21}Q_{hpt} + \alpha_{22}D_v + \alpha_{23}Z_{ht} + \alpha_{26}\tau_{hpt} + u_{2hpt}$,

(3) $C_{hpt} = \alpha_{30} + \alpha_{31}Q_{hpt} + \alpha_{35}D_h + \alpha_{36}\tau_{hpt} + u_{3hpt}$,

where:

$C_{hpt} = \{0,1\}$ is equal to 1 if the household has the plot on its land certificate, 0 otherwise,

Q_{hpt} is a vector of plot specific biophysical characteristics,

D_v is a vector of community dummies,

τ_{hpt} is years since certification,

Z_{ht} is a vector of observable household characteristics,

D_h is a time-invariant vector of household dummies,

u_{1hpt}, u_{2hpt}, u_{3hpt} are the error components for the three alternative models.

In the first model (1), village fixed effects were tested as instruments to predict administrative failures. The "years since certification" variable was used as an instrument for loss of certificates or for changes in household heads with new heads failing to obtain a certificate. The detailed model results are presented in Appendix 1, table A1. Table A3 shows that only 7.1% of the households without a certificate was predicted correctly. The weak predictive power may indicate that these instruments are poor or that the process was largely random. A further test of the latter was attempted by including observable household characteristics in specification (2). If such characteristics significantly affect certification, then there are reasons to worry about endogeneity bias. As seen in Appendix 1, table A1, two of these variables, livestock holding and farm size, were significant. Households with fewer animals and a larger farm size were more likely to have a certificate. Livestock may be a sign of wealth and influence, which may be positively correlated with tenure security, whereas under the old policy regime, households with larger land holdings were likely to be more tenure insecure and more prone to losing land in the next redistribution. However, model (2) was even weaker when it came to predicting households without a certificate, predicting only 1.2% of these households correctly (table A3). To further test whether unobserved household heterogeneity may explain certification, model (3), a linear probability model with household fixed effects, was tested. The results are shown in table A1 and its predictive power in table A3 and indicate that the model's predictive power for households without a certificate was 88.1%. This was substantially better than the two other models. However, it leaves an unexplained error that is uncorrelated with unobserved household heterogeneity. The Certpr3 variable also captures random administrative errors that caused some households to be excluded from certification. Therefore, using Cererror3 as a test of certification impacts is a very conservative test.

We used predictions from all three certification models and the actual certificate variable for more robust testing of the impacts of certification on investment and land productivity. The innovative aspect of this procedure is that the error terms of the second and third certification models may be seen, respectively, as weak and strong estimators of randomly allocated certificates. The sensitivity analysis included use of actual certificates, the weak and strong estimates of random certification (Cererror2 and Cererror3), and the IV approach with the weak instruments.

Following is a description of the different econometric models used for the impact assessment.

Investment Models

Models for farm-plot level investments in stone terraces, soil bunds, maintenance and improvement of soil conservation structures, and trees have the following general reduced form formulation for capturing the certification impacts:

(4) $I^{P}_{hpt} = \alpha_0 + \alpha_1 Q_{hpt} + \alpha_2 \hat{C}_{hpt} + \alpha_3 I^{F}_{hpt} + \alpha_4 Z_{ht} + \alpha_5 Z_v + \alpha_6 \left(C_{hpt} - \hat{C}_{hpt} \right) + \alpha_7 T_t + \zeta_h + e_{hpt}$

where:

I^{P}_{hpt} is private investment on plot p of household h in period t,

Q_{hpt} is a vector of plot level time-varying biophysical characteristics,

C_{hpt} is the actual certificate variable,

$\hat{C}_{hpt}$ is the predicted certificate using alternative approaches,

$\left(C_{hpt} - \hat{C}_{hpt} \right)$ is the certificate error variable with alternative approaches,

I^{F}_{hpt} is a public investment dummy on plot p of household h in period t,

Z_{ht} is a vector of household characteristics,

T_t is a time trend variable,

ζ_h is an alternative error component,

e_{hpt} is the transitory error component.

The dependent investment variables required the use of alternative models, as follows: a) stone terraces and soil bunds: household random effects probit and fixed effects logit panel data models;[xxii] b) maintenance/improvement of soil conservation structures: household random effects proportional odds ordered logit panel data models; and c) tree stock and tree planting models: random effects Tobit panel data models.[xxiii] Fixed effects models with limited dependent variables suffer from the incidental parameter problem, which leads to biased estimators (Greene 2004; Wooldridge 2005). Unlike investments in new conservation structures, maintenance and improvement of conservation structures is the sole responsibility of individual households and may therefore be a better indicator of individual incentives.

The four alternative specifications for the certification variables were used to check robustness. Bootstrapping was used to obtain robust and corrected standard errors for the predicted variables. As the survey design involved random sampling of households within villages, we re-sampled households in the bootstrapping process. Household random effects were used because plots within households are not independent.

The public investment variable should both control for its direct impact at plot level and its indirect crowding in or crowding out effects on private investment. We ran models with and without this variable to test the sensitivity of the findings.

Productivity Impact Models

The impacts on land productivity of land certification were estimated using parametric regression models with household fixed effects (GLS) as follows:

$$y_{hpt} = \beta_0 + \beta_1 Q_{hpt} + \beta_2 I_{hpt}^{F} + \beta_3 \hat{C}_{hpt} + \beta_4 D_t + \beta_5 \left(C_{hpt} - \hat{C}_{hpt} \right) + \vartheta_h + e_{hpt},$$

where ϑ_h is the unobservable time-invariant household, plot, and village characteristics that can be controlled for using household fixed effects. The dependent variable $\left(y_{hpt} \right)$ was specified as the log of the total value of output per ha. The log-transformed data had a more favorable (less skewed) distribution. The other variables on the right-hand side are as specified in the earlier models, including the alternative certification specifications.

Model Selection

The sensitivity analysis required a large number of models to be run and it is only possible to present a small part of the results in this article. We have made a selection of models for presentation based on the following logic. We have not presented models where the results are highly unstable across the model, making it difficult to reach conclusions. This was the case with the soil conservation investment models. Where we had to rely on random effects models, as for the tree investment models, we present results with the actual certificate and with Certpr3 and Cererror3. In the latter case, we assume that the Certpr3 controls for unobserved heterogeneity and that Cererror3 serves as a test of the effect of random certification. We included only one model with the Certpr3 and Cererror3 variables for the random effects proportional odds ordered logit models for maintenance or improvement of soil conservation structures, including the public investment in conservation variable, as the results were not sensitive to this variable. Finally, we present a summary of the sensitivity analysis for the fixed effects land productivity models, which includes only the coefficients and significance levels for the alternative certificate variables. The sensitivity analysis illustrates the stability of the alternative specifications and also serves as a basis for a discussion of the alternative approaches.

Results and Discussion

The analyses of the impacts on investment are presented first, followed by the analyses of the impacts on land productivity.

Effects on Soil Conservation Investment

A thorough testing was carried out for a large number of model specifications with alternative certificate variables, including random effects and fixed effects models, with and without time-varying household variables, and with and without the public investment variable (Public investment) for investments in stone terraces and soil bunds. For the soil bund models, the certificate variables were never significant. In the stone terrace regressions, the IV approach (Certpr1) yielded significant and positive results in five of the eight models, the actual certificate variable was significant in two out of eight models, and Cererror3 was significant in only one out of eight models. Although all coefficients were positive, this is only weak evidence of a positive response to certification. The weak response may be the result of the strong role of public investments and local collective action in soil conservation. The Public investment variable was highly significant and positive in all model specifications, indicating that much of this investment was driven by public efforts.

Effects on Maintenance or Improvement of Conservation Structures

We hypothesized that land certification has enhanced the efforts to improve or maintain existing soil conservation structures. We used proportional odds (ordered logit) models to test this hypothesis with the maintenance/improvement of conservation structures variable as the dependent variable. We present the results (table 3) from the household random intercept models with and without the public investment dummy variable because private incentives for maintenance of soil conservation structures may be affected by whether the structures were established through public or private efforts. Household fixed effects models were infeasible and, therefore, we specified the models with Certpr3 as a means to control for unobservable household characteristics and assessed the impact of random certification from the Cererror3 variable.

Table 3 shows that the effects of certification (Cererror3) were positive and significant at the 10% level in both models, in line with our hypothesis H1. The public investment in conservation (Public investment) variable had no significant effect on the incentives for maintenance of conservation structures. In addition, we found that maintenance was better on homestead and larger plots and poorer on shallower and more distant plots.

Table 3 *Impact of Certification on Maintenance and Improvement of Soil Conservation Structures*

Variable	OLOG1
Certpr2	0.94 (0.317)
Cererror2	2.152* (0.973)
Year	1.131*** (0.04)
Public investment	1.12 (0.161)
Homestead plot	1.585*** (0.254)
Homestead plot 06	0.60 (0.192)
Plot size	1.174** (0.093)
Shallow soil	0.496*** (0.086)
Medium deep soil	0.722* (0.124)
Flat slope	1.07 (0.397))
Low hill	0.774 (0.297)
Mid hill	1.173 (0.545)
Soiltype Cambisol	1.095 (0.202)
Soiltype Vertisol	0.704* (0.134)
Soiltype Regosol	0.835 (0.166)
Distance to plot	0.989*** (0.003)
Sex of househ. head	0.93 (0.258)
Age of househ. head	1.00 (0.007)
Education of hh head	0.99 (0.114)
Female labor force	1.01 (0.115)
Male labor force	1.10 (0.104)
Oxen per farm size	0.94 (0.131)
Other livestock per farm size	0.896* (0.052)
Farm size	1.01 (0.035)
Cut point 1	1.9e+105*** (1.30E+107)
Cut point 2	3.7e+106*** (2.60E+108)
Household variance	4.402*** (0.54)
Number of observations	1410
Log likelihood	-1199.935
Chi2	74.97749
p	3.76E-07

Note: Proportional odds (ordered logit) models with household random effects and predicted certificate variable using certpr2 and cererror2. * indicates p<0.10, ** indicates p<0.05, *** indicates p<0.01. Bootstrapped standard errors, corrected for clustering at household level, included in parentheses.

Effects on Investment in Trees

The restrictions on tree planting, especially eucalyptus trees, on arable land caused us to launch an alternative hypothesis (H2) for the effects of certification on tree planting. However, eucalyptus may be the most profitable crop to grow for rural households in Ethiopia (Holden et al. 2003; Jagger and Pender 2000) and local norms and attitudes towards tree planting may differ from the rules stated by the law. The results from four household random effects panel Tobit investment models, including models with eucalyptus, indigenous trees, young trees (2–5 years old), and tree seedlings (< 2 years old) are presented in table 4, using actual certificate. At the bottom of the table, we show the results for the Certpr3 and Cererror3 variables when they replaced the actual certificate to control for unobserved household heterogeneity.

Table 4 shows that the actual certificate variable was significant at the 5% level and had a positive sign in all four models. Models with Certpr3 and Cererror3 had a positive and significant effect (at the 10% level) for Cererror3 in the eucalyptus and seedling models, while Certpr3 was significant and positive in the indigenous trees and seedling models. We can therefore reject hypothesis H2. Land certification has stimulated tree planting, including planting of eucalyptus, even with the restrictions on tree planting on arable land.

Table 4 *Impact of Certification on Plot Level Investments in Trees*

Variables	Eucalyptus trees	Indigenous trees	Young trees	Tree seedlings
Certificate	58.740**	135.873**	47.110**	57.308**
	(26.57)	(56.04)	(20.49)	(22.47)
Year	26.387***	91.987***	18.667***	0.464
	(4.23)	(10.60)	(3.68)	(4.18)
Public investment	-27.898*	-24.185	-37.428***	-34.055***
	(15.29)	(37.11)	(12.60)	(13.03)
Homesteadplot	66.740***	224.798***	73.061***	102.008***
	(16.85)	(44.60)	(14.21)	(14.85)
Homestplot 06	24.398	-69.26	-26.858	34.068
	(30.18)	(71.24)	(30.88)	(30.87)
Sex of household head	49.745*	-77.3	8.608	-4.841
	(27.71)	(67.21)	(24.64)	(27.53)
Age of household head	0.392	0.284	0.054	0.648
	(0.58)	(1.30)	(0.47)	(0.50)
Education of househ. head	21.449**	16.245	10.785	8.24
	(9.13)	(23.20)	(7.30)	(7.72)
Female labor force, log	-11.345	-23.99	-14.957	-2.244
	(18.43)	(45.55)	(15.46)	(15.99)
Male labor force, log	28.721*	-40.185	22.827*	27.188*
	(15.34)	(38.51)	(13.40)	(14.16)
Oxen per farm size, log	-22.407	-75.336	-31.996*	-22.116
	(20.35)	(52.23)	(17.96)	(18.06)
Other livestock per farm size	10.107	37.721	11.509	23.465
	(18.15)	(45.58)	(15.34)	(16.30)
Farm size	3.52	7.43	3.01	3.956
	(3.00)	(7.36)	(2.49)	(2.68)
Plot size	-7.187	43.070***	-8.217	-5.402
	(7.89)	(14.29)	(6.83)	(6.44)
Shallow soil	-34.870*	-90.118**	1.379	-23.311
	(19.91)	(44.26)	(15.72)	(17.15)
Medium deep soil	15.03	-143.708***	0.235	5.569
	(17.93)	(47.07)	(15.38)	(15.92)

Table 4 Continued

Flat slope	-52.465	151.844	-4.147	2.323
	(51.83)	(188.26)	(46.37)	(50.13)
Low hill	-46.601	230.242	38.257	34.838
	(52.53)	(188.01)	(46.63)	(50.09)
Mid hill	-88.471	430.400**	32.777	-2.499
	(66.85)	(202.24)	(55.49)	(64.01)
Soil type Cambisol	-0.67	12.922	37.543**	12.328
	(18.69)	(46.57)	(15.63)	(16.02)
Soil type Vertisol	2.831	13.012	40.792**	14.355
	(21.58)	(55.06)	(17.45)	(18.42)
Soil type Regosol	15.581	79.003	17.566	25.365
	(20.00)	(49.28)	(17.47)	(16.97)
Distance to plot	-4.107***	-4.805***	-1.589***	-2.670***
	(0.94)	(1.30)	(0.41)	(0.58)
Constant	-5.30e+04***	-1.85e+05***	-3.76e+04***	-1215.956
	(8461.02)	(21251.48)	(7375.73)	(8364.61)
Household panel variance	49.454***	0.001	34.111***	41.229***
	(13.32)	(140.82)	(12.37)	(12.88)
Residual variance	99.262***	311.258***	100.423***	106.317***
	(8.57)	(18.43)	(7.18)	(7.83)
Number of observations	1073	1089	1077	1079
Log likelihood	-772.910	-1207.955	-976.718	-1091.378
Chi-2	120.996	158.166	110.385	113.731
p	0.000	0.000	0.000	0.000
Rho (Household variance fraction)	0.199	0.000	0.103	0.131
Model results with certpr2	and cererror2			
Certpr2	53.032 (38.919)	154.929*** (56.908)	55.332 (36.477)	57.769* (31.300)
Cererror2	98.451* (57.289)	25.146 (79.492)	8.269 (48.676)	53.525* (32.174)

Note: Household random effects tobit models. * indicates p<0.10, ** indicates p<0.05, *** indicates p<0.01. Bootstrapped standard errors in parentheses, based on 500 replications, re-sampling households.

There was a negative and significant correlation between public investments in conservation structures on plots and stocks of eucalyptus, young trees, and tree seedlings. This may be related to the restrictions on tree planting. Homestead plots had significantly more trees of all types, whereas the number of trees was significantly lower on distant plots, as indicated by the strongly significant and negative effect of distance to plots. This may also be the result of lower tenure security on distant plots.

Productivity Impacts of Certification

The robustness of the productivity impacts was scrutinized with a series of parametric regressions with alternative specifications. The results are summarized in Table 5 for models with alternative certificate specifications, for models with and without plots prior to certification (1998 year plots), with and without time-variant household variables, and with and without the public investment in conservation variable. As can be seen, there were significant and positive effects of certification in 21 out of 32 models and coefficients were also positive in the other models. The IV estimator (Certpr1) gave very unstable results, whereas our alternative conservative estimator, Cererror3, appeared to be much more stable across different model specifications and gave a significant and positive effect of certification in all specifications. The productivity increase is about 45% based on this estimator.The actual certificate variable and the Cererror2 estimator were unstable across specifications but followed each other closely. When we compare these models with the Cererror3 specifications, it appears that they are sensitive to unobserved household heterogeneity that affected the allocation of certificates. We consider that these results provide new insights and give credit to our conservative approach in situations where there is a shortage of good instruments.

Table 5 *Sensitivity Analysis for Land Productivity Effects of Land Certification with Household Fixed Effects Models*

Sample	Time-variant household charact.	Public Investment included	Certificate variable			
			Actual certificate	Certpr1	Cererror2	Cererror3
BA+WW	Yes	Yes	0.086	0.339	0.084	0.375 **
WW	Yes	Yes	0.370 **	1.165***	0.372**	0.370**
BA+WW	Yes	No	0.087	0.334	0.086	0.377**
WW	Yes	No	0.366**	1.163***	0.368**	0.366**
BA+WW	No	Yes	0.106	0.456*	0.092	0.398***
WW	No	Yes	0.374**	1.357***	0.388**	0.384**
BA+WW	No	No	0.107	0.459	0.093	0.399**
WW	No	No	0.371**	1.357***	0.385**	0.371**

Note: BA+WW: Includes before (1998) and after (2001 and 2006) data, WW includes only data from 2001 and 2006 (with and without only). * indicates p<0.10, ** indicates p<0.05, *** indicates p<0.01, based on bootstrapped standard errors with 500 replications, re-sampling households

Finally, we included the conservation investment variables in the productivity models but did not have good instruments for predicting these. Such structures are more likely to be found on steeper slopes and these are associated with lower yields. We found no significant productivity effects from these conservation investment variables, but this could be due to their correlation with plot characteristics. When nearest neighbor and kernel matching methods were used to measure the impacts of investments in stone terraces on land productivity,[xxiv] we found a significant (at the 5% level) and positive effect of such investments on land productivity. Thus, the investment impacts may partially explain the productivity impacts.

Conclusion

Farm households' perceptions indicated that the low-cost land certification program that was implemented on a broad scale in the Tigray region in Ethiopia in the late 1990s contributed to increasing tenure security and reducing land disputes. Using a unique household farm-plot panel data set covering the year before implementation of certification and up to eight years after certification, we found that land certification has contributed to increased investment in trees, better management of soil conservation structures, and enhancement of land productivity. The productivity increase due to land certification was estimated to be about 45% based on the conservative cererror3 estimator. Strong public investments in soil conservation may explain why no effects of certification were found for such investments. It is noticeable that our second hypothesis stating that restrictions on tree planting on arable land have prevented investment in trees, especially eucalyptus, had to be rejected. One may question the current restrictions on tree planting, especially on land marginally suited for crop production as such land is well suited for profitable tree production which could be a better way to enhance the food security of such households which could use the income from selling of trees to buy food. The findings lends support to this low-cost and highly participatory, coordinated approach to certification. It appears not to be anti-poor like the conventional high-tech demand-based approaches that have dominated the policy efforts and that have tended to exclude the poor because of their high costs.

It appears that the investment effects of certification only partially can explain the productivity effects of certification. Holden, Deininger and Ghebru (2007) have shown that land certification has stimulated the land rental market in Tigray and this may partially explain the remaining productivity impact because inefficient land managers are less likely to cultivate the land themselves after receiving certificates. It is also possible that land certification has stimulated use of inputs like manure, fertilizer and improved seeds but that requires further investigation and is left for future research.

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Appendix 1

Instrumentation models for land certificate

Lack of certificates may be due to random administrative errors but may also be endogenous and correlated with observable and unobservable household and plot characteristics. In order to test for the importance of this and to test the robustness of the key results, two instrumentation approaches were chosen for the potentially endogenous certificate dummy variable:

1) Standard IV approach: Village dummy and years since certification variables are used as instruments. It is assumed that these variables capture random administrative errors causing some households not to have certificates (Model COP1 below). Certpr1 is the predicted certificate variable based on these instruments. As can be seen these instruments may be weak in prediction.
2) Weak instrumentation approach: Estimate determinants of having land certificate using observable household and plot characteristics. The residual, Cererror2=Certificate-Certpr2, from this model (COP2) is used as a (weak) predictor of households having randomly been allocated certificates.
3) Strong instrumentation approach: Estimate determinants of having land certificate with a linear probability model using household fixed effects and observable plot characteristics to predict certificate. The residual, Cererror3=Certificate-Certpr3, from this model (COP3) is seen as a strong predictor of households having randomly been allocated certificates. This approach controls for time-invariant observable and unobservable household and plot characteristics.

The results from these three models are presented in table A1.

Tables A1 and A2 show that the Certpr1 predicted variable created with the standard IV approach based on the exogenous village dummies and years since certification variables, and the Certpr2 predicted variable using observable household and plot characteristics, have means and standard deviations with much poorer fit than the model using household fixed effects and observable plot characteristics. If the cut-off point for correct prediction is set at 0.5, Certpr1 predicts only 7.1% of the plots without certificates correctly and Certpr2 only 1.2%, while the household fixed effects model predicts 88.1 % of these plots correctly, see table A3 below. There appears therefore to be substantial randomness in relation to plots not having certificates and the exogenous instruments used to identify households without certificates do very poorly. The same is the case for observable household and plot characteristics (Certpr2). Only the linear probability model with household fixed effects and plot characteristics has a reasonable ability to predict households without certificates with 88.1% correct predictions. Based on these findings we think it is reasonable to assume that lack of certificate is either random and use of actual certificate may be the best estimation strategy, or it is determined by unobservable household characteristics. If the first is true, this opens for use of non-parametric matching estimators as one of the approaches that is worth testing. If the second is true, Certpr3 may be used to control for unobserved household heterogeneity and use of Cererror3 may be the best strategy to assess the impact of random certification.

***Table A1** Determinants of Households Having Land Certificate*

Variables	COP1	COP2	COP3
Years since certification	-0.100***		-0.011***
	(0.02)		(0.00)
Homestead plot	1.078***	1.058***	0.088***
	(0.18)	(0.18)	(0.02)
Homestead plot 06	0.071	-0.053	0.017
	(0.29)	(0.28)	(0.03)
Plot size	-0.002	-0.039	0
	(0.06)	(0.06)	(0.01)
Shallow soil	-0.034	-0.043	-0.003
	(0.14)	(0.15)	(0.02)
Medium deep soil	-0.082	-0.119	-0.015
	(0.15)	(0.16)	(0.02)
Flat slope	0.101	0.05	0.007
	(0.28)	(0.29)	(0.04)
Low hill	-0.078	-0.071	-0.016
	(0.30)	(0.31)	(0.04)
Mid hill	0.014	-0.109	-0.019
	(0.34)	(0.35)	(0.05)
Soiltype Cambisol	0.182	0.217	0.021
	(0.17)	(0.17)	(0.02)
Soiltype Vertisol	0.021	0.031	0.005
	(0.16)	(0.16)	(0.02)
Soiltype Regosol	-0.204	-0.257	-0.028
	(0.17)	(0.17)	(0.02)
Distance to plot	-0.001	-0.002	0
	(0.00)	(0.00)	0.00
Public investment		-0.022	
		(0.14)	
Sex of household head		-0.135	
		(0.26)	
Age of household head		-0.002	
		(0.01)	
Education of household head		0.106	
		(0.12)	
Female labor force, log		0.136	
		(0.11)	
Male labor force, log		-0.053	
		(0.09)	
Oxen per farm size, log		-0.097	
		(0.12)	
Other livestock per farm size		-0.147***	
		(0.05)	
Farm size		0.071**	
		(0.03)	
Village fixed effects	Yes	No	No
Household fixed effects	No	No	Yes
Constant	2.320**	2.003***	1.040***
	(1.07)	(0.65)	(0.16)
Household panel variance	1.575***	1.723***	
	(0.20)	(0.20)	
Number of observations	1985	1967	1985
Log likelihood	-625.2304	-633.5256	
Chi-2	9.09E+01	7.61E+01	3201.326
P	7.69E-09	3.61E-08	0
Rho (Panel variance fraction)	0.8285212	0.8484596	0

Table A2 *Basic Statistics for Alternative Predictors for Certificate*

Variable	Obs.	Mean	Std.Dev.	Correct predictions: Have certificate	Correct predictions: Do not have certificate
Certificate	2024	0.790	0.407		
Certpr1	1985	0.920	0.134	97.1	7.1
Certpr2	1967	0.950	0.079	99.7	1.2
Certpr3	1985	0.789	0.331	98.8	88.1

Footnote

[1] Modern technologies such as total stations, GPSs, computers, advanced software, etc., were not used. Plots were demarcated using local materials and measured with ropes in the presence of all neighbors as witnesses. Information was recorded on a single page for each household with a number of plots. The data were entered in registry books kept at community and district levels.

[2] The variable has a range from -1 to 1 and the positive mean values indicate that the maintenance status of such structures has improved over time.

[3] Using household fixed effects models meant the loss of a substantial number of observations.

[4] Household fixed effects models were infeasible because of too few observations with a positive number of trees.

[5] The results are available from the authors upon request.

[6] 1 tsimdi is the area a pair of oxen can plough in a day and is approximately 0.25 ha.

Certification and Land Investment: The Case of Tigray Region, Northern Ethiopia

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Abstract

Land titling or registration is widely believed to improve efficiency of land use and agricultural production by increasing farmers' incentives to adopt new technology, on-farm investment, and soil conservation practices. Towards this end, governments have been engaged in various initiatives to title holdings hoping that titling will boost farmers' sense of security, which, in turn, is expected to encourage investment on erosion-reducing and land quality enhancing technologies. The evidence so far is mixed. The study intended to explore whether land registration\certification enhanced feeling of security of tenure and thereby induced increased investment on land. Furthermore, it explored the determinants of the probability and intensity of investment after registration by controlling for initial status of investment, year of registration[1]and whether all plots were certified, and, a vector of household characteristics and resource endowments and a vector of time invariant variables such as plot characteristics and village characteristics. We used random effects and modified random effects probit and truncated regression models. The study used a cross sectional data from a representative sample of 437 households from 18 Peasant Associations (Kebeles) in six zones of Tigray region, northern Ethiopia.

Findings indicated that land registration has enhanced holders' feeling of security. Yet increasing population growth, increasing landlessness and government land takings posed serious sources of insecurity to users. This study also indicated that there was significant increase in probability and composition of investments (more profitable investments than the usual soil and water conservation measures) and increased proportion of plots conserved through private initiatives relative to those conserved through public programs.

On the determinants of adoption, we found out that tenure duration had a significant effect on probability and intensity of investments. .On the other hand, households that reported to have lost land during the last land redistribution were found to be less likely to make investments pointing to the disincentive effect of recurrent redistribution and the associated losses. Likewise, households that reported to have lost land during the last land redistribution and whose land was taken away by the government for various purposes were found to have made lower investments strengthening the disincentive effect of insecurity caused by recurrent redistribution, the associated loss of holdings and through land takings. Households operating rented in land were found to be less likely to and invested less on land indicating that they may want to maximize immediate benefits without committing more resources to long-term investments. Most interestingly, initial investment had a very significant effect on the likelihood and intensity of investment after registration. The results here strengthen that there are household levels characteristics that predispose many

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[1] Households do not get holding certificates automatically once their land is registered; there is a need to control both for registration and certification, even if they could be highly correlated.

households to carry on making land investments in the presence or absence of land policy changes. Furthermore, households with access to food-for-work markets were found to be more likely and have made higher investment on land underscoring the significance of access to food-for-work in relieving households' cash constraints and enhancing long-term investment. Unlike in the probit models, intensity of investment seems to have significantly been influenced by the year of registration. Important policy implications and policy recommendations are drawn.

***Key words*:** registration/certification, tenure security, land investment, random effects model; Ethiopia

1. Introduction

Land is one of the most critical assets to the livelihood of rural households in developing countries. In Ethiopia, until recently, rural households' access to land was met through regular government sponsored land redistribution and informal land transactions. Formal land sales have been prohibited during the last three decades or more. Land is declared the property of the state; hence, it may not be sold or mortgaged. Peasants and pastoralists have only user rights (Rahmato, 1992; FDRE, 1995; Joireman, 2001).

The land issue has a strong bearing on a wide range of issues and policy concerns, including agricultural development, food security, natural resource management, poverty reduction and even human rights (Feder and Nishio, 1999; Rahmato, 2003; Deininger and Chamorro, 2004). In Ethiopia, while there is still policy debate on the choice of ownership type, there is a move in the policy realm to give rural land users a title of 'ownership', by issuing user certificates, to the land they received during the last land redistribution or through inheritance from their close kins. One such case is the process that unfolded in Tigray region, northern Ethiopia after 1997. The regional government of the national state of Tigray undertook land inventory and registered all rural lands before issuing title certificates to users. This process continued later on in areas where land registration took place thereafter (e.g. in the recent resettlement areas) and to other people who obtained land recently through partial community redistribution processes.

Land titling or registration is widely believed to improve efficiency of land use and agricultural production by increasing farmers' incentives to adopt new technology, on-farm investment, and soil conservation practices (Feder and Nishio, 1999; Rahmato, 2004). The motivation for the government's initiative seems to have come from this imperative: boosting farmers' sense of security, which, in turn, is expected to encourage investment on erosion-reducing and land quality enhancing technologies (FDRE, 2005). But it is also possible that the policy measures might have triggered other outcomes, intended or otherwise. Similarly, it is also possible that the expected and other potential outcomes have not materialized due to various factors such as household resource endowments, institutional constraints and factor market imperfections. This provides, hence, an important case study for drawing important policy lessons on the impacts of land certification.

There is an on-going discussion about the differentiated effects titling may have on tenure security and labor-intensive land conservation investment. The evidence so far is mixed. There are evidences from Africa and elsewhere that indicates that such government sponsored titling enhances tenure security (Feder et al., 1988; Binswanger et al., 1996: Firmin-Sellers and Sellers, 1999). On the other hand, there are evidences that call against land registration and tilting as the cost of land registration is quite high, and its effects contrary to expectations (Atwood, 1990).

The process of land registration and certification in Tigray region, the problems faced, people's attitude on the registration and institutions involved is well documented by Haile et al. (2005; Deninger et al., 2007). The impact of registration/titling on the functioning of land markets has been the subject of study by Holden et al. (2007) and their study results revealed that the land reform contributed to increased land rental market participation. However, there exist no previous studies that have attempted to quantify the impacts of registration on tenure security and land investment or land productivity.

This study, which is the first of its kind in the region, hence, explores whether exogenous registration and titling improved land users' feeling of security and whether there has been an increase in land investment after certification. The study utilizes data from 437 randomly selected households operating 1696 plots collected during 2004/05 in eighteen selected communities (*tabias*) located in the five zones of the Tigray Regional National State. In the survey, we tried to capture investments made before and after registration in order to assess whether there is significant increase in long-term land investment after the registration in terms of likelihood and intensity of investment. Once this was established, we explained the probability and intensity of investment after registration by controlling for initial status of investment, year of registration[2]and whether all plots were certified, and, a vector of household characteristics and resource endowments and a vector of time invariant variables such as plot characteristics and village characteristics using Probit and Truncated regression random effects models. Random effects and pooled OLS model estimators are consistent only under the assumption that unobserved heterogeneity is uncorrelated with the observable explanatory variables. To obtain consistent estimates of the effects of registration/certification, we need to control unobserved heterogeneity that may be correlated with observed explanatory variables. One way to do that is to exploit the panel nature of our data set (repeated cross-sectional plot observations per household). We used a modified random effects[3] model framework proposed by Mundlak (1978), whereby we included on the right-hand side of each equation the mean value of plot varying explanatory variables (For a similar approach see Kassie et al., 2008). The effect of certification is estimated by the inclusion of the year of registration/certification in the model and relies on sufficient variation in this variable (for a similar approach see Deininger and Chamorro, 2004).

The paper is outlined as follows: in part 2 we present a short description of the process of land registration and certification followed by presentation of a simple conceptual framework to understand the effect of land registration/titling on investment. In section three we present the empirical model and the methods of estimation. Sections 4 and 5 present the study sites and sampling strategy employed together with empirical findings. The final part concludes by summarizing the findings and drawing relevant policy conclusions.

2. Background and process of land registration and certification in Tigray

The land tenure system in Ethiopia has been substantially affected by past and current government policies (Rahmato, 1992; Joireman, 2001; EEA/EEPRI, 2002; Teklu, 2003). Land is declared the property of the state; hence, it may not be sold or mortgaged. Peasants and

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[2] Households do not get holding certificates automatically once their land is registered; there is a need to control both for registration and certification, even if they could be highly correlated.

[3] We could not use fixed effects model as we have many households with only a single plot.

pastoralists have only user rights. Holding rights are defined in the Federal Constitution (FDRE, 1995) as "the right any peasant shall have to use rura11and for agricultura1 purposes as well as to lease and, while the right remains in effect, bequeath it to his family member; and includes the right to acquire property thereon, by his labor or capita1, and to sell, exchange and bequeath same" (Art 2 Sub Art. 3). The state has the ultimate power to enact laws about utilization and conservation of land. Art. 51 of the constitution states that the Federal Government shall enact laws for the utilization and conservation of land and other natura1 resources (FDRE, 1995). Art. 52 also states, that Regional Governments have the duty to administer land and other natura1 resources according to Federa1 laws and on behalf of the same. A law was enacted in July 1997 on "Rura1 Land Administration Proclamation, No. 89/1997" (FDRE, 1997) that vested Regiona1 Governments with the power of land administration (defined as "the assignment of holding rights and the execution of distribution of holdings"4 (Art. 2.6)). The Federal land policy states that farmers have a perpetual use right on their agricultural holdings, and that this right will be strengthened by issuing certificates and keeping registers (Deininger et al., 2006).

A new land policy enacted in the Regional National State of Tigray in 1997[5], and subsequently revised three times, prohibited further redistribution, except in cases where major public-led infrastructure development (e.g. irrigation) were made or vacant[6] or communal (waste) lands are distributed to landless youth. By prohibiting further land redistribution, the policy hopes to stop further land fragmentation. The 1997 and subsequent laws also formalized land-lease practices among farmers and between farmers and investors with contracts up to three years if the leaser uses traditional technology and up to 20 years if modern technology. However, the definition of use of "modern technology" was left to be decided by regional guideline. The policies also triggered the process of registration and titling of holdings of users. In line with the provisions of the constitution, the land polices granted holders use rights, rights to bequeath, and rights to rent land. In the spirit of this legal provision, the regional government in Tigray undertook land inventory surveys and issued use-right certificates to current users (Hagos et al., 1999) starting 1998. By doing so the regional government hoped to boost farmers' sense of security, which, in turn, may encourage investment on erosion reducing and landing quality enhancing technologies without the state losing its right of ownership to land. Lately different regional governments in Ethiopia have also initiated a process of land registration and certification (Deininger et al., 2006, p. 5).

The latest land policy also outlines obligations of the land users: not to cut trees on farm, protect plot boundaries, undertake soil and water conservation measures and plan trees, among others. Failing to do so could lead upto withdrawal of the household's holding rights (RNST, 2007; p. 10). The policy also provides guarantees to land users against expropriation without proper compensation. This is expected to increase farmers incentives to make land related long-term investments. The subject of this study is the impact of land registration and certification undertaken in Tigray after 1997. The process of land registration and certification in Tigray region, the problems faced, people's attitude on the registration and institutions involved is well documented by Haile et al. (2005). We present a brief description of the last land redistribution and registration and certification in Tigray so that we understand the context under which the later took place.

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[4] The latest Federal legislation on land administration and use is proclamation No. 456/2005 which also calls for regional states to come up with proclamations and regulations to implement the federal proclamation.

[5] This first law follows in the spirit of the 1997 Federal Rural Land Administration Proclamation while the latest one Proclamation No. 136, 2007 follows in the spirit of Federal legislations No 455/2005 and 456/2005..

[6] Land of deceased people without heirs and permanent migrants is claimed by the community and redistributed among the youth.

Most of the cultivated land had been redistributed for the last time in Tigray between 1989 and 1991 although exact dates vary a bit from place to place. By the time of the last distribution, most people, even many of those who had lost land, said they thought a fair distribution had been achieved (Haile et al., 2005). Since that time, land distributions have (with a few exceptions) only occurred – to date – when 1) a new micro-dam created newly irrigated land and the existing land holders' holdings were reduced and distributed; 2) when people abandoned land (e.g., left their village for more than 2 years) or died without "legal heirs"[7] and the land returned to the *tabia baito* (local village government) for distribution; or 3) when some government improvement or infrastructure development (e.g., roads) cause land to be taken rendering compensation necessary. Otherwise, the vast majority of land holdings have not changed hands since about 1991 in Tigray, based on a policy that recognized lower investment incentives would arise due to the uncertainty of possible future land redistributions. Nonetheless, farm households do not rule out future land redistribution even if it is ruled out in the current land policy.

It is roughly eighteen years since the last redistribution, most of the children under eighteen at that time have come of age but have not received land. This probably accounts for something like half to two-thirds of adults today. Some have received land through inheritance but due to high population growth and prohibitions against further fragmentation of land, most have not obtained land of their own. The problem of landless youth is today one of the growing problems in Ethiopia in general and Tigray in particular (EEA, 2007) and is becoming a cause of growing tenure insecurity.

Registration and certification of most cultivated land was completed in Tigray between 1996 and 1998 and appears not to have changed the size of holdings. The registration of cultivated land had been preceded for seven or eight years by fairly strong and clear policy statements that there would not be any further land distributions in the foreseeable future. So, existing landholdings were simply registered. For each household the plots of cultivated land held by the household (whether brought to it through marriage or given in the last distribution or a more recent distribution) were recorded in *Tigrigna*, the local language, by hand in ink on a pre-printed page in a record book at the *tabia* office, with each page listing each parcel of land held by the household, the approximate size of each plot (in *tsimdi*, a local unit of measure that is the amount of land that can be cultivated in one day using oxen plough and averages about 0.25 hectares), the type of land of each plot (poor, medium, and fertile), and describing each plot only by the local area name or a geographical marker and the names of the neighboring land holders on the north, south, east and west sides. In addition, the family size is registered. The certificate was typically issued in the name of the household head, who in most cases is male. The certificate is nearly identical in form and content to the registration book page and is also written in ink on a preprinted form in the local language; that is Tigrigna in all of our sites.

In most cases "technicians" trained at the Agbe Youth Training Center working together with the local Agricultural Development Agent and community members (usually men who had been involved in the last land distribution), performed a study of land ownership and recorded the land details on a pre-printed form. In almost all cases these findings of the study were then reviewed publicly with the landholders. In some cases landholders were also involved in the study of their land.

[7] The Tigray land law excludes some heirs allowed by the Civil Code, e.g., those with another source of income.

The State Agriculture Bureau designed the general process and the 3 pre-printed forms (study, registration book, and certificate). The study and registration processes were modified somewhat at the *tabia* level by the *tabia baito* and implemented at the *tabia* level with supervision from the *Wereda* (District), particularly the agricultural development agents. The Social Courts and *Wereda* Courts, as well as the administrative law functions of the *tabia baito* play a role in enforcement.

3. Conceptual framework

The notion that the greater tenure security accorded by possession of registered land title will be associated with higher levels of investment is a key element in the literature (Feder et al., 1986; Feder et al, 1988) and the relationship between possession of title and higher levels of land-attached investments has been confirmed in the literature (Binswanger et al., 1996; Deininger and Chamorro 2004) although there are also evidences of weak or non-existent land-attached investments in spite of land titling (Atwood, 1990; Mighot-Adholla et al., 1991; Carter et al., 1991; Roth et al., 1994; and Place and Mighot-Adholla,1998).

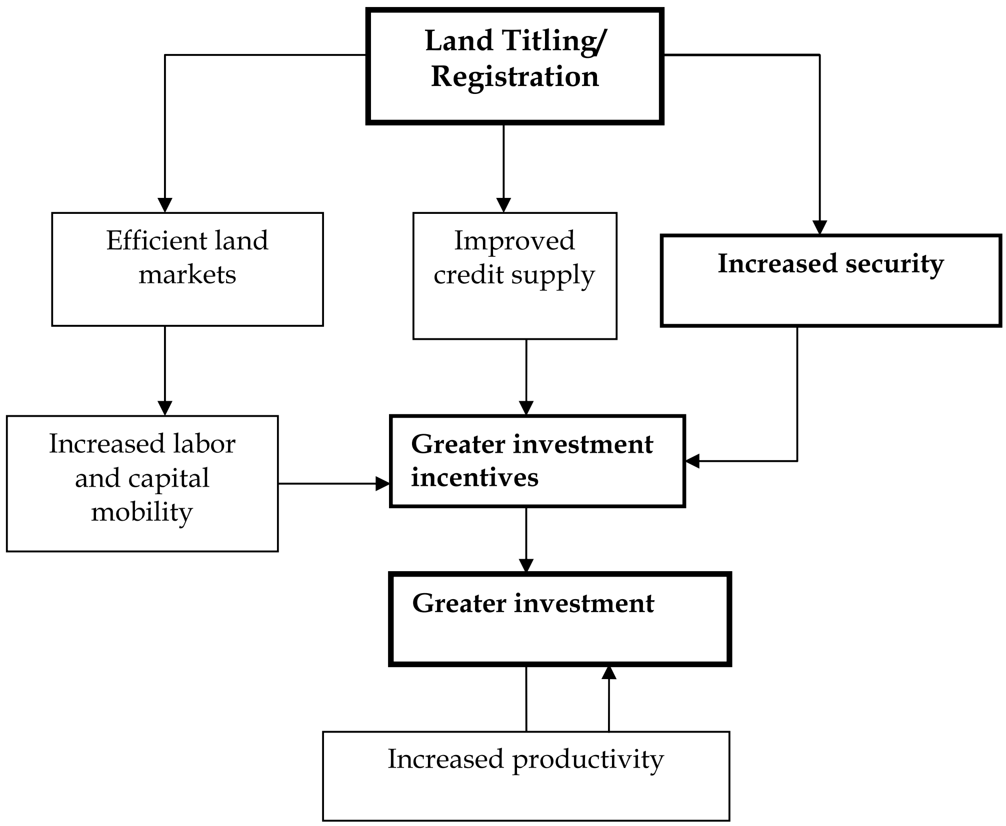
From the literature (Feder et al., 1986; Feder et al, 1988; Besley, 1997; Feder and Nishio, 1999; Deininger and Chamorro, 2004), we gather that secure property rights in land are generally considered to be a precondition for economic growth and development for three reasons: (i) land titles have positive effect on land tenure security and provide investment incentives for owners to undertake land-related investments; (ii) land titling reduces the transaction costs in land markets thus helping increase cost and allocative efficiency; and (iii) formal land titles improve access to institutional credit by creating collateral value for land. We briefly outline each of these linkages and put it together into a schematized graph in Figure 1 below.

Land tenure security, which accrues from land registration/titling, removes uncertainties on whether or not land owners can reap the benefits from any long- term investment they make such as on-farm soil and water conservation, water harvesting structures and trees. With positive expectations about the exclusive enjoyment of any returns earned from investment, landowners develop interest in investing in land improvements as well as making land-based investments in agriculture. This boosts demand for investment which in turn increases demand for complementary inputs including labor and agricultural inputs (including capital). There are empirical evidences in support of the positive impact of land registration on investment (see Feder et al., 1986; Feder et al, 1988; Binswanger et al., 1996: Feder and Nishio 1998; Firmin-Sellers and Sellers, 1999; Deininger and Chamorro, 2004).

Land registration provides the necessary information to overcome the asymmetries in information available between two contracting parties to a land transaction. Consequently, land registration plays an important role in reducing land transaction costs and thereby raising the efficiency of whichever planned investment. This may enhance efficiency in land use by creating a market in land and/or increases market efficiency, thereby enabling property rights in land to move from less efficient to more efficient users of land. There is emerging evidence that land registration contributed to increased land rental market participation in Ethiopia (Holden et al. 2007).

Land titles are associated with collateral in the following way: when borrowers apply for loans, land titles are often pledged as collateral. The pledging of titles as collateral, accompanied by registration of mortgage transactions, helps to overcome the problem of asymmetric information and the related incentive problems of moral hazard and adverse selection. These collateral arrangements are crucial for lending institutions and the credit market because they partly or fully shift the risk of loan loss from the lenders to the borrowers since a default on the loan would trigger the loss of collateral to the borrower. A combination of an increase in investment demand and credit supply associated with land registration leads to more investment, greater use of variable inputs, higher output per unit land area, greater income and higher land values. Feder and Nishio (1998) found that land registration led to: higher land values in Thailand, Philippines, Indonesia, Honduras, Brazil and Peru although other have found hardly any linkage between land titling and better credit market performance, particularly in Africa (Roth et al., 1994).

Figure 1 *The effect of registration and land tilting on land related investment: Conceptual framework (Feder et al., 1988)*



In this paper, we focused on the land tenure security and investment incentive effects instead of the land title, collateral and credit linkages because foreclosure of land is not within the law in Ethiopia, while livestock or other property may be confiscated for indebted people. Land is not used as collateral to access formal credit markets by smallholder farmers, the focus of this study, although commercial farmers do so. The land markets, transactions and efficiency linkages of land registration/titling in Ethiopia has been accessed by Holden et al. (2007) by exploring on the functioning of land markets and market participation before and after registration. This paper intends to explore if land registration/certification has led to improved tenure security and whether this is translated to increased investment in land conservation, the so-called land tenure security and investment incentives effect, by focusing on the case study from Ethiopia. Furthermore, we identify the most important determinants of land conservation investment by smallholder farmers in northern Ethiopia.

4. Empirical model and econometric approaches

Availability of data on investment before and after titling allowed estimating if there is a significant difference in the likelihood and level of investment which in turn enables us to capture the impact of land registration and titling on land-related investments before and after titling. We could have explained differences in investment before and after (see Deininger and Chamorro 2004), if (1) the same households have been observed before and after registration, (2) it is possible to run a household fixed effects model. The later required adequate variation in plot level variables and year of registration/titling within the same household, which was hardly the case. We, hence, used a random effects probit and truncated regression models to identify determinants of probability and intensity of investment. We also tried a modified random effects model as suggested by Mundalk (1987).

The approach we took is as follows. We established whether there was significant difference in the likelihood and level of investment (by type) using simple mean separation tests (t-test and X^2/ Z-tests). Next we explained the determinants of probability of investment and level of investment using maximum likelihood estimation techniques of the form:

Let the amount of conservation made on farm plot by a household i be given by:

$$y_1 = x_1\beta_1 + \mu_1 \qquad (1)$$

where y_1 is the length of conservation structures per land area that is expected to depend on the vector x_1 regressors. y_1 is non-continuous variable which is censored from below. We assumed that the level of investment made by each household on each plot is a result of rational decision whether to make the investment or not. We used the physical measures of land-related investment that were made after registration. The measures include stone and soil bunds, terraces, tree planting, gully stabilization measures and water harvesting structures, among others. We regress this variable on set of covariates x_1 such as year of registration, whether all plots are certified, whether there was any initial investment on the plot before registration/ or the size of initial investment, whether the households lost land because past land redistribution and/or land taking, and a vector of time invariant plot characteristics such as tenure regime and observable plot characteristics such as soil type, slope, topography, soil fertility and susceptibility to erosion and plot distance from homestead and other household characteristics such as age, sex of the head and education of the head to obtain an estimate of the impact of an exogenous change in land rights on investment. We also controlled for household level asset holding (land area, labor, livestock holding, and household's cash situation) and village level factors such as distance to market and agro ecology.

The participation equation, whether the household decides to invest or not, is given by:

$$y_2 = 1[x\delta_2 + v_2 > 0] \qquad (2)$$

where (x, y_2) are always observed whereas y_1 (in eq. 1)is observed only when $y_2 = 1$. We assume that (u_1, v_2) is independent of x with mean zero implying that x is exogenous, and $v_2 \sim N(0,1)$. We used same set of explanatory variables in equation (2) and in equation (1). Equations (1) and (2) are estimated using random effects Probit and truncated regression models, in the latter we took only positive investments.

Random effects model estimators are consistent only under the assumption that the unobserved heterogeneity is uncorrelated with the observable explanatory variables. To obtain consistent estimates of the effects of registration/certification, we need to control for unobserved heterogeneity that may be correlated with observed explanatory variables. One way to do that is to exploit the panel nature of our data set (repeated cross-sectional plot observations per household). We used a modified random effects model framework proposed by Mundlak (1978), whereby we included on the right-hand side of each equation the mean values of plot varying explanatory variables. The rationale for including the mean values of plot varying explanatory variables as right hand side variables is check if the unobserved heterogeneity that influence decisions are somewhat related to the observables (For a similar approach see Kassie et al., 2008). In this case let, the model is given as:

$$y_1 = x_1\beta_1 + \upsilon_h + \mu_1, \qquad (3)$$

where υ_h captures the unobserved household characteristics that affect household's decision to invest in land conservation. Assuming that the unobserved effects υ_h are linearly correlated with some of the observed explanatory variables,

$$\upsilon_h = \bar{x}\gamma + \eta_h, \eta_h \sim iid\left(0,{}^{2}_{\eta}\right) \qquad (4)$$

where $\bar{x}$ is the mean of plot-varying explanatory variables within each household, γ is the corresponding vector of coefficients, and η is the random error term uncorrelated with the $\bar{x}$'s. In our case, it is important to include average plot characteristics such as average soil quality, plot size, depth, slope, and the average size of initial investments, which may have greater impact on adoption decisions. The vector γ will be equal to zero if the unobserved explanatory variables are uncorrelated with the random effects. For sake of comparison, we report results from the random and modified random effects models in this paper.

5. Study site and data description

Soil erosion, gully formation and loss in soil fertility are considered the three major land degradation problems facing the Tigray region, northern Ethiopia (Hagos et al. 1999; Hagos and Holden, 2002). To reverse the land degradation problem, concerted efforts have been going on in the region in terms of soil and water conservation activities (Geberemedhin, 1998; Hagos et al. 1999; Hagos and Holden, 2002). Land conservation strategies focused mainly on the construction of technologies of physical structures depending on the land use pattern, through strategies that combine community–led mass mobilization and food/cash-for-work schemes and private investment (Hagos and Holden, 2002). Additional incentives are devised to encourage individual households to undertake conservation measures on their holdings through increased provision of extension advice and incentives related to tenure security, where titling of land is considered as one such measure. The study is partly an attempt to understand how recent changes in land policy have affected farmers' conservation investment behavior.

The study is based on a cross sectional data covering 437 randomly selected households, operating about 1695 plots gathered in June-Sept. 2005 in Tigray, northern Ethiopia. The survey covered 18 villages (tabias), four tabias strategically selected from each of the three zones (central, eastern, and southern) and 5 from the North Western and 1 from Western zones[8]. The last two tabias (1 each from Western and North Western) were purposively selected from the low land areas recently affected by the on-going human resettlement program to explore the effects of resettlement on tenure security and land investment. The selection of the 16 communities was based on differences in distance to market, agricultural potential conditions (due to variations in altitude and rainfall variability), population density and presence of irrigation projects. The study assessed farmers' perception of land titling, and its impacts, and the magnitude and quality of conservation investments made on farm through private initiative and/or public-led programs between before and after registration. The data gathered a host of household related variables as well as plot level data on the plots' biophysical features, including production and input use data, which are used for statistical analysis as reported in the subsequent sections.

6. Results and discussion

In this section we report, the results of our analysis. The summary of the descriptive statistics and mean separation tests are reported in Tables 1 and 2. The results fo the regression analysis are presented in Tables 3 and 4.

Descriptive summary

Although land registration started in 1998, land registration and certification was still going on during the survey period (2004-2005) in some areas. This is especially the case in the lowland resettlement areas of the region. About 80 percent of the plots were registered during 1998-99. In the registration process it was found out that about 96 percent of the plots were registered (only 4 percent indicated as not registered) and the demarcation process was also made both on paper and on the ground. In the registration process, it was found out that in about 14% of the plots there was change of boundary and about 8 % of the plots were registered to somebody other than the owner. In about 13 percent of the plots there was dispute with a neighbor during the registration and demarcation of the boundaries. It was also found that about 14 percent of the holdings are not certified. Title certificates were given to the household head (99.3 %).

From the results of the survey, we found out that there were households who received land through land redistribution up until 2005. The bulk of the plots (about 80%), however, were allotted to the current holders before 1991/92. During these redistributions about 31 percent of the households claim to have lost land while 69 percent didn't. About 39 % of the households believed that there will be future land redistribution even if land redistribution is ruled out by law (against 61 % that did expect land redistribution). As a consequence households expect that they will loose land due to redistribution. About 44 % of the respondents who expect land redistribution believed that they will loose land against 56 percent who believed that they will not loose land. The major reasons for fearing future land redistributions included increasing population and landlessness, and too small land holding. Those who do not fear to loose land in a future land redistribution expect to get more land (7.2%), or at least would get their share (6.4), or have landless member (3%) and they hope will get more land from a redistribution. Of those who do not expect future land redistribution, only about 5.7% of the households indicated that there will not be further redistribution as it is prohibited by law and titles have already been issued and about 1%

[8] There have been recent changes in the boundary and number of zones in the region. The former Western zone is subdivided into North western and western zones.

believed that resettlement is reducing pressure on further redistribution. Furthermore, 18 % of the households also reported land takings for various reasons by the government (against 82% who reported no land takings) and about 43 percent of those who lost land reported to have received compensation. In nutshell, non-negligible proportions of the households are apprehensive about or keen to see of future land redistributions perhaps indicating that the feeling of tenure insecurity is pervasive even after the land registration/titling.

Asked about the benefits of land registration, about 18 percent of the households perceived that land after certification can be used to access formal capital markets and slightly higher (21%) to access informal credit markets. About 10 percent also believe that they can temporarily sell it against about 1 percent of the households who perceived that they can permanently sell their land, although the law stipulates differently.

Table 1 *Description and summary of important variables (n= 1695)*

Variable name	Description	Mean	SE
Latest redistribution	Proportion of land redistributed until 1991	0.79	-
Registration	Whether land is register or not (dummy)	0.96	-
Certification	Whether land is certified or not (dummy)	0.86	-
Change of boundary	Change of boundary during registration	0.14	-
Registered to somebody	Plots were registered to somebody other than the owner	0.08	-
Dispute	dispute with a neighbor during the registration	0.13	-
lost land	lost land during the latest land redistribution	0.31	-
Future land redistribution	Expect future land redistribution	0.39	-
Future land taking	Expect future land taking	0.26	-
Will loose land	will loose land in future redistribution	0.44	-
land takings	Land takings by government after registration	0.18	-
Compensation	Received compensation after land taking	0.43	-
Access to formal credit market	Increased access to formal credit market because of land registration	0.18	-
Access to informal credit market	Increased access to informal credit market because of land registration	0.21	-
Temporary sell	Temporary transfer through sell	0.10	-
Permanent sell	Permanent transfer through sell	0.01	-
Tenure security	More secure because of land registration	0.77	-
Tenure regime: owner operated	Proportion of owner-operated plots	0.75	-
Tenure regime: rented-in	Proportion of rented in plots	0.14	-
Tenure regime: rented-out	Proportion of rented-out plots	0.11	-
Conserved before	Proportion of plots conserved before registration	0.34	-
Conserved after	Proportion of plots conserved after registration	0.42	-
Conservation by holders before	Conservation by holders before registration	0.52	-
Conservation through public programs before	Conservation through public programs before registration	0.48	-
Conservation by holders after	Conservation by holders after registration	0.66	-
Conservation through public programs after	Conservation through public programs after registration	0.44	

Comparison of important variables between those who invest and did not invest					
		Invest		**Not invest**	
Variable name	**Description**	**Mean**	**SD**	**Mean**	**SD**
Labor endowment (adult male)	Average number of male adults	1.74	1.28	1.56	1.23
Land holding	Average parcel area	1.26	1.39	1.75	2.80
Livestock (oxen)	Average oxen holding	1.16	1.19	1.16	1.13
Credit access	Average farm loan size (in ETB)	4763.3	43107.0	3222.1	36280.6
Distance	Average distance (in min)	19.4	27.2	35.01	61.53

Increased tenure security seems to have been also one the most important benefits of land registration/certification. About 77 % of the households believed that they feel more secure about their holding rights after certification in spite of anticipated future land redistribution and fear of future land takings. Nonetheless, a non-negligible portion fo the households feel insecurity of tenure even after the land registration/titling, although the majority seem to have a feeling of security.

Furthermore, be as it may, whether this increased feeling of tenure security is translated to actual changes in behavior is another question which is the main interest of this paper. We surveyed the plots conserved before and after the registration. The results show that about 34% of the plots were conserved before the registration as compared to 42% of the plots after the registration. Hence, there is a slight increase in the number of plots conserved after the registration. The dominant types of land investment, before registration, include establishment of stone terraces followed by soil bunds, gully control, tree planting and other conservation investments on 24 %, 11%, 2%, 2% and 5 % of the plots respectively. Soil bunds and terraces remained dominant conservation structures established by farmers on their plots after registration both accounting for 26 and 14 percent of the plots. Gully stabilization (3%) and tree planting (2.4%) remain important as well. However, there are new introduction to land investment, most notably construction of water harvesting structures (3.3 %) such as ponds and wells, since recently.

Before registration, about 52% of the investments were made by owners themselves and tenants, and 48% by public programs both mass mobilization and Cash/Food-For-Work programs. After registration, about 66% of the investments were made by owners themselves and tenants (who rent-in their land), and 44% by public programs, both mass mobilization and FFW programs indicating an increase in private investment while public investments have also showed a decline.

In the resettlement areas, new settlers occupy about 4 percent of the plots of which nearly 80 percent are registered and certified. About 20 percent of the households expect that there will be further settlers in the future triggering fear of losing more land. About 7 percent of the households indicated that there is land related conflict in the new resettlement areas. About 27 percent believed that those conflicts are between old and new settlers. One of the major sources of land related conflict in the resettlement areas are illegal expansion of farm holdings and unequal distribution of land. About 97 percent of the respondents from the resettlement areas, however, believed that there are institutions involved in solving land related disputes.

Mean Separation tests

We explored if there is a significant difference in the proportion of plots conserved by households before and after registration. The simple mean separation result indicates that there is a significant change in conservation after registration (p-value 0.000) Likewise, on whether there is a significant difference in private investment before and after registration, the results indicated that there is a significant increased in private investment (p-value 0.000) after registration.

It is interesting to look at the changes in composition of investment before and after registration. From the mean separation tests we gathered that while the proportion of stone remains the same soil bunds and other conservation measures have changed significantly (see Table 2).

Table 2 *Mean proportion/separation tests (n= 1695)*

Variables	Mean proportion		Difference	X^2/Z/t-test
	Before	After		
Proportion of conserved plots	0.335 (0.011)	0.415 (0.01)	-0.076 (0.016)	-4.62 (0.000)
Proportion of private investment	0.18 (0.01)	0.27 (0.011)	-0.093 (0.01)	-6.49 (0.000)
Proportion of stone terraces	0.23 (0 .010)	0.25 (0 .010)	-0.021 (0 .015)	-1.45 (0.145)
Proportion of soil bunds	0.105 (0.01)	0.138 (0.01)	-0.033 (0 .011)	-2.95 (0.003)
Proportion of other conservation investments	0.046 (0.005)	0.08 (0.006)	-0.034 (0..008)	-4.14 (0.000)
Level of investment (length of conservation measures in metres)	22.9 (2.08)	25.6 (3.73)	-2.66 (3.57)	-0.7446 (0.456)
Level of investment (amount of labor man days)	18.83 (2.96)	16.59 (1.89)	2.23 (2.12)	1.0523 (0.293)

We also conducted a mean separation test on the changes in levels of investment made both in terms of the level of physical measures and labor man days used for conservation. Both tests show that there are no statistically significant differences in levels of investment before and after registration. We can, hence, conclude that although there is significant increase in likelihood of making investment on land, the intensity remains the same.

Regression results

Here we present the results of the regression analyses: probit and truncated regression random effect and modified random effects models for the investments after registration while controlling for the level of initial investment, household and plot level covariates, and changes in policy (i.e. year of registration and whether all plots are certified),

From Table 3 we can see some of the most important variables in explaining likelihood of land investment after the registration. The year of registration and whether plots are certified or not had no significant effect on the probability of investment indicating there is no difference between those who got their land registered and secured their certificate earlier on and those who obtained certificates recently. This may imply that registration and certification may not have created the required security incentive for increased land investment. Year of last redistribution, which could be a good proxy for the duration of holding, is found to have a negative effect on land investment implying that those who obtained land during the recent land redistributions were less likely to invest on their land. In other words, households that kept their holdings longer were found to be likely to make investment compared to households that obtained land recently. Households that reported to have lost land during the last land redistribution were also found less likely to make investment on their land pointing to the disincentive effect of recurrent redistribution and the associated loss of holdings. Households operating rented in land were found to be less likely to invest on land indicating that they may want to maximize immediate benefits without committing more resources to long- term investments. This may point to incentive problems as renting duration is usually for one year or two but rarely longer. Most interestingly, initial investment had a very significant effect on the likelihood of investment after registration. What this result indicates is that those who have been making investment earlier on are also making the investments after titling. This may imply that, regardless of whether land registration or titling has taken place or not, there were/are households that are likely to make investments on their land A host of factors related to asset holdings and access to labor and capital markets had significant effect on probability of investment. Households with more livestock holding and adult male labor (although only in the random effects probit and at 10 % level of significance) were found to be more likely to make investments on land. Households who average land holding is relatively larger were found to be less likely to make investments on land perhaps pointing to inverse relationship between the likelihood of investment and farm size. But this result was significant in the modified random effects model. Furthermore, households with access to food-for-work markets were found to be more likely to invest. However, those who have obtained higher loan from formal credit organizations were less likely to invest perhaps indicating that those who access for more loan invest it somewhere else than in land investment.

Table 3 *Survey probit regression*

Dept. variable: Investment after registration (0/1)						
	Random effects			**Modified random effects model**		
Variables	**Coef.**	**Std. Err.**	**ME**	**Coef.**	**Std. Err.**	**ME**
Household characteristics						
Age of household head	-0.001	0.004	-0.001	-0.0004	0.005	-0.0001
Education of household head (literate)	0.026	0.049	0.008	0.044	0.052	0.013
Female-headed household (Reference male-headed)	0.234	0.162	0.075**	0.283	0.167*	0.092*
Asset holding						
Number of Male adults	0.060	0.042	0.018*	0.041	0.043	0.013
Number of female adults	-0.002	0.065	-0.001	-0.001	0.065	-0.0003
Livestock holding	0.047	0.031	0.014**	0.051	0.032	0.015**
Land holding	0.001	0.001	0.001	-0.014	0.004**	-0.003**
Access to FFW income	0.0004	0.0002**	0.0001***	0.0005	0.0002**	0.0001***
Amount of Farm loan taken	-0.0001	0.0001	-0.000	-0.0001	0.0001**	-0.00004**
Land policy related variables						
Last year of land redistribution	-0.069	0.017***	-0.021***	-0.071	0.018***	-0.22***
Year of registration	0.015	0.048	0.005	0.025	0.051	0.007
Lost land during last redistribution (yes)	-0.147	0.104	-0.045*	-0.150	0.106	-0.045*
Land taken after registration (yes)	-0.094	0.132	-0.028	-0.005	0.131	-0.001
All plots registered (yes)	-0.257	0.345	-0.086	-0.034	0.339	-0.011
All plots certified (yes)	0.199	0.193	0.058	0.250	0.203	0.072
Duration of land holding (since year)	0.005	0.007	0.001	-0.017	0.011	-0.005
Tenure form: rented-in (reference owner operated)	-0.302	0.141**	-0.086**	-0.235	0.146*	-0.068*
Tenure form: rented-out(reference owner operated)	-0.197	0.171	-0.057	0.218	0.210	0.071
Whether plot conserved before registration (yes)	1.092	0.111***	0.390***	0.761	0.123***	0.265**
Plot characteristics						
Plot area (tsimad)	0.028	0.018	0.008	-0.001	0.001	-0.0002
Distance (in minutes)	-0.005	0.002***	-0.001***	-0.007	0.002***	-0.002***
Soil type: Walka (reference Baekel)	-0.037	0.123	-0.011	-0.084	0.120	-0.025
Soil type: Sandy (reference Baekel)	-0.067	0.117	-0.020	-0.128	0.113	-0.038
Soil type: Red soil (reference Baekel)	0.069	0.1222	0.022	-0.085	0.129	-0.026
Soil type: Red soil: other (reference Baekel)	0.532	0.248**	0.189*	0.136	0.244	0.044

Table 3 Continued

Soil depth: medium (reference shallow)	0.026	0.104	0.008	0.008	0.106	0.002
Soil depth: deep (reference shallow)	-0.006	0.128	-0.002	0.029	0.141	0.009
Soil slope: foothill (reference flat)	0.220	0.122**	0.071**	0.088	0.119	0.027
Soil slope: mid hill (reference flat)	0.358	0.130**	0.121***	0.147	0.157	0.047
Soil slope: steep hill (reference flat)	-0.041	0.279-	-0.012	-0.333	0.298	-0.090
Soil quality: medium (reference poor)	0.078	0.115	-0.024	-0.093	0.124	-0.028
Soil quality: good (reference poor)	0.011	0.147	0.003	0.085	0.180	-0.025
Susceptibility to erosion: medium (reference high)	0.250	0.159	0.081*	0.381	0.179**	0.126**
Susceptibility to erosion: low (reference high)	0.271	0.135**	0.087**	0.355	0.157**	0.0115**
Susceptibility to erosion: none (reference high)	0.216	0.135	0.068*	0.274	0.142**	0.087**
Village level characteristics						
Distance to woreda market	-0.0001	0.0005	-0.000	-0.0002	0.001	-0.0001
Distance to DA office	0.002	0.0002	0.000	0.002	0.003	0.001
Altitude: Midland (reference highland)	0.040	0.120	0.012	0.049	0.126	0.015
Altitude: lowland (reference highland)	-0.094	0.143	-0.028	-0.125	0.152	-0.037
Average time-invariant plot characteristics						
Average soil type	-	-	-	0.157	0.088*	0.048**
Average soil depth	-	-	-	0.015	0.127*	0.004
Average soil slope	-	-	-	0.239	0.129*	0.074**
Average soil quality	-	-	-	0.099	0.159	0.031
Average susceptibility to erosion	--	-	-	0.064	0.106	0.019
Average form of tenure	-	-	-	-0.373	0.159**	-0.115**
Average plot area	-			0.118	0.044**	0.036**
Average distance	-	-	-	0.002	0.001	0.001
Average duration of holding (in yrs)	-	-	-	0.031	0.015**	0.009**
Average probability of investment	-	-	-	0.891	0.243***	0.275***
Intercept	94.409	84.07	-	58.25	92.29	
	Number of obs = 1439 F(39, 354) = 6.56 Prob > F = 0.0000			Number of obs = 1439 F(49, 354) = 5.73 Prob > F = 0.0000		

Note: *, **, *** significant at 10, 5 and 1% respectively.

Some plot level characteristics were also found to be significant. Investment on land was significantly higher on plots that are moderately sloppy and moderately susceptible to erosion. This results show that households avoid making investments on highly susceptible and steep slopes perhaps the cost of investment are prohibitively high. Finally, plots located far away from the homestead are less likely to be conserved mainly because the cost (e.g. transport costs) of making and maintaining those investments is very high. These results are also confirmed by earlier studies on investment in Ethiopia (Hagos and Holden, 2006).

The inclusion of time-invariant plot characteristics does not change much the results, although not a negligible number of the included variables themselves turned out to be significant, individually and jointly. We could conclude that the major results are quite robust.

Many of the results from the probit model were also confirmed in the truncated model random effects and modified random effects models. We also get new insights as many variables turned out significant in explaining levels of investment made by households. In this case, duration of holding significantly determines the level of investment made by households. Households that received land very recently were found to have made significantly lower investment than households that kept their holdings for along time. Unlike in the probit models, intensity of investment seems to have significantly been influenced by the year of registration, i.e. level of investments has decreased as the year of registration was delayed. Households that reported to have lost land during the last land redistribution and whose land was taken away were also found to have made lower investments strengthening the disincentive effect of recurrent redistribution, the associated loss of holdings and through land takings. The influence of initial investment on the level of investment was also found to be significant. The results here strengthen that there are household levels characteristics that predispose many households to carry on making land investments in the presence or absence of land policy changes.

Consistent with the results in the probit model, households with access to food-for-work markets were found to be have made higher investment on land underscoring the significance of access to food-for-work in relieving households' cash constraints and enhancing long-term investment (Holden et al, 2006; Bezu and Holden, 2004). Furthermore, household factors such as age of household head and education of head have a significant influence on the intensity of investment. In this case, households with relatively older heads invested less while households with better educated heads made higher investment on land underlying the importance of better human capital endowment for land investment.

From environmental and plot level variables, the level of investment made on land depends on altitude indicating agro-ecological variations in land degradation and the need for SWC. The level of investment is significantly higher in midland communities than high altitude. The level of investment also varies by soil and plot level characteristics. Accordingly, the level of investment varied by soil type, quality, depth and slope. Investments were found to be higher on relatively deeper soils than shallow soils; on relatively more fertile soils than poor soils pointing to the economic considerations of investment by farmers. Distance has also the same negative effect on the level of investment as we found in the probability of investment. This could be understood in the light of the fact that making investments and undertaking proper maintenance on far away plots is costly. Farm lands located away from homesteads usually turn to common grazing lands during the dry season increasing the chance of destruction of conservation structures by livestock.

Table 4 *Truncated random effects model*

Dept. variable: Intensity of investment						
	Random effects			**Modified random effects model**		
Variables	**Coef.**	**Std. Err.**	**ME**	**Coef.**	**Std. Err.**	**ME**
Household characteristics						
Age of household head	-44.68	16.97***	-0.320***	-4.36	16.41	-0.033
Education of household head (literate)	968.77	221.03***	6.94***	787.43	216.15***	6.10***
Female-headed household (Reference male-headed)	191.95	573.89	1.37	862.89	584.36	6.68
Asset holding						
Number of Male adults	201.38	148.49	1.44	236.08	161.5	1.83
Number of female adults	109.06	246.05	0.78	68.35	259.4	0.529
Livestock holding	-278.78	126.38**	-1.99**	-29.42	115.85	-0.228
Land holding	87.67	72.77	0.62	78.17	0.835	0.606
Access to FFW income	3.632	0.789***	0.026***	2.518	0.762***	0.019***
Amount of Farm loan taken			-0.001	-0.093	0.278	-0.0007
Land policy related variables						
Last year of land redistribution	-239.14	112.69**	-1.71**	-191.06	114.05*	-1.481
Year of registration	-829.21	304.05***	-5.93***	-818.13	111.5***	-6.341***
Lost land during last redistribution (yes)	1648.92	466.55***	11.81***	2063.8	513.5***	15.998***
Land taken after registration (yes)	-2213.40	668.24***	-15.85***	-1704.97	652. 85***	-13.21***
All plots registered (yes)	-878.50	2025.5	-6.29	-967.56	1919.06	-7.50
All plots certified (yes)	1139.19	828.11	8.15	1463.27	32.75	11.34
Duration of land holding (since year)	6.476	589.17	0.046	-84.16	32.75***	-0.652***
Tenure form: rented-in (reference owner operated)	1266.03	589.17**	9.06**	349.8	600.31	2.71
Tenure form: rented-out(reference owner operated)	297.16	709.17	2.13	-625.70	832.7	-4.84
Whether plot conserved before registration (yes)	3.522	0.734***	0.025***	1614.1	490.7***	12.51***
Plot characteristics						
Plot area (tsimad)	-341.34	236.11	-2.44	-206.82	207.8	-1.60
Distance (in minutes)	-8.824	9.639	-0.06	-5.329	8.469	-0.041
Soil type: Walka (reference Baekel)	-1878.0	576.53***	-13.45***	-2572.25	634.08***	-19.94***
Soil type: Sandy (reference Baekel)	-3055.77	649.82***	-21.88***	-1950.05	617.23***	-15.12***
Soil type: Red soil (reference Baekel)	-1278.58	579.83**	-9.16**	-1458.8	654.65**	-11.31**
Soil type: other (reference Baekel)	520.8	935.39	3.73	11.43	951.94	0.088
Soil depth: medium (reference shallow)	678.16	446.82	4.85	396.83	501.29	3.076
Soil depth: deep (reference shallow)	1813.03	586.13***	12.98***	1122.0	649.03*	8.69*
Soil slope: foothill (reference flat)	977.94	542.05*	7.00*	1019.04	503.38**	7.89**
Soil slope: mid hill (reference flat)	3225.9	652.53***	23.10***	2888.9	783.1**	22.39**
Soil slope: steep hill (reference flat)	790.34	1464.01	5.66	456.22	1390.56	3.53
Soil quality: medium (reference poor)	1333.36	581.41**	9.55**	673.08	671.46	5.217
Soil quality: good (reference poor)	2650.7	768.18***	18.98***	1712.90	920.37*	13.27*
Susceptibility to erosion: medium (reference high)	979.88	911.77	7.01	-822.43	897.98	-6.37
Susceptibility to erosion: low (reference high)	1125.28	848.54	8.06	-816.42	769.71	-6.32
Susceptibility to erosion: none (reference high)	147.37	904.90	1.05	-1873.69	917.42**	-14.52**
Village level variables						
Distance to woreda market	-0.182	2.128	-0.001	1.90	2.06	0.014
Distance to DA office	27.37	10.15***	0.0196***	23.09	8.72***	0.179***
Altitude: Midland (reference highland)	3627.9	666.89***	25.98***	2216.48	557.80***	17.181***
Altitude: lowland (reference highland)	207.01	915.33	1.48	-469.64	853.03	-3.640

Table 4 Continued

Average time-invariant plot characteristics						
Average soil type	-	-	-	121.49	356.65	0.941
Average soil depth	-	-	-	331.91	512.40	2.572
Average soil slope	-	-	-	-173.56	583.94	-1.345
Average soil quality	-	-	-	715.31	744.1	5.544
Average susceptibility to erosion	-	-	-	-281.78	744.07	-2.18
Average form of tenure	-	-	-	1010.758	547.34*	7.835*
Average plot area				29.93	358.52	0.232
Average distance	-	-	-	-0.117	6.243	-0.001
Average duration of holding (in yrs)	-	-	-	65.59	61.87	0.508
Average probability of investment	-	-	-	-3845.7	1182.02***	-29.81***
Intercept	2100080	648603***	15042.2***	2031827	-	-
	Number of obs = 420 Wald chi2(39) = 99.48 Prob > chi2 = 0.0000					

Note: *, **, *** significant at 10, 5 and 1% respectively.

Contrary to our expectations, we found that investments were significantly higher by households that are located far away from the Development Agent Office, which we used as a proxy for access to extension service. Whether this is capturing the effects of access to extension service or not is difficult to tell. The results of truncated regression model are also quite robust.

6. Conclusions and recommendations

The study intended to explore whether land registration\certification enhanced feeling of security of tenure and thereby induced increased investment on land. The evidence that comes out of this cross sectional study is that land registration and certification has enhanced household's feeling of security. Yet increasing population growth, increasing landlessness and land takings in peri-urban settings are posing as serious sources of insecurity to users.

This study also indicated that there was significant increase in probability of land investment after registration although the mean level of investment remained about the same. There is also a change in the composition of investments (increased investment on trees, gully stabilization and water harvesting structures than the usual soil and water conservation measures using stone and soil bunds) and increase in the proportion of plots conserved through private investment. Using random and modified random effects models, we assessed the factors that influenced the probability and intensity of investment.

From the regression results we found out that households that kept their holdings longer were found to be likely to make and have made more investment compared to households that obtained land recently. On the other hand, households that reported to have lost land during the last land redistribution were also found less likely to make investment pointing to the disincentive effect of recurrent redistribution and the associated losses. Likewise, households that reported to have lost land during the last land redistribution and whose land was taken away were also found to have made lower investments strengthening the disincentive effect of insecurity caused by recurrent redistribution, the associated loss of holdings and through land takings. Households operating rented in land were found to be less likely to and invested less on land indicating that they may want to maximize immediate benefits without committing more resources to long-term investments. This may point to incentive problems as renting duration is usually for one year or two but rarely longer. Most interestingly, initial investment had a very significant effect on the likelihood and intensity of investment after registration. The results here strengthen that there are household levels characteristics that predispose many households to carry on making land investments in the presence or absence of land policy changes. Furthermore, households with access to food-for-work markets were found to be more likely and have made higher investment on land underscoring the significance of access to food-for-work in relieving households' cash constraints and enhancing long-term investment. Unlike in the probit models, intensity of investment seems to have significantly been influenced by the year of registration, i.e. level of investments has decreased as the year of registration was delayed indicating the security effect induced incentive for land conservation.

Finally, some time invariant environmental and plot level factors such as altitude, soil type, quality and depth, distance and land area were found to have significant effect on investment.

The most important policy implications of these results are that land registration and titling could induce positive security effects on holdings with positive effect on land investment. But for this to materialize policy makers need to minimize the potential sources of insecurity such as threats of future land redistribution and land taking without proper land compensation. Moreover, there is a need to reduce the incentive problems of land rental markets perhaps by extending the duration of land rental rights among farmers, which is currently limited to 2 years. Furthermore, there is a need for continued support to households in the form of food-for-work. Such programs not only reduce households' vulnerability to food insecurity but also generate required resources to make long-term investments.

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Adoption of Organic Farming Technologies:

Evidence from Semi-Arid Regions of Ethiopia

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Abstract

In the wake of resource constraints faced by farmers in developing countries in using external farm inputs, sustainable agricultural production practices that rely on local or farm renewable resources present desirable options for enhancing agricultural productivity. In this paper we use plot-level data from the semi-arid region of Ethiopia, Tigray, to investigate the factors influencing farmers' decisions to adopt sustainable agricultural production practices, with a particular focus on conservation tillage and compost. While there is heterogeneity with regards to factors influencing the choice to use either practice, results from a multinomial logit analysis underscore the importance of both plot and household characteristics on adoption decisions. In particular we find that poverty, and access to information, among other factors, impact the choice of farming practices significantly. We also find evidence that the impact of gender on technology adoption is technology specific while the significance of plot characteristics indicate the decision to adopt specific technologies is location-specific. Furthermore the use of stochastic dominance analysis supports the contention that sustainable farming practices enhance productivity -they even prove to be superior to the use of chemical fertilizers- justifying the need to investigate factors that influence adoption of these practices and use this knowledge to formulate policies that encourage adoption.

Keywords: Sustainable agriculture, Adoption, Productivity, Compost, Conservation tillage, Ethiopia.

JEL Classification: Q12; Q16; Q24

Introduction

Sustainable agriculture can be broadly defined as an agricultural system involving a combination of sustainable production practices in conjunction with the discontinuation or the reduced use of production practices that are potentially harmful to the environment (D'Souza et al., 1993). More specifically, the Food and Agricultural Organization (FAO) argues that sustainable agriculture consists of five major attributes: it conserves resources (e.g. land, water, etc), is environmentally non-degrading, technically appropriate, and economically and socially acceptable (FAO, 2008). In practice, sustainable agriculture uses less external off-farm inputs (e.g. purchased fertilizers), and employs locally available natural resources as well as purchased inputs more efficiently (Lee, 2005).

Conservation agriculture (CA) and the use of organic fertilizers (e.g. compost) are two examples of sustainable agriculture practices. CA seeks to achieve sustainable agriculture through minimal soil disturbance (i.e. zero- or minimum-tillage farming, stubble tillage), permanent soil cover and crop rotations. The potential benefits from CA lie in not only conserving but also in enhancing the natural resources (e.g. increase soil organic matter) without sacrificing yield levels; making it possible for fields to act as a sink for carbon-dioxide; increasing the soils' water retention capacities and reducing soil erosion; and reducing the production costs through reducing time and labor requirements as well as costs associated with mechanized farming e.g. costs of fossil fuels (FAO, 2008). It is due to its ability to address such a broad set of farming constraints that makes CA a widely adopted component of sustainable farming (Lee, 2005). The use of organic fertilizers such as compost, on the other hand, is part of an organic farming system which emphasizes maximum reliance on locally or farm-derived renewable resources. Compost is an organic fertilizer and mulch which has the advantage that it is cheap (if not free); improves soil structure, texture, and aeration; increases the soil's water retention abilities; and stimulates healthy root development (Twarog, 2006). Thus, both conservation tillage and compost are appealing options for enhancing productivity to resource-poor farmers especially in developing countries.

The agriculture sector in Ethiopia is the most important sector for sustaining growth and reducing poverty. However, lack of adequate nutrient supply, the depletion of soil organic matter and soil erosion are a major concern for sustained agricultural production (Grepperud, 1996; Kassie et al., 2008a). The key to a sustained increase in agricultural production is improvement in productivity, which can be achieved through technological and efficiency changes. Inorganic fertilizer remains the main yield augmenting technology being aggressively promoted by the government and institutions. Despite this, inorganic fertilizer adoption rates remain very low. Until recently, only 37 percent of farmers were using inorganic fertilizer, and application rates remained at or below 16 kg/ha of nutrients (Byerlee et al., 2007). In addition to low application rates, there are significant evidences suggesting dis-adoption of fertilizer (EEA/EEPRI, 2006). Escalating prices and production and consumption risks have been cited as one of the factors limiting the use of inorganic fertilizers in Ethiopia (Kassie et al., 2008b; Dercon and Christiaensen, 2007).

Thus given the aforementioned challenges to inorganic fertilizer adoption, a key policy intervention for sustainable agriculture is to encourage adoption of agricultural technologies that rely to a greater extent on local or farm renewable resources. Organic farming practices such as compost and conservation tillage are among such technologies. The water retention characteristics of these technologies (Twarog, 2006) make them especially appealing in water-deficient farming areas, as is the case for our study area, Tigray region of Ethiopia. In addition to reducing natural risks, it enables poor farmers to avoid the financial risk of taking chemical fertilizer on credit, and given that compost and conservation tillage are available when needed they overcome the prevailing problem of late delivery of chemical fertilizer. Since 1998 Ethiopia included conservation tillage and compost as part of extension packages to reverse extensive land degradation (Edwards et al., 2007; Sasakawa Africa Association, 2008). There exist ample evidences to show that compost and conservation tillage can result in higher and/or comparable yields compared to when chemical fertilizer is used (Edwards et al. 2007; Hemmat and Taki, 2001; SG2000, 2004; Mesfine et al., 2005; UNCTD and UNEP, 2008). This implies that these organic farming techniques create a win-win situation whereby farmers are able to reduce production costs, provide environmental benefits and at the same increase yields.

While numerous studies have been conducted in Ethiopia to examine the determinants and the resulting economic impact of chemical fertilizer, improved seeds, and physical conservation structures (e.g. Croppenstedt et al., 2003; Dercon and Christiaensen, 2007; Hagos, 2003; Kassie *et al*., 2008a, 2008b; Negatu and Parikh,1999; Shiferaw and Holden, 1998), no study, to best of our knowledge, has investigated the determinants of adoption of compost and conservation tillage by farmers in Ethiopia. The objective of this paper is to do this by investigating how socio-economic and biophysical characteristics determine adoption of compost and/or stubble tillage (hereafter conservation tillage)[9] in the semi-arid region of Tigray, Ethiopia. By identifying significant characteristics associated with adoption of sustainable agricultural production practices such as compost and conservation tillage, we are able to better inform policies that seek to promote adoption of such practices. In addition we use a dataset that has data on crop production and organic technology adoption (compost) to perform a stochastic dominance analysis with the aim of examining whether adoption of these technologies has any productivity impacts. This is to show the importance of organic farming practices in enhancing productivity and thus justify the need to further investigate the factors that condition their adoption. Our results reveal a clear superiority of the use of compost compared to chemical fertilizers when it comes to crop yields. With regards to determinants of adoption decisions; we find that while there is heterogeneity with regards to factors affecting the choice to use compost or conservation tillage, both plot and household characteristics influence adoption decisions. Interestingly we find evidence that the impact of gender on technology adoption is technology specific while the significance of plot characteristics indicate the decision to adopt a given technology is location-specific.

The rest of the paper is structured as follows: section 2 presents the analytical and econometric framework that forms the basis of the empirical approach used in the paper. The data used in the analysis is discussed in section 3 while a discussion of the empirical results is done in section 4. Section 5 concludes the paper with policy recommendations.

The analytical and econometric framework

We start the analysis by using a non-parametric technique, the stochastic dominance analysis (SDA), to assess how the use of organic farming technology impacts crop productivity. Due to data limitations we are only able to examine how the use of compost impacts crop production. Stochastic dominance analysis is used to compare and rank distributions of alternative risky outcomes according to their level and dispersion (riskiness) of returns (Mas-Colell et al., 1995). The comparison and ranking is based on cumulative density functions (CDF). Unlike other non-parametric (e.g. matching method) and parametric (e.g. linear regression models) methods, the entire density of yields is examined in SDA instead of focusing only on mean yield. The reason for this analysis is to motivate the use of organic farming technologies by establishing support for the fact that they enhance productivity. Thus assuming that the main goal of farmers is to realise increased productivity of their plots, the next interesting research question is then to investigate the factors that limit or encourage adoption of organic farming technologies and formulate policies accordingly.

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[9] It is a type of conservation tillage where farmers entirely retain the stubble on soil's surface and mix the stubble with the soil surface with rough tillage right after harvest to avoid grazing by livestock as well as to facilitate decomposition of organic materials before the next copping season starts.

In investigating this, we posit that both plot and households' socioeconomic characteristics are important in influencing the decision to adopt technologies. Plot characteristics condition the decision to adopt a specific technology over another through their impact on the increment of plot profit or the productivity impact derived from participation. Farmers' socioeconomic characteristics and preferences, on the other hand, might result in different adoption decisions even when plots have similar characteristics. Accordingly the maximization of farmers' utility forms the basis of our econometric model and estimation strategy. This framework posits that if adoption of several farming practices is possible, it is expected that to decide on adoption of one or several practices, a farmer compares the indirect utility values associated with each practice or a combination of practices.

Consequently, to study the *i*th farmer's choice we postulate random utility models, each one being associated with the *j*th choice of farming practice, such that:

$$V_{ij} = \mathbf{X}_i' \boldsymbol{\beta}_j + \varepsilon_{ij}, \quad (1)$$

where V_{ij} is the indirect utility level which the *i*th farmer associates with the *j*th farming practice, $\mathbf{X}_i$ is a vector describing the farmer's socioeconomic characteristics as well as plot characteristics. The vector of parameters to be estimated is denoted by $\boldsymbol{\beta}$ while ε is the stochastic error term. Given the two organic farming practices we focus on i.e. conservation tillage and compost, we have four feasible choices available to the farmer. These are classified such that *j*=0 if neither of the two practices is adopted, *j*=1 if compost is adopted, *j*=2 if conservation tillage is adopted and *j*=3 if adoption of both compost and conservation tillage takes place.

Given a dummy variable, d_{ij} capturing the choice of the *i*th farmer regarding the *j*th farming practice, the farmer's decision rule then becomes

$$\begin{cases} d_{ij} = 1 \\ d_{im} = 0 \ \forall m \neq j \end{cases} \Leftrightarrow \left(V_{ij} > V_{im} \quad \forall m \neq j \right). \quad (2)$$

To make the econometric model operational we assume that the disturbances of the different combinations are independent and identically distributed with the Gumbel cumulative distribution function which implies that the probability of choosing the *j*th combination becomes (Greene, 1997):

$$P_{ij} = \Pr(d_{ij} = 1) = \frac{\exp(\mathbf{X}_i' \boldsymbol{\beta}_j)}{\sum_{m=0}^{j} \exp(\mathbf{X}_i' \boldsymbol{\beta}_m)}, \quad (3)$$

which is the multinomial logit model, characterised by the independence of irrelevant alternatives, which implies that from equation (3) we can arrive at the following:

$$\frac{P_{ij}}{P_{im}} = \exp(\mathbf{X}_i' (\boldsymbol{\beta}_i - \boldsymbol{\beta}_m)) \quad \forall m \neq j, \quad (4)$$

a condition which holds whatever the subset of eligible combinations which include *j* and *m*. Given that the model is based on the difference of expected utility levels in each pair of combinations, we draw on the assumption that $\boldsymbol{\beta}_0 = 0$ to solve the problem of the indeterminacy which could complicate the estimation of the model (Greene, 1997). The maximum likelihood procedure is used to solve the model.

The data and descriptive statistics

This study benefits from two datasets. The first data is a cross-sectional dataset collected in 2006 in Ofla districts of Tigray region to analyze the determinants of adoption of compost and conservation tillage. It includes a random sample of 130 households, 5 villages, and 348 plots. In addition to information on adoption of compost and/or conservation tillage, the dataset had data on household and plot characteristics, and indicators of access to infrastructure which, based on economic theory and previous empirical research, are included in the analysis. The descriptive statistics of variables used in the regression analysis are presented in Table 1.

Table 1 *Descriptive statistics (means) of variables used in the analysis*

Variable	Description	Non-adopters	Compost	Conservation tillage	Both
Socioeconomic characteristics					
Male	Sex of household head (1= male; 0= female)	0.83	0.67	1.00	0.98
Age	Age of household head	44.17	41.00	38.36	38.98
Dependents	Number of economically inactive household members	2.71	2.50	2.61	2.54
Household labour	Number of economically active household members	2.23	2.28	2.51	2.46
Illiterate	Household head has no education (1= yes; 0= otherwise)	0.60	0.28	0.38	0.42
Religious education	Household head has religious education (1=yes; 0= otherwise)	0.11	0.11	0.05	0.07
Formal education	Household head has formal education (1= yes; 0= otherwise)	0.29	0.61	0.58	0.51
Farmer organizations	Membership in farmers' organization (1= yes; 0= otherwise)	0.08	0.22	0.25	0.22
Extension	Household extension contact (1= yes; 0= otherwise)	0.56	0.83	0.82	0.83
Livestock	Household livestock holding, in Tropical Livestock Units	2.92	4.09	3.69	3.42
Farm size	Total farm size, in hectares	0.83	0.92	1.39	1.09
Market distance	Distance from residence to the district market, in hours	2.01	2.30	2.48	2.07
Plot characteristics					
Ownership	Whether the household owns the plot (1=yes; 0= otherwise)	0.71	0.83	0.67	0.83
Distance	Distance from residence to the plot, in minutes	0.62	0.69	0.64	0.61
Flat to moderate slope	Plot is of flat to medium slope (1=yes; 0= steep slope)	0.35	0.17	0.30	0.17
Fertile soil	Plot is of fertile soil (1= yes; 0= infertile)	0.33	0.50	0.36	0.32
Black soil	Predominantly black soil (1=yes; 0= otherwise)	0.57	0.50	0.72	0.61
Deep soil	Deep soil depth (1= yes; 0= otherwise)	0.39	0.50	0.30	0.44
Moderately deep soil	Moderately deep soils (1= yes; 0= otherwise)	0.24	0.11	0.31	0.15
Shallow soils	Shallow soil depth (1= yes; 0= otherwise)	0.37	0.39	0.39	0.42
Degradation	Plot perceived as being degraded (1=yes; 0= otherwise)	0.36	0.28	0.38	0.37
Number of observations		202	18	87	41

Source: Authors' own calculation.

Around 5, 24 and 12 percent of the plots used compost, conservation tillage and a combination of both, respectively. Regarding household's perceptions of compost and reduced tillage; about 40 and 74 percent of compost and reduced tillage adopters perceived positive impacts of these technologies on soil fertility; about 20 and 42 percent of compost and tillage adopters, respectively, believe that these technologies reduce soil erosion; and 32 and 69 per cent of compost and reduced tillage adopters, respectively, believe these technologies are labor intensive. The data also reveals that adopters of compost have more livestock compared to tillage adopters. On the other hand, tillage adopters have more farm size compared to compost adopters which is expected to enable them to produce more straw for livestock feed and use stubble mulch tillage to increase soil fertility.

The fact that the first dataset does not include production data, limits our use of this dataset to analyze how adoption of these technologies impacts crop production. To achieve this objective we employed a second dataset to conduct a stochastic dominance analysis. It is cross-section time series on-farm production data collected between 2000 and 2006. The primary objective of collecting this data by the Institute for Sustainable Development (ISD), which is engaged in the promotion of organic agriculture in Ethiopia, was to investigate the impact of compost on crop production and soil fertility. The dataset covers eight districts and nineteen villages of Tigray region, which includes Ofla district. Of the nineteen villages, seventeen are located in drought prone areas of the Southern, Eastern and Central zone of Tigray region. The soils are poor and rainfall is erratic in these areas. The institute only collected agronomic data, grain and straw yields, for eleven crops from 974 plots. The FAO crop sampling method was used to collect yield data from those plots which had received compost, chemical fertilizer, and no inputs (control plots). Three one-meter square plots were harvested from each field to reflect the range of conditions of the crop. All the crop management practices including the amount of compost and fertilizer application was decided by the farmers themselves. The responsibility of the ISD is to provide information and training on compost making and application and recording grain and straw yields data during harvest in collaboration with farmers. The average amount of compost application ranges 5-15 tons per hectare depending on availability of materials (Edwards et al., 2007) and that of fertilizer is 0-275 kg per hectare (the average being is 40 kg per ha) (Kassie et al., 2008a). The average per hectare cost of applying compost is about ETB 370 whereas commercial fertilizer (DAP and Urea) is about ETB 594 (Edwards of ISD director, personal communication).

Estimation results

In this section we present the stochastic dominance analysis and multinomial logit adoption model results. The stochastic dominance analysis is used to investigate the impact of compost on crop productivity while the multinomial logit model is used to investigate factors that determine the decision to adopt compost, conservation tillage and/or a combination of both.

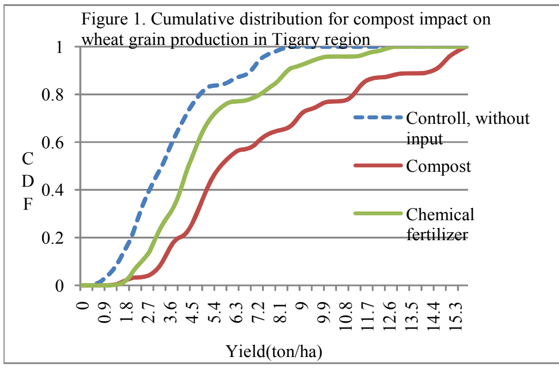
Stochastic dominance analysis

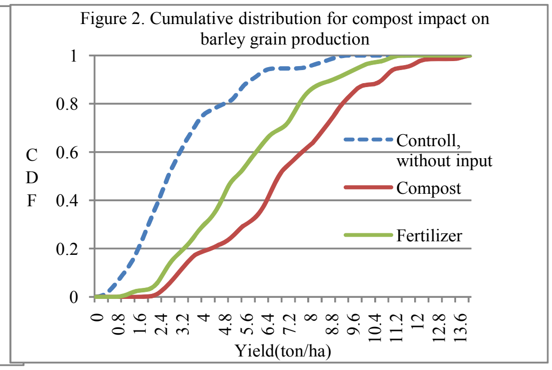
For the purposes of this analysis we focused on four major crops (wheat, barley, *teff*[10] and hanfets (mixture of barley and wheat) and compared yield distributions obtained from compost, chemical fertilizer, and control (without any input) plots. The outcome variable is

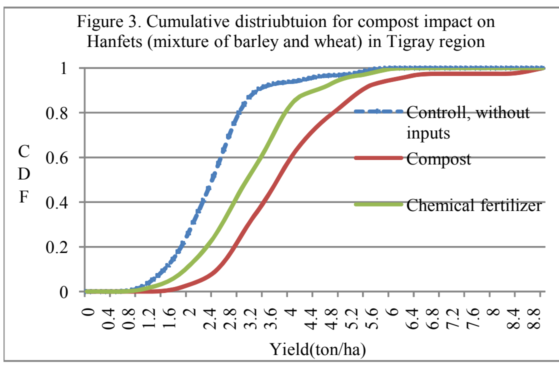
[10] Teff is a small grain crop endemic to Ethiopia.

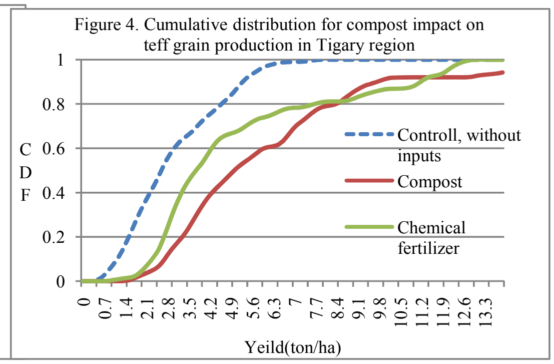
physical grain yields (ton/ha) of the respective crops. Figures 1-4 show cumulative density functions for yields obtained from compost, chemical fertilizer, and control plots.

Figures 1-4 *Stochastic dominance analysis of the impact of compost on crop productivity*









As illustrated in the figures, for all crops the yield cumulative distribution with compost is entirely to the right of the chemical fertilizer and control yield distributions, indicating that yield with compost unambiguously holds first-order stochastic dominance over chemical fertilizer and control plots. The non-parametric Kolmogorov-Smirnov statistics test for first-order stochastic dominance (or the test for the vertical distance between the two cumulative density functions (CDFs)) also confirmed this result (see Table 2 below). Interestingly, compared to control plots and plots that use chemical fertilizer, plots with compost give higher yield levels. Furthermore, except for hanfets crop, yield distribution of plots with chemical fertilizer dominated yield distributions of control plots i.e. plots without any input.

Table 2 *Kolmogorov-Smirnov statistics test for first-order stochastic dominance*

Crop	Treatments		
	Compost + control	Compost + fertilizer	Fertilizer + control
Barley	0.355 (0.000)***	0.192 (0.008)***	0.241 (0.000)***
Wheat	0.484 (0.000)***	0.384 (0.000)***	0.270 (0.000)***
Teff	0.591 (0.000)***	0.195 (0.003)***	0.396 (0.000)***
Hansfet	0.363 (0.000)***	0.330 (0.000)***	0.132 (0.407)

Note: *** significant at 1%

The foregoing analysis reveals an interesting finding; adoption of sustainable or organic farming practices such as the use of compost is not inferior, in terms of its impact on yields, to the use of chemical fertilizers. In fact, as the results show, use of compost can lead to significantly higher yields. This means that adoption of organic technologies presents multiple benefits; reduction in production costs, environmental benefits and at the same increased yields. Thus given these potential benefits what then constrains farmers from adopting such technologies and if they decide to adopt, what determines their choice of organic technology? We attempt to answer these questions by estimating a multinomial logit model as outlined in the discussion of the econometric strategy we pursue. We discuss the results in the following section.

Multinomial logit model results

Table 3 below gives the multinomial logit estimation results for the impact of both plot and socioeconomic characteristics of the household on the decision to adopt a given farming practice. The base outcome is adopting neither of the practices i.e. j=0. This implies that the ensuing discussion of the results focuses on the impact of the explanatory variables on a specific choice relative to no adoption. The model was tested for the validity of the independence of the irrelevant alternatives (IIA) assumptions using the Hausman test for IIA. The test failed to reject the null hypothesis of independence of the adoption of organic farming technologies, suggesting that the multinomial logit specification is appropriate to model adoption of organic technologies.

Table 3 *Multinomial Logit estimates*

	Compost		Conservation tillage		Both	
Variable	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Socioeconomic characteristics						
Male	-1.99**	0.79	19.60***	0.92	2.21**	1.11
Age	-0.01	0.03	-0.06***	0.02	-0.06***	0.02
Dependents	-0.23	0.18	-0.20**	0.10	-0.17	0.12
Household labour	-0.14	0.42	0.40**	0.20	0.36	0.24
Religious education	0.39	1.06	-0.53	0.67	-0.31	0.76
Formal education	1.41*	0.73	0.14	0.39	0.25	0.47
Farmer organizations	0.90	0.77	1.46***	0.47	1.24**	0.58
Extension	1.95**	0.85	1.00**	0.40	1.09**	0.51
Livestock	0.20**	0.10	0.05	0.05	0.06	0.07
Farm size	0.31	0.42	0.54***	0.20	0.39	0.25
Market distance	0.16	0.16	0.06	0.09	-0.07	0.12
Plot characteristics						
Ownership	1.38*	0.78	0.41	0.34	1.29**	0.50
Distance	0.64	0.44	0.51*	0.26	0.43	0.33
Flat to moderate slope	-1.26	0.78	-0.74**	0.37	-1.35***	0.52
Fertile soil	0.56	0.62	0.20	0.36	-0.16	0.45
Black soil	-0.57	0.61	0.65*	0.36	0.25	0.42
Moderately deep soil	-0.68	0.86	0.38	0.41	-0.74	0.57
Shallow soils	0.52	0.71	0.50	0.43	0.40	0.50
Degradation	-0.32	0.64	0.14	0.34	0.02	0.42
Number of observations	348					
Pseudo R2	0.23					
LR chi2(54)	168.60***					
Log likelihood	-287.18					

Note: Base outcome= no adoption, * significant at 10%; ** significant at 5%; *** significant at 1%

The results suggest that both socioeconomic and plot characteristics are significant in conditioning the households' decisions to adopt sustainable agricultural production practices. While there is heterogeneity with regards to factors influencing the choice to adopt compost and/or conservation tillage, our results suggest that significant determinants of adoption can be broadly classified into; socio characteristics of household head, labor intensity, access to information, wealth, and plot characteristics which includes whether or not the household owns the plot.

There is a heterogeneous impact of the gender of the head of the household on adoption decisions regarding the two practices. Specifically we find that households with a male head are less likely to adopt the use of compost while they are more likely to either adopt conservation tillage or to combine it with the use of compost. While some researchers have found that male-headed households are more likely to adopt sustainable agricultural technologies (Adesina et al., 2000); our results underscore the need to avoid generalizing the impact of gender on farm technology adoption, emphasizing that the impact of gender on technology adoption is technology specific. In this study area it seems male-headed households have a comparative advantage in conservation tillage while female-headed households enjoy an advantage in the use of compost. Still on the characteristics of the household head, we find a negative and significant impact of age on the likelihood of adopting conservation tillage as well as combining it with compost. This could be suggesting that younger farmers are better able to try new innovations and in addition they might have lower risk aversion and longer planning horizons to justify investments in technologies whose benefits are realized over time. The result suggests the need to develop gender and age specific technologies instead of blanket recommendations of technologies regardless of farmers' type for encouraging adoption of sustainable agricultural practices.

Labor concerns seem to be more of concern in the decision to adopt conservation tillage. Specifically the probability to adopt conservation tillage, relative to no adoption, increases with the number of household members that actively provide farm labor. This is in line with the descriptive statistics results where about 69 per cent of conservation tillage adopters reported that conservation tillage adoption is labor intensive. This is not surprising because stubble tillage is done during the peak period of one of the agricultural activities, crop harvesting. This underscores the importance of labor availability in technology adoption, consistent with findings by Caviglia and Kahn (2001) and Shiferaw and Holden (1998). In such circumstances it is important to consider strengthening and structuring the existing local labor sharing mechanism. On the other hand, this probability declines with the number of dependents in the household, capturing the intuitive expectation that the time spent caring for dependents shifts labor away from adoption activities.

Access to information on new technologies is crucial in creating awareness and attitudes towards technology adoption (Place and Dewees, 1999). In line with this we find that access to agricultural extension services, indicated by whether or not the household has contact with an extension worker, impacts adoption of all technology choices positively. Contact with extension services allows farmers to have access to information on new innovations and advisory inputs on establishment and management of technologies. In most cases, extension workers establish demonstration plots where farmers have the possibility of learning and experimenting with new farm technologies. Consequently, access to extension is thus often used as an indicator of access to information (Adesina et al., 2000; Honlonkou, 2004). Also as an indicator of information that shapes management skills or simply human capital, having formal education as opposed to no education at all increases the probability to adopt the use of compost relative to not adopting any practice at all. This could be suggesting that using compost is relatively knowledge intensive and thus management skills are crucial in its adoption. It has been argued that farmer associations and unions constitute one of the important sources of information available to farmers (Caviglia and Kahn, 2001). Our results confirm this; we find that household's membership of at least one farmers' organization significantly increases the likelihood of practicing conservation tillage as well as the likelihood of choosing to combine both the use of compost and conservation tillage. These results underscore the role of public policy in encouraging the adoption of sustainable agricultural practices.

The fact that we find evidence that livestock ownership limits the adoption of compost while the household's total landholdings limit the adoption of conservation tillage as well as combining the two practices, suggests that poverty significantly limits technology adoption. Wealth intuitively affects adoption decisions since wealthier farmers have greater access to resources and may be better able to take risks. It must be acknowledged, however, that the wealth measures we use might be confounded with other factors related to adoption. For example the use of livestock ownership as an indicator of wealth may be compromised by the fact that oxen provide draft power as well as manure, which, being organic matter could be a component of compost. Furthermore as the data shows, adopters of compost have more livestock compared to tillage adopters and thus the result here could be implying that the opportunity cost of crop residue is small for tillage adopters than compost adopters. The size of total landholdings, on the other hand, though measuring farmers' wealth, could also suggest for economies of scale in production using conservation tillage as well as the social status of the household which could also influence its ability to obtain credit (though in the case of Ethiopia, credit markets are highly imperfect). All the same these results suggest that policies that alleviate poverty and increase crop productivity among farmers will impact the adoption of sustainable agricultural practices positively.

Given the fact that the benefits from investing in both compost and conservation tillage accrue over time, this inter-temporal aspect implies that secure land access or tenure will impact adoption decisions positively. In this analysis we use plot ownership as a proxy for assured land access. Our results reveal that this particularly impacts positively the decision to use compost and the decision to combine the two practices. Ownership of the plot increases the assurance of future access to the returns of investments. In the same vein the positive impact of distance from the homestead to the plot on the decision to adopt either conservation tillage or the use of compost could be reflecting the fact that further away plots present tenure security challenges since they are more difficult to monitor; consequently farmers might invest more in them as a way of securing tenure.

Sustainable agricultural systems are intuitively site-specific (Lee, 2005). This is further confirmed by the finding that plot characteristics influence the decision to adopt conservation tillage as well as to combine it with the use of compost. In particular we find that the likelihood of households choosing to practice conservation declines with the perceived slope of the plots. This could be reflecting the fact that plots with steeper slopes are more prone to experiencing soil erosion thereby necessitating the adoption of farming techniques such as conservation tillage since these are meant to mitigate soil erosion and subsequent nutrient losses. The plot slope impacts the decision to combine both the use of compost and conservation tillage in a similar way. We also find that conservation tillage is more likely to be practiced on plots with predominantly black soils, indicating the role of soil type and quality in influencing adoption decisions. Interestingly plot-specific characteristics seem not to impact the decision to only adopt the use of compost. These results imply that for sustainable agricultural practices to be successful they must address site-specific characteristics as these condition the need for adoption as well as the type of technology adopted.

Conclusions and policy implications

The viability of the agricultural production systems in Ethiopia is, as in many semi-arid areas in developing countries, highly constrained by inadequate nutrient supply, depletion of soil organic matter and soil erosion. This problem is further compounded by an increasing population which is not accompanied by technological and/or efficiency progress. Efforts by the government to promote the adoption of chemical fertilizers have not been successful owing largely to escalating fertilizer prices and production and consumption risks associated with fertilizer adoption. Given these constraints it can be argued that sustainable agricultural production practices create a win-win situation whereby farmers are able to reduce production costs (by relying on local or renewable farm resources), provide environmental benefits and at the same time increase yields. In this paper we use plot-level data from the semi-arid region of Tigray, Ethiopia to investigate the factors influencing farmers' decisions to adopt sustainable agricultural production practices, with a particular focus on the adoption of compost and conservation tillage. By identifying significant characteristics associated with adoption of these practices, we are able to better inform policies that seek to promote adoption of sustainable agricultural production practices. Furthermore the use of stochastic dominance analysis supports the contention that these sustainable farming practices enhance productivity, further justifying the need to investigate factors that influence adoption of these practices.

While there is heterogeneity with regards to factors influencing the choice to adopt compost and/or conservation tillage, our results underscore the importance of both plot and household characteristics on adoption decisions. Our findings imply that public policy can play a role in affecting adoption of sustainable agricultural production practices. In particular we find that poverty limits adoption which implies that polices aimed at alleviating poverty will impact adoption decisions positively. In addition the significant and positive impact of access to information indicates that public policies aimed at improving access to information as well as the quality of these sources will help promote adoption of organic farming practices.

Furthermore we find evidence that such public polices should acknowledge the fact that there could not only be gendered differences in adoption of different technologies but age of the household head, by affecting aversion to risk and/or life cycle dynamics, will have a differential impact on adoption depending on the type of technologies. In the same light availability of household labor conditions the choice of technology adopted, given that the labor requirements differ from technology to technology. Thus public policy should factor in the impact of these socioeconomic characteristics.

We find evidence for the significance of land rights in influencing adoption and this impact varies from technology to technology. This indicates that assurance of access to future returns to adoption is vital in adoption decisions and thus policies should strive to create security of tenure among farmers.

In addition the significance of plot characteristics indicates the decision to adopt specific technologies is site-specific, and as such public policy should be informed by analyses of how different sustainable agricultural practices are conditioned by plot characteristics. Thus the next interesting research question would be to analyze how plot characteristics affect the productivity implications of different practices.

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Rural Household Income Diversification, Poverty and Their Coping Strategies: Asset Base Approaches In Ethiopia The Case From South Eastern Tigray.

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Abstract

The overall objective of this paper is to develop an appropriate conceptual and analytical framework to better understand how prospects for growth and poverty reduction can be stimulated in rural South Eastern Tigray. We employ complementary quantitative and qualitative methods of analysis, driven by an asset-base approach. We focus on household assets (broadly defined to include natural, physical, human, financial, social and location assets) and their combinations necessary to take advantage of economic opportunities. The paper examines the relative contribution of these assets, and identifies the combinations of productive, social, and location-specific assets that matter most to raise incomes and take advantage of prospectus for poverty-reducing and over all economic growth.

Factor and cluster analysis techniques are used to identify different livelihood strategies along with the basic coping strategies practiced and econometric analysis is used to investigate the determinants of different livelihood strategies and the major factors that affect well being.

Our research resulted in five key findings with important strategic implications. First, there exists significant heterogeneity of rural areas in South Eastern Tigray in terms of their asset endowments which affect the choice of livelihood strategies and wellbeing of households differently. Second, Poverty in general and drought in particular is widespread and deep in rural South Eastern Tigray which calls for the application of the different coping strategies and adaptive strategies. Third, agriculture should form an integral part of the rural growth strategy in South Eastern Tigray, but its erratic nature contributes for the potential limitation of the economy, which in turn invites policy intervention. Over the last many centuries, agriculture has been serving as main source of income for rural society of Ethiopia particularly in rural Tigray, though not satisfactory. This implies that high reliance of rural households on agricultural and related income means that any strategy targeted to these areas will have to build upon the economic base created by agriculture. Even though agriculture alone cannot solve the rural poverty problem, those remaining in the sector need to be more efficient, productive and competitive. Strategic actions and investments involving food security, and access to land and forests, infrastructure provision, improved natural resource management, non-agricultural rural employment and migration are needed to create broad-based and sustainable agricultural growth and reduced rural poverty. Fourth, there is a need to move from geographically untargeted investments in single assets to a more integrated and geographically based approach of asset enhancement with proper complementarities. A multicultural investment program is required to upgrade and improve access to household assets, with proper and more explicit complementarities as asset holding

is found to be a basic determinant for both choice of livelihood strategy and household well being. Asset investment programs need to be adapted according to the specific needs of regions and households. While some household assets programs should be national in nature, others require more local adaptation and must be carried out in tandem, according to specific needs of regions and households. Investment strategies should be formulated on broad regional bases, but options within regions should be modified to local asset bases.

Finally, the paper invites the best suitable coping mechanisms and adaptive strategies to cope up with the aforementioned poverty and its associated agricultural calamities. In line with this the paper suggests that; the coping mechanisms reflect the awareness of the local people about the resource available on their environment; the most vulnerable and with low coping opportunity are marginalized societies with low asset holding; preparedness serves as a better standing stone for the better efficiency of the coping strategy and government relief is still vital in the study area and was visible.

Introduction

Poverty has most commonly been assessed against income or consumption criteria. In this interpretation, a person is poor only if his/her income level is below the defined poverty line, or if consumption falls below a stipulated minimum. However, when the poor themselves are asked what poverty means to them, income is only one of a range of aspects which they highlight (Chambers, 1987). Others include: a sense of insecurity or vulnerability; lack of a sense of voice vis-à-vis other members of their household, community or government; and levels of health, literacy, education, and access to assets, many of which are influenced by the scope and quality of service delivery.

Dissatisfaction with the income/consumption model gave rise to basic needs perspectives, which go far beyond income, and include the need for basic health and education, clean water and other services, which are required to prevent people from falling into poverty. More recently, poverty has been defined in terms of the absence of basic capabilities to meet these physical needs, but also to achieve goals of participating in the life of the community and influencing decision taking.

A sustainable livelihoods (SL) approach draws on this improved understanding of poverty, but also on other streams of analysis, relating for instance to households, gender, governance and farming systems, bringing together relevant concepts to allow poverty to be understood more holistically. The framework identifies five types of capital asset, which people can build up and/or draw upon: human, natural, financial, social and physical. These assets constitute livelihood building blocks. To a limited extent they can be substituted for each other. Thus, the poor may draw on social capital such as family or neighborhood security mechanisms at times when financial capital is in short supply. One of the most visible vulnerabilities that the rural poor face is the problem of food security[11]. The rural poor are particularly vulnerable to food insecurity caused by natural factors such as drought (in Ethiopia), cyclones (in Bangladesh) causing famine conditions, but mainly due to the Poor's lack of entitlement and deprivation (Sen, 1981), which do have short and long–term impacts on their welfare. All development policy is based implicitly on a conceptualization of why people are poor and what interventions, if any, are needed to facilitate or accelerate their climb out of poverty. But the poor are a heterogeneous lot. Some people fall into poverty temporarily and are soon able to climb back out, while others are poor from birth or suffer a serious setback of some

[11] Food security involves availability, access to and use of food to meet adequate nutritional intake for a active and healthy life.

sort and stay poor for a long time thereafter. The latter two types of poor people may be ensnared in a poverty trap, while the former type retains economic mobility. Appropriate interventions may differ fundamentally according to the nature of the target subpopulation's poverty.

Under prevailing theories of economic growth and development, the poor enjoy higher marginal returns to productive assets than the rich do, so capital should flow disproportionately to the poor, enabling them to catch up economically. This follows logically from the standard simplifying assumption that there are diminishing marginal returns to assets in production. Moreover, this assumption implies that shocks cause merely temporary setbacks and that everyone enjoys the same latent opportunities. Under the prevailing orthodoxy, all should enjoy economic mobility and persistent poverty should reflect merely a slow climb up from a low initial welfare level.

Tigray is the northern most region of Ethiopia. The region is one of the poorest regions in the Ethiopia and still a predominantly inhabited by rural society, with about 85% of the population living in rural areas. Drought and famine are more frequent in the region. Severe environmental degradation problems, mainly soil erosion, nutrient depletion and moisture stress constrain agricultural production in the region (Hagos et al., 1999). The mainstay of the economy is agriculture, which is mainly rain-fed, in a region where rainfall is erratic and drought is prevalent. Furthermore, after a period of relative stability during 1991 to 1998, following a prolonged civil war, a war erupted between Ethiopia and Eritrea in May 1998 that ended two years later with serious consequences on household welfare.

The vast majority of rural people live in areas classified as land degraded areas with limited agricultural potential. The dominance of food and agriculture-related activities in the livelihoods of most rural people and the fact that most of the poor are located in highly degraded areas raises important questions about how agriculture can serve as an engine of growth to reduce poverty. Current policies in the country put emphasis on agricultural development, particularly in the smallholder sector (MEDaC, 1999; FDRE, 2000). The development strategy of the region builds upon the national strategy of Agricultural-Led Development Strategy (ADLI) by taking into account the agricultural constraints and potentials of the region, and the extent of environmental degradation. Analysts acknowledge that new strategies are needed to promote sustainable poverty reducing economic growth in rural Ethiopia in general and the region in particular. A central theme of this literature is that agriculture cannot serve as the sole engine of poverty-reducing rural growth unless accompanied by poverty coping strategies applicable and relevant to a specified victim area so that balanced and integrated multi-sectoral approaches are needed (Jansen and Hazell 2005, Cuellar 2003, Echeverría 2001). Such approaches should consider differences in asset endowments.

Objective of the study

The main objective of this study is to assess the figurative livelihood of the rural society in rural society of northern Ethiopia and their coping strategies to the drought and poverty using the asset base approach.

More specifically we have the following specific objectives to be addressed

- Assessing the general behavior of household livelihood and its basic practices

- Identifying and evaluating the common copying strategies practices for the prevailing drought and poverty
- Quantifying well being and its determinants using the asset based approach
- To forward policy implications for policy makers

Conceptual Framework

Framing development assistance and copying strategy practices in terms of poverty reduction requires conceptual frameworks and analytical approaches that truly capture the nature and dimensions of poverty, that distinguish the proximal and distal causes and correlates of poverty, and that integrate across enterprises, sectors and social-spatial scales. Some progress has been made. The World Bank "Voices of the Poor" studies and its World Development Report 2000/1 made a compelling case for the need to consider poverty in terms of low purchasing power, limited asset holding, high vulnerability to social, economic and ecological shocks, and lack of voice and accountability (Narayan and Petesch, 2002). Improved data, analytical methods and communication techniques have led to greatly improved understanding of the spatial distribution of poor people and environmental resources, the vulnerability of different population groups, coping strategy of poverty, the quality of national governance, and the correlates of poverty at different scales (Elbers, Lanjouw and Lanjouw, 2001; McCay and Lawon, 2003).

Of special interest to those concerned with rural development policy is the analytical focus on livelihood strategies, rather than more specific production or marketing strategies. The sustainable livelihoods framework depicts the five types of capital that rural residents access – physical, social, natural, financial, and human – the policies and institutions that define people's options for using that capital, the livelihood strategies that people use to transform assets into income, service and product streams, and the way that income and product streams are translated into welfare outcomes (Bebbington, 1999, Scones 1998, Ellis 2000). The sustainable livelihoods framework informs much of the empirical analysis presented in other chapters of this volume.

We propose that the livelihoods framework can be further strengthened through more explicit conceptual and empirical attention to dynamic poverty traps. The essence of the relation between livelihood strategies and dynamic poverty traps can be distilled into four general points. First, there is often a clear and shared preference ordering among the multiple livelihood strategies that are observed among individuals or households within a particular rural population. Second, specific assets often constrain the level of welfare associated with a livelihood strategy. Third, thresholds in the relationships that transform assets into outcomes mean that households that accumulate higher stocks of assets are sometimes able to generate much higher marginal returns than households that accumulate lower stocks of assets. Fourth, systematic imperfections in rural financial markets mean that individuals, households and communities commonly need to self-finance most capital accumulation. In this paper we develop these points and discuss the implications for analysis and policy.

The Asset-Base Approach

Our conceptual framework is anchored to an asset-base approach (Siegel, 2005). The asset-base framework includes the following components: assets (productive, social, location specific), the context (policies, institutions and risks), household behavior (livelihood strategies), and outcomes (measures of household well-being). Household and community decisions determine outcomes such as household well-being, environmental preservation, and community prosperity. The welfare-generating potential of assets depends on the asset-context interface.

Policy reforms and building of assets need to be considered in tandem. A household's assets consist of the stock of resources used to generate well-being (Moser 1998, Siegel and Alwang 1999, Rakodi 1999). Assets span human capital including age, education and training, and family structure; natural capital (e.g. climate, land, soil water deficits, soil fertility); physical capital (equipment, livestock); financial assets (transfers, credit, savings); location-specific factors such as access to infrastructure and public services; and social capital measured by the household's participation in various types of organizations. In the asset base framework, the poor are "asset-poor," with limited or low-productivity assets. Certain assets are effective only if combined with others; asset complementarity matters. For example, access to land has different implications for well being depending on its location relative to markets and other infrastructure, on access to credit and inputs, and on education of the landowner. Education may have markedly different implications for welfare generation depending on location and the functioning of labor markets and related institutions. Other important determinants of asset productivity include regulatory and legal systems, which determine the security and transferability of assets, and the existence of means of exclusion. These factors are part of the context. The context in which households operate helps determine the welfare-generating potential of assets and prospects for improved well-being. The political, legal, and regulatory contexts affect how assets are managed and whether successful livelihood strategies can be undertaken (Zezza and Llambi, 2002).

Household management of its asset portfolio constitutes its behavior or livelihood strategy. Livelihood strategies refer to the way households use their assets such as land and labor allocations, investments in education, migration, and participation in social capital building. Livelihood strategies include a range of on- and off-farm agricultural and nonagricultural activities (Berdegué et al. 2001, Corral and Reardon 2001). Asset accumulation and livelihood strategies are important drivers of sustained improvements in well-being.

We are concerned with outcomes that reflect household well-being and prospects for growth over time. The asset-base conceptual framework leads us to consider a variety of measures of household well-being and to use quantitative and qualitative analyses. In addition to income and consumption, poor rural households are concerned about food security, health status, vulnerability in general, empowerment and self-esteem, participation in community affairs, environmental quality, and hopefulness toward the future (Narayan et al., 2000).

Amenable to growth-oriented interventions and whether the poor are likely to benefit from such investments. The spatial distribution of poverty provides information on historical impacts of regional interventions on poverty reduction and provides guidance for targeting future investments and programs.

Quantitative household analysis

Two sub-national surveys: (i) conducted in 2000-01 for a land tenure and rural finance study of the University of Wisconsin, in both hillside areas and valleys; (ii) carried out in 2001-02 by the International Food Policy Research Institute in cooperation with

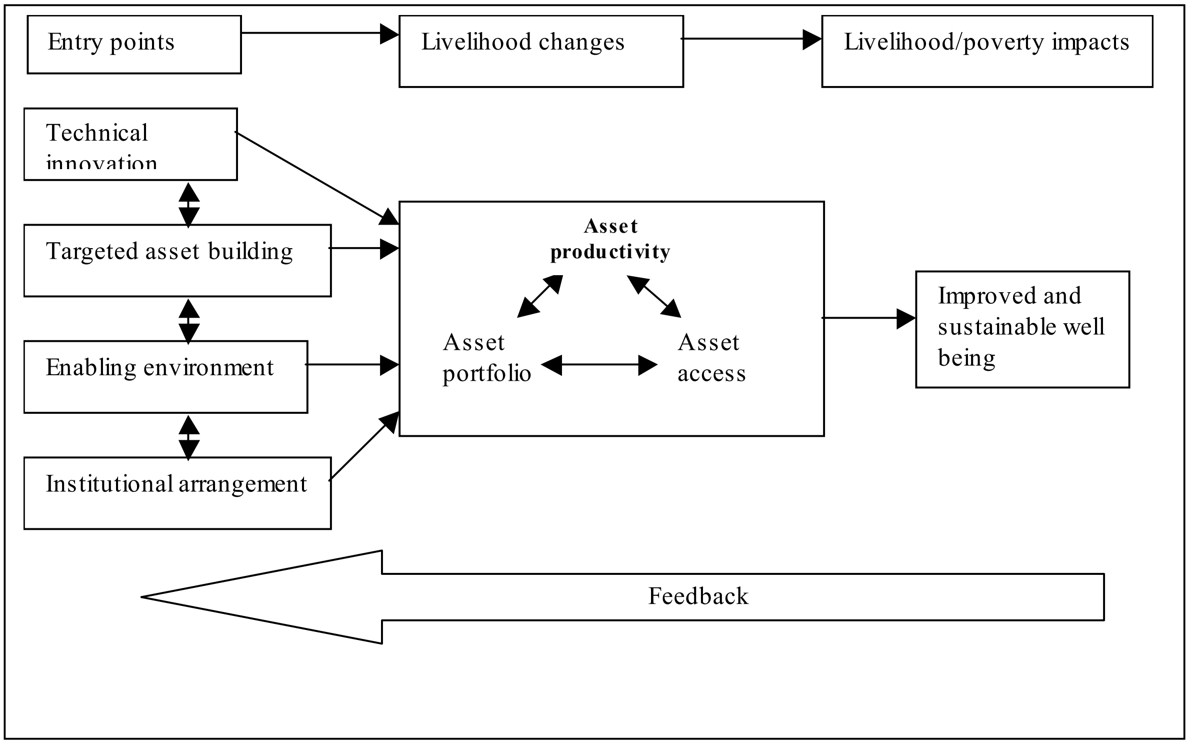

Figure 1

Methods and data

Implementation of the asset-base approach requires multiple analytical techniques and data sets. Each technique helps inform the others so that the analysis is fully integrated into the spirit of the asset-base approach. We begin by examining the spatial distribution of assets and economic potential. This spatial analysis provides a broad view of rural heterogeneity in the region, identifies areas where assets might be conducive to broad-based growth, and identifies potential conflicts between growth and poverty-reduction objectives in rural areas.

The department of Natural Resource Economics and Management of Mekelle University did two rounds of household survey on 400 households during 2005 and 2006 in Tigray, Northern Ethiopia. The survey covered two Weredas in 16 communities (tabias)[12] with diverse agro-ecological, distance to market, population density and agricultural potential conditions. Stratification and sampling was done based on altitude, market access, population density and access to irrigation. We will select 13 households from each community from a list of these households so that totally 208 household using a simple random sampling technique. Through multi-purpose questionnaires, the department gathered information on household income, expenditure, access to public safety nets (FFW and Food Aid), off-farm income, and household assets alongside a host of other information related to production and sale of agricultural products, farmers' attitudes to and investment on land conservation, and an array of plot level information finally we will take relevant information from this collected data for our analysis.

[12] A Tabia, equivalent to a Peasant association (PA) in other parts of Ethiopia, is the lowest administrative units in Tigray.

The quantitative analysis builds on the spatial analysis by addressing the issue of how household livelihood strategies and levels of well-being are determined within these heterogeneous rural areas. It begins by regressing household livelihood strategies on basic assets controlled by the household. These assets encompass the broad classes identified and discussed above (human, natural, physical, financial, locational and social capital). Subsequently we will employ a model to measure household well-being as dependent on livelihood strategies and assets. The basic model is:

1) $Lj = f(Xj, Yj, Zj)$

2) $\ln Wj = f(Xj, Zj, Lj)$

Where Lj represents the livelihood strategy pursued by household j, Wj the welfare measure for household j, and X, Y and Z are vectors of household-specific and location assets. The Z-vector contains, in some cases, tabias dummy variables, and census segment-level, community-level means of variables (such as participation in social capital-building activities, and population density and change). The function f (.) is a generic functional form and we use single equation estimators appropriate to the nature of each dependent variable. We use a multinomial logit model to estimate equation 1 since Lj is a polychotomous choice variable.

We use a linear form to estimate equation 2 with OLS. Equations 1 and 2 represent a simple model of livelihood strategy choice and production of household well-being or income. The idea is that its asset portfolio shapes a household's livelihood strategy and that more and better assets produce higher levels of household well-being. Assets that are especially significant or have an especially powerful effect may be targets for strengthening interventions.

Issues of exogeneity and causality are difficult to sort out in regressions of the sort of equations 1 and 2. The problem is one of theory and inference and is particularly relevant for equation 2: we wish to know, for example, if an increase in education of the household head will lead to higher household well-being, all other assets held constant. If education level and well-being are endogenously determined, if the model is missing household-specific variables affecting both education and well-being, or if errors in measurement of education levels are correlated with the error term in equation one, then problems emerge. The regression parameter will be a biased estimate of the true (a theoretical) relationship between education and the well being, and we cannot be sure if a policy to improve educational attainment will improve well being.

This bias is likely to become more important as we investigate variables that are more subject to immediate household choice, such as livelihood strategies. We will address the bias in several ways when conducting the analysis and interpreting the coefficients. For example, when we examine the impacts of livelihood choice on household well-being, we use instrumental variables based on equation 1 to purge the effects of the endogenous nature of the choice on our estimate of well-being. We account for endogeneity using a two-stage estimation process. In the first stage we estimate determinants of livelihood strategy (equation 1).in the second stage when examining the impacts of household livelihood strategies on well-being outcomes, we use predicted household livelihood class on the right hand side of the well-being regression. The variable L^* in equation 2 indicates that the livelihood choice is endogenously determined by unobserved factors. We also allow interactions between some asset variables (to measure the strength of asset complementarity). We assured proper identification of the system by including Y_j in equation 1 but not in equation 2.

Body Analysis

Table 1

Variable	Livelihood strategy						Well being (hh member percapita)	
	Off and on farm		On farm		Relief and remittance			
Explanatory variable	Coef.	p-value	Coef.	p-value	Coef.	p-value	Coef.	p-value
sedummy	-0.2476	0.646	0.031	0.973	0.001	0.998	-0.0932	0.605
eduhh	0.0782	0.304	-0.147	0.257	0.1347	0.222	0.0470	0.013
hhsize	-0.0085	0.922	-0.203	0.018	0.008	0.931	-0.137	0.000
tland	-0.0806	0.531	0.192	0.037	0.0179	0.897	0.069	0.000
dummirr	1.882	0.027	1.264	0.198	1.656	0.95	0.0250	0.878
dummyseed	-0.172	0.779	1.381	0.112	0.16297	0.841	0.265	0.019
dummyfer	0.132	0.826	-1.464	0.127	-0.048	0.949	0.0577	0.613
dummycred	-0.136	0.766	0.363	0.623	-0.245	0.668	-0.116	0.260
lnagehhh	-0.452	0.532	-1.81	0.018	1.747	0.240	0.08577	0.604
lndistroad	-0.858	0.000	-.4087	0.243	-0.630	0.010	0.0651	0.194
lndismarket	-0.305	0.365	-0.899	0.013	0.333	0.296	0.0200	0.770
lnlivest	-0.174	0.242	-0.075	0.718	-0.2980	0.109	0.1290	0.008
Constant	5.8546	0.121	10.39	0.012	-6.595	0.312	5.7845	0.000
Off and on farm							-0.5205	0.119
On farm							-0.204	0.455
Relief and remittance							-0.320	0.359

Determinants of livelihood strategies

The results of the multinomial model estimation (equation 1) are shown in table. Together the explanatory variables reflect the main elements of the household asset portfolio. The model results generally support our use of an asset-base approach as the fit was relatively good and the results are plausible. The variables included in each model were chosen based on availability within the data set, model misspecification tests, and consistency with the asset-base framework.

Better-educated families are more likely to depend on remittances and on and off farm even if it has no significant effect on the second strategy have (table 1), which mainly included only agricultural producers, education does not have a strong impact on choice of on farm livelihood strategy over another (table, 1).

On farm strategy is more common among households who own more land, are female headed and have more female adults, and where the head is younger. As households have less land, they seek and are forced to diversify into on and off-farm activities as well as in relief and remittance. As the time spent to market and road less households try participating in off and on farm the livelihood strategy

Among agricultural households, land ownership increases the likelihood of an on farm livelihood strategy while the household family size, education, age and as distance to market and road increases making livelihood less likely: as households become more mature, they seek and able to diversify other activities.

Several location-specific assets, including access to technical assistance and distance to key facilities affect livelihood choices. The result suggest that the lower the distance from the road and market the better the households to pursue market production and move away from less remunerative livelihood strategies based on basic grains production for food security while access to credit is not important for all livelihood strategy. This is may be because of the altitude of the farmers and/or the existing system of the micro finance institutions, as more than 39% of the households that take credit stated that they take for consumption smoothing and to buy some agricultural commodities

Determinants of household well being

Rural household livelihood strategies can have major impacts on outcomes such as levels of well-being, rates of poverty, and an area's growth potential. In the asset-base framework, livelihood strategies reflect conscious household decisions about allocation of their primary productive resources, mainly labor and land. But, as shown above, the specific strategy adopted by households depends on other assets, including natural, human and social capital, and location specific assets. A major issue is whether the assets themselves cause improved well-being, or it is only through adoption of a livelihood strategy. Livelihoods are closely related to household well-being, but the nature of causality is open to question: do better-off households engage in certain strategies because they are better off, or does the strategy "cause" the household to become better off? To shed light on this question, household income was hypothesized to depend on the household's livelihood strategy and asset portfolio. But on the fact of the ground the model it signified that well being is almost independent of the livelihood strategies as most of the strategies do not consider economic viabilities. The respondents was asked about the possible reason for choice of their strategies, finally 75% of their choice is made based on inherited experiences, cultural value of the activities, resource rather than considering the profit motive. To assure proper identification, we excluded from the well-being regression asset related variables that can reasonably be assumed to affect income only through their influence on livelihood strategies. In addition to the effects on income of individual assets, we investigated a number of interaction effects, in order to identify possible synergies and/or substitution between pairs of assets. These interaction effects included land ownership and credit, farm size and market access, farm size and education, market access and education. The regression results for equation 2 are presented in table,2 and show how livelihood strategies, individual assets as well as asset interactions affect rural household well being.

Livelihood strategies

After controlling for other assets, the livelihood choice is a relatively limited determinant of household well being. Instead the different assets them selves has due determination effect on the well-being of the rural household.

Human capital

The estimated coefficient of the average level of household head's general education is found to be statistically insignificant in affecting the general well being of the rural society under study. Household size has a strong negative impact on well being with an elasticity of about -.14. As the household size increases by one the income per person in the household decreases by 0.14 as the result the population growth rate has significant effect on the well being of the society.

Physical assets

Land holding has become a good (positive and significant) determinant of the well being (with elasticity of about .13) as well as the livelihood strategies as stated above. Access to live stock as landholding has positive and significant impact on the well being of the society and the regression showed that as the value of livestock increases by one the well being of the society increases by 0.13. Finally the regression result does not reveal any synergy among the assets under consideration so that we finally arrived on the decision that the assets have no substitutability and complementarities nature among themselves. But this may be due to not lack of well-defined property rights on land.

Location-specific assets

The significant and negative coefficient of the distance to market access variable, together with the negative coefficient of distance to road in the sample confirm the negative influence of living at remote areas on well-being. Market and road access variables suggest that, in terms of their effect on household well being, good market access and proximity to main road can compensate to some extent for deprived social assets of the marginal farmers.

Social capital

Participation in community organizations such as education, taking modern seed has a positive effect on household well being. The qualitative analysis at the community level through focused discussion confirms that a larger portion of the society participates in different social activities through collective actions and/or individual actions such as credit, education but still they themselves revealed it has not brought an observable change in their livelihood and well being which may be caused by misallocation of social assets, misleading perception towards credit, cultural attitudes to the practices and the prevailing deep rooted poverty. Finally the same analysis witnessed the due contribution made by NGO's (such as CRS,REST) in building social assets that can serve as a standing stone for better livelihood and well-being through the introduction of better farm technologies, alternative income generating activities such as safety net program.

Coping Strategy

Coping strategy had been defined by, Davies (1993) as individual or community response to change in environmental conditions, or responses to its consequences such as responses to declining food availability. In some literature coping strategies are used synonymously with the term adaptive strategies. But coping strategies is short term response in securing livelihood by stem to periodic stress where as the term **adaptive strategies** means the way in which individuals, house holds and communities have changed their mix of productive activities, and modified their community rules and institutions over the long term in response to economic or environmental shocks or stresses, in order to meet the livelihood needs. Like wise, the term preparedness is some times used interchangeably as a substitute with coping strategy. But still these terms have quite different meaning & perception.

Preparedness is seen as a means by which the anticipated adverse effects of extreme events can be reduced and new opportunities seized, white preparedness represents an advance action based on past experiences and anticipated outcomes, coping strategy represents actual measures to adjust once the event occurred.

Since poverty in general and drought in particular is a regular phenomenon in our study area, the society keeps vigilant eye to such calamities devising better and applicable coping mechanisms. The rural households in the study area defend the different calamities adapting various coping mechanism and adaptive strategies. Some of them are individual measures; while others are community based requiring group/collective/ action. The coping strategies can be visualized as a network to maximize utility of resources from both livestock keeping and agriculture. The adapted strategies and coping mechanisms depended on household's perception on extreme events, existing possible alternatives, resource endowment and the problem associated with it. The collected household leaders were made to identify the common knocking problems, which call for preparedness & cope up. Therefore 85% of the members prioritized the problem in such a way as crop failure the most common, low yield, concomitant declining employment opportunity, escalation of food prices, and decrease in grazing land and fodder availability. Finally they ware asked to forward the strategies practiced to cape up with the above calamities,

- Reducing consumption, changing consumption patterns and reducing social obligations
- Livestock keeping,
- Change of occupation
- Mortgage household assets (Drawing down household inventory)
- Drawing up on common property resources
- Casual and permanent migration

Consequently there was a need to elaborate and prioritize the common coping strategies.

1. Reducing consumption, changing consumption patterns and reducing social obligations

In the crisis period, due to shortage of food they have little amount of food to eat the labor price is low while consumer price is very high. There fore they have to cope with such situations. As the result large no of the respondents (65%) mainly the farmers which practice only On farm activities, drastically cut food intake during such calamity years. Further more, household's preparedness to consume the small-allotted diet helps match the demand and the restricted supply in the situations. Common diet during such calamity years of the society is mainly relief wheat and somewhat previous years' saved local products (grains).

In regard to the consumption pattern, society makes some arrangements on in take pattern and feeding frequencies. Therefore adults consume two times a day and children three times a day. In line with this some respondents (35%) avoid break fast to decline feeding frequencies and cope with calamities. Finally families are forced to defy discharging their social obligations as severity of the problem extends. By this issue children are used by their families as a source of income during calamity being with draw from school and other human investment sectors.

2. Change of occupation

The primary occupation in the study area is totally traditional agriculture. But due to crop failure many households (50%) tried to survive extending their occupation to the off farm activities. some respondents (20%) depended on selling of forest products such as fire wood to the regional town (Mekelle), the remaining respondents reported that they engage in wage laboring in the near by towns while others reported they participate in sand mining.

3. Livestock keeping

This strategy also serves as a way to diversify the agricultural activities and cope with the calamities. Practicing this strategy may take different forms such as changing the livestock composition and De-stocking of animals.

Live stock composition; some respondents (15%) also practice these systems as a way to escape from the problem through shifting from common animals (cattle) to goats, poultry and other drought resistant animals.

De-stocking of animals; during or after any calamity, de-stocking of animals is a important strategy followed by little less than (15%) house holds. This includes mainly sale of the common animals after immediate harvests and buy them after eight months for the next harvest. These systems save the fodder that could be consumed by the animals sold, but it was observed that the selling price after immediate harvest is mostly lower than the buying price for the next production period.

4. Mortgage of household assets (Drawing down household inventory)

To overcome regular crop failures and escape from the present sever situation many people (those with no better stock) are forced to mortgage their land and other household assets temporarily having their own modality in the form of rent agreement. Like wise some potential farmers draw their inventory, mostly grain as they came across with such calamities. In the study village many people mortgage their house and other assets to local rich farmers termed as "Haftam Gebar" farmers

5. Casual and permanent migration

Due to regular crop failure associated with drought some people lost their purchasing power, investment capacity and above all economic and ecological base in their native palace. Hence, some of the people migrates to the near by towns such as Mekelle, Humera, and mostly to new areas guided by the resettlement program of the government. Another consequence of these situation is that some girls migrates to the near by towns and practice socially immoral practices.

Some reflections (conclusions on coping strategies of the study area

- The coping mechanisms reflect the awareness of the local people about the resource available on their environment but some practices defy the environmental bans.
- The most vulnerable and with low coping opportunity are marginalized societies with low asset holding.
- Preparedness serves as a better standing stone for the better efficiency of the coping strategy.
- Government relief is still vital in the study area and was visible.

Conclusion and Recommendation

The paper has tried to develop an appropriate conceptual and analytical framework to better understand how prospects for growth and poverty reduction can be stimulated in rural South Eastern Tigray. We employ complementary quantitative and qualitative methods of analysis, driven by an asset-base approach. We focus on household assets (broadly defined to include natural, physical, human, financial, social and location assets) and their combinations necessary to take advantage of economic opportunities. The paper examines the relative contribution of these assets, and identifies the combinations of productive, social, and location-specific assets that matter most to raise incomes and take advantage of prospectus for poverty reducing and over all economic growth.

Therefore, the regression result asserts that physical assets (land &livestock), human assets (education) positively affects the choice of livelihood strategy while location assets (distance to market and to road), social assets (household size) significantly determines the choice of livelihood strategy negatively.

Having this in mind well being was expected to be a function of the livelihood strategy adopted and the different assets endowed which are mentioned above. In contradict to this hypothesis the model revealed that household well being measured by income per individual family member is independent of the livelihood strategy adopted but dependent on the different assets mentioned above. To elaborate it, physical assets (land & livestock), human assets (education) affects the well being of the household positively while social assets (household size) significantly determines the well being of household negatively. This implicitly invites public investment in access to land, livestock management, infrastructure, education and clear population policies towards family planning.

Inline with this our research resulted in five key findings with important strategic implications. First, there exists significant heterogeneity of rural areas in South Eastern Tigray in terms of their asset endowments, which affect the choice of livelihood strategies and well being of households differently.

Second, Poverty in general and drought in particular is widespread and deep rooted in rural South Eastern Tigray, as can be observed from the household income which calls for the application of the different coping strategies and adaptive strategies.

Third, agriculture should form an integral part of the rural growth strategy in South Eastern Tigray, but its erratic nature contributes for the potential limitation of the economy, which in turn invites policy intervention. Over the last many centuries, agriculture has been serving as main source of income for rural society of Ethiopia particularly in rural Tigray, though not satisfactory. This implies that high reliance of rural households on agricultural and related income means that any strategy targeted to these areas will have to build upon the economic base created by agriculture. Even though agriculture alone cannot solve the rural poverty problem, those remaining in the sector need to be more efficient, productive and competitive. Strategic actions and investments involving food security, and access to land and forests, infrastructure provision, improved natural resource management, non-agricultural rural employment and migration are needed to create broad-based and sustainable agricultural growth and reduced rural poverty.

Fourth, there is a need to move from geographically untargeted investments in single assets to a more integrated and geographically based approach of asset enhancement with proper complementarities. A multicultural investment program is required to upgrade and improve access to household assets, with proper and more explicit complementarities as asset holding is found to be a basic determinant for both choice of livelihood strategy and household well being. Asset investment programs need to be adapted according to the specific needs of regions and households. While some household assets programs should be national in nature, others require more local adaptation and must be carried out in tandem, according to specific needs of regions and households. Investment strategies should be formulated on broad regional bases, but options within regions should be modified to local asset bases.

Finally the paper tried to deal with the basic coping strategies prevailing in the study area and found out the following mechanisms to struggle against the natural and man made calamities: Reducing consumption, changing consumption patterns and reducing social obligations; livestock keeping; change of occupation; mortgage of household assets (Drawing down household inventory); Drawing up on common property resources and as a last resort engaging in casual and permanent migration. Inline with this the paper identified the first as the most common mechanism practiced and the last as the final resort for treating such calamities. Beyond this, the paper invites the best suitable coping mechanisms and adaptive strategies to cope up with the aforementioned poverty and its associated agricultural calamities. In line with this the paper concludes that; the coping mechanisms reflect the awareness of the local people about the resource available on their environment; the most vulnerable and with low coping opportunity are marginalized societies with low asset holding; preparedness serves as a better standing stone for the better efficiency of the coping strategy and government relief is still vital in the study area and was visible.

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Institutions and Sustainable Land Use: the Case of Forest and Grazing Lands in Northern Ethiopia

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Abstract

Land is an essential factor of production for agriculture, horticulture, forestry as well as other land related activities. Institutions that govern its use determine the sustainability and efficient use of this essential resource. In Ethiopia all land is publicly owned. Such an institutional setting has resulted in major degradation of Ethiopia's land resources and dissipation of the resource rent, as available forest and grazing lands are exploited in a suboptimal fashion. An alternative to current institutional setting is to assign private property institution, but this will lead to welfare costs. In this paper, we examine the welfare effects (from consumer perspective) of change in institutional setting to forest and grazing lands using a unique data set covering 200 cross-section households in Tigray, Northern Ethiopia. Finding suggest that changing the current institutional setting could indeed be welfare reducing. Given the finding, it is little wonder the government is reluctant to impose a private property institution on Ethiopia, despite continued land degradation.

Key words: institutions; sustainable land use; economic welfare; Tigray; northern Ethiopia.

JEL *classification*: K11; Q12; Q2; Q28

Introduction

Land is an essential factor of production for agriculture, horticulture, forestry as well as other land related activities. In many developing countries, inefficient use or exploitation of land reduces the amount of resource rent that can be collected, while lowering available future resource rents as land resources degrade over time in suboptimal fashion. Consequently, increasing poverty combined with lack of appropriate institutions governing land use causes peasants to invest too little in land improvements. A cycle of land degradation occurs because, as forests are mined, people turn to grasses, crop residues and livestock dung for fuel, which deteriorates the land further (Pearce and Warford 1993, p.25).

This is quite true in Ethiopia too where degradation of forest and grazing lands is a major problem. In general, the problem seems to have more to do with population pressure, market and government failure. The substantial increase in human population which required more land even at constant productivity expanded frontier cultivation also the substantial increase in livestock population implied overgrazing. But more importantly, on top of factors like population pressure, market and government failures, it is quite common knowledge the absence or ineffectiveness of institutions in terms of use regulations of the land resources also resulted in severe degradation. Land in Ethiopia is publicly owned. Except for trees that fall in private backyards and farmlands forests/ trees and grazing lands remain largely free access resources. For example, free collection accounted for the dominant part of all household fuel uses in our sample (Table 1). Natural forests and grazing lands were found to be the major sources of freely collected fuels while the private sources constituting a lesser proportion (Table 2).

Table 1 *Distribution of sample households by mode/way fuel acquired in rural Tigray (in %) (n=200)*

Mode of acquisition	Fuel type	
	Fuel wood	Dung
Free collection	85.2	72.3
Buying	11.2	0.6
Own source (tree/cattle manure)	3.6	27.1
Total	100.0	100.0

Table 2 *Distribution of sample households by source of freely collected fuels by type (in % of households involved) n=200*

Source	Fuel type		
	Wood	Dung	Crop residues
Own farmland/backyard	15.0	33.0	62.5
Others' farmland	-	5.0	35.5
Grazing land	33.0	50.5	-
Forest land	52.0	-	-
Total	100.0	88.5[a]	98.0

[a] The remaining are households not using dung at all.

Under such an institutional setting or an unrestricted access condition agents would maximize benefits by putting effort to the extent that total cost is equal to total revenue, instead of marginal cost being equal to marginal revenue (Van Kooten and Bulte, 2000). Apparently, no agent will have an incentive to delay harvest, as doing so would only enhance the harvest opportunities of others. The outcome is excess depletion and dissipation of the resource rent. Therefore, it would indeed be of public interest to alter this situation. An interesting question in here is how would a public policy aiming at altering the status quo affect welfare of private agents? What would be an optimal one or worth doing in terms of addressing the problem? By and large, there appear to be two opposing and perhaps diverging views as regards to to land use/ownership in the country. One favours the status quo, i.e., state stewardship of land, and the other favours private property institution. Though all these policy options are contemplated on the grounds of efficiency and sustainability they are not without welfare costs at individual household level. Therefore, it would be of great interest to empirically examine what the policy of completely enforcing private property institution to forest and grazing/dung resources would mean in terms of welfare of private agents.

The purpose of the current study is to examine the potential of the policy of assigning an alternative institutional setting, i.e., private property institution, using a unique data set covering 200 cross-section households in Tigray province, northern Ethiopia. More specifically, in this paper we examine the welfare effects (from consumer perspective) of change in institutional setting to forest and grazing lands. Such a change in institutional setting could be envisaged to counter the dissipation of the resource rent and hence the degradation of agricultural and forest lands. Finally, we draw implications of our findings. We begin in the next section with land use in Tigray, the theory on institutions and resources degradation is presented in section 3. Then, in section 4, we present the theoretical model of household's maximization problem along with a framework for analyzing/capturing the welfare effects of the change in institutional setting. In section 5, we outline an empirical model, and then section 6 results and discussions. We conclude by drawing some policy implications.

Land Use in Tigray

Tigray region covers a total of about 50 thousand square km surface/land area (Table 3). Of this total landmass about 25 percent is cultivated or agricultural land. Forest/shrub and grazing land account for over half of the total land area of the region. Historically, institutions/ property rights to land in Ethiopia were vested in either the *risti* system, the *gulti* system/ private land holding, or the church. The *risti* system was the dominant type of land tenure in Tigray before the 1975 land reform. It was a communal land tenure in which the right to land was not exclusive but shared. Members of each community have a common cognatic descent and lineage to a certain pioneer father who originally established a recognized claim over that defined unit of land. Under this system, an individual had usufruct rights to land (*risti* rights) in a given community only if he was able to establish a direct line of descent from the recognized original holder of the land. As was the case in the rest of Africa (Besley, 1995), *risti* system/ communal land tenure may be regarded as egalitarian in the sense that the distribution was based on the principle of equality, with the land allocated by lottery after being divided into parcels according to quality. Nevertheless, the individual's usufruct rights to land were not transferable to others through sale or mortgage, though there was room for temporary lease. Moreover, as the right to land under the *risti* sytem didn't imply a right to any specific parcel, land redistribution was undertaken periodically to ensure that new entrants/ family members were granted access. This implied land fragmentation. In addition, the fact that anybody's land parcels might be reallocated to a distance kinsmen and that no one could sell them for a profit nor leave it to a heir reduced a farmer's incentive to invest in long-term land improvements and, hence, implied land quality deterioration (Hoben, 1995; Hagos et al, 1999). The *gulti* system was characterized by absentee owners, as it was the royal kinsmen/ women who had the *gulti* holdings.

Table 3 *Population size by sex, area and density, Tigray overall and by zone: July 2005*

Zone	Population ('000)			Area (square km)	Density (persons/km²)
	Male	Female	Total		
Tigray overall	2,080.0	2,143.0	4,223.0	50,078.64	84.3
Western	135.0	129.6	264.6	12,441.26	21.3
Northwestern	359.3	354.9	714.2	12,267.58	58.2
Central	614.6	637.5	1,252.1	10,353.50	120.9
Eastern	378.4	408.6	787.0	5,705.34	137.9
Southern	510.7	532.6	1,043.3	9,286.52	112.3
Mekelle (Metropolitan)	82.0	79.7	161.7	24.44	6,617.8

Source: CSA (2004)

With the 1975 land reform (Proclamation No. 31, 1975), the previous system of tenancy was abolished. The proclamation made all land the collective property of the Ethiopian people and a concomitant measure of land redistribution was taken all over the country. Land was redistributed to the tillers (Nickola, 1988). Land transfer rights through mortgaging, leasing, selling, or bequests as well as hiring of labor was prohibited. In addition to this countrywide phenomenon, subsequent land redistribution measures were also undertaken by the then rebels TPLF (Tigray People Liberation Front) in Tigray in the years between 1980 and 1990. After the change in regime in 1991 a new constitution was drafted. Article 40 of the Constitution states: "the right to ownership of rural and urban land is exclusively vested in the state ... and shall not be subject to sale or exchange" (FDRE, 1995). The constitution guarantees the rights of access to land for peasants and pastoralists. It also specifies the right of individuals to improvements they made on land including the right to bequeath, transfer, remove or claim compensation for such improvements as the right expires. The mechanisms as to how these rights can be assured and other details on land issues are left to the regional states. Following the constitution, the current land use policy of the region states that land is collectively owned by the state and the people (TNRS, 1997). Hence, land is public property. Land redistribution stopped in Tigray since 1991. The current land policy of the region officially prohibits further redistribution except for areas where public irrigation or other major infrastructural investments have been built. The current policy has certain merits in a sense that it allows some transfer rights relative to the 1975 land reform. It provides the holder the right to lease, the use of hired labor as well as the rights to rent and bequest. However, land cannot be sold or exchanged. The policy also prohibits the leasing (renting) of land for an indefinite period of time.

As was the case in much of the rest of the world (Runge, 1986), traditionally common property institution has been in place and grazing lands in the region were collectively owned and managed by the respective communities (Gebreegziabher et al, 1998). The 1975 agrarian reform also left the rights on grazing lands to the discretion of the PAs, either to be used collectively or redistributed for use by individual farmers (Hagos et al, 1999). As a result of the free and uncontrolled grazing system that is prevalent in the region, livestock stay outside for most of the day both grazing/ browsing and searching for feed. Eventually, the animals leave their manure/ dung, which is free for use by any one and there is no defined ownership right to it. Even on regulated grazing lands where the cattle tend to concentrate for some period during the year and, larger quantities of manure/ dung are expected, dung remains an open access resource with no defined owner. In the end, dung/manure decomposes, which is unlikely, or most often it is collected freely by the villagers, or people from nearby towns, primarily for fuel purposes. For example, dung collected from rural hinterlands accounts for a significant portion of total household cooking fuel in some towns in Tigray (ENEC and CESEN, 1986c; Newcombe, 1989, Gebreegziabher, 2001). In addition to the energy loss of livestock searching for forage, the free access condition of grazing lands reduces the availability of manure/ dung for the owner, which represents a negative externality. If it gets decomposed, whether the animals leave their dung on grazing lands or cultivated lands, it represents a positive externality to the system. It is not clear if the costs exceed the benefits. Who should be compensated or how should the externalities be internalized? These are important empirical issues.

Institutions and Resources Degradation: Theory

Renewable natural resources such as forests, grazing lands, fisheries, etc, constitute a significant part of our planet. Rural communities in developing countries depend primarily on these resources for fuel wood, construction material and livestock grazing. These resources are also important sources of livelihood elsewhere in the rest of the world. Due to unrestricted access by users or in the absence of effective use regulations (rule structures), these resources are subject to over-exploitation on first-come, first-served basis. Under such an institutional setting agents are conditioned to maximize benefits by putting effort to the extent that total cost is equal to total revenue, instead of marginal cost being equal to marginal revenue (Van Kooten and Bulte, 2000). Apparently, no agent will have an incentive to conserve/ delay harvest, as doing so would only enhance the harvest opportunities of rivals. The outcome is excess depletion and dissipation of the resource rent.[13] Therefore, it would be of public interest to alter this situation. An interesting question in here is how would a public policy aiming at altering the status quo affect welfare of private agents? Would there be an optimal way of addressing the problem?

Alternative theories have been developed to explain the common pool resources problem. The propositions/ policy prescriptions of these theories also vary from one to the other. Of course, each of these alternatives is contemplated on the ground of welfare improvement. Three alternative theories are quite apparent in the literature. The structure of these theories range from a single agent decision framework (e.g., Gordon, 1954) through to game theoretic framework involving strategic interaction among multi agents (e.g., Cheung, 1970; Runge, 1981). One of these theories ascribes the common pool resource problem as 'the free-rider problem'. According to this theory, motivated by narrow self-interest each individual would tend to choose and/or behave independently to utilize the resource at an exploitative level in the expectation that others will do the same, leading to a situation in which all are made worse off. Because part of the cost is born by the entire group involved in using the resource, the social cost of harvesting an additional unit of a common pool resource exceeds the private cost. This is presumed to give individual agents an incentive to enjoy 'free-riding, which finally ends up in overexploitation. Often, a simple prisoner's dilemma game model is used to explain the situation. Therefore, the incentive for free-riding could be avoided through completely defined private property rights to the resources. Implicit in the private property solution is that the social optimum is consistent with the private optimum and rational individuals manage their own private resource (firewood resource, grazing areas, etc) at a rate consistent with the time preference of society as a whole.

For others like Hardin (1968) and Johnson (1972) the problem of common property externality "the tragedy of the commons" can only be resolved through imposition and enforcement of use rules by an external enforcer, the government. Hardin sees 'mutual coercion, mutually agreed upon by the majority of the people affected', and an external authority, the 'custodians', by which restrained access can be enforced as the only viable option. According to this line of theory when a group of people are placed in a setting, where upon all adopting a rule of restrained use of a common pool resource they could mutually benefit, they will not do so in the absence an external enforcer of agreements. Because each agent has an incentive to ignore the social cost of his harvest for fear that other agents will capture the benefits ahead of him. Moreover, for Johnson, private property rights regime is superior to both central control and communal system, where it already exists. Otherwise, the cost involved in moving from one system to the other is so prohibitive that central control is preferred to assigning private property rights. Nonetheless, we can safely rule out this theoretical possibility in the case of Ethiopia, as all land is publicly owned and the status quo is tantamount to open access condition.

The third line of theory belongs to the cooperative or conditional cooperative view. Give much importance to what they called 'assurance and uncertainty' in predicating behavior patterns of actors and argue that the institutional rules innovated by the users that help to reduce uncertainty and coordinate expectations are the best solutions to resolve the problem (Runge, 1981). This line of argument emphasizes on the idea that individuals are interdependent because of the non-separability of the cost functions that face them and thus, each individual bases her decisions on the expected actions of others. For them, the problem of the common property externality is uncertainty and some kind of institutional solutions

[13] For details about property rights/institutions, economic dynamics and rent capture see Van Kooten and Bulte 2000.

that can confirm assurance can easily solve it. Indeed Runge argues that no player has an incentive to defect in a situation where everybody co-operates, it is possible for the players to assure each other that everybody chooses to co-operate and thus reach a stable co-operative Nash equilibrium. Moreover, he argues that the "assurance game" describes the common property problem much better than the prisoner's dilemma game. He emphasized the existence of non separable externalities among users and argues that the joint use of common property resources is not separable decision. Unlike in the prisoner's dilemma, in the assurance game no player has an incentive to defect once co-operation is reached. Defection is superior only in the event that the other players defect as well.

Institutions are systems of rules/norms that specify certain forms of action as permissible, others as forbidden, and provide for certain penalties and defense when violations occur (Runge, 1984). Through shaping the behavior of people with respect to each other and their belongings, possessions, and property; institutions provide assurance by setting the 'rules of the game'. These rules, hence, affect the welfare of agents through their effect on the rate of resource use and the distribution of returns. By coordinating behavior and reducing uncertainty in the realm of human interaction, they increase the value of a stream of benefits associated with economic activity.

Theoretical Model

Household's maximization problem

Consider the case of a farm household who is assumed to behave as if maximizing a well-behaved utility function defined over the quantities of commodities consumed q and environmental and household characteristics z, subject to budget constraint m. Let the household's utility function be specified as (Sadoulet and de Janvry, 1995):

$$u = u(q, z) \qquad (1)$$

Solving for the Lagrangian function of the household's utility maximization problem in the usual procedure and assuming the second-order conditions are satisfied gives us the ordinary (observed) demand function $q(p,m,z)$. Substituting the demand function derived from this constrained maximization into u gives us the indirect utility function:

$$u = v(p, m, z) \qquad (2)$$

Note that $v(\cdot)$ is the maximum utility that the household can reach for given prices p and income m.

Welfare effects of change in institutional setting

Now consider a change in price of ith good p_i from p_i^0 to p_i^1 resulting from some public policy. For instance, such a public policy might emanate from the intention to change the existing institutional setting governing forest and grazing lands, e.g., wood and dung, to alter the open access condition and curb the devastation. Specifically, we assume that price of wood and dung change with all other things remaining unchanged. Imagine of a public scheme aimed at enforcing private property institution to forest/wood resources and grazing lands. Three policy alternatives could be envisaged at the disposal of policy maker: one, completely defining/enforcing private property institution only for wood resources with grazing lands left intact; two, completely defining private property institution only for grazing lands with forest/wood resources left intact; and, three, defining private property institution both on forest/wood resources and grazing lands simultaneously. For tractability of the problem at hand we make the following simplifying assumptions: (i) the cost of completely defining private property rights is zero; (ii) to circumvent the scepticism private property institution might lead to imperfect completion and guarantee that harvests are socially optimal, we assume that the privatization scheme is reasonably fair and does not result in imperfect competition; (iii) buyers and sellers (resource owners) face same equilibrium price; (iv) as wood and dung are no more freely collected, privatization ultimately translates itself into increased prices.

There are two reasons that enforcing private property institution ultimately translates itself into increased prices: first is due to marginal user cost. Agents will take care of the scarcity rent of the resource. Think of prices that would prevail in an efficient market facing scarcity over time. An efficient market would have to consider not only the marginal extraction cost for the resource, but the marginal user cost as well. Whereas in the absence of scarcity the price would equal the marginal cost of extraction, with scarcity the price would equal the sum of marginal extraction cost and marginal user cost. Renewable resources such as forests require time to regenerate. Therefore, resource owners distribute their cutting over time in an optimal manner. When resources are scarce, greater current use diminishes future opportunities. Hence, the marginal user cost is the present value of these forgone opportunities at the margin. More importantly, producing forest products/wood involves silviculture costs that resource owners balance the costs of silviculture today against future benefits. Second reason that the value of the resources is greater under the private property institution than under the status quo pertains to the risk averse behavior of agents, i.e., resource owners. Even risk neutral producers are affected by risk if there is any correlation between their own production and the price level. This is more likely to occur in relatively segmented markets and with more homogenous conditions of production across producers (Sadoulet and de Janvry 1995). Nonetheless, in general, the extent to which prices increase cannot be determined a priori.

The mechanism for operationalizing private property instution is that agents are granted an endowment of tradable/transferable permits/deeds to the *in situ* resources, which they control over time. These deeds carefully defined/ specify the boundaries, as boundaries are so important in resolving disputes. Deeds are distributed in lots through lottery method, as experienced in the previous distribution of cultivated land. And that each lot has fair share of the present natural resource stock. The role of the regulator is confined to choosing the initial allocation of the endowments of permits/deeds and developing the rule governing the game.

Suppose that (p_i^0, m^0, z) and (p_i^1, m^1, z) for i=f,d, fuelwood and dung, respectively, as in above are two budgets that measure the prices and incomes that our representative consumer would face under the two (different) policy regimes. It can best be conceived of (p_i^0, m^0, z) as being the status quo and (p_i^1, w, m^1) as being the proposed change. How would, then, such price (policy) change affect the agents' well being? Following Sadoulet and de Janvry, (1995) the welfare change involved in moving from (p_i^0, m^0, z) to (p_i^1, m^1, z) can be expressed as the difference in indirect utility function:

$$\Delta u = v(p_i^1, m^1, z) - v(p_i^0, m^0, z) \qquad (3)$$

The intuition is that if the utility difference in equation (3), as far as our agent is concerned, turns out to be positive the change in institutional setting would be worth doing it and not worth doing it if it turned out to be negative. However, note that utility theory/measure as in equation (3) is purely ordinal and we cannot quantify the utility change. Therefore, we need a convenient monetary measure of changes in our agent's welfare. We considered the equivalent variation (EV) as the motivation in here is to get a reasonable indicator of the likely welfare effects of price (policy) change being examined.[14] More importantly, the equivalent variation (EV) is quite strait away in that it uses current prices as the base and asks what income change at the current price would be equivalent to the proposed change in terms of its impact on utility. Therefore, we specify the equivalent variation EV as follows:

$$EV = e(p^0, u^1, z) - e(p^0, u^0, z) = e(p^0, u^1, z) - m^0, \quad (4)$$

where p^0 and m^0 represent initial prices and income levels and u^1 stands for utility level with changed prices.[15] Given initial prices and income, equation (4) could be computed for individual or simultaneous price (policy) changes. Apart from the magnitude the direction of change as implied by the sign of the outcome is also important.

Empirical Model and Data

Empirical model

Essentially equation (4) is the relationship that enables us to measure/capture the effects of price (policy) change in some monetary form. Note that the first term in equation (4), $e(p^0,u^1)$ is the income level at which our representative agent achieves exactly utility level u^1, at prices p^0. And $e(p^0,u^1)$- m^0 is the net change in income that causes our agent to get utility u^1, at prices p^0. Assuming Cobb-Douglas utility function from the indirect utility function, equations (2), and making use of the expenditure function, we computed the welfare effects using. After deriving For numerical computation of the welfare changes we used the following money metric indirect utility function:

$$\Delta W = m\frac{\overline{p}_f^{\alpha}\,\overline{p}_d^{\beta}}{p_f^{1\alpha}\,p_d^{1\beta}} - m^0 \quad (5)$$

where *W* stands for welfare and the symbol Δ for change.

Three things appear quite important for the numerical computation of welfare change using equation (5): numerical estimates/values of the substitution elasticities, i.e., α and β parameters; prices, p^0_i and p^1_i; and income, *m*. Assuming the utility function associated with wood and dung is of the form $u(q)=q_f^{\alpha}q_d^{\beta}$, where q_f and q_d are quantities of wood and dung consumed by household with $\alpha,\beta \in (0,1)$ and $\alpha+\beta< 1$. Note that wood and dung are substitutes in cooking. Therefore, we considered the variable cooking frequency as a reasonable proxy for the estimation of substitution elasticities. Hence, given initial prices and income, and parameter values, we calculate the welfare effects for three different scenarios: independent price (policy) change for *i*th good holding the other constant and simultaneous price (policy) change for both goods.

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[14] For a further understanding about alternative welfare measures, CV (compensated variation) and CS (consumers' surplus) see Varian (1992), pp 160-163, Mas-Colell, Whinston and Green (1995), pp 80-91.

[15] Note that, alternatively, equation (7) could also be represented as $EV = e(\overline{p}, v(p^1, m)) - e(\overline{p}, v(p^0, m)) = e(\overline{p}, v(p^1, m)) - m^0$, for an arbitrary price vector $\overline{p} >> 0$ and gives the income required to reach the utility level $v(p,m)$ when prices are $\overline{p}$.

Data and sampling design

The data used in this paper come from a survey of 200 cross-section households conducted in 2000 in Tigray province, northern Ethiopia. Two-stage sampling was used to select the sample households. First 50 *tabias* – the smallest administrative unit in the region – were randomly selected from a total of 600 available *tabias*, and then a random sample of 200 households was selected from these *tabias*. Both quantitative and qualitative data were collected on cooking/baking frequencies of household, household's production (collection) and consumption of various biomass fuel types, and issues regarding household income; demographic characteristics of the household including age, sex and literacy level of the household head and household size. Also obtained from the survey were family resource endowments including total land holding, land area cultivated, and livestock holdings of household, village level factors including agro-ecological conditions or altitude range and distance traveled (time spent) to collect different fuels. Summary statistics of the variables considered in the analysis has been presented in Appendix Table A1.

Data on cooking/baking frequencies of household was weighted for respective end use share in the total household fuel (EESRC, 1995).

Results and Discussion

At first, empirical estimates of parameters of substitution elasticities between the two goods was obtained using Cobb-Douglas utility function. All the coefficients/parameters turned out to be highly significant, i.e., at 1 percent level. Results have been presented in Table 4. Having estimated parameters α=0.5, β=0.25; and considering p_f^0=1.50 (Eth Birr), p_d^0=0.25, and m^0=140.00 as initial prices and income we analyzed the likely effect(s) of price change, say from p_i^0 to p_i^1, resulting from change in institutional setting that could be envisaged to alter the open-access conditions of the fuel resources, on the well being of a representative agent/consumer. The respective average values in the dataset were taken as initial prices and income for our representative agent. Effects on agent's well being were analyzed numerically under three alternative scenarios: first, price of dung (p_d) changes while wood price is held unchanged; second, price of wood (p_f) changes and price of dung held unchanged; and, three, simultaneous change in both prices. Because the extent to which the change in policy increases prices cannot be determined a priori, we computed the welfare effects of the policy change for alternative price levels. Three different levels of prices, i.e., 25%, 50% and 100% increase in price were considered. Our findings reveal there are private welfare costs involved, be it an independent price (policy) change in *i*th good or simultaneous price (policy) change in both goods. Results show that an independent 25% increase in price of *i*th good would lead to a welfare loss of some one-tenth of agent's income, whereas a simultaneous price increase of similar amount would lead to a welfare loss of two-tenth. We found that a simultaneous 25% increases in prices of wood and dung results in welfare loss equivalent to an independent 50% increase in wood price, with dung price held constant or 100% increase in dung price, with wood price held constant. The details are provided in Table 5.

Table 4 *Estimation results (standard error in parenthesis) of substitution elasticities (parameters)/Cobb-Douglas utility function (n=200)*

Variable	Coefficient [a]
Wood	0.602 (0.027)***
Dung	0.250 (0.030)***
R^2	0.974
F-statistic	2967.27
Prob > F	0.000

a *** indicate significance at the 1%.

Table 5 *Welfare effects of price (policy) change for a representative household under alternative scenarios and price levels (for α=0.5, β=0.25)*

Scenario + Price combination	Income (m) (Eth Birr)	Price (Eth Birr)		ΔW (Eth Birr)
		Dung (p_d)	Wood (p_f)	
Initial (m^0, p_i^0)	140.00	0.25	1.50	-
25% increase in p_d & p_f held constant	140.00	0.31	1.50	-14.00
25% increase in p_f & p_d held constant	140.00	0.25	1.825	-14.00
Simultaneous 25% increase in p_f & p_d	140.00	0.31	1.825	-28.00
50% increase in p_d & p_f held constant	140.00	0.375	1.50	-14.00
50% increase in p_f & p_d held constant	140.00	0.25	2.25	-28.00
Simultaneous 50% increase in p_f & p_d	140.00	0.375	2.25	-42.00
100% increase in p_d & p_f held constant	140.00	0.50	1.50	-28.00
100% increase in p_f & p_d held constant	140.00	0.25	3.00	-42.00
Simultaneous 100% increase in p_f & p_d	140.00	0.50	3.00	-56.00

Theoretically open access leads to rent dissipation. This implies that if land is privatized, rent would be captured (maximized), which according to economic theory is welfare-improving. That is, when price increases, income of the resource owner increases. Hence, the welfare impact of privatization for those who sell fuelwood increases. However, the results presented in here represent only the consumer side of the problem.

Conclusions

In Ethiopia all land is publicly owned, so traditional fuels are collected freely under open access conditions. Such an institutional setting has resulted in major degradation of Ethiopia's land resources and dissipation of the resource rent, as available forest and grazing lands are exploited in a suboptimal fashion. An alternative to current institutional setting is to enforce private property institution. Using dataset from 200 cross-section households in Tigray province, northern Ethiopia this paper estimated substitution elasticities between two fuel goods wood and dung. We then use these to derive crude estimates of the potential welfare costs of implementing a private property institution.

Considering average values in the dataset as initial prices and income for our representative agent/consumer, we numerically analyzed the effects on our agent's well being of the policy of enforcing private property institution under three alternative scenarios: first, price of dung changes while wood price is held unchanged; second, price of wood changes and price of dung held unchanged; and, three, simultaneous change in both prices. Because we cannot determine a priori the extent to which the change in policy increases prices, we considered three different price levels. Albeit simplifying assumptions, our findings reveal that privatization of the currently public/common pool resources such as forest and grazing lands/dung might indeed be welfare reducing. The findings hold be it an independent price (policy) change in one good or simultaneous price (policy) change in both goods, for different price levels. The loss in well being is some 14.00 to 56.00 Ethiopian Birr, or 10 to 40% of household average monthly incomes. Given the magnitude of the estimated loss, it is little wonder the government is reluctant to impose a private property institution on Ethiopia, despite continued land degradation and dissipation of the resource rent.

However, the analysis considered only the consumer side of the problem and did not consider the producer side. Therefore, further research is needed to include the producer side and evaluate the net effects.

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Appendix

Table A1 *Summary statistics of variables considered in the analysis (n=200)*

Variable	Mean	Std Dev	Min	Max
Family size	5	2	1	12
Household income (monthly) (Eth Birr)	140.012	94.227	9.958	647.083
Number of cattle	4	3	0	14
Cooking frequency (monthly)	52.989	19.670	12.742	210.315
Wood price/shadow (Eth Birr)	1.483	7.285	0	18.376
Dung price/shadow (Eth birr)	0.266	0.849	0	3.618
Wood consumption (kg/month)	117.875	86.310	0	420
Dung consumption (kg/month)	90.034	94.570	0	628.5
Kerosene consumption (lit/month)	1.745	6.890	0.11	97.68

Conclusion and Way Forward

The core of the workshop agenda was addressed in the second day of the workshop where group discussions were held in three thematic areas: land and water, biodiversity and socio-economics and policy. Each group was given questions for discussion. The question included:

- Identify the research work done so far? What are the major research findings?
- Identify major research gaps in the area?
- How to improve research–policy linkage? What is expected of the researcher? What is expected of the policy makers?
- Steps forward in institutionalizing research-policy linkages

Each group presented its findings into the plenary. Overall, the group couldn't come up with an exhaustive list of research work done so far, or list the major findings and research gaps. All groups called for an inventory of the major research undertakings in SLM and documentation of their major findings. The groups came up with various ideas on improving research-policy linkages and mechanisms to institutionalize it which led to passionate discussions in the plenary session about: what research is all about, how it could be made relevant for policy making, research approaches and ways of disseminating research outputs, etc critical issues that also defined the way forward for the workshop organizers.

What Research Should Be?

The most important issues raised included: how to go about doing research? Are we still following the popular metaphor of "PUBLISH or PERISH"? Some workshop participants pointed out the danger of such research approach as a result of which research outputs are shelved or remain without being communicated to policy makers. Others also raised the importance of having an appropriate forum through which research outputs could be disseminated. In this respect, it was suggested that while strengthening regional SLM forum is important, it is also of great relevance to do it nationally. Hence, the need to establish a national SLM forum was underscored. This forum could be used to collect, process and finally disseminate the research outputs to relevant stakeholders, including policy makers.

In terms of orienting research, the workshop participants reached consensus on making research more policy relevant to help solve development problems in the country. Research needs to serve the needs of the development community. Making research more relevant can be ensured by involving relevant stakeholders in identifying researchable questions. But it does not and should not stop there. The issue is not only making research relevant by choosing pertinent research questions but also delivering quality outputs. Ensuring the right research quality is another challenge to researchers. This may also call for getting good data from development agents. It was noted that, researchers very often do not get the required data because they are not either available or there is lack of will by development actors (or those who have custody to it) to share data to researchers.

One issue that drew the participants' attention is on the issue of striking the right balance between applied and basic research. On the one hand, it is important to understand that research doesn't have one single mandate. Research strives to influence policy, to change livelihood and to extend the horizons of knowledge.

On the other hand, there were who argued basic research is essential (it should continue) since you cannot proceed to applied unarmed with some basic research outcomes. It should have a long term objective than an applied research. It answers several questions and at the end it is going to be useful. For instance, we are scared for our life since climate is changing and some basic research may come up with a solution on how to overcome the problem. Another example is what sources of energy do we have? So many and take research on solar energy, the way we transform it is inefficient and prohibitively expensive and I can understand the ultimate benefit of basic research on how to harness sun energy in to direct electric energy. Having said that the time research is done for its own sake is no more with us. As an Ethiopian should I have to spend on basic research? No there is no need and I have to wait since the riches are doing it. There is an immediate question we need to answer: the welfare of our people. Simply there are several immediate questions that we need to answer before we head in to basic research. There is a need to prioritize the research: applied research first then basic research. I would prioritize the basic research if and only if there is a very important issue I need to address and there will not be others who do it. The researcher must make sure that his/her outputs are usable. It should be judged not on how brilliant he is rather on how the brilliant his/her mind tackles the question. If the research outcomes are not usable then kick out the researcher.

Research-Policy Linkage

Once research outputs are generated, and then making the outputs accessible to policy makers is another challenge. This requires proper packaging and choice of communication media. As one speaker noted, one of the problems with researches is their inability of dialogue (language and communication). In case of farmers it is almost taken care but researchers still are not good in communicating their outputs. I like the saying "let's skip the Greek". So let us present our research findings in a way that is easy and simple to be understood in order to facilitate the consumption of research outputs by various stakeholders.

However, this also needs looking into incentive mechanisms for researchers to consider policy impact of their research outputs as an important input for their evaluation than merely to assess their merit on the basis of the number of articles they published in an academic journal. Conventional approaches to reward researchers are based on their success to publish rather than wider research impact. This calls for developing mechanisms to consider the impact of a given research output that goes beyond publication and dissemination of results. Furthermore, researchers may not have the required skills to properly package and communicate their research outputs. This may call for capacity building (e.g. training in policy brief preparation, etc) and soliciting help from communication experts.

Equally important in bridging research-policy linkage is the increased participation of relevant policy makers and development practitioners in workshops or forum. In most workshops important stakeholders do not participate in workshops and conferences even if they are invited. Is it lack of interest or lack of time is not clear? One speaker asked: Where are other people from Bureaus? Such workshops and presentations should enable us to make dialogue. We have to use appropriate languages and appropriate mediums to communicate our results in such fora. This is basic since we have to communicate our results sometimes to low or middle level professionals (development agents) and sometimes to farmers.

There was also a call for strong farmer involvement in SLM research. It was noted that sometimes farmers are well ahead of researchers and we can tap that to research's benefit. Farmers are open to us but researchers are not. There is a lot of scope for participatory technology innovation by involving researchers, development agents (DAs) and farmers. We could also help farmers in making evaluation of their innovations. They could also be actors in development without waiting for instructions from DAs.

Finally let us carefully think on what are we getting out of this workshop (it was not cheap to run this workshop)and what language are we going to use and how are we going to communicate or distribute the workshop outputs are critical issues.

Way Forward

The discussants finally agreed on the following points, which could serve as entry points for further action by the workshop participants and organizers.

- There is an urgent need to conduct an inventory of SLM research work done in the region and beyond and make it ready for researchers and policy makers alike. It could specifically take the form of an annotated bibliography. The importance of such inventory is to know what was done in the past and identify critical research gaps that need to be addressed in the future.
- There is also a need to communicate the key findings and recommendations of the key research outputs presented in the workshop. In doing so we need to simplify language or translate them into the local language to reach policy makers and end users.
- Scaling up research outputs to reach policy makers and end users is another important work to be done.
- We need to establish a kind of forum (platform) where we could share our research outputs and organize discussions pressing issues.
- At the regional level we need to identify a working group, involving major stakeholders, to institutionalize the forum and support the work of the forum.

This led to the closing speech by the guest of honor.

Closing Speech

Dr. Zenebe on behalf of the organizer reminded participants the main issues discussed in the two days workshop cover wide ranging issues such as regional development policies and strategies, research outputs on several themes focusing on water, forest, land, and institutions, and, during the second day critical issues related to research and policy linkages were covered. He indicated that we had two fruitful days and we are coming to a close now. Then he called up on his Excellency Dr. Teweldebirhan Gebreegziabher, Director of Ethiopian Environmental Protection Authority, to give a closing speech.

HE, Teweldeberhan Gebreegziabher closing speech

His Excellency, Dr. Teweldeberhan started his closing speech expressing his enjoyment of the workshop and he further expressed his happiness that the young researchers have struggled and shared their research outcomes in the workshop. Then, he commented the organizers to make sure that they know what this program need to have a good conclusion. He said I encourage you to continue and to always remember where you are? Where you want to go? And where are you from?

He proposed to form a voluntary group from the participants in the workshop and let it open ended. Then he requested participants to volunteer after he expressed his willingness to volunteer and become member of the group. Besides, he proposed Belete Tefera (Deputy Head, BOARD) to be member of the group owing to his duty that makes him important for the group [Belete expressed his will to volunteer], and Dr. Mitiku Haile (President, Mekelle University) expressing his absence is only for he is abroad now on official duty. Following this, Professor Fisseha-tsion volunteered on behalf of the faculty of Law, Mekelle University, Dr. Yohannes (from Addis Ababa University) volunteered, Sue Edwards (from ISD) substitutably with Hailu Araya (from ISD) volunteered to join the voluntary group.

He requested the organizers of the workshop to produce a report collecting all papers presented, making summaries of the workshop and the results of the discussions of the three thematic issues (land, water and socioeconomic) in both Tigrigna and Amharic, to make them simple and understandable to policy makers and communicate them to all relevant stakeholders.

Once the report is out, he volunteered (together with Belete Tefera) to go and brief the outcomes of the workshop to the regional government of Tigray. And he expressed his belief that the regional government of Tigray would have been in the workshop if they could. He also told the participants that the regional government of Tigray never dumped his ideas when he went to them with clear ideas. Besides, he said if needed we can do all the necessary links to have our outcomes are communicated and used.

His Excellency continued saying that usually it is claimed that Football is invented in England though not true since each culture has it since we love kicking some thing. He promised to stimulate the linkages and told participants that it requires continuous commitment of all the participants.

He requested the participants to help decision makers to decide in the right way. Instead of saying this rubbish government, bla bla [I understand it is some times out of frustration, he added]. He gave an example comparing the American agricultural earning, in trillions, versus Ethiopian agricultural earning, 1.5 billion birr (the most highest). So given this difference it may not be right to wish to bring everything the developed nations have and do. We need to bring something from abroad and weigh it in our context. He told the participants his experience in AAU, when he came back from abroad there were 3 Ethiopian academicians in Biology and there was no good facilities but we thrived in that environment.

He advised all that let us be useful for ourselves and then for the country. Even the most selfish of us need to see a better country at least since he has children and other linkages. Finally, he said "a better country not only for me to enjoy and love, my love is extendable to all human beings". Further, he added "very selfish (for myself), selfish (for my child), a little selfish (for my species)". He ended his closing remark requesting all to work hard for a better country and thanked all.

Annex I

Workshop Report

According to the workshop schedule invited guests, participants, and His Excellency Dr. Tewelde–Berhan Gebreegziabher, General Manager of the Ethiopian Environmental Protection Authority have taken their seats until 8:40 AM.

Dr. Zenebe Gebreegziabher, Head of the Department of Economics of Mekelle University announced the workshop schedule to participants and invited Dr. Menale Kassie from the EEPFE/EDRI to give speech on the major activities of the EEPFE/EDRI and objectives and expected outputs of the workshop.

Dr. Menale Kassie, Research Fellow of the Environmental Economics Policy Forum for Ethiopia (EEPFE) of the Ethiopian Development Research Institute (EDRI), gave speech on behalf of the EEFPE/EDRI. He outlined the operation and scope of the EEPFE/EDRI and objectives, expected outputs of the workshop.

According to Dr. Menale, the EEPFE is one of the six Environment-for-Development (EfD) initiative centres funded by SIDA through the University of Gothenburg. Established in 2003, EEPF has the mission to provide quality environmental economics policy advice to the government and other institutions based on quality objective research to reduce poverty and contribute to sustainable development. Thus the Forum undertakes collaborative and independent macro and micro level research on environment, sustainable land management, and related issues.

Dr. Menale noted that the researches of the Form and other research institutes are not properly communicated with policy makers and development agencies. Thus, an important objective of this workshop is to communicate with researchers and civil servants for effective dissemination of the findings and outputs of researches. Hence this workshop will propose strategies that will assist sustainable research information flow to decision-makers and development agencies of the Tigrai region. EEPFE would continue to play a major role in organizing research information flow in all regions of the country and will provide support to establish SLM platforms in most regions. Moreover, the researches and the workshop will help regional and national policy makers to develop strategies to better serve leaders and poor farmers in their mission to eliminate poverty and land degradation in Ethiopia.

Finally, Dr. Menale invited Ato Aregawi Gebremichael to give his speech.

Ato Aregawi Gebremichael, Dean of the Faculty of Business and Economics, gave a speech on behalf of the faculty. According Ato Arageawi, the Department of Economics is one of the leading departments in Mekelle University with regard to research, consultancy and community services. Research has to be conducted in light with the poverty reduction and development strategy of a country. Moreover, the findings of the researches should be communicated to policy-makers, development agencies, and the public at large so that they make informed decisions.

Ato Aregawi outlined that the workshop is expected to create common understanding on the available SLM policy and strategies and implementation barriers of the Tigrai region; share experience on currently available research outputs on agriculture and natural resource issues including policies as well as identify gaps and future research interventions; examine the role of research and development institutions on the Tigrai National Regional State in future collaborative research and capacity building; promote inter-institutional and cross-sectoral cooperation and networking efforts between Mekelle University, EEPFE and relevant institutions in Tigrai that have actual and potential involvement in research and capacity building endeavours; and create strong platform to bridge the gaps between research, extension, and policy making process. Ato Aregawi emphasize that the workshop is a good opportunity to create close relationship with the EDRI and other national and international organizations.

Finally, he invited Dr. Abdulakdir to give speech

Dr. Abdulkadir Kedir, Associate Vice President for Research and Graduate Programs of the Mekelle University (MU) deliberated a speech on behalf of Mekelle University. He explained that MU has been engaged in academic, research and community services since its establishment. The workshop on the theme 'Sustainable Land Management Research and Institutionalization of Future Collaborative Research' is one aspect of its triple role and commitment in serving the society at large and the region in particular.

He further explained that Ethiopia is typically an agrarian country, with agriculture continuing to be the largest sector in its economy. Enhanced productivity of the agricultural sector rests on sustainable management and use of the country's land resource. Accordingly the workshop is of particular relevance in the sense that it deals with the core issue of 'sustainable land management'. It also fits with the broader 'Agricultural Development Led Industrialization' (ADLI) strategy of the country.

According to Dr. Abdulakdir, different institutes and individuals have carried out extensive research to assess the problems of land degradation, their causes, remedies and impacts on agricultural development and sustainable resource use. However, these research results are hardly known to policy-makers and development agencies. Therefore, he emphasized that the workshop will overcome this problem, identify issues for future research, and ensure information flow to stakeholders, particularly on what has been done so far on sustainable land management (SLM) research for informed decisions. In addition, the workshop and the papers presented will open the avenue to create a common understanding on existing policies and strategies of the region and implementation barriers as well as to share experience on currently available research outputs on sustainable land management. Moreover, it creates strong platform to bridge the gap between research, extension, and policy making processes. Furthermore, the workshop will identify future research needs and suggest on implementation mechanisms including partnership arrangements (through creating strong collaborative research platform).

Finally Dr. Abdulakdir declared the opening of the workshop and called upon His Excellency Dr. Tewelde-Berhan Gebreegziabher to deliver his keynote speech for the workshop.

Sustainable Land Management: Research and Policy Challenges*

By Tewolde Berhan Gebre Egziabher

1. Introduction

Of all the living species, it is we, humans that have the greatest impact on the biosphere. Our impact on the atmosphere, climate change, is already affecting the whole biosphere. However, since we are terrestrial, it is the land that has received our impact the longest. And since we are gathered here today to look specifically at land management, I will touch on climate change only obliquely to the extent that it interacts with land management and land degradation.

Land degradation is of particular importance to Ethiopia because the Ethiopian environment is mountainous and thus very easy to degrade. The main economic sector in Ethiopia is, and for thousands of years has been, agriculture; and agriculture is the main human agent for causing land degradation.

The terms “organic agriculture” and "ecological agriculture" were coined in the second half of the 20th century to qualify the crop and domestic animal production system that has sustained us for 10,000 years. The terms were needed to contrast the farming that has always been with its new petrochemical-based modification, industrial agriculture. I prefer the second term. This is because the term "organic" is now being used to imply that artificial chemical inputs, whether petrochemical or not, should never be used in agriculture. But I see no problem with the occasional chemical input into the agricultural ecosystem when that input will help to quickly re-establish stability. My more fundamental objection is to the added expense. Since ecological agriculture has thus established its credentials for 10,000 years, for me the real question is, “Can the decades only old intruder, industrial agriculture, continue to satisfy human needs into the indefinite future, especially now that the chemical inputs it uses are largely derived from petroleum, and petroleum is getting very expensive?"

You can, however, legitimately ask if ecological agriculture can feed the population size of the present world, which is much larger than that which had been at any time before industrial agriculture intruded into its domain. This question implies that ecological agriculture cannot produce as much as industrial agriculture presently does. It is a legitimate question, and it must be answered. I know that other speakers will answer this question in this workshop. An at least equally legitimate question is, "Can this new comer, industrial agriculture, continue satisfying human needs in a sustainable biosphere for the coming 10,000 years and more?" I must now try to answer this critical question. Therefore, I need to start by looking at agriculture and ecological stability for the simple reason that stability is a pre-requisite for thinking of perpetuity.

2. Agriculture and Ecological Stability

A natural terrestrial ecosystem is approximately stable because its functional components, the producers, consumers, decomposers, soil, water, air and temperature positively respond to

* Keynote speech delivered at the Sustainable Land Management Workshop, Mekelle, 8-9 August 2008, based on a lecture on "Can Organic Agriculture Feed the World?", given to the Soil Association in London on 12 July 2005.

negative feedbacks triggered by changes induced from outside. In the ecological agricultural ecosystem, the crop plants and their weeds are the producers. Human beings, domestic animals and at least some wild animals, including many in the soil, are the consumers. Soil fungi and bacteria are the decomposers. The humus binds the inorganic particles into units that determine the soil's structure. Air and water become optimally available in the crop plant root zone because of the thus optimised soil structure. The soil particles, especially the humus, also maintain the appropriate pH and supply plants with nutrients[1]. When humus is in this way allowed to remain dominant in the soil, much carbon is sequestered thus mitigating climate change. In contrast, industrial agriculture reduces soil humus, degrades soil structure and transfers the carbon that had been in the humus in the soil into the atmosphere, thus exacerbating climate change.

2.1 Agriculture and Niche Simplification

Unaided by informed ecosystem management, even ecological agriculture as it has mostly been practiced does not fully obey these rules that ensure ecological stability and sequester carbon. All forms of agriculture, including ecological agriculture as has mostly been practiced, cause niche simplification. But industrial agriculture does so the most. It is also in its market-oriented nature to reject the comprehensively informed management that would have led to the ecosystem itself ensuring its own stability.

In agriculture, our interest is the maximization of biomass production in the crops and/or domestic animals which we use for food or for other purposes. Therefore, agriculture reduces the number of species growing in the farm.[1] In nature, species that grow together complement one another to combine together and fully exploit the different niches of their ecosystem. For this reason, though intensive chemical inputs may become productive in a given season, sustained productivity over years is not possible with the monocultures that are the norm in industrial agriculture,[2] i.e. when only one of the green plant niches is occupied. The occupation of a critical minimum number of green plant niches is necessary for ecological stability, also referred to as homeostasis, and the increase in the number of species will thus raise production because more room for growth becomes available in the same area. The minimum number of complementing species for maximizing production is small, but that for ecological stability or homeostasis is much larger.[2]

The species of crops and domestic animals the biomass of which we want to maximize are smaller in number than those that naturally grow in that ecosystem. This means that even when based on a polyculture, agriculture reduces niche utilization. Therefore, it also correspondingly reduces the positive responses to the negative signals induced by disturbances of the natural homeostatic processes and thus also reduces biomass yields. For this reason, the agricultural ecosystem normally fails to adjust as effectively as the natural ecosystem it has replaced and land degradation sets in. That is why losses of structure and fertility of the soil occur.[3] The hydrological cycle also gets disrupted, often resulting in soil salinization,[4] and even more often in increased runoff and soil erosion.[5]

Many civilizations have been eclipsed by such agriculturally induced devastations, e.g. owing to salinization in the Tigris and Euphrates Valleys, and owing to soil erosion and sedimentation in Ephesus[6] and the rest of Asia Minor.

2.2. Techniques Used by Farming Communities for Compensating for the Loss of Ecosystem Components

Over the thousands of years of the history of ecological agriculture, farming communities have learnt various biological and physical methods of coping with the problem of land degradation, which is the continuing degradation of the components of the ecosystem. Two examples are terracing and fallowing. But perhaps the most significant examples are those that make the conscious use of species with special traits to provide positive reactions to the negative feedbacks induced by inappropriate agricultural practices. For example, mixed farming,[7] i.e. combining crop and animal production, enables manuring, or better still, the making and use of high quality compost to build up soil fertility. They do so by helping keep biological production, consumption and decomposition in tune in the farm. Their application at the time of planting provides crops with nutrients optimally beginning at the start of the growing season, thus maximizing the biological production that is wanted by agriculture. Turning manure, human waste and other biological materials into compost clears them of weed seeds, pests, diseases and parasites. Therefore, a systematic making and use of compost both maximizes the availability of nutrients to crops, and builds up the ecosystem's homoeostasis.

Deep rooted crops return leached nutrients up to the surface soil from where they become available to the next crop generation. Leguminous plants, including crops, fix nitrogen to replace what is denitrified and lost to the atmosphere. Sorghum, barley and similar crop species are deep rooted and, besides bringing up nutrients to the surface, withstand dry spells which agriculture exacerbates by deforesting the land and thus changing the microclimate. Deforestation exacerbates waterlogging as well. Teff and similar species slow down their own growth to survive waterlogging, and rice even grows optimally under waterlogged conditions. The positive impacts of agricultural biodiversity on the ecosystem can thus be made to occur simultaneously by planting the species in polycultures and/or sequentially by crop rotation in monocultures or even in polycultures.

The physical methods developed by farming communities reduce or prevent soil erosion, loss of water, excess water, or even bring water from afar or from under the soil for irrigation. Both irrigation and drainage can influence the physics and/or chemistry of the soil, e.g. by causing salinization.[4] They have thus caused much loss of good soil and biodiversity. But, in combination with appropriate biodiversity and a high soil humus content to maintain good soil structure and thus also fertility, they can be used sustainably. High soil humus content also sequesters carbon and helps maintain the climate stable. It also helps crop species remain resistant to diseases and pests.[8]

2.3 Industrial Agriculture: Creating the Ecosystem Market

Industrial agriculture abandons trying to bring about homoeostasis into the agricultural ecosystem. Instead, it tries to produce a homogenous environment of marketable components irrespective of the diversity and complexity of the pre-existing ecosystems. To achieve this, it uses irrigation extensively even where it is not needed. It thus creates a captive market for pumping and irrigation equipments. It also creates contracts for building dams, drilling bore holes and making irrigation and drainage canals. In this way, it geographically extends the age-old problems associated with irrigation.

It divorces animal production from crop production. It disposes of both animal and human wastes and plant residues as if they were poisonous. It plants single variety monocultures as a continuum over very extensive areas. This reduces nutrient cycling and ecological disruption thus becomes inevitable. One indicator of such an ecological disruption is the regular and quick collapse of the uniform crop variety that is in use over a wide area as a monoculture. The collapse occurs owing to emerging vulnerabilities to diseases and pests.[9] This keeps breeders specially trained to keep out diversity and produce uniformity employed. It also gives chemical companies that produce and supply pesticides and herbicides a captive market. Both the breeders and suppliers of agrochemicals are now increasingly the same multinational companies.[10] This is understandable since combining both sectors enables the breeding of varieties that can be relied upon to need the agrochemicals. By so doing, industrial agriculture marginalizes the farming community breeders [11] who have been maximizing diversity to adapt agriculture to ecosystem complexity and have thus given humanity the various crops and the thousands of varieties of each crop as well as the ecological methods of using diversity to increase yields and forestall diseases and pests.

Thus marginalized, they lose confidence in their proven and customarily acquired systems and become dependent on the monocultures and helpless when confronted by the diseases and pests that they used to prevent effectively.

Nutrients are leached out and washed away and have to be replenished externally at very short intervals. This gives chemical companies that produce and supply fertilizers a captive market.

Soil structure deteriorates and compaction becomes a serious problem. This gives agricultural machinery companies a captive market. The natural components of the ecosystem are thus replaced by tradable artificial components that are bought and sold in the market.

The replacement agricultural ecosystem that these purchased replacement ecosystem components of industrial agriculture constitute is not stable. Unlike the natural components, these replacement components fail to respond to feedbacks effectively. Therefore, the more they replace the natural components, the less homeostatic the agricultural ecosystem becomes. This is because of their inability to replicate the complexity of interactions in the natural soil.[12] In this way, they steadily destroy the natural components of the agricultural ecosystem and make themselves indispensable in the steadily degrading land.

The suppliers of these replacement components want to increase their profit and they often come up with highly simplistic quick-fixes for the market-making fundamental agricultural ecosystem flaws which they have created. The most recent quick-fix, genetic engineering, is being championed not as a means of increasing homeostasis and yields in stable agricultural ecosystems of high innate soil fertility, but as a means of producing crops that will grow in degenerating agricultural ecosystems.[13] The logical end result of degeneration is destruction. If genetically engineered crops could grow in an environment under destruction, they would have become harmful enough since they would have lulled us into accepting the situation until it becomes too late to reverse. As it is, so far, genetically engineered crops have been used only to put more disruptive factors into the industrial agricultural ecosystem: poison to some invertebrate animals in the case of Bt transgenic crops, and universal poison to other plants in the case of herbicide tolerant transgenic crops. No transgenic crops with other traits have been cultivated extensively. Transgenic crops with other traits are thus so far merely a tantalysing promise.

3. Research and Policy Implications

The impacts of industrial agriculture impinge upon, and are themselves modified by, other sectors of the globalizing economic system. As you know, agrochemicals are derived from petroleum. You will recall that recently, the price of petroleum went up above 140 U.S. dollars per barrel. Predictions are that it will continue to rise further. Do you think that we can continue to depend on petrochemical-based industrial agriculture? It is my considered opinion that industrial agriculture in financially poor Ethiopia is dying on its track. Even in the financially rich industrialized world, it has to undergo a serious reorientation and converge with ecological agriculture if it is to continue contributing to human development.

This can be done only if it is made to contribute to maximizing the biomass that we require while at the same time strengthening the homeostasis of the agricultural ecosystem to match that of the natural ecosystem. Will ecological agriculture do this for us more easily and more effectively?

The answer is yes, but only if we take it seriously and do all the research and development to compensate for the time that we have lost on industrial agriculture. This will obviously require appropriate management policies to bolster rather than shunt the natural cycles that improve the functioning of the ecosystem as a whole, including those parts of it that are not cultivated. In this way, ecological and industrial agriculture would harmonize and the schism in agriculture of the last 5 decades would disappear.

Can this be done? Will research and conducive policies suffice to produce the needed harmony? Why not? Previous farming communities have been learning from their past mistakes and have been successively and successfully harmonizing agriculture with ecological stability for thousands of years. With our increased scientific knowledge based on systematic research, we should much faster do much better than they have been doing.

Unfortunately, I realize, as I am sure that all of you do, that agricultural research in the last 5 or so decades has globally ignored ecosystem stability and focused on selecting varieties that maximize yields under irrigation and chemical fertilizers. What is needed is a commensurate amount of research on land management for maximizing innate soil fertility, on sustaining the thus maximized soil fertility, and on selecting crop varieties that maximize yields under increasing innate soil fertility. Breeding for crop varieties that are adept at grabbing chemicals before they are washed away to pollute water bodies should stop. There would then be no doubt that the results would be agricultural systems that are better than petrochemical based industrial agriculture with its inbuilt land degrading impact. But of course, in contrast to industrial agriculture, these agricultural systems would cost less money to maintain, would minimize pollution and would remain sustainable into the indefinite future.

Therefore, if it is given all the attention in research and policy focus for effective management that industrial agriculture now enjoys, I am sure that the renovated ecological agriculture will feed the world. I am also sure that, unless ecological agriculture is renovated and re-expands and tames industrial agriculture, land degradation will expand even further than it has already done and the human component of the biosphere will soon shrink. And, if climate change, which is being exacerbated by industrial agriculture, is not curbed, there will be no biosphere as we now know it and no land as we now have it, let alone food as we now love it.

Thank you all for hearing me out.

Endnotes

14. Heywood, V. H., and R. T. Watson, 1995, **Global Biodiversity Assessment**, Published for UNEP by Cambridge University Press: Cambridge, p. 443.

15. **Ibid**, pp. 402-405, and p. 448.

16. **Ibid**, pp. 326-452 give additional information on how this soil deterioration occurs.

17. Salinization as a consequence of irrigation, especially when water drainage is not properly carried out, is a well documented phenomenon. Therefore, even though it may at first sound counter-intuitive to associate excess salts with excess water, it is lack of proper drainage that causes simultaneous waterlogging and salinization, and land lost to both is usually lumped together. Brown, L. R., and C. Flavin, 1997, **Vital Signs, 1997,** World Watch Institute: Washington, p. 42 state that 2 million hectares of irrigated land are lost annually to waterlogging and salinization. Pretty, J. N., 1995, **Regenerating Agriculture,** Earthscan Publications Ltd.: London, pp. 126-127, gives the lower estimate of 1.5 million hectares per year. But either figure is equally frightening.

18. World Resources Institute, United Nations Environment Programme, United Nations Development Programme and The World Bank, 1998, 1998-99 **World Resources- A Guide to the Global Environment,** Oxford University Press: Oxford, p. 157, state that soil is being eroded globally at a rate of 16 to 300 times than it is being formed. This shows that we are eating up nature's investment and investing in death for future generations.

19. On 24 September 1995, the participants of the "Revelation and the Environment, AD 95-1995" symposium visited the ruins of the ancient city of Ephesus. While in the ruins of the city, dug out by archaeologists, we were told that it was soil eroded from the surrounding hills that had sedimented out and buried the city. The hills were now mostly rocky.

20. Howard, A., undated, **An Agricultural Testament,** The Other India Press: (Reprinted. First published in London in 1940), pp.1 and 32-38 describes the system. Note that there is no mixed faming in industrial agriculture. It is, however, extensively used by farming communities of the South, including Africa.

21. Unless it is owing to our lack of access to the complete literature, modern papers and books on soil science do not deal with the health implication of soil organic matter (humus). But it may also be because modern authors are so engrossed with ecosystem replacement agrochemicals for dealing with crop diseases and pests that they do not focus on natural cures. However authors that published before agrochemicals were as widely used as now wrote on the issue. Howard, A., **Ibid**, pp. 143-174, shows the importance of high humus content and a balanced agricultural ecosystem in keeping crops physiologically fit and thus not succumbing to diseases and pests. He argues that the use of agrochemicals for fighting diseases and pests is of limited efficacy since the diseases and pests adapt to the chemicals. More recently but still before agrochemicals became so ubiquitous, Russel, E. W., 1961 **Soil Conditions and Plant Growth,** Longman, Green and Co. Ltd.: London, has repeated the same basic theme, with more precise information, pp. 210-221 on how a balanced soil microflora helps, and pp. 523-534 on how soil organic matter helps by keeping plants healthy and resistant to pests and diseases. In Tigray, Northern Ethiopia, we have noted that tef grown on soil where compost has been applied withstands tef shoot fly, while that grown on chemically fertilized soil is severely attacked.

22. Fowler, C., and P. Mooney, 1990. **Shattering: Food, Politics, and the Loss of Genetic Diversity,** The University of Arizona Press: Tucson, Arizona, p.135, report that between 1974 and 1977, new barley varieties in the U. K. were losing their resistance about every 3 years.

23. Fowler, C., and P. Mooney, 1990. **The Threatened Gene: Food, Politics and the Loss of Genetic Diversity,** The Lutterworth Press: Cambridge, pp. 115-139.

24. The specially trained plant breeders who produce the homogenous varieties for industrial agriculture have been denying that farming communities are breeders and that they merely select what nature provides. This is indeed true, however not only of farming communities, but also of plant scientists. That is why to conjure up a distinction, the industrial agriculture breeders call the varieties produced by farming communities “land races”, connoting that it is the land and not the farming community that produced the variety. Albeit grudgingly, even industrial agriculture plant breeders are now recognizing farming communities also as breeders, e.g. Duvick, D. N., "Plant breeding and biotechnology for meeting future food needs," in: Islam, N., (ed), 1995. **Population and Food in the Early Twenty-First Century: Meeting Future Food Demand of an Increasing Population**, International Food Policy Research Institute: Washington D. C., pp. 221-222, recognizes both as breeders and distinguishes their contributions as "professional plant breeding" and "plant breeding by farmers".

25. Pretty, J. N., 1995. o*p. cit.*, pp. 26-93, Conway, G. R. and Pretty, J. N., 1991. **Unwelcome Harvest**, Earthscan Publications Ltd.: London, pp. 17-369, Heywood, V. H., and R. T. Watson, 1995 *op. cit.*, pp. 326-452, Shiva, V., 1991. **The Violence of the Green Revolution**, Third World Network: Penang, Malaysia, pp. 103-150, among many others, have described the specifics of how this loss of homeostasis occurs.

26. The United Nations Development Programme, 2001, **Human Development Report 2001**, Oxford University Press: New York, p. 35, states, "Biotechnology offers the only or the best 'tool of choice' for marginal ecological zones... home to more than half of the world's poorest people..." In the next paragraph, the UNDP states, "There is a long way to go before biotechnology's potential is mobilized." In so saying, the UNDP admits that biotechnology as 'the only tool' has not been tested in marginal areas to prove itself as the best tool, or even as any tool. Therefore, it is only a dream to state that it is "The only tool". Each of us can dream, of course, including those manning the UNDP. But dreams cannot become food. We know that there has not been even one successful transgenetic crop developed for the marginal areas of the poor and used extensively enough to prove itself. Assuming that biotechnology could indeed produce adequate food in marginal areas, how are "the world's poorest people", who are mostly not even monetized, nor even literate in their own languages let alone in English, going to deal with the intricate negotiations with patent holders, who will most probably be all foreign and from the North, in order to use patented transgenic varieties, and how are they to pay the royalties? In spite of a discussion on IPRs (see pp. 102-109) the UNDP is silent on the issue. This certainly turns its dream into a nightmare!

Sustainable Land Management: Research, Practice and Development Strategies

1. Development Strategies in Tigray, Challenges and Opportunities

By Ato Yemane Yosef

2. Challenges in Implementing Sustainable Land Management Practices and Rural Development in Tigrai

Ato Belete Tafere

Discussion

Discussion on Session I

After the presentations, the chair of session opened the floor for discussion. The following issues were discussed by participants on the presented papers under the theme Sustainable Land Management: Research, Practice and Development Strategies:

Question1:

2. The strategies of development package programs in Tigrai are part and parcel of the MDGs and MDGs targets. So with the strategy we have, do we expect to meet MDGs by 2015?
3. Sustainable development depends mainly on sustainable land management. Sustainable land management has been affected by global environmental problems (Eg. Global warming, green house effect, ozone layer depletion etc). And this global environmental problem affects our economic growth and development. So what is the current international community response and what is our start?

Answer:

By Yeman Yosef

Given the strategy of the regional government of Tigrai, my expectation is it will meet the MDG targets set to be met by 2015 since there are good indicators in poverty reduction and other social goals. In regard, whether we are on track to meet the income poverty ($1 per day objective/person) because of the household package a survey is underway and there are promising results. Besides, we are working hard to create access to infrastructure. We are on good track in meeting the targets, but we are left with 129 villages for electrification and hopefully we will achieve universal access of those basic infrastructures very soon. However there are tradeoffs, what is important is to manage the tradeoffs.

Question 2:

Would you please comment on the ecological agriculture, industrial agriculture versus accelerated growth strategy of the government?

Answer:

Two replies were forwarded: one from the presenters and the other from a participant.

Yemane Yosef:

There is quite large number of components or issues when we talk of accelerated growth (it is very broad concept), so there may not be a contradiction in our growth strategy and the agricultural strategy.

Dr. Teweldeberhan Gebreegziabher (rephrased question 2 and gave the answer):

I will ask on the contrary does industrial agriculture produce more than ecological agriculture per area? No, it does not. In the long run no difference between them in terms of output or productivity but ecological agriculture takes care of the biological species while industrial agriculture destroys the nature and introduces toxicity to the sphere we are living in.

Comment / Question 3:

Sue Edwards: A participant forwarded a comment, that is:

There is a dichotomy between BoFED with focus on households and the BoARD where effective environmental rehabilitation needs community participation. Moreover, there is inadequate support for community/neighbourhood by-laws at tabia level/social courts and wereda courts. There is need for better support for environment issues at local levels.

Answer:

In reply to the comments by Ato Belete Tafere:

The law is there but not effectively being implemented even by the judges. There are bylaws which are effective enough, however in some areas the bylaws are ignored. In some places there are simply attitudinal problems so that laws are not implemented properly. However, when communities are well aware, they themselves are guardians of their environment. However, there is need for coordination between policies and laws and their implementation.

Yemane Yosef:

The household packages of Tigrai are to ameliorate the existing poverty problem. There is no gap between BoFED and BoARD since participation by community is within the strategy.

Question 4:

Given 79% land mass in Tigrai is covered by soil and water conservation and 68% of soil loss is saved what is the increase in yield? If yield is not increasing is it possible to feed the population without industrial agriculture?

Answer:

Belete Tafere:

It has been improved and I cannot give figures since I haven't carried out research (so it's future research issue)

Question 4:

The household extension package which encourages increase in household's animal stock is affecting sustainable land management. How can this be reconciled? The issue of population is the missing element, while it constitutes a major role in the whole system?

Answer:

Belete Tafere:

The existing livestock we have is not beyond the carrying capacity of the biomass. It's the underutilization or inefficient utilization of the biomass which is a critical problem. Moreover, carrying capacity is relative. It is related to how we manage the environment and what we want to get out of it. Population growth and human economic activity should be in balance with the carrying capacity of the environment. It is not a major problem but still at regional policy level it is entertained.

Yemane Yosef:

Environment is a public good and I can say that it is effectively being managed by community through participation than at household level. However, household packages are also important. In terms of livestock, the emphasis is on enhancing quality and productivity of the livestock varieties than quantity.

Comment:

Dr. Teweldeberhan Gebreegziabher gave his comment on the issue of carrying capacity and said 'my view is that the carrying capacity is still there. It is not a matter of absolute carrying capacity rather other issues are more important and worrying, which we need to address. Having said this, on the whole I am all in reducing the population to keep the biosphere globally but not Ethiopian population only. From the global perspective, there is a need to keep a balance.

I. Water Harvesting and Watershed Approach for SLM

1. Challenges and Opportunities of Watershed Approach in Tigrai

Yohannes Gebremichael

2. Prioritization of Micro-watersheds on the Basis of Soil Erosion Risk in the Source Region of the Blue Nile River Using RUSLE Model, Remote Sensing and GIS: Case Study in the Muga watershed

Ermias Teferi, Dagnachew Legesse, Belay Simane, Weldeamlak Bewket

The presenter started discussing the background of the study, problem statement and significance of the study. Then he proceeded on presenting the data issues, reviewed past studies, and stated the objective of the study and methodology of the study. Finally, he presented the findings and concluded the presentation stating the main conclusions and recommendations of the study.

Then presenter, Mr. Ermias begun the presentation stating the background and significance of the study. Soil erosion and consequent degradation of agricultural land is a serious environmental and socio-economic challenge in the highlands of Ethiopia that harbour 88 and 75% of the human and livestock populations respectively, and constitute 43 % of the countries and dominated by high soil fertility that covers 95% of the cultivated lands. In these areas only, an annual soil loss reaches to 200 - 300 ton per hectare, while the soil loss movement can reach to 23400 million ton per year (FAO, 1984;). As a result soil erosion threatens the productive capacity of the highlands and hence constrains development options. In a predominantly agrarian society like Ethiopia, soil degradation is one of the ominous threats to the food supply. Hence there is an urgent need for policy interventions and soil conservation practices to alleviate soil degradation.

He further stated the objective of the study, which is to estimate soil loss and map soil erosion risk zones and prioritize micro-watersheds for conservation and thereby, maximize benefits of soil erosion control from minimum inputs enhancing efficiency of process of restoring the resource base. Methodologically, the study utilized RUSLE model that integrates Universal Soil Loss Equation (USLE) empirical model, and the technique of the Geographic Information System (GIS) and Remote Sensing to quantify soil erosion. The study is carried out at Muga watershed, one of the choke mountain watersheds, located in the northern highlands of Ethiopia.

Mr. Ermias then went on presenting the results of the estimation. The mean annual soil loss of the Muga watershed is 15.28t/ha/year and this result is greater than the average annual rate of soil loss in Ethiopia (12 tons/hectare/year). This result falls within the ranges of the findings of FAO (1984). According to the estimate of FAO (1984), the annual soil loss of the highlands of Ethiopia ranges from 1248 – 23400 million ton per year from 78 million of hectare of pasture, ranges and cultivated fields through out Ethiopia. Previous studies conducted on soil erosion assessment in Ethiopia shows different rate of soil erosion. For example, Hellden (1987),calculated mean total soil loss for Ethiopia of 150 t/ha/yr at Mertule Mariam, and studies conducted by FAO,(1986), in the Ethiopian high lands shows 100t/ha/yr soil loss from cropped lands taking in to consideration the redeposit. Another study conducted by Soil Conservation Research Program (SCRP) at Anjeni research station revealed that the annual soil loss rate to be 131 - 170 t/ha (SCRP, 1996) .Another study by Solomon Abate, (1994), shows soil loss from newly cleared forest land for crop production purpose to be 130 t/ha/yr. The Ethiopian Highland Reclamation Study (EHRS) estimated a gross average loss of 35 tones/ha/yr or some 1 900 million tons of soil per year from the highlands as a whole. Of this, 80% was estimated to come from the croplands, or about 130 tons per hectare of cropland per year.

Then, he concluded the presentation stating that the study demonstrated the effectiveness of the Remote Sensing and GIS technologies in assessment of the spatial variability of soil erosion hazard and prioritization of micro-watershed for soil conservation works. The outcome of this type of studies not only necessary but also a vital concern to achieve sustainable land management for decision makers to guard against land degradation and for future development projects in the study area. Finally, it can be said that remote sensing and GIS in combination with USLE model can be used as appropriate tools for micro-watershed prioritization.

Finally, he put his recommendations as follows: Since protecting and conserving the entire watershed is costly, MW1, MW2, MW5, MW27, MW28, and MW29 are prioritized for conservation. 38% of the micro-watersheds in the study area require immediate attention with regard to application of soil conservation practices. The prioritized micro watersheds are found at the pick of Choke Mountain and at the foot of Muga River.

3. Poverty and Inequality Impacts of Agricultural Water Management Technologies in Ethiopia

Fitsum Hagos, Jayasingne, Gayathri, Awulachew S.B. and Loulseged,M

The next presenter, Dr. Fitsum, delivered his presentation on *'Poverty and inequality impacts of Agricultural Water Management Technologies in Ethiopia'*. He said that farmers in rural Ethiopia live in a shock-prone environment. The major source of shock is considered to be the persistent fluctuation in the amount and distribution of rainfall. The dependence on rainfall increases farmers' vulnerability to shocks while also constraining farmers' decision to use yield-enhancing modern inputs. This exacerbates household's vulnerability to poverty and food insecurity. As a response, the government of Ethiopia has embarked on massive investment in low cost agricultural water management technologies (AWMTs). Despite these huge investments, their impact remains hardly understood.

He then stated the objective of the study, which includes inventory of Agricultural Water Management Technologies and Practices in Ethiopia and assessment of the poverty impacts of most promising technologies. He further said that the main focus of the study was to explore whether adoption of selected AWMTs has led to significant reduction in poverty and inequality and if they did identify which technologies have higher impacts.

Then he briefed the audience on the methodologies followed to explore the impact of adoption on poverty: mean separation tests, propensity score matching and poverty analysis are the approaches employed in the study, Dr Fitsum said. And a unique dataset from a representative sample of 1517 households from 29 kebeles in four regions of Ethiopia used in the study, according to Dr. Fitsum.

He then proceeded on presenting the findings of the study as follows:

There are significantly low poverty levels and lower inequality among users of AWMTs compared to non-users.

There is significant difference between technologies in terms of their poverty impact. Accordingly, deep wells, river diversions, and micro dams are the most promising technologies in terms of reducing poverty. On the other hand in-situ technologies do not seem to significantly contribute to poverty reduction.

The study identified the most important determinants of poverty; which are asset holdings, educational attainment, underutilization of family labor and poor access to services and markets.

Finally, he forwarded the policy implications of the findings in order to enhance the contribution of AWMT to poverty reduction, these are: i) build assets; ii) develop human resources and iii) improve the functioning of labor markets and access to markets (input or output markets). These areas could provide entry points for policy interventions to complement improved access to AWMT in Ethiopia, according to Dr. Fitsum.

Discussion on Session II

Question 1

to Ermias Teferi:

Why did you use the RUSLE model to assess soil loss erosion while there are other models? How do you validate the approach? Do you recommend the approach for the country or the region? We are compromising economies of scale as a result of intervening at micro level. So how do you see loss from scale economies versus micro level watershed development? How can we match your results with international standards and realities?

Answer

I used RUSSEL model because data requirement is not high. It is valid for most of the highlands in East Africa for instance in Eritrea. I used only the 2003 satellite images and my result is towards that year 20 micro-watersheds and all have their own problems. Since it is costly to intervene in all, by prioritizing or ranking on the basis of the severity of the problem one can address the problems. Regarding the validity of my findings, I used FAOs figures as reference, mine ranges within those figures.

Question 2

to Dr. Fitsum Hagos:

Why the marginal contribution of labour to poverty negative? Is the use of the term "technology (ies)" in the presentation an appropriate and correct use of terminology? Instead "technique", "system", "method" might be more appropriate

Answer:

This could be from existing hidden unemployment in both rural and urban areas. We have coefficient for adult male and female labour and they turned out to be negative. But there may be more consumers than producers. Regarding the word "technology", it is just common practice that we use it as Agricultural Water Management Technology and we need to come up with a better terminology. Words of thanks for the concern!

II. Economics of Investment on Land and SLM Technologies

1. Estimating Returns to Soil Conservation Adoption In the Northern Ethiopia Highlands

Menale Kassie, John Pender, Mahmud Yesuf, Gunnar Kohlin, Randy Bulffstone, Elias Mulugeta

In session III, the first presenter, Dr. Menale Kassie, presented a paper on *'Estimating Returns to Soil Conservation Adoption in the Northern Ethiopia Highlands'*. He began the presentation throwing few statements as background: Land degradation in the form of soil erosion and nutrient depletion presents a threat to food security and sustainability of agricultural production in many developing countries. Governments and development agencies have invested substantial resources to promote soil conservation practices as part of an effort to improve environmental conditions and reduce poverty. Despite the efforts made, the adoption and adaptation of soil and water conservation practices were limited. And posed a question, why we have limited success?

He then presented the primary objective of the study, which was to investigate the impact of stone bund adoption on crop yields using multiple plot observations per household in low and high rainfall areas of the Ethiopian highlands. And mentioned the difference in his study with other previous studies that is some of previous studies have focused on technology adoption and some others have limitation from methodological view point.

In regard to the methodologies used in the study, Dr. Menale said that they have used modified random effects models, stochastic dominance analysis (SDA) and matching methods to ensure robustness. The parametric regression and SDA estimates are based on matched observations obtained from nearest neighbour matching using propensity score estimates. This is important, because conventional regression and SDA estimates are obtained without ensuring that there actually exist comparable conserved and non-conserved plots on the distribution of covariates. They used matching methods, random effects and Mundlak's approach to control for selection and endogeneity bias that may arise due to correlation of unobserved heterogeneity and observed explanatory variables. And he further said that the new thing in program/treatment evaluation or technology adoption you have to make sure that your observations are comparable.

The data used for the study are from a farm survey conducted in 1999 and 2000 in the Tigray and Amhara regions of Ethiopia. Plots analyzed were located above 1500 meters. The Amhara region dataset includes 435 farm households, 98 villages, 49 *kebeles* and about 1365 plots after deleting missing observations for some variables, while the Tigray dataset include 500 farm households, 100 villages, 50 *kebeles* and 965 plots after deleting missing observations. Using the nearest neighbor matching method based on propensity scores estimates and Mundlak's approach, we are left with a sample of 382 (232 conserved and 150 non-conserved plots) and 573 (390 conserved and 183 non-conserved plots) plots in the Amhara and Tigray region, respectively. Without using Mundlak's approach we are left with a sample of 391 (232 conserved and 159 non-conserved plots) and 590 (390 conserved and 190 non-conserved plots) plots in the Amhara and Tigray region, respectively. Having said this, he described important variables used in the estimation of the model.

According to Dr. Menale, the estimates from the three methods employed in their study tell a consistent story. Stone bunds have a positive and statistically significant productivity impact in low rainfall areas. For instance, the results from propensity score estimates show the existence of a crop value premium of ETB 412 (US$ 59) for conserved plots compared to non-conserved plots in low rainfall areas (Tigray region) of the Ethiopian highlands. This is the opportunity cost of not conserving plots, which is a significant amount of money compared to the average value of crop production in the Tigray highlands, which averaged ETB 1614 per hectare in the survey sample. This yield effect is not observed in high rainfall areas, he added, suggesting that the productivity impact of stone bunds is agro-ecology specific. Then he uttered out the policy implication of the findings which is the importance of developing and disseminating soil conservation technologies that are appropriately tailored to agro-ecological zones instead of making blanket recommendations that promote similar conservation measures to all farmers.

2. The Impact of Compost Use on Crop Yields in Tigrai, Ethiopia, 2000-2006 inclusive

Sue Edwards, Arefayne Asmelash, Hailu Araya, and Tewolde Berhan Gebreegziabher

The presenter, Sue Edwards, delivered her presentation on The Impact of Compost Use on Crop Yields in Tigray, Ethiopia, 2000-2006 inclusive. She started here presentation by elaborating the history of crop cultivation in Ethiopia. According to here presentations, crop cultivation in Ethiopia has a long history of at least 5000 years (Clark, 1976), and implements for cutting and grinding seed have been found in stone age sites, such as Melka Konture by the Awash River in central Ethiopia, dating back much earlier. Its long history is also reflected in the high agricultural biodiversity, including endemic crops, the best known of which is the cereal teff. The high diversity in crop species and genetic diversity within crops is a reflection of the environmental and cultural diversity of Ethiopia. Many crops, like durum wheat, that are known to have their centres of origin in the fertile crescent of south-west Asia, now have their highest genetic diversity in Ethiopia. The treatment of *Triticum* for the Flora of Ethiopia and Eritrea recognizes a highly variable endemic species, *T. aethiopicum*, which is more usually considered as a subspecies or variety of *T. durum*. Now over 100 plant species used as crops in Ethiopia have been identified. European travellers including Poncet (1967), who visited Ethiopia between 1698 and 1700, described their experience with the words, "no country whatever better peopled nor more fertile than Aethiopia". They described even the mountains they saw as all well cultivated "but all very delightful and covered with trees".

According to Sue, despite the above past realities, Ethiopia since 1974 has been portrayed as a food deficit country with its people and animals suffering from drought and famine. In January 2002, over 5 million people were identified as being food insecure, and this number had risen to around 14 million by the end of the year because of the failure of the rains in much of the eastern parts of the country.

She further explained how the political process and the centralized system of administration that Ethiopia adopted since the second half of the 19^{th} century systematically destroyed local community governance. Loss of local governance undermined local natural resource management with loss of protection of woody vegetation, lack of repair of old terraces, and general undermining of any attempts at communal management of natural resources. The feudal landlord system was maintained with the bulk of the population existing as serfs. As Ethiopia entered into the world market, these landlords mined the land resources with nothing going back to the land. Civil war exacerbated these impacts. There were no inputs in technologies or ideas to help these small holder farmers improve their productivity. They had to continue to rely for their survival on their indigenous knowledge and the rich agricultural biodiversity that they had developed, but were unable to continue effectively using collectively for fear of political reprisal. The most visible physical impacts have been gully formation eating away the soil with vegetation recovery prevented by free-range grazing and the unregulated felling of trees for firewood and other purposes.

Under the military government, after 1974, there were massive efforts at land rehabilitation through mass mobilization for soil and water conservation, planting of tree seedlings, and the provision of external inputs through cooperatives. However, administration remained centralized and coercive—overall productivity did not increase. The farmers continued to be ordered about and exploited as had been done under the over-centralized feudal regime. There were also frequent and disruptive redistributions of land. The farmers had no possibility for taking collective decisions on natural resources management and no interest or incentives to invest in improving their land.

Then she briefed the audience about the existing governance system and the emphasis given for new agricultural technologies. A new constitution that required decentralization of power and encouraged local community governance was adopted in 1995. In 1993, the Sasakawa-Global 2000 approach was launched to provide high external inputs—principally chemical fertilizer—to farmers. As from 1995, this program was taken up by the National Extension Program of the Ministry of Agriculture and Rural Development. At the beginning, fertilizer cost was subsidized, but as from 1998, the subsidy has been removed and the local price of diammonium phosphate (DAP) and urea, the chemical fertilizers used in Ethiopia, has doubled. Overall grain production in the country as a whole has increased each year since 1998. However, this has not benefited the people living in the drought prone areas of the northeast and east, who continue to depend on aid. These people have become chronically food insecure requiring annual inputs of aid as food. Whilst this food may save lives, it does not and cannot replenish productive assets that would enable people to reduce their poverty. *According to the presenter, i*t was in line with that, in 1995, the Institute for Sustainable Development (ISD) developed a project to work with local farming communities of small holder farmers in Tigray using an ecological, low external input approach.

She proceeded on presenting the objective of the ISD project and the methods and the finding of the study. The objective of the project was to find out if an ecological approach could help restore soil fertility and raise crop yields, particularly for farmers in degraded areas. Hence, starting from 2000, yields have been taken from plots in farmers' fields in 19 communities in 8 of the 53 weredas of Tigray Region. The majority of the communities (17) are found in the drought prone areas: Alamata of the Southern Zone (2 communities), and all parts of the Eastern (6 communities) and Central (9 communities) Zones of Tigray. The soils of these areas are generally poor and the rainfall is erratic. However, 2 communities are found in better endowed areas: Adi Abo Mossa in the valley of Lake Hashenge of Southern Tigray where the soils are deep, rainfall more reliable and some farmers have larger cultivated areas and large herds of cattle, and Adi Aw'ala in Western Tigray where the rainy season is generally 2-4 weeks longer than the rest of the Region. Adi Abo Mossa was included in the project because of a concern that increased use of chemical fertilizer could lead to eutrophication of Lake Hashenge.

The fields for taking the yield samples were selected with the farmers and chosen to represent the most widely grown crops, each of which had been grown with compost, or with chemical fertilizer, or without any input (the check). The amount of compost applied ranged from the equivalent of 5 to 15 tonnes per hectare. It was assumed that farmers had applied the recommended rates of urea and DAP, i.e. 120 kg/ha. The method used to collect the yield data, according to the presenter, was based on the crop sampling system of FAO. Three one-metre square plots were harvested from each field to reflect the range of conditions of the crop. The harvested crop was then threshed and the grain and straw were weighed separately. For comparison, all yields were converted into kg/ha.

Finally, she presented the findings and conclusion of the study. Data for 9 crops were subjected to linear regression analysis by treatment based on the values obtained from fields where compost was applied, chemical fertilizer (DAP and urea) was applied and no input (check) was applied. The null hypothesis used was that the treatments have no impact on the yields. The probability that this null hypothesis could explain the results was found to be less than 0.05. In other words, the confidence limit was found to be above 95 percent. The increase in grain yields in fields where chemical fertilizer was applied was significantly higher (95% confidence limit) than in the fields where no input (check) was applied, and the grain yields in fields where compost was applied were also significantly higher (95% confidence limit) than in the fields where chemical fertilizer was applied. The significance in the differences among the straw yields for each treatment was similar. The differences among treatments in the yields of each of the crops were also similarly significant. The results show that compost not only increases the overall biomass yield, but also increases the proportion of the grain to straw in the yield. The most striking crop is field pea where the proportion of grain in the total yield exceeded 50% for both the check and the compost treatment, but the field pea 'check' was probably grown in fields that had received compost in previous years. For all the other crops, the proportion of grain in the total harvested yield ranged from 28% for hanfets to 35% for sorghum in check fields, from 28% for hanfets to 43% for maize in fields treated with compost and from 32% for finger millet and teff to 43% for maize in fields where chemical fertilizer had been applied.

3. A Sustainable Strategy in Parthenuim Weed Management in the Alamata-Mehoni Lowlands of Southern Tigrai

Hailu Araya, Arefaine Asmelash and Sue Edwards

4. Sustainable Land Management: Identifying Best Practices

Sintayoh Fisseha

The third presenter, Dr. Sentayoh, begun here presentation saying that in everywhere and especially in the developing countries land is a primary means of production, to the country economy, and generate a livelihood for large proportion of the population. Accordingly, land issues in developing countries in general, and in Ethiopia in particular is becoming a central focus and a concern of many scholars and policy makers.

Then she went on stating that land question of 1960s in Ethiopia resulted in exploitation of peasants by a few landlords and the ruling aristocrats came to an end in 1975, which nationalized all land and provided usufruct right to the farming population. Similarly the EPRDF government that took power from the Derg, has also maintained the land holding system as it was. But to avoid the previous limitations the current government has introduced certain modification on the problems related to efficiency, tenure insecurity, reducing farm size focusing on the agricultural productivity through provision of some agricultural packages. However, despite all these efforts the problem faced by the rural community and agriculturalists still persists, and current land policy is becoming a debatable issue.

She told the participants that up to now the arguments are revolving around two main streams. While some tried to stick to the political and economic passion, support the present land holding system (public ownership) presuming that the existing land policy is a special precondition to maintain sustainable land management procedure and have rural social security. The second groups are criticizers of the existing land policy stating: the present land holding system and its impact on economic, environment, social and political process remains negligible- instead it lead to unsustainable use of resources

Having said this, she stated the main focuses of this paper as it is to examine different land management practices, and identify the best sustainable land management procedures and technologies used mainly by smallholder farmers either in the high potential and/or food insecure areas but are increasingly becoming vulnerable to land degradation and food insecurity. Therefore, understanding/examining of how different land management practices tend to lead to different evolution or intensification processes as well as which factor (economic, social, environmental, etc) have been most critical in enabling some communities and farmers to prosper is necessary. In this paper the term sustainable land management systems refers to striking the challenges, and maintaining an appropriate balance between land use and conservation that ensures increasing of income and better well being of the rural community. Hence the intuition of the paper is to come up with approaches that are regarded as important to help the region, and the community so as to develop coherent sustainable land management procedures, policies and actions that contribute to efficient and socially desirable method, enhancing the positive and mitigating the negative effects of different methods of land use or management practices.

She proceeded on presenting her findings. Particularly development packages related to Mixed farming and participation in agroforestry are proved to be very effective to improve individual's wellbeing and sustainable use of land resource. These development strategies (packages) have encouraged farmers to spend much of their time on their land, and increase competition among themselves. This assures how effective government support and introduction of development programs according to the choice and priority need of farmers has allowed to the increasing of their income and the development of a conservation culture. Conservation of soil and forest has become a high profile activity of the farmers and has played a crucial role on the land resource management. Hence to achieve sustainable development any development program should follow a holistic approaches and needs to a long term perspective with a strong focus on public education.

Finally she concluded that from the reviews and observations, following win-win strategies are the best way of managing resource that guarantees sustainable resource utilization and environmental protection - using of resources in ways that does not affect its long run economic, social, and environmental implication. This is supposed to be realized by the ability to draw all stakeholders: government, none-government and civil community organizations to participate in environment protection (effective and cost-less) through implementation of action oriented environmental protection and rehabilitation programs.

Discussion on Session III

Question 1

to Sue Edwards:

According to your presentation, yield response is higher to compost use than fertilizer use. Is it possible to say that compost use can result on more yields without taking other factors such as rainfall, differences in soil, etc. into account?

Question 2

to Dr. Sentayoh:

What gaps do you sense in your review on tenure security? Can we avoid the damage to the environment if we follow resettlement strategies? It seems that we have to cut trees to settle people who are relocated from their home.

Answer 1

Sue Edwards:

It may be difficult since lots of farmers are using compost and fertilizer at the same time; and fertilizer use also is increasing. And in general, agricultural output in the region is increasing. But what we did was to observe a random sample of farmers and our result shows that 25% of farmers who use only compost have registered higher increase in productivity.

Answer 2

Dr Sintayoh:

The way issue of tenure security handled in Ethiopian in general is not good. Besides, urban land distribution that range from $500m^2$ to $175m^2$ also does not seem well planned. Urbanization is sign of development, but it should not be at the expense of agriculture and SLM. In general, land policy in Ethiopia is neither pro-private nor pro-government ownership. One can not completely avoid environmental damage due to resettlement and other interventions as far as one is relocating people, but it is possible to minimize the damage as far as one controls the greed of the settlers to have large area via several mechanisms.

Question 3

to Dr Menale:

How can premium co-exist with wrongly built soil conservation methods? What are the social resistances that you face when implementing the project? How does productivity vary with intensity of soil conservation structure? Have you measured that?

Answer 3:

We did not calculate the cost because farmers can do that during the slack season. If the technology is profitable, it is less likely for farmers to dismantle it and resist implementation. We did not measure the impact of intensity of soil conservation structure on difference in productivity. But it could be a point for further research.

Question 4

to Sue Edwards:

What is the cost of making compost? Can we really talk about up scaling without weighing the cost and the benefit? What could be the challenges for up scaling compost use?

Answer:

The cost of preparing compost is 370 Birr/ha. One can compare this with the cost of chemical fertilizer 790 birr per hectare. Definitely, one should not attempt scaling up with out analysing the cost and benefits. And if you compare the costs and benefits, compost is more beneficial and less costly since you have sufficient biomass regardless of the time; and compost is better in dry season compared to chemical fertilizer but with a few challenges in scaling up. The biggest challenge is Water. This can be approached via animal and human urine (that contains nitrogen and water). Other challenges is are provision of training on compost preparation (people are not willing to put in their hand to prepare the compost), turnover of the extension services that are trained in compos preparation, additional training requests for each new extension services and lack of practical training (they train theoretically). A solution for some of this can be to train farmers as farmer trainers.

Question 5

to Sue Edwards:

Does compost preparation compromise household fuel consumption? If yes, is it your strong recommendation to be implemented or practiced? What is the opportunity cost for farmers?

Answer:

It does not compromising fuels consumption of households. The resource (inputs) are scattered and lot of it not utilized. Compost is prepared after the middle of September (farmer's slack period), so there no significant opportunity cost to farmers.

Few comments on the session by participants:

I kindly request presenters to minimize jargons (technical terms) – and I suggest that while using jargons they should indicate (show) relatively communicable equivalent term in parenthesis.

Future research and policy agenda:

- ❖ The interface between Urban and Rural as a process of transformation – crop production, urban agriculture and urban settlement. These need more studies than romanticizing agriculture.
- ❖ The issues related to what is the best effective, efficient and sustainable land and water management are also issues that pre-occupied us for more than 30 years. The question is if the minister of agriculture and those involved in designing policies related to such issues were here, what are the best policies that they should adopt in order to ensure success and sustainable land management. Academicians and researchers can continue to provide us different options but policy makers need to decide and find solutions to concrete problems. So the question is what is the best way forward from the point of view of adopting the right policy? On diversity of research output (options) versus policy making.
- ❖ What is the cost of compost? The Cost Benefit Analysis of compost can be another future research area.

III. Biodiversity, Productivity and Risk

1. Agro-Ecosystem Productivity in Developing countries: The Economics of Crop Bio-diversity in the Highlands of Ethiopia

Jean-Paul Chavas and Salvatore Di Falco

The presenter started discussing the background of the study, problem statement and significance of the study. Then he proceeded on presenting the data issues, reviewed past studies, and stated the objective of the study and methodology of the study. Finally, he presented the findings and concluded the presentation stating the main conclusions and recommendations of the study.

According to Mr. Salvatore, the objective of the study is to develop a general analysis of the productive value of crop biodiversity, with an application to an agro-ecosystem in the region of

Tigrai, in the highlands of Ethiopia. As the rest of Ethiopia, Tigrai has one of the highest rates of soil nutrient depletion in Sub-Saharan Africa (Grepperud, 1996; FAO, 2001). This coupled with harsh climatic conditions has contributed to harvest failure and famine. Indeed, during the last millennia, at least 25 severe drought periods were recorded, and crop production in most areas "never topped subsistence levels" (REST and Noragric, 1995 P. 137). The paper investigates the value of biodiversity as it relates to the productive value of services provided by an ecosystem. It analyzes how the value of an ecosystem can be "greater than the sum of its parts." First, it proposes a general measure of the value of biodiversity. Second, this measure is decomposed into four components, reflecting the role of complementarity, scale, convexity and catalytic effects. This provides new information on the sources and determinants of biodiversity value. Third, the methodology is applied to analyze the productive value of diversity of an agroecosystem in the Highlands of Ethiopia. The analysis provides estimates of the value of diversity and its components.

He went on presenting the methodology of the study. Hence the analysis develops a methodology to measure the productive value of biodiversity. The technology underlying ecosystem functioning is represented by a multi-output production function which is used to characterize the value of biodiversity. The methodology applies under general conditions, allowing for non-convexity, and lack of free-disposal in environmental goods. First, we propose a general measure of the value of biodiversity. While not relying on a fixed index, the proposed measure captures how the value of an ecosystem can be "greater than the sum of its parts." Second, we show that the value of diversity can be decomposed into four additive parts: one associated with complementarity, one with scale effects, one with convexity effects, and one with catalytic effects. This provides new information on the sources and determinants of biodiversity value. The analysis provides estimates of the value of diversity and its components. Applied to farm survey data from the Highlands of Ethiopia, the value of diversity is estimated to be positive. The complementarity component is found to be large and statistically significant. This provides evidence that complementarity provides the main source of biodiversity value in this agroecosystem of Ethiopia. However, the convexity component is negative. This shows that nonconvexity contributes to reducing the value of biodiversity.

He further presented the fndings of his study. Accordingly, results show that the value of crop diversity is positive. The complementarity effect was found to positive and significant at the 5 percent level. In the context of the Ethiopian agroecosystem, this provides evidence that each crop tends to stimulate the marginal productivity of other crops. The complementarity effect is estimated to generate a 9.3 percent increase in productivity. Thus, our analysis shows that complementarity provides a positive and significant contribution to the productive value of crop diversity in the Ethiopian agroecosystem. We also found evidence that the convexity component of diversity value is negative and statistically significant. This corresponds to a technology that is not convex, i.e. where marginal products of outputs are not diminishing. This means that the convexity component provides an incentive to specialize. In general, the (negative) convexity component is dominated by the (positive) complementarity component, generating a positive overall value of diversity. However, as these two terms tend to cancel each other, our estimate of the overall value of diversity is not statistically significant. Our empirical analysis did not find statistical evidence that either the scale effect or the catalytic effect played a significant role in the value of biodiversity. The lack of evidence of a scale effect means that farm size does not have a large impact on the functioning of the agroecosystem in Ethiopia. However, our empirical results did suggest that both complementarity effects and convexity effects may increase with farm size. While our investigation focused on the productive value of agro-biodiversity, we should note that this value is only a part of the total value of an ecosystem.

Finally he concluded that the findings indicate the need to place the analysis in the broader context of ecological-economic interactions. This would include the value of biodiversity to consumers. Under uncertainty, this means examining the role of risk preferences and their implications for the design and implementation of risk management schemes. And in a dynamic context, this would include addressing the issue of how new information that becomes available over time is used in ecosystem management. Finally, while our analysis of an Ethiopian agroecosystem illustrated the usefulness of our approach to biodiversity valuation, we should keep in mind that our empirical findings may not apply to alternative ecosystems. There is a need for additional empirical investigations of the productivity implications of ecosystem functioning. These appear to be good topics for future research.

2. Sustainable Biodiversity Conservation For Improved Land Management in Ethiopia: Five Decade Analysis

Frew Mekbib

Mr. Frew, begun his presentation by defining the concept of SLM. According to World bank (2006), Frew said, SLM is defined as a knowledge-based procedure that helps integrate land, water, biodiversity, and environmental management (including input and output externalities) to meet rising food and fiber demands while sustaining ecosystem services and livelihoods. After defining SLM, he talked on the reason behind dealing with SLM. SLM is needed for three major reasons, according to Frew:

1. Adequately supply safe, nutritious, and sufficient food for the world's growing population.
2. Significantly reduce rural poverty by sustaining the farming-derived component of rural household incomes.
3. Reduce and reverse natural resource degradation, especially that of land.

He further presented the challenges of SLM as below:

- At the global level, a large area of formerly productive land has been rendered unproductive.
- The potentially deleterious effects of global climate change and natural catastrophes (earthquakes, tsunamis, hurricanes, and volcanic activity) on land resources are proving difficult to anticipate.
- Misaligned policies and incentives; unclear property rights, especially use rights; and weak enforcement capabilities, often aggravated by corruption and governance problems.
- Its trans-boundary effects.
- Property rights to resources such as land, water, and trees have been found to play a fundamental role at the nexus of poverty reduction, resource management, and environmental management.

Then he mentioned few justifications for SLM

1. Land quality is an important issue for global food supply.
2. Additional cropland will be substantially less.
3. Global supplies of irrigation water will be increasingly constrained.
4. Accessing genetic material from wild relatives and plant breeding are likely to contribute to enhanced food supplies.
5. Climate variability will continue, but neither detract from nor enhance food production possibilities.

6. Property rights—clearly specified, well defined, and enforceable—are quite important in facilitating good resource management directly or via appropriate policies and incentives.
7. Based on previous yield improvements in cereals and reductions in environmental costs of agriculture, and anticipating major breakthroughs in disease resistance and crop yield potentials, food supplies will be adequate to meet demand.

He lastly said that the issue of justifying SLM is easier said than done. And he added it is more important for us, LDCs since the current hotspots of deforestation for subsistence and plantation crops are in LDCs and LDCs agriculture is extensive.

He proceeded on stating the warning given by Millennium Ecosystem Assessment (MEA) and related the issue with MDG target, which is reducing poverty by half by 2015. According to Frew, the MEA warned that approximately 60 percent of the ecosystem supporting life on earth was being degraded or used unsustainably and that the consequences of degradation could grow significantly worse in the next half century (MEA 2005). The typology of poverty is explicitly linked to the environment and the sustainable management of land and natural resources.

Then he said that biodiversity is part and parcel of SLM and it also indicates how sustainably the land is managed, and gave a definition of agro-biodiversity: encompasses the variety and variability of plants, animals, micro-organisms at genetic, species and ecosystem level that are necessary to sustain key functions in the agro-ecosystem, its structure and processes for, and in support of, food production and food security.

Having said this, he stated the problem statement of the study. He said that cereal production accounts the largest allocated area for crop production in the globe. Moreover, globally, more improved varieties with monocultures and biodiversity loss are observed in cereals compared to other crops and it is in the cereal production fields where the largest amount of resources is mined. In addition to this, there is short life cycle which results in the frequent turnover of resources and more disturbance of land. Given this, the main objective of this study focuses on one of the cereal type famous in Eastern Ethiopia, Sorghum, in order to assess on farm genetic erosion (GE) of sorghum.

Methodologically, the study used various approaches, Frew said. He presented the audience that the data was gathered using focused group discussion with 360 farmers, on farm monitoring and participation with 120 farmers, key informant interviews with 60 farmers and development agents, and semi-structured interviews with 250 farmers. In addition to this, he mentioned that he used diversity fairs with over 1200 farmers. The collected data analyzed using various methods; namely, temporal method (comparing 1960 and 2000 collections), area method, and semi-structured interview method at individual, community or *wereda* level and causes of varieties loss from other various perspectives, in fact despite the complexity of assessing GE, he told.

Before presenting the findings of the study, Frew talked on why he focused on Sorghum and showed the participants the varieties of ways local people use in preserving Sorghum and their taxonomy tree. Then he went on presenting the findings.

He said that, farmers perceive GE as the reduced importance of the variety as indicated by lower proportion in the varietal portfolio. *The five most important factors for varietal loss at individual farmers' level were reduced benefit from the varieties, drought, Khat expansion, reduced land size and introduction of other food crops respectively.* The study revealed that GE was not affected by wealth groups and ecological regions. Farmers do not make simple replacement as a strategic mechanism for genetic resources management. According to Frew, GE at regional level was quantified by temporal and spatial method and the finding is there is a complementation not rivalry between Farmer Varieties (FVs) and Improved Varieties (IVs).

He told the participants that the whole process of GE is explained by three models, namely: Bio-eco-geographic enhanced genetic erosion model, Farmer induced genetic erosion model and Farmer-cum-bio-eco-geographic genetic erosion model. He said, my findings reveal that sorghum genetic erosion behaviour is completely different from other food crops such as tetraploid wheat. And the prediction in the late seventies that complete erosion of FVs by IVs by the end of the eighties, the principle of GE that competition between IVs and FVs, favours the former and results in the replacement of the latter is not valid in the context of sorghum in Ethiopia. Hence, maintenance of the on farm genetic diversity of sorghum is a reality but GE is rhetoric, he concluded.

Besides, he presented the important motives behind farmers value for on farm biodiversity like multiple food values, risk aversion (against biotic and abiotic stresses), secondary values (feed, fuel wood, construction), Higher output (yield) or economic gain, a few among others.

He concluded the presentation with the following remarks:

1. Production practices such as no-till production, conservation tillage, or mixed cropping that combines food crops with cover crop legumes and/or tree and shrub species—can greatly facilitate SLM.
2. Enhanced management, improved varieties of crops, and trees can also significantly increase resource use efficiency in agro-ecosystems and plantations and reduced pressure on pristine lands, including primary and healthy secondary forests.
3. Integrated soil, nutrient, crop and water conservation approaches that combine technologies based on biological, chemical, and physical principles.
4. Preventing land degradation is usually far less expensive and more effective than rehabilitating badly degraded lands; the first priority should be to prevent the degradation of currently productive land.
5. Rehabilitate moderately degraded lands and then the severely degraded lands via measures that facilitate the recovery of soil biological communities essential to efficient nutrient conservation and soil physical integrity.
6. Local community and government priorities should take precedence when deciding what needs to be done in any particular location

3. On Genetic Diversity, Farm Productivity and Risk Exposure: Evidence form Barely Production in the Tigrai Region, Ethiopia

Salvatore Di Falco and Jean-Paul Chavas

Discussion on Session IV

Question 1

to Ato Firew:

Study shows farmers maintain genetic biodiversity for many years. Then what is the reason? Can you imagine any threat for the erosion of biodiversity? Why biodiversity matters?

Answer:

There are ecological, geographical, economical reasons for farmers to maintain biodiversity in Eastern Ethiopia. The threats, yes I have a fear: chat is completely replacing crops so in the coming decades it will erode everything. Agricultural incentives in Europe are eroding biodiversity since farmers are forced to shift to selected varieties only. Technology may and may not be a threat. It depends on how it is introduced in the field. In nutshell, there two main reasons why biodiversity matters: *productivity enhancement and risk management*; and farmers use it as a coping strategy against risks.

Question 2

to Salvatore:

Would you please give us more rational information to any genetic erosion from the global perspective; and any relevance of bio-diversity to Nano-technology?

Answer:

At global level, yes there is genetic erosion. In developed countries, there is a focus on selected species and varieties. For Nano-technology: Nano-technology is atomic level engineering of materials used in genetic engineering applied outside of crop and livestock production, but it may have impact on environment.

Question 3

to Salvatore:

1. The complementarities of wheat and barely is acceptable in terms of environmental preferences- how do we explain it in terms of spatial variation.
2. How could we integrate the experience, knowledge or interest of biologist/ genetists since they are looking at within and between varieties/populations?

Answer:

Farmers in a community maintain the community genetic diversity (CGD) or the verities for which they attach inherent value. This is true since improved verities of seed entering or being accessible for farmers do not replace their community genetic diversity (CGD). For integrating knowledge, I am not sure how we do it?

Question 4

to Salvatore:

How to show that biodiversity can be reconciled with the challenge of market uniformity and quantity. Is market dictating farmers or farmers dictating the market? Do you think genetic biodiversity is needed due to missing markets or failing states to maintain biodiversity?

Answer:

Farmers do not have market problems, they know what to sell. The market forces case: markets may derive out diversity and it also may cancel the diversity. Therefore, niche market is required. If market and states fail to maintain crop varieties in long run, the optimal solution is bio-diversity or specialization with improved market.

IV. Tree Planting and Conservation

1. Greening Ethiopia for Food Security

Sue Edwards

The presenter started highlighting background of Ethiopia in terms of population growth of the country, topography, educational coverage, the role of agriculture in the Ethiopian economy, and the number of agricultural development agents being gradated and trained to facilitate farmer and agricultural productivity.

She continued presenting the environmental challenges the country facing. According to her presentations, the Ethiopia faces a number of environmental challenges resulting directly or indirectly from human activities, exacerbated by rapid population growth and the consequent increase in the exploitation of natural resources. The challenges mostly revolve around land degradation due to the removal of self governance by local communities of smallholder farmers starting around the second half of the nineteenth century. Consequently, this left the farmers only able to exercise some control over their land when it was growing a crop and the traditional systems of land management were undermined. The most visible physical impacts have been gully formation eating away the soil with vegetation recovery prevented by free-range grazing and the unregulated felling of trees for firewood and other purposes. The central control of local farming communities continued under the military government (1974-1991) and did nothing to restore farmers' confidence to control their own affairs and invest in their land. The exploitation of natural resources includes burning dung as fuel instead of using it as a soil conditioner. Losses to crop production from burning dung and soil erosion are estimated at over 600 000 tonnes annually, or twice the average yearly requests for food aid. She went on presenting that these negative trends are now being reversed through the present government's emphasis on the decentralization of power down to the wereda and tabia levels. She further stated that Ethiopia has accumulated one of the largest stockpiles of obsolete pesticides in the continent, estimated to be over 3 000 tonnes in 2006, one of the threats to the environment

She further stated that agricultural production is threatened by environmental pollution from chemical applications in state run farms, from the manufacture of industrial products, and outbreaks of migratory pests, particularly Quelea birds, army worm, desert locust, pachnoda beetle and the endemic Wollo bush cricket.

She then proceeded on presenting opportunities of Ethiopian traditional agriculture. According to here, traditional agricultural production is highly diverse and is the main source of food for the population. The high diversity in crop species and genetic diversity within crops is a reflection of the environmental and cultural diversity of Ethiopia and the antiquity of crop cultivation in the country. Two of the main staple crops, the cereal teff and the root crop enset are endemic. In addition, Ethiopia is one of the eight major centres for crop diversity in the world. Other important crops with high genetic diversity in Ethiopia include the cereals—barley finger millet, and sorghum; pulses—faba bean, field pea, chick pea and grass pea; oil crops—linseed, niger seed, safflower and sesame; and root crops—anchote 'Oromo or Wollaita dinich', and yams. Over 100 plant species used as crops in Ethiopia have been identified.

She further, explained emphasise given to organic agriculture by the Ethiopan government. Accordingly, the Environmental Policy of Ethiopia, issued in 1997, has incorporated a basic principle similar to one adopted in organic agriculture: "Ensure that essential ecological processes and life support systems are sustained, biological diversity is preserved and renewable natural resources are used in such a way that their regenerative and productive capabilities are maintained, and, where possible, enhanced...; where this capacity is already impaired to seek through appropriate interventions a restoration of that capability.

She went on presenting that the key elements of the policy. According to here presentation, the policy covers soil husbandry and sustainable agriculture and provide the framework for the development of more specific policies, strategies and regulations for organic agriculture. These include promoting the use of appropriate organic matter and nutrient management for improving soil structure and microbiology; maintaining the traditional integration of crop and animal husbandry in the highlands, and enhancing the role of pastoralists in the lowlands; promoting water conservation; focusing agricultural research and extension on farming and land use systems as a whole, with attention to peculiarities of local conditions and the central role of smallholder farmers; promoting agroforestry/farm forestry; ensuring that potential costs of soil degradation through erosion and pollution are taken into account; maintaining the emphasis in crop breeding on composites and multi-lines to increase adaptability to environmental changes and to better resist pests and diseases; using biological and cultural methods, resistant or tolerant varieties or breeds, and integrated pest and disease management in preference to chemical controls; and applying the precautionary principle in making decisions. This enabling policy context dovetails with a unique experiment in sustainable development and ecological land management conducted with farmers in Tigray and the birth of an organic agriculture movement in the country as a whole. An important feature of the Tigray Project is that it is largely the farmers supported by local wereda-based experts from the BoARD who have led the project. They choose which crops to treat with compost and which with chemical fertilizer.

She then presented the method used to collect the yield data. Data collected based on the crop sampling system developed by FAO to estimate a country's potential harvest and identify threats to local food security. Three one-metre square plots were harvested from each field to reflect the range of conditions of the crop. The harvested crop was then threshed and the grain and straw were weighed separately. For comparison, all yields have been converted into kg/ha in the following table. The fields for taking the yield samples are selected with the farmers and chosen to represent the most widely grown crops. There are three treatments: 'check' means a field which has received neither compost nor chemical fertilizer, although it may have received compost in one or more previous years. 'Compost' is for fields treated with mature compost; the rates of application range from around 5 t/ha in poorly endowed areas, such as the dry Eastern Zone of the Region, to around 15 t/ha in the moister Southern Zone. 'Fertilizer' is for fields treated with the chemicals DAP (diammonium phosphate) and urea. The recommended rates are 100 kg/ha of DAP and 50 kg/ha of urea. The original data were collected community by community and included 13 crops, but here they have been compiled for the four most widely grown cereals and the most important pulse, viz. barley, wheat, maize, teff, and faba bean.

Finally she presented the findings of the study. Compost gives the highest yields for all crops; typically double those of the 'check', and better than those from chemical fertilizer by an average of 30.1 percent (from 17.8 percent for faba bean to 47.4 percent for wheat). Pairwise comparisons (not shown) of treatments for all crops are highly significant (at the 0.1 percent level or better), except for compost versus fertilizer in faba beans, where there are too few observations for treatment with fertilizer. This is hardly surprising as faba bean is a pulse capable of fixing its own nitrogen. Traditionally farmers improve soil fertility for growing faba bean by applying animal manure and ash, but not chemical fertilizer, to the soil. Hence the analysis reported is an independent confirmation of the highly significant impacts of the use of compost on crop yields reported from a linear regression analysis of the same data presented at the FAO International Conference on Organic Agriculture and Food Security.

2. Household Tree Planting in Tigrai: Tree Species, Purposes and Determinants

Zenebe Gebreegziabher & Gebreyohannes Girmay

The presenter started discussing the background of the study, problem statement, and significance of the study. Then he proceeded presenting the role of trees in the livelihoods of rural people and on the environment. Accordingly to him, trees have multiple roles in rural livelihoods and provide significant economic and ecological benefits for poor farmers. For example, by providing the household with wood products that can be converted into cash or used as firewood, planting trees increases household incomes. Planting trees also decreases soil degradation..

He then presented the methodology used in the study and the data issues. He presented that in the study they empirical analyzed the determinants of household tree planting using a unique data set covering cross-section of 200 households from the Tigrai province, northern Ethiopia. Key questions were: What factor(s) enhance the likelihood of involvement in tree planting as well as the extent of tree growing? What are the most important purposes for which households' plant trees? The following lessons or conclusions could be drawn. They investigated two attributes of household tree growing, i.e., a household's decision to grow trees and the extent of tree growing, in an econometrically consistent framework. They used logistic model to determine most important purpose(s) for which households plant trees.

Dr. Zenebe went on presenting the findings of the study. Accordingly, as regards to factors underlying the households' decisions to plant trees and the extent of tree planting, both household characteristics, characteristics of the household head and village level factors were found to be the most important determinants. The findings reveal a clear pattern, that exactly the same factors do underlie the two aspects of tree growing. Moreover, the findings also point to intra-household patterns of resource endowments or allocation such as male versus female labor availability in the household's decision to grow trees as well as the extent of tree growing.

Then he concluded the presentation saying that trees have multiple roles in rural livelihoods and the multiplicity of purposes involved in household tree planting. Finally he noted that most of the trees considered were found to involve diversity of purposes.

3. Conservation and Production Potential of Afforestation Activities in Tigrai

Sara Tewelde-Berhan and Emiru Berhane

The presenter, Mrs Sara, started discussing the background of the study, problem statement and significance of the study. Then she proceeded on presenting the methodology of the study and data issues, reviewed past studies, and stated the objectives of the study.

She continued presenting the seriousness of environmental degradation of Ethiopia and Tigray, and the extent of documentation of the problem in several studies. She then noted that the complex problems of land degradation are partly addressed with the various efforts in afforestation. In line with this the efforts being undertaken in Tigray are impressive and substantial though not satisfactory.

Then she presented the findings of her study stating that the current efforts in afforestation concentrate around private woodlots, area closure, community plantations and hillside distributions. The private woodlots show a high level of biomass gain and survival of seedling however do not cover a substantial land area. The area closures have a good social mobilization impact, economic gains and good success in environmental rehabilitation, however the biomass gains and actual productivity volume is not substantial. The community plantations cover a substantial land mass and show good biomass gains, however do not have a good seedling survival rate. Hill side distribution interventions, though promising also have some room for improvement. She concluded her finding by emphasizing that the interventions combined still fall short in meeting the demand for forest products and fuel wood demands.

In concluding, she went on saying that the overall low survival rates of seedlings planted in the community plantations, the low biomass production of all land use categories, especially that of area closures shows that the efforts underway need to be strengthened through research and management of these natural resource bases that we have. Thus there is need for improved extension services supported by research on mainly fast growing indigenous species with potentials to produce fuel wood, fodder and/or timber

This being the fact, the only way to solve this problem is when all aspects of the land resource are managed properly and sustainably, with substantial efforts being made to meet the day to day needs of the local communities.

Finally, she strongly that more intensified management options need to be laid down and with the full participation of the local communities the management of these communal resources worked out.

Discussion on session V

Question 1

to Sue Edwards:

What is Ethiopia's strategy regarding market for organic products. What initiatives has ISD taken in diffusing organic fertilizer for organic farming? Where is your level of attention?

Answer:

Strategy appropriate for organic market in Ethiopia is: Nitch markets for coffee, honey… There is no market problem for organic products; Ethiopia has huge and sophisticated market in the world. Demand for organic products is growing in the world. However, our interest is on small farmers, we have visited participatory guarantee system in many parts of the world; ISD is exerting pressure on government to complete the legislation on organic market; to start implementing participatory guarantee approach to smallholder farmers. Our approach is not niche market; we want to start at community level. We are working with different stakeholders to materialize these.

Question 2

to Sue Edwards:

Are you aware of the activities of national fertilizer company in Ethiopia? What are you doing to fill the gap of Nitrogen as fertilizer? Do you have strategies to bring NGOs in to the scene?

Answer:

I am aware of the National Organic Fertilizer Company; Compost is bulky, however, in small settlement areas they will not be destructive so that, SG-2000 promotes organic fertilizer. There are NGOs but NGOs are not good in linking each other.

Question 3

to Dr. Zenebe:

How do you see the conflict between the agronomic practices of tree planting versus other cropping practices of farmers? You used the Heckman Model and your variable specification seems to have an endogenity problem. So would you comment on this? What are your views on tenure security and tree planting?

Answer:

It is obvious that tree planting competes with other land use practices. However, tree planting in Tigrai does not conflict with other land use decisions because ++++. So there is no conflict. Endogenity is there but I had no option and I could not get other proxies and left it. Tenure security and policy restriction are assumed as given and I tried to see the impact of other factors in tree planting decision.

Question 4

to Sara:

Development has gone so far, but research is lacking behind. How far have research institutions gone in the supply of tree seedlings for drylands to reverse deforestation?

Answer:

Dryland tree seed management system is non-existent. My view as well as expectation is that agro-forestry sciences address these issues. We (Mekelle University) and other institutions shall conduct research on tree seedlings and seed development. I am not supporter of centralization of tree seedlings.

Question 5

to Sara:

Regarding Eucalyptus, farmers like it because it is fast growing but there are alleged negative environmental impacts. There are opposing views regarding the benefits and negative impacts of the tree. Would you please forward your comments? Researchers feel that area enclosures have opportunity costs to society. What is your standpoint?

Answer:

Eucalyptus is fast growing and has helped the country in filling the imbalance between fuel demand and fuel wood supply. Regarding area enclosure, area enclosures with other forms of interventions can be more productive. For example, hillside under area enclosure can be rich in terms of biomass and productivity; then if biomass production is boosted, the areas can be more productive and overweigh opportunity costs.

Chair H.E Dr. Tewelde-birhan Gebreegziabher:

Until Eucalyptus came, there was serious problem on fuel wood supply. However, the controversy regarding the costs and benefits of the tree is complex. There are some species of Eucalyptus that are good for the environment and others are bad. Researchers are lagging behind. Therefore, multidisciplinary research or discussion is recommended and the results should be presented in a simple manner so that policy makers could act.

V. Land Tenure & Land Investment

1. Implication of Land Titling on Tenure Security and Long-term Land Investment: Case of Kilte Awela'elo wereda, Tigrai, Ethiopia

Dagnew Menan, Fitsum Hagos, Nicck Chsholm

Mr Dagnew began his presentation saying that in Ethiopia in general and in Tigray in particular, land is still the main source of livelihood and investment, for majority of the population. However, studies have indicated that degradation; land fragmentation, tenure insecurity, landlessness etc. have been cause of food insecurity in Ethiopia and the region a well.

Then he went on stating the problem statement of the study. He said, land issue in Africa is much more complex, due to various socio-cultural, institutional, economic, and environmental factors associated to the definition of land tenure security or insecurity than just the presence or absence of private property rights. In the past Ethiopian context, the state-interventions on land were more of redistributive than geared towards one of introducing formal title or individualization (according to (Atakilte, 2001) he added. Moreover, Dagnew said that a study by Binswanger (2003) on the status of land tenure security and land-related investment was undertaken in most regions of Ethiopia, including Tigray. And the study noted that in Ethiopia land tenure appears to be quite insecure and the rights to transfer land permanently or for longer time were severely restricted.

Accordingly, he said, for the benefit of appropriate land policy formulation and implementation in Ethiopia/Tigrai, there is a need for more empirical studies to assess the effectiveness and nature of different land tenure arrangements in solving land tenure constraints in relation to the inherent conditions of regions or farming systems. Hence, this research work has focused on studying the implication of land certification policy institution on farmers' perception of tenure security on the land they own and their subsequent actions on long-term investments on their holding.

He then presented the objective of the study and the research question of the study. Mr Dagnew said that the main intention of the study was to identify and record the changes in perception of farmers on tenure security and the implication of land certification institution issued in the region in 1998-2000 on land investment behaviour. In order to achieve the objective of the study the following research question posed: has land certification policy has been serving its purpose in enhancing ownership security of small farmers and initiating them to undertake long-term investments on their holdings?

Theoretically, he told the participants at least three relationships can be assumed for such a study that relates tenure security through land titling: *decision and enhancement in land investment, regulated transferability of land and role of credit, extension services and market access on land investment.*

In regard to his methodology, he said that he followed a three stage sampling: woreda selection purposively, Tabia/Kushet randomly and household selection based on ownership of land but randomly from list of land registry. And the sampled 135 households were interviewed using structured questionnaire. Besides, he added semi-structured interviews carried out with key informants and focus group discussion carried out to gather additional information. The collected data analyzed using appropriate statistical tools like t—test, Chi-square test and binary logit model estimated to understand behind the likelihood of investment.

Having said this, he presented his findings. He said that the study found that, land investment practices of long-term nature were underway before and after certification in the study tabias; however, the variety, quantity, quality and number of farmers involved in, had significant mean difference especially on fruit tree and shallow wells investment (an overall growth observed by 34.1%, after titling). Moreover, he added, before land certification, the attributes of long-term investments were more of the traditional types promoted through mobilizing communities as compared to the latter being largely of private initiative tending towards income generating and observable shift of interventions towards water based technologies. In addition to this, the study revealed that majority of households surveyed (96.3%) hold use right certificate of their entire holding, while small minority (3.7%) do not have user right certificate due to un-materialized land transfer procedures of family holdings. Moreover, Dagnew told workshop participants that the study found 81% of the households feelin sense of ownership and rated the current system as satisfactory; as opposed to 19% of the households that feel moderate and low insecurity.

Therefore, he said one can conclude that land certification institution contributed in enhancing the sense of relative security and transferability of land rights that provided incentives for long-term land investment decisions in the study areas.

2. Impacts of Low-Cost Land Certification On Investment and Productivity

Stein Holden, Klaus Deininger, Hosa'ena Ghebru

The next presenter of the session was Hosa'ena Hagos, Lecturer department of Economics, Mekelle University and PhD fellow from Norwegian University of Life Sciences (UMB). He told participants that the study is an ongoing research based on 10 yrs collaboration between Mekelle University and UMB.

Having said that, he uttered that issue of land reform is high on the development agenda for several pull and push factors, political and economic justifications. And presented some of the issues in land reform: *are private property rights preconditions for economic development? [China?], does formalisation of land rights enhance economic development? How can land certification (or titling) be made more pro-poor? What kinds of land reforms are appropriate in Africa?*

He briefly presented the evolution of land tenure since 1974, land rental market and land certification in Ethiopia. Then he proceeded presenting the objective of the study, which was *assessing the investment and productivity impacts of the low cost non-freehold land certification implemented in Tigrai.*

According to Hosa'ena, the study used a unique and detailed data set with household and plot panel data from 1998, 2001, and 2006 covering 16 representative communities in 11 districts in the Tigrai region, where certification was implemented first in Ethiopia. The last survey round was eight years after the reform, which in away that enables assessing some of the longer-term impacts of certification, he added.

Next, he presented the hypotheses of the study as follows:

Hypothesis 1: Having a certificate for a farm plot enhances investments on the plot in terms of the building of new conservation structures, the improvement/maintenance of existing conservation structures, and the planting of trees.

Hypothesis 2: Restrictions on tree planting in the land proclamations (especially on eucalyptus) have prevented investment in trees. Therefore, land certification has not stimulated this type of investment and there will be no difference between plots with and without a certificate.

Hypothesis 3: Land certification has enhanced land productivity.

After stating the hypotheses; he discussed the data issues, econometric models employed, and estimation issues and went on presenting the main results of the study.

First, in regard to the effects of land certification on soil conservation investment, he said we found no significant effect. This can possibly be explained from the strong public investments in soil conservation. Second, in regard to the effects of land certification on improvement of conservation structures, he said that the land certification has contributed to better management of soil conservation structures, which is a positive significant effect.

Third, in regard to the effects of land certification on i*nvestment in Trees, it was* found to have positively and significantly contributed to increased investment in trees.

Last, in regard to the effects of land certification on productivity, the study found that land certification has contributed to enhancement of land productivity. The productivity increase due to land certification was estimated to be about 45% based on the conservative estimator employed in the study.

He further said, one can conclude based on the aforementioned findings that the analysis of the low-cost and high-speed land registration and certification program that was implemented in Northern Ethiopia provides evidence that the a low-cost approach has stimulated investment *(maintenance of conservation structures & tree planting)* and *enhanced land productivity* of the poor rural households living in the region

Finally he posed a question (Why has the land certification been so successful?) and talked on possible reasons and future challenges. According to Hosa'ena, some of the future challenges are: emerging landlessness in the most densely populated areas (the population pressure is eroding land as safety net), higher food and energy prices increase the poverty gap (this lead to increasing dependence on food aid and food for work and the related costs), and provision of ladders out of poverty.

He also suggested a future research agenda, that is the land certification may have stimulated use of inputs like manure, fertilizer and improved seeds and this requires further investigation.

3. Certification and Land Investment: The Case of Tigrai Region

Fitsum Hagos

Dr. Fitsum started the presentation by giving a few background and introductory notes. He told the participants that the Tigrai regional land proclamation prohibits further land redistribution. The land registration/certification process in Tigrai started in 1998 and is also done in some other regions like Amhara. He said that land titling or registration is widely believed to improve efficiency of land use and agricultural production by increasing farmers' incentives to adopt new technology, on-farm investment, and soil conservation practices. Towards this end, governments have been engaged in various initiatives to title holdings hoping that titling will boost farmers' sense of security, which, in turn, is expected to encourage investment on erosion-reducing and land quality enhancing technologies. The evidence so far is mixed he added.

Next he presented the intention of the study, which was to explore whether land registration\certification enhanced feeling of security of tenure and thereby induced increased investment on land. He said that the study used a cross sectional data from a representative sample of 437 households collected in 2004/05 from 18 Peasant Associations (Kebeles) in six zones of Tigray region, northern Ethiopia. And in order to analyze the data both mean separation tests and regression analysis (probit and truncated regression models estimated) was used, he told the audience.

Then he went on presenting the results of the study: In regard to land redistribution, he said the study indicated that land registration has enhanced holders' feeling of security as can be evidenced from the survey results where only 39 % of the households believe that there will be future land redistribution. Yet, increasing population growth, increasing landlessness and government land takings posed serious sources of insecurity to users.

In regard to land taking, his study found 26 % of the households reported land takings for various reasons. Though about 50% of the households who lost land have received compensation, the majority thought that the compensation is not fair, his study revealed.

In regard to land registration/certification, Dr. Fitsum presented that his study indicated that about 97% of the plots were registered and the land registration certification processes started in 1998 has been going on till the survey period. He further said that the study revealed that the demarcation process was done both on paper and on ground and it resulted on only few changes in the boundary of the plots.

According to his findings in regard to land transfer right and sense of security: only few perceive that they can either temporarily transfer or temporarily sell their land. And in general about 77 % of the households believe that they feel more secure about their holding rights after certification.

Then he proceeded to presenting the regression results both on probability of investment and intensity of investment. His study indicated that there was significant increase in probability and composition of investments (more profitable investments than the usual soil and water conservation measures) and increased proportion of plots conserved through private initiatives relative to those conserved through public programs.

After discussing the regression results, he concluded his presentation summarizing the main findings and forwarding policy implication of the findings and recommendations as below:

- Growing population, land scarcity and mass of landless people and other internal factors pose important sources of insecurity even in the presence of land use titles. Besides, fear of land takings is also other source of insecurity. However, relative tenure security seems to have been achieved.
- There was significant increase in the likelihood of investment after registration.
- There is no significant difference in the level of investment (length of conservation measures in meters or amount of labor man days) before and after registration. However, some significant changes in some of the conservation investments observed.
- Land registration has a significant effect both on the probability and intensity of investment.
- Initial investment has a strong effect on later investments→ "carry over" effect than title effect!
- Insecurity of tenure (due to expected future land redistribution/land taking) decreased likelihood of investment. And expected future land taking leads to low investments.
- Access to credit, Food-for-Work, labor holdings and education access encourage investments

According to Dr. Fitsum, the most important policy implication of the results is that land registration and titling could induce positive security effects on holdings with positive effect on land investment. But for this to materialize, he recommended:

- Policy makers need to avoid or minimize all sorts of insecurity such as threats of future land redistribution and land taking without proper land compensation.
- Moreover, policy maker should work on certifying the remaining lands for enhanced investment.
- They should also adjust the land policy in a way that accommodates longer period leases for better investment.
- Lastly, efforts should be exerted towards improving the functioning of both credit and labor markets.

Discussion on Session VI

Question 1

to all presenters:

Is there any difference between land registration and land certification and what is its legal implication? What do you understand its implication for investment on land? Many of the presenters said that right of ownership to land is less significant; however ownership right is important for investment and security, then what is your view?

Answer

Dr Fitsum:

Registration refers to registered information about the land with geographic demarcation while certification is getting the title for owning and using the land. Theoretically, a secure ownership is important for investment. The question is how we set up tenure security - private versus public ownership. The assurance and security effect is important for investment but it does not necessarily mean it should be freehold. If farmers are not given long-tem security, the worry is that they might use land for temporary benefits.

Question 2

to Dr Fitsum:

What is the impact of land certification on fertility? I wonder if land certification has impact on birth rate.

Answer:

We have not yet done any research on impact of certification on fertility and birth rates? However, it can be important research topic (area).

Question 3

to Dr Fitsum:

Have you netted out the effect of certification on land investment form the effect of public investment on land productivity? For example, have you controlled the contribution of Development Agents on land productivity?

Answer:

There are various interventions which may affect our result and I did my best to pick only the "private investments". We specifically singled out whether investment was done by public or household. Even though there are the same packages, I observed different households picking different types of investments. It would be reasonable to take several factors controlled in the regression analysis; and it would be a mistake if one does not do that in analysing determinant of an issue.

Question 4:

How about the collateral issue related to land certification? And, have you classified plots having different values (irrigated versus degraded)?

Answer:

There is new land policy that allows land to be used as collateral for investors in Tigrai. I skipped on presenting but I controlled for bio-physical, household and village characteristics. Theoretically, secured tenure has positive impact on using land as collateral. The controversy is on how to assure security – private versus public ownership.

Question 5

to Dr Fitsum:

Is it a choice to invest on sustainable land management than a must?

Answer 4:

Investment is a choice because households choose to invest or not to invest on their land.

Question 6

to Dr. Fitsum:

Is investment the same for households before and after certification; and is there difference on investment after registration?

Answer:

There are contributions of other policies to land investment decision. There were households who have been doing investment before and after certification but there is increased investment after registration. We also see increased investment in water harvesting after registration.

Question 7

to Ato Dagnew and Dr Fitsum:

Are there any contradiction between your analysis and findings?

Answer:

We use difference in sample size and our studies are in different weredas (tabias)

IV. Sustainable Land Management and Livelihood

1. Understanding Farmer's Perception and Determinants of Uses of Sustainable Land Management Practices: the case of Ofla wereda, Southern Tigrai, Ethiopia

Kebede Manjur, Tesfaye Lemma, Alemayehu Gebrehiwot

The first presenter of this session was Kebede Manjur. He started the presentation stating that land degradation problems are particularly severe in the highlands of Tigrai and *Ofla woreda,* one among the six w*oredas* of southern Tigrai zone*,* is not an exception. In recognition of this fact, the regional government of Tigrai has been undertaking massive program of investment in land conservation since 1991. Despite such efforts, little impact has been achieved in promoting productivity enhancing land management practices (LMP). One possible reason for this may be low adoption rate of LMP by farmers. In fact little has been known about how farmers perceive different LMP and the determining factors behind adopting either indigenous or introduced LMP, at least in the study area.

Hence, he said, the study tried to assess farmers' perception of land management practices and identify factors, which determine farmers' decisions on adoption of compost and rough tillage in *Ofla woreda*. In order to achieve the objective of the study, he raised questions like: what is the perception of farmers' about indigenous and introduced land management practices? What are the physical, socio-economic and institutional factors that affect farmers' introduced land management practices adoption decision?

Then, Mr Kebede discussed the methodologies employed in the study. The data was collected using two- stage sampling procedure using simple random sampling; where in the first stage 5 peasant associations (Pas) out of 19 PAs of the woreda selected and in the second stage, 130 household heads out of 8531 of the 5 PAs household heads randomly selected, according to

Kebede. He further added that the data collected analyzed using descriptive statistics and binary logit model specified and estimated.

He told the participants that farmers used different criteria to evaluate the land management practices that include: erosion control, soil fertility improvement, expenditure (or cost), labor requirement, yield, perceived economic advantage and health hazards. Given these considerations, farmers' perception on certain LMP documented and presented as below, according to Kebede:

In regard to *crop rotation,* farmers have positive perception on fertility maintenance, erosion control, increasing productivity, and profitability but negative perception on erosion reduction.

In case of *manure,* farmers held positive perception regarding soil fertility improvement, yield increment, profitability, and erosion protection but are not in favor of manure owing to the labor requirement, and difficulty of transporting.

For *compost,* farmers have positive perception on the attributes of compost regarding soil fertility improvement; yield increment, profitability and erosion protection. Though, they have negative perception due to the difficulty in transportation and expected health hazards.

In regard to fertilizer, farmers held positive perception on the attributes of fertilizer regarding soil fertility improvement, yield increment and profitability but negative perception regarding erosion protection, and indivisibility.

And for Rough tillage, farmers held positive perception on the attributes of RT regarding soil fertility improvement, productivity, profitability and erosion protection. They are not in favor of rough tillage in view of its labor requirement

He further discussed the determinants of adoption of land management practices. He presented that the adoption of compost was positively and significantly influenced by perceived risks of land degradation and water logging. While factors like by female headship of household, tenure arrangement and plot slope negatively affected adoption of compost.

And for the rough tillage adoption, male headship of household, labor availability, size of land holding, membership in farmers' organization, distance of the woreda market from dwelling, perceived risks of land degradation and water logging are positive determinants. While age of the household head and plot slope have a significant and negative influence on the adoption decision of rough tillage.

Finally, Mr. Kebede concluded his presentation saying that the socio-economic, institutional characteristics of the household and environmental risk perception of farmers and physical characteristics of the farm plot are important factors for the adoption of compost and rough tillage in *Ofla woreda*. Thus, he said, in order to enhance the adoption of LMP like compost and rough tillage, concerned parties should consider the following recommendations:

- Inter household and inter plot variation and the importance of farmers' perception should be considered.
- Increasing farmers' awareness of land degradation risk perception enhances adoption of sustainable LMP.
- Extension has to provide to farmers with a basket of sustainable LMP option so as to allow the farmers to select LMP that are most suitable to their specific situations.

A significant number of farmers are not aware of compost. Hence, there is a need to popularize the practices--organizing extension field days and tours for farmers to learn from each other.

2. Rural Household Income Diversification, Poverty and Their Coping Strategies: Asset Base Approaches in Ethiopia: The case from South Eastern Tigrai

Mulubrahan Amare and Kibrom Araya

The presenter, to Ato Muluberhan began his presentation saying that poverty has most commonly been assessed against income or consumption criteria. However, when the poor themselves are asked what poverty means to them, income is only one of a range of aspects which they highlight. Then the dissatisfaction with the income/consumption model gave rise to basic needs perspectives, which go far beyond income, and include the need for basic health and education, clean water and other services, which are required to prevent people from falling into poverty. More recently, poverty has been defined in terms of the absence of basic capabilities to meet these physical needs, but also to achieve goals of participating in the life of the community and influencing decision taking. A sustainable livelihoods (SL) approach draws on this improved understanding of poverty. The framework identifies five types of capital asset, which people can build up and/or draw upon: human, natural, financial, social and physical. These assets constitute livelihood building blocks. To a limited extent they can be substituted for each other.

He further said that all development policy is based implicitly on a conceptualization of why people are poor and what interventions, if any, are needed to facilitate or accelerate their climb out of poverty. But the poor are a heterogeneous lot. Therefore, appropriate interventions may differ fundamentally according to the nature of the target subpopulation's poverty.

And looking into prevailing theories of economic growth and development, the poor enjoy higher marginal returns to productive assets than the rich do, so capital should flow disproportionately to the poor, enabling them to catch up economically. This follows logically from the standard simplifying assumption that there are diminishing marginal returns to assets in production. Moreover, this assumption implies that shocks cause merely temporary setbacks and that everyone enjoys the same latent opportunities. Under the prevailing orthodoxy, all should enjoy economic mobility and persistent poverty should reflect merely a slow climb up from a low initial welfare level.

Tigray is the northern most region of Ethiopia. The region is one of the poorest regions in the Ethiopia and still a predominantly inhabited by rural society, with about 85% of the population living in rural areas. Drought and famine are more frequent in the region. Severe environmental degradation problems, mainly soil erosion, nutrient depletion and moisture stress constrain agricultural production in the region. The mainstay of the economy is agriculture, which is mainly rain-fed, in a region where rainfall is erratic and drought is prevalent. Furthermore, after a period of relative stability during 1991 to 1998, following a prolonged civil war, a war erupted between Ethiopia and Eritrea in May 1998 that ended two years later with serious consequences on household welfare.

He further presented the overall objective of this paper is so as to develop an appropriate conceptual and analytical framework to better understand how prospects for growth and poverty reduction can be stimulated in rural South Eastern Tigray.

Then he presented the data and methodology issues. They employed complementary quantitative and qualitative methods of analysis, driven by an asset-base approach. They focused on household assets (broadly defined to include natural, physical, human, financial, social and location assets) and their combinations necessary to take advantage of economic opportunities. The paper examines the relative contribution of these assets, and identifies the combinations of productive, social, and location-specific assets that matter most to raise incomes and take advantage of prospectus for poverty-reducing and over all economic growth.

Factor and cluster analysis techniques are used to identify different livelihood strategies along with the basic coping strategies practiced and econometric analysis is used to investigate the determinants of different livelihood strategies and the major factors that affect well being.

He then presented the findings and recommendations of the study. The research resulted in five key findings with important strategic implications. First, there exists significant heterogeneity of rural areas in South Eastern Tigray in terms of their asset endowments which affect the choice of livelihood strategies and wellbeing of households differently. Second, Poverty in general and drought in particular is widespread and deep in rural South Eastern Tigray which calls for the application of the different coping strategies and adaptive strategies. Third, agriculture should form an integral part of the rural growth strategy in South Eastern Tigray, but its erratic nature contributes for the potential limitation of the economy, which in turn invites policy intervention. Over the last many centuries, agriculture has been serving as main source of income for rural society of Ethiopia particularly in rural Tigray, though not satisfactory. This implies that high reliance of rural households on agricultural and related income means that any strategy targeted to these areas will have to build upon the economic base created by agriculture. Even though agriculture alone cannot solve the rural poverty problem, those remaining in the sector need to be more efficient, productive and competitive. Fourth, there is a need to move from geographically untargeted investments in single assets to a more integrated and geographically based approach of asset enhancement with proper complementarities. A multicultural investment program is required to upgrade and improve access to household assets, with proper and more explicit complementarities as asset holding is found to be a basic determinant for both choice of livelihood strategy and household well being. Asset investment programs need to be adapted according to the specific needs of regions and households. While some household assets programs should be national in nature, others require more local adaptation and must be carried out in tandem, according to specific needs of regions and households. Investment strategies should be formulated on broad regional bases, but options within regions should be modified to local asset bases.

3. Institutions and Sustainable Land Use: the Case of Forest and Grazing Lands In Northern Ethiopia

Zenebe Gebreegziabher

Land is an essential factor of production for agriculture, horticulture, forestry as well as other land related activities. In many developing countries, inefficient use or exploitation of land reduces the amount of resource rent that can be collected, while lowering available future resource rents as land resources degrade over time in suboptimal fashion. This is quite true in Ethiopia too where degradation of forest and grazing lands is a major problem. In general, the problem seems to have more to do with population pressure, market and government failure. But more importantly, the absence or ineffectiveness of institutions in terms of use regulations of the land resources also resulted in severe degradation. Land in Ethiopia is publicly owned. Except for trees that fall in private backyards and farmlands forests/trees and grazing lands remain largely free access resources. Natural forests and grazing lands were found to be the major sources of freely collected fuels while the private sources constituting a lesser proportion.

Under such an institutional setting or an unrestricted access condition agents would maximize benefits by putting effort to the extent that total cost is equal to total revenue, instead of marginal cost being equal to marginal revenue. Apparently, no agent will have an incentive to delay harvest, as doing so would only enhance the harvest opportunities of others. The outcome is excess depletion and dissipation of the resource rent. Therefore, it would indeed be of public interest to alter this situation.

An interesting question in here is how would a public policy aiming at altering the status quo affect welfare of private agents? What would be an optimal one or worth doing in terms of addressing the problem?

He went on presenting the objective of the study and said that the purpose of the study is to examine the potential of the policy of assigning an alternative institutional setting, i.e., private property institution, using a unique data set covering 200 cross-section households in Tigrai province, northern Ethiopia. More specifically, the paper examines the welfare effects of change in institutional setting to forest and grazing lands. Such a change in institutional setting could be envisaged to counter the dissipation of the resource rent and hence the degradation of agricultural and forest lands.

He further presented the data set used, methodology and findings of the study. The current study examine the welfare effects (from consumer perspective) of change in institutional setting to forest and grazing lands using a unique data set covering 200 cross-section households in Tigrai, Northern Ethiopia. Methodologically, the research numerically analyzed the effects on the agent's well being of the policy of enforcing private property institution under three alternative scenarios: first, price of dung changes while wood price is held unchanged; second, price of wood changes and price of dung held unchanged; and, three, simultaneous change in both prices. Because we cannot determine a priori the extent to which the change in policy increases prices, we considered three different price levels. Albeit simplifying assumptions, our findings reveal that privatization of the currently public/common pool resources such as forest and grazing lands/dung might indeed be welfare reducing. The findings hold be it an independent price (policy) change in one good or simultaneous price (policy) change in both goods, for different price levels. The loss in well being is some 14.00 to 56.00 Ethiopian Birr, or 10 to 40% of household average monthly incomes. Given the magnitude of the estimated loss, it is little wonder the government is reluctant to impose a private property institution on Ethiopia, despite continued land degradation and dissipation of the resource rent.

Discussion on Session VII

Question 1

to Kebede:

It is true that it has health impact (locally known as '*mech*'). The solution is to do it in the evening.

Answer:

Yes I agree on the solution.

Question 2

to Mulubirhan:

On coping strategies, the last is casual work and migration but it is doubtful for me since it is top rated in some other empirical works.

Answer:

It is rated as the last in our empirical finding (causal and migration is last). This is empirical research we conducted and farmers ranked their coping strategies as what has been presented.

Question 3

to Mulubirhan:

Incomes from different strategies are complementary in your finding, what is the justification behind your contradictory result?

Answer:

Because it is fact that there are complementarities among on farm and off-farm activities.

Future Research Questions:

VII. General Discussion on Three Themes

The chair of the session, Dr. Menale invited Dr. Fitsum to brief on the group discussion and forward the questions for discussion groups.

Dr. Fitsum, thanked the chair of the session and said that last evening we discussed and identified 3 themes to be discussed by groups. The themes and the chairs of each discussion group were as follows:

Group1: Land Water (in land mgt perspective)-H.E. Dr. Teweldebirhan

Group 2: Bio-diversity (in land mgt perspective) - Dr. Salvatori

Group 3: Socio-economics and policy issues (in land mgt perspective)-Dr. Fitsum

He told the workshop participants that each group should raise the following questions for discussion:

Questions for Discussions

1. Identify the research work done so far? What are the major research findings?
2. Identify the major research gaps in the area?
3. How to improve research-policy linkages? What is expected of the researcher? What is expected of the policy maker?
4. What steps forward in institutionalizing research-policy linkages?

Presentation by group discussion reporters:

Chair Dr. Yohannes

I. Land and Water

The chair of the Land and Water theme presented the following points after discussing in group.

What's done so far? What are the major findings? What are the research gaps?

- There is some research on LWM. But much of it out of-date (e.g. state of LD) and it is not comprehensive.
- There is a need for an inventory of research done land and water management.
- We need an inventory of the traditional indigenous knowledge and techniques on land and water management.

- We need an inventory of local community innovations on LWM.
- There is a need to match soil conditions and geological diversity (which is enormous in Tigray) to understand variations in soil fertility and thus recommendations for SLM.

Improving Research-Policy Linkages and Steps Forward in Institutionalizing…

Challenges:

- Most research is not problem oriented.
- Influencing policy and bringing positive impacts is seldom the priority of researchers.
- Researchers fail to involve major stakeholders (policy makers and farmers) in the research process. In addition, they seldom share their results to the stakeholders.
- Therefore, there is a need to create a forum where these limitations can be avoided and research can be made relevant, and reach policy makers efficiently.
- Such a forum can only be successful if there is compatibility of incentives and the research done, especially on the side of researchers.
- In order such a forum to work, research institutions and universities should work hard to channel incentives so that researchers do policy relevant research and communicate their output with policy makers in ways they clearly understand (e.g. preparations of short policy briefs).
- Relevance of researchers should be based on the usefulness of their research output.
- There is also a need to use modern communication tools like the internet to keep an up-to-date inventory of completed and ongoing research.

II Bio-diversity

What has been done so far?

- Flora has been completed (Institute for biodiversity conservation, ILRI)
- Small ruminants – some work.
- Animal domestic resources.
- Wild animals/ mammals/birds.
- Endangered species (red fox) – difficult to know for those outside parks.
- ddis Ababa University identified landraces and classified for their drought tolerance + DCG – impact of improved species to income in Sorghum (significant impact on farmers income)
- Morphological and molecular diversity on small ruminants
- Soil biodiversity (biota) – invertebrates: we do not know.
- Production pest resistance/animal production.
- Response of crops to different irrigation systems.
- Forest biodiversity: work on introduction of exotic species. Indigenous species (roughly 20) + forest gene banks.
- There are study on one specific species
- Landraces (IBC did some work but missing info of biodiversity in Tigray)
- Evidence of positive correlation between biodiversity and productivity and risk for some selected crops.

Gaps

- Ecosystem approach
- Biodiversity as related to indigenous knowledge.
- The role of women – they are seed keepers, plant rotations
- Farmers management – how it is affected by extension (is it getting more dependent?)
- Special varieties – niche markets.
- Some crops/ trees/medical plants.
- Resistance to biotic stress (invasive species/ new weeds). Keystone species.
- Afforestation – trees.
- Climatic change and its impact on biodiversity
- Wildlife, flora, traditional plants (secretive nature of indigenous knowledge. lack of knowledge from medical sciences – research is needed to bring the knowledge).
- Habitats. Wetlands as ES providers (South Wollo) – Perception on wetlands is negative. These are live gene banks.

Improve research policy linkages

- Language (policy brief/audiovisuals).
- Widen the audience! Researchers and policy makers should be more approachable (both ways).
- Researchers XXXX
- More orientation towards farmers need formultidisciplinarity. More dialogue.
- More participation from policy makers. Policy makers should have a more proactive role on setting up the research agenda. When possible take them to the field (SLM). Show them things in practice. Policy makers should provide incentives to keep research in the research system – especially in remote area. Staff development.

Steps forward

- Link policy makers with their respective field.
- They have a panoramic view of the field.
- We need champions!
- Role models or crucial individuals that have a better understanding of the conditions of Tigrai?
- Accessibility of information (PhD Thesis).
- Data should be decentralized. Share more information.

III. Socio-economics and policy issues

1. What is the research works done so far? What are the major research finding and important policy implications?

- Difficult to come up with complete inventory of research works that have been conducted.
- The challenges that participants faced to come up with list of topics signifies extent of the gap between the researches made and the dissemination of the findings.
- What ever is done is done on piece meal basis

- Few among which are:
    - Effectiveness of conservation strategies in different agro-economic regions
        - Amhara Vs Tigray region
    - Extensive studies on the Raya-valley
        - Fails to address the issue of sustainable land management (too fragmented land holdings to be used for deep well irrigation)
- Land management (misuse of land by investors) in the western and south-western zone
- The potential of cactus in southern zone
- A question on "blanket recommendation" of fertilizer application
        - Going for in-organic fertilization due to the of economic justification should be case (region specific)
- The socio-economic impact of land-settlers (organized by REST)
        - Has there been an abuse in land management of newly settled areas
            - Determinants of fertilizer adoption
            - Impact of micro-finance on sustainable land use
            - MU-REST and NORAGRIC
        - Area enclosure
        - Water harvesting
- Economics of area enclosure
- Influence of institutions on watershed management
- Impact of extension intervention (packages) on production
- Adoption of integrated striga management
- Welfare effects of various policy interventions on sustainable land management are studied – e.g. BoARD
- Welfare effects of various NGO interventions on sustainable land management are under studies – BOA
- Difficult to identify and where to look for such research findings (lack of proper dissemination and documentation).
- Need to compile an inventory of research work hitherto done!

2. Research Gaps

- What are the real payoffs of zero grazing Vs free grazing – especially the economic benefits
- Gender issues in relation to SLM
- Environmental accounting while calculating the regional GDP
- Land degradation Versus Pollution
- The research gap is not only on the impact assessment but policy makers are faced with preliminary assessments of policy measures before they have been adequately implemenated (e.g. Revising the land certification problem … GPS versus Geo mapping)
- Identifying socio-economic potentials of the region (should not only focus on impact assessments)

Problems in research

- Budget problem - The problem is even more pressing at the university level
- Lack of panel data so as to study the inter-temporal effects

Consultations to identify research need of the development community

3. How To Bridge The Gap

a. How to improve research-policy linkages?

- Researchers and policy makers need to work in coordination requiring commitments from researchers and policy makers.
- develops the sense of ownership from both sides (researchers and policy makers)
- *Main problem:* the flow is one way – from researchers to policy makers. Therefore, the flow has to be in both directions.

b. What is expected of the researchers?

- Researchers focus more on academic endeavours rather than targeting the policy makers; research need to be problem solving. knowing the environment and addressing the pressing issues will interest policy makers reducing the effort to disseminate results
- Research outputs need to be properly communicated.

Recommendations

- Research should not be donor driven.
- Reorientation in how research is done

c. What is expected of the policy makers?

- Value research as input for policy making

4. Steps Forward In Institutionalizing Research-Policy Linkages

- Multi-stakeholder forum at some intervals with physical exchange of ideas of theoretical and empirical evidences.
- Publication of proceeding for wider dissemination (in local language)

Discussion on the presented themes

After each group presented the group discussion results, the chairman opened the floor for discussion and the following issue were raised:

How to go about doing research?

- Are we still following the publish or perish or other approach
- Some of the research outputs are shelved or not disseminated (e.g. translated) in a way to be consumed by policy makers
- National forum is needed to discuss on SLM issues nationally

- There is national and regional forum for environment and extension that appraise the research agendas for the future
- A centre is needed to collect process and finally disseminate the research outcomes to relevant stakeholders
- Should we need to pass all the existing steps or do we need reorientation in research?

It is also mentioned that the farmers or practices are ahead of our research.

Research need owner since research is done to research the issues that can help the development strategies and ambition of the nation, region, ..e.t.c. It has to comply with the government policy.

- It is an incentive that diverge researchers to look for academic oriented journal published outcomes. So, why not look or put some incentive here to attract them.
- There is no controversy between basic (academia) versus applied research Every organ should be participating and there should be synergy and this requires striking balance between basic and applied research
- Do we have the capacity and competency to come up with standard scientific result that can be translated to policy?
- We should focus on reality and resources we have.
- What policy makers can make to access the information [do they have documentation centres]
- Research has to be up to the need of the policy-makers
- Researchers couldn't get the simple information available in the corridor from development practitioners
- Development practitioners throw the research outputs in the shelf
- There is no way that some one argues research need its own way than being subservient to the development need
- They (farmers) are open to us but we are not.
- There is participatory technology innovation (researchers, development agents(DAs) and farmers)
- They (farmers) make evaluation of their innovations and we are not there to verify and help them rather we write and hide it until published some where.

Dr. Fitsum

I strongly believe that research need to be relevant. Research aims to to influence policy, to change livelihood and to extend the horizons knowledge. So research serves multiple objectives and multi stakeholders. While we strive to influence policy makers, it does not mean that they (policy makers) will pick it up whenever we do research and come up with some sort of recommendation. Policy making follows its won momentum. This is not only a problem of least developed countries but it is also of developed countries. The point is: how to better communicate our results to whomsoever we think will use it. If policy makers want policy relevant research outputs they should also influence the the research agenda besides seeking advices and makeing comments on ouptuts.

H.E Dr. Teweldeberhan

I agree and disagree substantially with the aforesaid points especially weather research in Ethiopia shall be basic or applied: The time research is done for its own sake is no more with us. It should be justified wherever it is. Basic research is essential (it should continue) since you can not proceed to applied unarmed with some basic research outcomes. It should have a long term objective than an applied research. It answers several questions and at the end it is going to be useful. For instance, we are scared for our live since climate is changing and some basic research may come up with a solution on how to overcome the problem. Another example is what sources of energy do we have? So many take researches on solar energy, the way we transform it is inefficient and prohibitively expensive and I can understand the ultimate benefit of basic research on how to harness sun energy into direct electric energy.

Having said this, as an Ethiopian should I have to spend on that basic research? No there is no need and I have to wait since the riches are doing it. There is an immediate question we need to answer, i.e. the welfare of our people. Simply there are several immediate quests that we need to answer before we head in to basic research. In saying this I am not differing from the last speaker (Dr. Fitsum) rather I prioritize the researches applied research first then basic research. I would prioritize the basic research if and only if there is a very important issue I need to address and there will not be others who do it.

The researcher must make sure that his/her outcome is usable. It should be judged not on how brilliant he/she is rather on how the brilliant mind tackles the question. If the research outcomes are not usable then kick out the researcher!

Sue Edwards

A problem I see in the researches and their outcomes is the inability of dialogue (language and communication); in case of farmers it is almost taken care of but researchers still are not good in communicating their outcome. I like the saying "let's skip the Greek". So let us present our research findings in a way easy and simple to be understood.

Another thing is the participation of relevant policy makers and development practitioners in such workshops or forums. Where are other people from the Bureaus? It is good some are back (Ato Yemane, Belete, Geremew,…) with us.

Such workshops and presentations should enable us to make dialogue. We have to use appropriate languages and appropriate mediums to communicate our discussions. This is basically important since we have problems in low or middle level professionals (development agents) and their impressive effort to communicate to the farmers. One they lack is good knowledge (lack of education) as they have a hell of responsibility (just after 12+3 years) to address farmers' problems.

It was during Derg regime there were lot of works in soil and water conservation. We went to a local restaurant to have super and saw a development agent reading and asked him what he was doing? He replied, I am reading an instruction on what I am going to do with the farmers tomorrow. This I think is wrong since without participatory approach just instructions on what to do gives a hard time for the development agents and it will create gaps between farmers and the development agents.

We heard and have seen quality research products these two days, but where is the dialogue. Where are the farmers, who are to be affected by our actions; the knowledge gap we have in practical implementation of projects is huge; I recommend a whole area of dialogue with communities, farmers, researchers for fruitful impact of research.

Why we produce development agents who are not really problem solving and who do not understand what farmers, really want/need. So we have to bridge the communication gap at different levels for materializing research and implementing policy. So we have to be very serious about dialogue and language in communicating research

Finally let us carefully think on what we are getting from this workshop (it was not cheap to run this workshop)? And what language are we going to use and how we are going to communicate or distribute the final output?

The participants finally agreed on the following points:

- We need an inventory of research work – annotated bibliography

- We need to summarize the key findings in a simple language and translate them into the local language r to reach policy makers and other end users
- We need a kind of platform that organizes discussions even in the existing situation.
- At regional level we need a working group/ stakeholders/members that can oganize and make the inventory.
- And so on

Dr. Zenebe on behalf of the organizer reminded participants the main issues discussed in the two days workshop: aggregate issues like research and development strategies at regional level and then to several things like water, forest, land, institutions…Then he called up on his Excellency Dr. Tewelde-Berhan Gebreegziabher, Director of Ethiopian Environmental Protection Authority to give a closing speech.

Annex II

Conference Programe

Day 1 (August 8, 2008)		
Time	**Activity/Session**	**Responsible**
8:00 – 8:30 AM	Participants Registration	Secretaries
8:30 – 8:35 AM	Announcing Workshop Schedule	Zenebe Gebreegziabher
8:35 – 8:40 AM	About EEPF/EDRI	Menale Kassie
8:40 – 8:45 AM	Welcome Speech	Aregawi Gebremichael
8:45 - 8:50AM	Opening Speech	Kindeya Gebrehiwot
8:50 – 9:15 AM	Keynote Speech: 'Sustainable Land Management: Research and Policy Challenges'	HE Dr Tewelde-berhan Gebreegziabher
9:15– 11:00 AM	**Session I: Sustainable Land Management: Research, Practice and Development Strategies, Chair: Prof. Dr. Fisseha-Tsion Mengistu**	**Presenter(s)**
9:15 – 9:40 AM	Development Strategies in Tigrai, Challenges and Opportunities	Ato Yemane Yosef (Deputy Bureau Head, Bureau of Finance and Economic Development)
9:40 – 10:05 AM	Challenges in Implementing Sustainable Land Management Practices and Rural Development in Tigrai	Ato Belete Tafere (Deputy Bureau Head for Natural Resources Sector, Bureau of Agriculture and Rural Development)
10:05 – 10:20 AM	***Tea Break***	
10:20 – 11:00	Discussion on Session I Presentations	**Facilitator**
11:00AM – 12:30 PM	**Session II: Investments in Land and Water, Chair: Belete Tafere**	**Presenter(s)**
11:00 – 11:15 AM	Challenges and Opportunities of Watershed Approach in Tigrai	Yohannes Gebremichael
11:15 – 11:30 AM	Prioritization of Micro-watersheds on the Basis of Soil Erosion Risk in the Source Region of the Blue Nile River Using RUSLE Model, Remote Sensing and GIS: Case Study in the Muga watershed	Ermias Teferi, Dagnachew Legesse, Belay Simane, Weldeamlak Bewket
11:30 – 11:45 AM	Poverty and Inequality Impacts of Agricultural Water Management Technologies in Ethiopia	Fitsum Hagos, Jayasingne, Gayathri, Awulachew, S.B. and Loulseged, M
12:00 AM – 12:30 PM	Discussion on Session II Presentations	**Facilitator**
12:30 – 2:00 PM	**Lunch Break**	
2:00 – 3:15 PM	**Session III: Land Investment Technologies, Chair: Fitsum Hagos**	**Presenter(s)**
2:00 – 2:15 PM	Estimating Returns to Soil Conservation Adoption In the Northern Ethiopia Highlands	Menale Kassie, John Pender, Mahmud Yesuf, Gunnar Kohlin, Randy Bulffstone, Elias Mulugeta
2:15 – 2:30 PM	The Impact of Compost Use on Crop Yields in Tigrai, Ethiopia, 2000-2006 inclusive	Sue Edwards, Arefayne Asmelash, Hailu Araya, and Tewolde Berhan Gebreegziabher
2:30 – 2:45 PM	A Sustainable Strategy in Parthenuim Weed Management in the Alamata-Mehoni Lowlands of Southern Tigrai	Hailu Araya, Arefaine Asmelash and Sue Edwards
2:45 – 3:00 PM	Sustainable Land Management: Identifying Best Practices	Sintayehu Fisseha
3:00 – 3:40 PM	Discussion on Presentation Session III	**Facilitator**
3:40 – 4:00 PM	***Tea Break***	
4:00 – 5:15PM	**Session IV: Biodiversity and Productivity, Chair: Menale Kassie**	**Presenter(s)**
4:00 – 4:15 PM	Agro-Ecosystem Productivity in Developing countries: The Economics of Crop Bio-diversity in the Highlands of Ethiopia	Jean-Paul Chavas and Salvatore Di Falco
4:15 – 4:30 PM	Sustainable Biodiversity Conservation For Improved Land Management in Ethiopia: Five Decade Analysis	Frew Mekbib
4:30 – 4:45 PM	On Genetic Diversity, Farm Productivity and Risk Exposure: Evidence form Barely Production in the Tigrai Region, Ethiopia	Salvatore Di Falco and Jean-Paul Chavas
4:45 – 5:15 PM	Discussion on Presentation Session IV	**Facilitator**

Day 2 (August 9, 2008)		
Time	**Activity/Session**	**Responsible**
8:00 – 9:15PM	**Session V: Tree Planting and Conservation, Chair: Kindeya Gebrehiwot**	**Presenter(s)**
8:00 – 8:15 AM	Greening Ethiopia for Food Security	Sue Edwards
8:15 – 8:30 AM	Household Tree Planting in Tigrai: Tree Species, Purposes and Determinants	Zenebe Gebreegziabher
8:30 – 8:45 AM	Conservation and Production Potential of Afforestation Activities in Tigrai	Sara Tewelde-Berhan and Emiru Berhane
8:45 – 9:15 AM	Discussion on Session V Presentations	**Facilitator**
9:15 – 10:30 AM	**Session VI: Incentives for Land Investment, Chair: Salvatore Di Falco**	**Presenter(s)**
9:15 – 9:30 AM	Implication of Land Titling on Tenure Security and Long-term Land Investment: Case of Kilte Awela'elo wereda, Tigrai, Ethiopia	Dagnew Menan, Fitsum Hagos, Nicck Chsholm
9:30 – 9:45 AM	Impacts of Low-Cost Land Certification On Investment and Productivity	Stein Holden, Klaus Deininger, Hosa'ena Ghebru
9:45 – 10:00 AM	Certification and Land Investment: The Case of Tigrai Region	Fitsum Hagos
10:00 – 10:30 AM	Discussion on Session VI Presentations	**Facilitator**
10:30 – 10:45 AM	*Tea Break*	
10:45 AM – 12:00 PM	**Session VII: Sustainable Land Management and Livelihood, Chair: Wilfred Nyangena**	**Presenter(s)**
10:45 – 11:00 AM	Understanding Farmer's Perception and Determinants of Uses of Sustainable Land Management Practices: the case of Ofla wereda, Southern Tigrai, Ethiopia	Kebede Manjur, Tesfaye Lemma, Alemayehu Gebrehiwot
11:00 – 11:15 AM	Rural Household Income Diversification, Poverty and Their Coping Strategies: Asset Base Approaches in Ethiopia: The case from South Eastern Tigrai	Mulubrahan Amare and Kibrom Araya
11:15 – 11:30 AM	Farmer Livelihood Strategies and Sustainable Land Management	Tsega Gebrekrstos
11:30 – 11:45 AM	Institutions and Sustainable Land Use: the Case of Forest and Grazing Lands In Northern Ethiopia	Zenebe Gebreegziabher
11:45 AM – 12:15 PM	Discussion on Session VII Presentations	**Facilitator**
12:30 AM – 2:00 PM	***Lunch Break***	
2:00 – 3:30 PM	Facilitated groups discussion on identifying gaps, networking and advocacy, influencing policy makings on SLM and institutionalization of future collaborative SLM research and capacity buildings	Organizers
3:30-4:00PM	Tea Break	
4:00 – 5:30 PM	Group Presentations and Discussion, Reflections	
5:30-6:00PM	Closing Speech	HE Ato Tsegay Berhe, President TNRS
6:00 – 7:30 PM	Workshop Dinner	

Annex III

List of Workshop Participants

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