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Agronomic and Economic Efficiency of Manure and Urea Fertilizers Use on Vertisols in Ethiopian Highlands

Teklu Erkossa[1] and Hailemariam Teklewold[2]

[1] International Water Management Institute, Addis Ababa, P.O.Box 5689, Ethiopia
[2] School of Business, Economics and Law, University of Gothenburg, Gothenburg, P.O.Box 640 SE 40530, Sweden

Abstract

Soil fertility depletion is among the major impediments to sustained agricultural productivity especially in the less developed countries because of limited application of fertilizers. Soil fertility maintenance requires a balanced application of inorganic and organic nutrient sources. This study was conducted on a Vertisol in Ethiopia to determine the optimum farm yard manure (M) and nitrogen (N) application rates for maximum return under cereal-pulse-cereal rotation system. The main and interaction effects of M and N significantly affected biomass, grain and straw yields of wheat (*Triticum durum*) and tef (*Eragrostis tef*), but the residual effect on chickpea (*Cicer arietinum*) was not significant. Application of 6 t M ha^{-1} and 30 kg N ha^{-1}, gave the largest grain yield of both crops but a comparable result was obtained due to 3 t M ha^{-1} and 30 kg N ha^{-1}. The economic analysis revealed that 6.85 t M ha^{-1} and 44 kg N ha^{-1} for wheat, and 4.53 t M ha^{-1} and 37 kg N ha^{-1} for tef were the economic optimum rates. The additional benefit obtained due to these rates was about 450 USD ha^{-1}. Therefore, application of the economic optimum combination of both organic and inorganic sources of nitrogen is recommended for use on cereals in the cereal-legume-cereal rotation system.

Key words: Ethiopia, vertisol, productivity, manure, economic optimum, rotation system

INTRODUCTION

A lasting economic feasibility of crop production requires the choice of suitable rate, type and source of nutrients. Nitrogen (N) is among the important inputs to maximize the yield of durum wheat (*Triticum durum* Desf.) and tef (*Eragrostis tef*), which are among the principal traditional crops grown on Vertisols in Ethiopia. Despite the continued increase in their price, fertilizers are increasingly applied to these crops. For economic and environmental reasons, attempts have been made to partially or fully substitute the inorganic fertilisers with locally available sources such as farm yard manure and composts.

Covering about 8 million ha in the highlands, Vertisols are considered suitable for cereals like wheat and tef as well as for pulses like chickpea. However, their low N supply capacity and meager organic matter content coupled with their severe water logging problems limit their productivity. Studies show that application of N fertilizer enhanced the productivity of Vertisols with the economic optimum rates of 55 kg N ha^{-1} for tef (Tekalign *et al*. 1996) and 64 kg N ha^{-1} for durum wheat (Workneh and Mwangi 1992). However, farmers often apply sub-optimal rates due to limited access to credit and limited supply of fertilizers (Gezahegn and Tekalign 1995) as well as continued price hike.

In the mixed farming systems of the Ethiopian highlands, farm yard manure (M) is probably the most important soil amendment to which farmers have a better access (Powell *et al*. 1995). However, unlike the western parts of the country where it is the major means of soil amendment (Teklu *et al*. 2004), M is largely used

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Correspondence Teklu Erkossa, Tel: +251-116172249, Mobile: 251911310239, E-mail: ERKOSSA@yahoo.com

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as a source of household energy in the central and the northern parts. Improving the efficiency of M may encourage farmers to use it as soil amendments (Karl *et al*. 1994) than as fuel. Among the issues of consideration to enhance its efficiency and profitability are storage and handling of M before application and its synergetic effects with inorganic fertilizers under the prevailing cropping systems.

The beneficial effects of M on crop production through improved soil fertility and physical properties of soil is an established fact (Singh and Sarivastore 1971). There are ample evidences showing that application of M alone or in combination with inorganic fertilizers enhances proper nutrition and maintenance of soil fertility (Salim *et al*. 1988; Talashiker and Rinal 1986). From a study conducted on a clay rich soil in Pakistan, Shah and Ahmad (2003) obtained a maximum biomass and straw yield of wheat due to a combined application of N from urea and M at nitrogen equivalent ratio of 75:25 followed by 50:50 of the recommended rate, where as applying 100% of the recommended level of N as urea gave significantly lower yield as compared to the combined application, although the total amount of N applied was the same. Consequently, they recommended that integrated use of urea and M is more efficient than the use of either urea or M alone for improved yields of wheat. However, little information is available on the cumulative effects of continued application of M and urea in cereal-pulse-cereal rotation systems like that of the central highlands of Ethiopia, where nitrogen fixation due to the pulses in the rotation is apparent.

Evaluating the nutrient management efficiency under such systems should take all crops in the rotation into account. Although farmers consider several factors when deciding to adopt a technology, one important factor influencing their decision is the economic return from the new technological alternative (CIMMYT 1988). This study analyzed the effect of different levels of composted M and inorganic N from urea on agronomic performance of the crops and economic benefits to the farmers under the wheat-chickpea-tef rotation system.

MATERIALS AND METHODS

The study site and composting of the manure

The study was conducted on a Vertisol at Debre Zeit (38°58´´E, 08°44´´N and 1 900 m asl) with 850 mm mean annual rainfall (Fig.1) and 17°C average temperature, for six years (1999-2004) under rainfed conditions. The soil of the area is characterized by

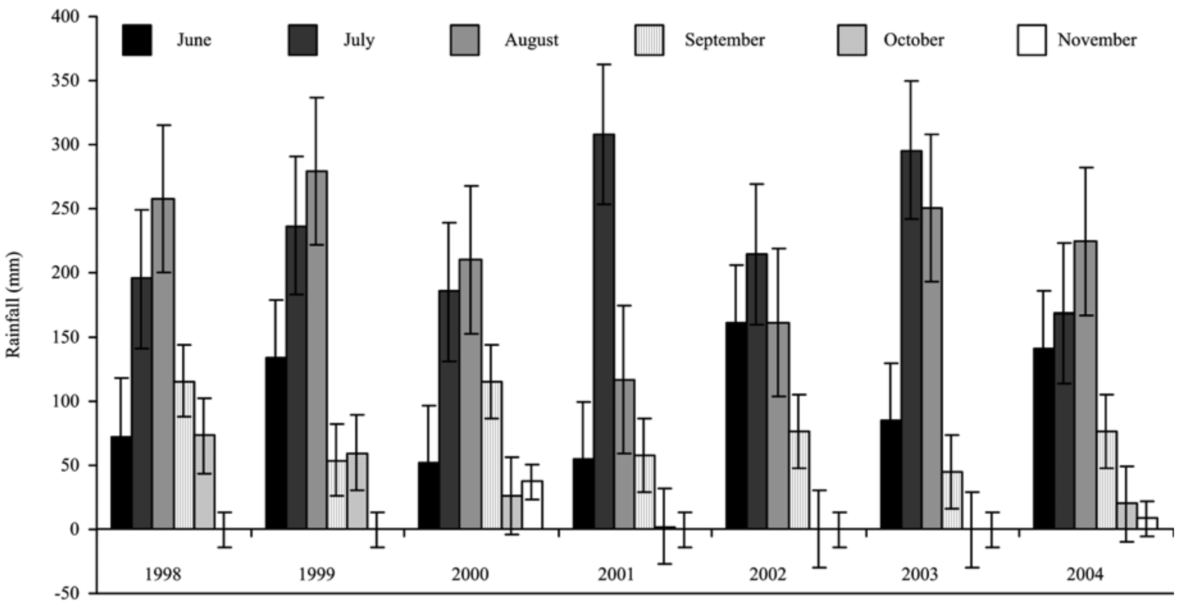

Fig. 1 Rainfall (mm) of the study site during the growing periods.

high clay content (71%), slightly alkaline reaction (pH = 7.2), very low organic matter (1.55%) and total nitrogen (0.03%) content. To compost the M, fresh dung, urine and litter from research managed dairy cows was collected and piled up on 2 m × 2 m level ground to decompose as described by Klapp (1967). The pile was kept covered by wheat straw with occasional stirring for at least six months before application. The moisture content of the mature M was determined just before application.

Experimental design and data collection

A split plot design with four replications was employed. Three levels of M (0, 3, and 6 t M ha^{-1} on dry weight basis) representing the control, medium and high rates of manure, respectively, were randomly assigned to the main plots, while three levels of N (0, 30, and 60 kg N ha^{-1}), representing control, medium and high rates of nitrogen, respectively, were assigned to the sub-plots. The M was uniformly spread on the plots and incorporated into the soil with hoe while urea was applied and incorporated with the soil by hand, just before sowing. The plot size was 16 m × 6 m for the main plots and 4 m × 6 m, for the sub plots. The treatments were kept permanent while three crops (one crop each year): durum wheat (*Triticum durum* Desf.), tef (*Eragrostis tef*) and chickpea (*Cicer arietinum*), respectively, were rotated following their traditional sequence. However, both M and N were not applied to chickpea, which is traditionally used as a break crop without fertilization. Improved crop varieties recommended for the area; boohai for wheat, DZ-01-196 for tef and Mariye for chickpea were used. Recommended seedbed types; broad bed and furrow (BBF) for wheat and chickpea, and flat beds for tef were employed (El-Swaify *et al.* 1985). Weed and pests were controlled by hand and chemical spray, respectively.

Grain and straw yields were recorded, and prices of inputs and outputs were estimated based on the market survey reports of the Debre Zeit Research Centre, Ethiopia. An opportunity cost of selling manure cake for use as fuel was used as proxy price for M. The discount rate is set equal to a common interest rate (7.5%), on the assumption that this would constitute the best alternative investment opportunity for the available funds and reflect the opportunity cost of capital in the market.

Agronomic data analysis

The two years grain and straw yield data for each crop was averaged for statistical analysis since there was no significant difference between years. For the analysis, a linear model for a randomised complete block design was fitted (Eq.1) using the Proc GLM procedures of the SAS computer package.

Model: $$y_{ij} = \mu + b_j + \alpha_1 + \alpha_2 + e_{ij} \quad (1)$$

Where, y_{ij} = estimated value of the *i*th treatment and the *j*th replication; μ = population mean; b_j = block effect (replication); α_1 = main plot effect (M); α_2 = sub plot effect (N); e_{ij} = error.

In order to capture the cumulative effect of the treatments on the subsequent crops in the rotation, the modified relative productivity index (RPI) (Teklu *et al.* 2006) was employed (Eqs.2-3). Accordingly, the biomass yield was considered as indicator of the overall effect of the treatments in terms of biological productivity. Thus, the biomass yield obtained from each plot was divided by the overall mean yield (Eq.3), so that a unit free index representing the relative productivity of the plots was obtained; and this was repeated every year. The index obtained in this way was statistically analysed using SAS as indicated above (Eq.1).

$$RPI = \frac{x_i}{\bar{X}} \quad (2)$$

$$\bar{X} = \frac{\sum_{i=1}^{n} x_i}{n} \quad (3)$$

Where *RPI* = relative productivity index; x_i = biomass yield of each plot; n = number of observations; $\bar{X}$ = overall mean.

Economic analysis

Considering crop rotation from a standard profit maximization model of farmers' behaviour, it was assumed that farmers maximize the discounted sum of expected future profits by choosing the optimum amount of M and N application in the traditional crop rotation system, defined as (Eqs.4-5) (Liam 1999; Jauregui and Sain 1992):

$$\underset{N,M}{Max\ NPV} = \sum_{t=1}^{6}\sum_{i=1}^{3} \frac{\pi_i}{(1+r)^t} \quad (4)$$

$$= \sum_{t=1}^{6}\sum_{i=1}^{3} \frac{P_{ig}Y_{ig} + P_{is}Y_{is} - P_nN_i - P_mM_i}{(1+r)^t} \quad (5)$$

Where, *NPV* represents the net present values calculated by aggregating the discounted profits of durum wheat, chickpea and tef grown in rotation over time 't'; π_i is profit from the *i*th crop; P_{ig} and P_{is} are the grain and straw prices of the *i*th crop, respectively; Y_{ig} and Y_{is} are grain and straw yields of the *i*th crop; N_i and M_i are *M* and *N* applied on the *i*th crop; P_n and P_m are prices of *M* and *N*; *r* is the discount rate.

The production function for the *i*th crop is conventional and is given as a function of *M* and *N*. In this case, the inputs were regarded as non-separable since it is not possible to distinguish the fraction that contributes to the grain and the straw production, respectively (Jauregui and Sain 1992). The response model for the *i*th crop is therefore, represented by two separate functions (Eqs.6-7):

$$Y_{ig} = f_g(N, M) \quad (6)$$

$$Y_{is} = f_s(N, M) \quad (7)$$

Maximization of equation (5) yields the following first order (optimality) conditions:

$$\frac{\partial NPV}{\partial N_i} = \frac{P_{ig}}{(1+r)^t}\frac{\partial Y_{ig}}{\partial N_i} + \frac{P_{is}}{(1+r)^t}\frac{\partial Y_{is}}{\partial N_i} - \frac{P_n}{(1+r)^t} = 0 \quad (8)$$

$$\frac{\partial NPV}{\partial M_i} = \frac{P_{ig}}{(1+r)^t}\frac{\partial Y_{ig}}{\partial M_i} + \frac{P_{is}}{(1+r)^t}\frac{\partial Y_{is}}{\partial M_i} - \frac{P_m}{(1+r)^t} = 0 \quad (9)$$

That is, *NPV* maximization requires that the discounted value of the marginal physical productivity of *M* and *N* be equal to their discounted marginal factor cost (or the nutrients price). The optimum quantities of nutrients (N and M) are found by simultaneously solving equations 8 and 9. Substituting these optimum levels in to the NPV (Eq.4) provides the optimum NPV levels.

The functional relationship between yield and application of varying levels of M and N fitted to the experimental data. Because of its mathematical simplicity and its ability to facilitate a more detailed technical and economic analysis, the quadratic regression model was used to estimate the mathematical relationship of yield and the nutrient rates. The quadratic function has been widely used in nutrient response function because it is easily generalized to models with more than one nutrient and it allows easy interpretation of linear, curvilinear and interaction effects (Heady and Dillon 1961; Jauregui and Sain 1992). The general quadratic functional form used for grain and straw is (Eqs.10-11):

$$Y_{ig} = \alpha_{ig} + \beta_{ig}M + \gamma_{ig}N + \theta_{ig}MN + \phi_{ig}M^2 + \lambda_{ig}N^2 + \varepsilon_{ig} \quad (10)$$

$$Y_{is} = \alpha_{is} + \beta_{is}M + \gamma_{is}N + \theta_{is}MN + \phi_{is}M^2 + \lambda_{is}N^2 + \varepsilon_{is} \quad (11)$$

Where, α_{ig}, β_{ig}, γ_{ig}, θ_{ig}, and λ_{ig} are the regression coefficients for quadratic grain yield function for the *i*th crop; α_{is}, β_{is}, γ_{is}, θ_{is}, and λ_{is} are the regression coefficients for quadratic straw yield function for the *i*th crop; ε_{ig} and ε_{is} are error terms for grain and straw yield regression function, respectively.

RESULTS AND DISCUSSION

Biomass yield

Evidently, the biomass yield of wheat and tef increased with increased level of treatments, but the effect of N diminished as the rate of M increased (Fig.2). However the residual effect of the treatments did not show any significant effect on the biomass yield of chickpea, confirming the previous findings in which no nitrogen was recommended for chickpea and other pulses grown on Vertisols in the area. The highest biomass yield was obtained with the application of 6 t M ha^{-1} together with 30 and 60 kg N ha^{-1} for wheat and tef, respectively. However, this was not significantly different from the yield obtained with the application of 3 t M ha^{-1} and 30 kg N ha^{-1} for both crops.

Grain yield

The M and N application rates as well as their interaction significantly ($P \leqslant 0.05$) affected the grain yield of wheat and tef, but their residual effect did not affect the yield of chickpea (Table 1). Evidently, the grain yield of wheat increased with increasing N rates under all levels of M, but with decreasing rate as M level increased. However, there was a slight drop when 60 kg N ha^{-1} was applied together with 6 t M ha^{-1} due to lodging resulted from the luxurious vegetative growth of the crop indicating over fertilization.

The highest grain yield of wheat (2 026 kg ha^{-1}) was obtained with the application of 6 t M ha^{-1} and 30 kg N ha^{-1}. This suggests that only half of the recommended N (30 kg ha^{-1}) from urea is sufficient for optimum yield of wheat, even when the precursor crop is cereal (tef), provided that 6 t ha^{-1} M is applied. The yield increase due to 60 kg N ha^{-1} was 300% as compared to the control under no application of M, but it was only 12.8% when 6 t M ha^{-1} was applied. This implies that the contribution of 6 t M ha^{-1} to grain yield was comparable to that of 60 kg N ha^{-1}, indicating the possibility of complete substitution of the urea through organic sources.

Similarly, the effect of M and N as well as their interaction was significant on grain yield of tef, which was sown after chickpea. Confirming the previous findings in which 30 kg N ha^{-1} was recommended for tef succeeding pulses (Selamyihun *et al*. 1999), the grain yield increased as N rates increased from 0 to 30 kg N ha^{-1}, but dropped with further increase regardless of M treatments. Although the highest grain yield of tef was obtained with the application of 6 t M ha^{-1} and 30 kg N ha^{-1}, similar to that of wheat, this was not significantly higher than the yield obtained due to the combined application of 30 kg N ha^{-1} and 3 t M ha^{-1}. Therefore, with the application of 3 t M ha^{-1} in two out of three years in a cereal-pulse-cereal rotation system, only 30 kg N ha^{-1} may be sufficient to optimize grain yield of

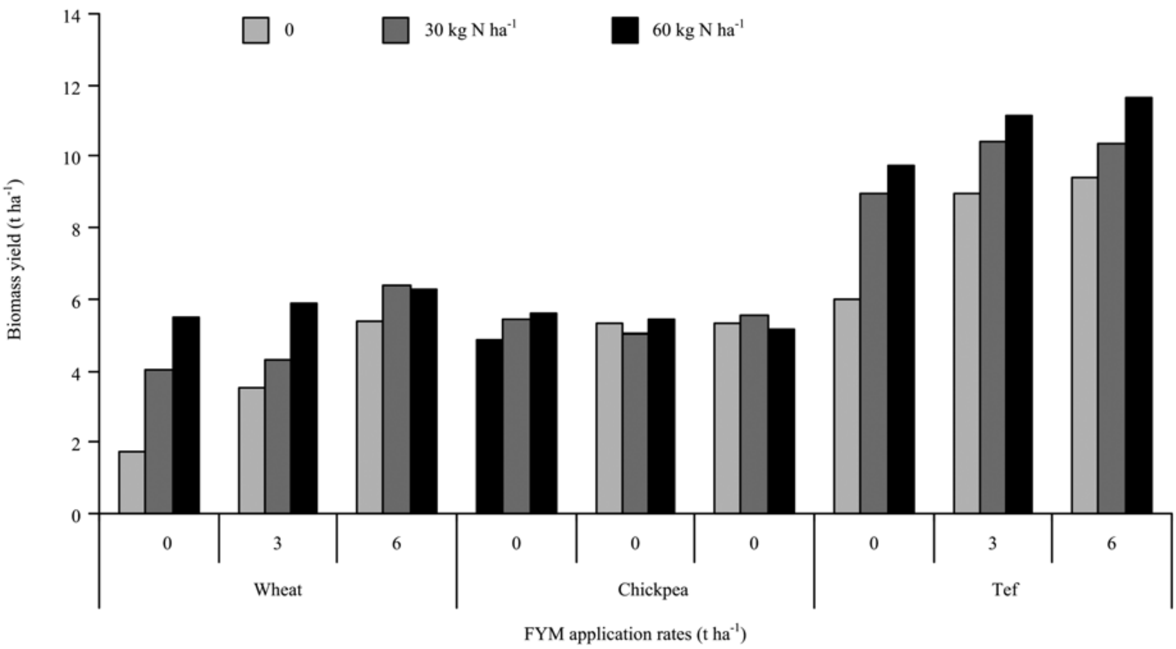

Fig. 2 Effect of farm yard manure (FYM) and nitrogen application rates on dry biomass yield of some crops.

wheat and tef, but this needs to be confirmed in economic terms.

Straw yield

Similar to that of grain, the straw yields of durum wheat and tef were significantly affected by the different rates of M and N, and their interaction (Table 2). While chickpeas' non-significant response was consistent with that of its grain yield, the straw yield of durum wheat increased constantly with the increased M and N rates. Unlike its grain yield, the maximum straw yield (4308 kg ha^{-1}) of durum wheat was obtained when the maximum rates of M and N (6 t M ha^{-1}, 60 kg N ha^{-1}) were applied, while the minimum (1276 kg ha^{-1}) was under the control. Similarly, the straw yield of tef increased with increased rates of M and N, attaining the maximum with the highest rates (6 t M ha^{-1} and 60 kg N ha^{-1}). Nevertheless, the increase in response to N increase from 30 to 60 kg N ha^{-1} was not significant ($P \leqslant 0.05$). The highest straw yield under the highest rates of M and N is in conformity with that of the biomass yield; hence the same strategy can be followed to optimise both.

Long-term productivity

The advantages of organic fertilizers like manure are often realized on a relatively long-term basis. Therefore, it may be desirable to compare the overall performance of the treatments on a long-term basis instead of a crop-by-crop analysis alone. Such comparison can be done in terms of agronomic productivity and financial benefits. In this study, the agronomic productivity was represented by the total dry biomass yield, which was expressed by the cumulative relative productivity index (CRPI). Three combinations of M and N rates including high M and high N (6 t M ha^{-1}, 60 kg N ha^{-1}), medium M and high N (6 t M ha^{-1}, 60 kg N ha^{-1}), or high M and medium N (6 t M ha^{-1}, 30 kg N ha^{-1}) have shown superior performance (Fig.3) in terms of agronomic productivity. This corroborates with the findings of Shah and Ahmad (2006), in which a combined application of N from urea and M at N equivalent ratio of 75:25 followed by 50:50 of the recommended rate revealed maximum biomass and straw yield of wheat. Partly, this can be explained by the fact that the combined application of organic and inorganic sources provide more total nutrients than one of them alone. Besides, Shah and Khan (2003) credited the improved performance under the combined application of M and urea to the immediate availability of N from urea and its delayed releases from the M, achieving a better synchrony with crop development.

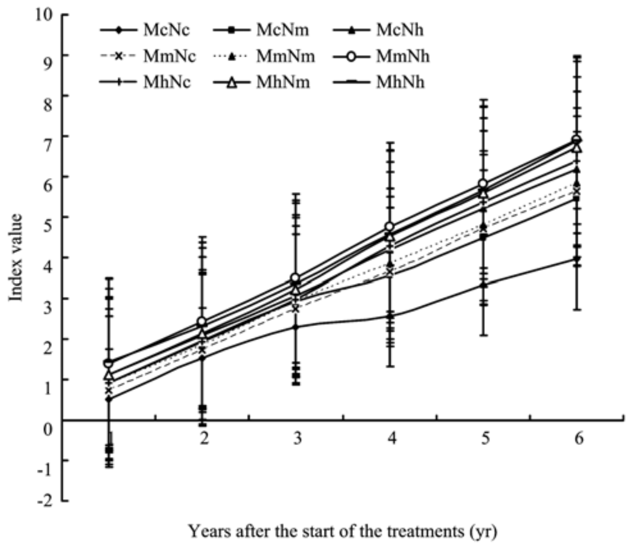

Fig. 3 Cumulative relative productivity index (CRPI) of the soil as affected by manure and nitrogen application rates. Nc, Mm, and Mh represent no M (control), medium M (3 t M ha^{-1}), and high M (6 t M ha^{-1}), respectively; and Nc, Nm, and Nh represent no N (control), medium N (30 kg N ha^{-1}), and high N (60 kg N ha^{-1}), respectively.

Table 1 Mean grain yield (kg ha^{-1}) of some field crops as affected by manure (M) and nitrogen applications rates (mean of two years)

M (t ha^{-1})	Nitrogen (kg ha^{-1})			
	0	30	60	Mean
		Wheat		
0	460	1311	1886	1118 C
3	1155	1437	1980	1591 B
6	1737	2026	1960	1941 A
Mean	1219 C	1524 B	1908 A	
CV (%)=26; LSD (5%) N=222; M=262				
		Chickpea		
0	2379	2650	2746	2488
3	2535	2347	2596	2553
6	2548	2664	2448	2610
Mean	2592	2493	2567	
CV (%)=22; LSD (5%)=NS				
		Tef		
0	1655	2160	2131	1926 B
3	2134	2203	2174	2192 A
6	1988	2213	2060	2122 A
Mean	1982 B	2170 A	2087 AB	
CV (%)=12; LSD (5%) N=127; M=121				

Means within the same column or row followed by the same letter are not significantly different at 95% confidence limit. The same as below.

Table 2 Mean straw yield (kg ha^{-1}) of some field crops as affected by manure (M) and nitrogen applications rates (mean of two years)

M (t ha^{-1})	Nitrogen (kg ha^{-1})			
	0	30	60	Mean
		Wheat		
0	1 276	2 717	3 600	2 430 C
3	2 369	2 903	3 906	3 319 B
6	3 645	4 337	4 308	3 938 A
Mean	2 531 B	3 059 B	4 097 A	
CV (%) = 27.87; LSD (5%) N = 524; M = 585				
		Chickpea		
0	2 517	2 758	2 842	2 680
3	2 777	2 670	2 846	2 765
6	2 747	2 866	2 685	2 791
Mean	2 706	2 765	2 766	
CV (%) = 16; LSD (5%) = NS				
		Tef		
0	4 352	6 824	7 591	6 192 C
3	6 825	8 222	8 981	7 727 B
6	7 399	8 134	9 607	8 726 A
Mean	6 256 B	8 009 A	8 380 A	
CV (%) = 16; LSD (5%) N = 486; M = 548				

Economic returns

Evidently, exclusively applying high M or high N alone can maximize the biomass productivity, although, a comparable result could be safely obtained by applying, either high M with medium N or high N with medium M, but the suitable rates may be further fine-tuned when it comes to the economic optimality.

The values of the *F*-statistics with (5, 66) degrees of freedom are relatively high for wheat and tef in the rotation, implying the overall significance of the independent variables, M and N (Table 3). In most of the cases, wheat and tef yields have shown positive and significant responses to the application of M and N.

The partial budget analysis (Table 4) reveals the economic performance of M and N fertilization in the crop rotation system. According to the optimality condition of the profit function, each crop in the rotation requires different efficient level of M and N to maximize profit per unit of land. In this wheat-chickpea-tef rotation system, 44 kg N ha^{-1} and 6.85 t M ha^{-1}, are required to produce the profit maximizing out put of 1.9 and 3.7 t ha^{-1} of wheat grain and straw, respectively in the first year followed by 2.6 and 2.8 t ha^{-1} of chickpea grain and straw, respectively in the second year. In the third year of the rotation, the optimum level of nutrients decreased to 37 kg N ha^{-1} and 4.53 t M ha^{-1}. The profit maximizing level of outputs with this level of nutrients is 2.2 and 8.9 t ha^{-1} of tef grain and straw, respectively. Under this scenario, application of the economic optimum level of M and N in the first and third years of the rotation cycle results in the discounted total cost of about 111 USD ha^{-1} providing NPV of about 3 948 USD ha^{-1} at 7.5% discount rate.

Traditionally farmers apply 46 kg N ha^{-1} to the first and third crops in the rotation. However, it is not clear how a change in fertilization under the prevailing cropping system affects the net benefit to the farmers. In the discounted cost-benefit analysis, NPV earned from using M and N was higher than that from the traditional fertilization (Table 5). Comparison between the two alternatives using the method of marginal analysis indicated that by adopting the optimum level of M and N, farmers incur an additional cost of 32 USD ha^{-1}. In return, they earn an extra benefit of 451 USD ha^{-1}. Thus, using optimum rate of M and N in the traditional crop rotation would provide farmers 1 387% marginal rate of return.

For producers, the provision of an economic incentive is a significant factor in decisions to adopt or reject new methods of production. The marginal rate of return (1 387%) obtained from adopting optimum rate of M and N was higher than the minimum acceptable rate, estimated to be about 50-100% by several studies for farmers already use fertilizers (Hailemariam and Gezahegne 2000; Hailemariam *et al*. 2006; CIMMYT 1988). The economic optimum rate of M and N for wheat (6.85 t M ha^{-1} and 44 kg N ha^{-1}) and tef (and 4.53 t M ha^{-1} and 37 kg N ha^{-1}) is less than the agronomic optimum.

The introduction of M into the system reduced the optimum N level by 20 kg N ha^{-1} for wheat and 18 kg N ha^{-1} for tef as compared to the optimum level recommended under no M application (Tekalign *et al*. 1996; Workneh and Mwangi 1992). Assuming 50% of the 8 million ha Vertisols in the highlands of Ethiopia to be under the same system, the use of M and N at the economic optimum rate may reduce about 0.106 million t of urea in three years and proportionally saves the country's foreign exchange expenditure.

Clearly, adjusting the fertilization method in the traditional cereal-pulse-cereal rotation system, is profitable to the farmers. However, the limited supply of manure due to its traditional use as a source of household energy and sell for income poses conspicuous impediment to the use of M as a means of soil amendment. Yet, the return

Table 3 Parameter estimates of quadratic grain and straw yield response to nitrogen and manure

	Rotation					
	Wheat →		Chickpea →		Tef	
Parameters	Grain, Y_{wg}	Straw, Y_{ws}	Grain, Y_{cg}	Straw, Y_{cs}	Grain, Y_{tg}	Straw, Y_{ts}
α	485.8***	1 316.4***	2 421.9***	2 544.0***	1 727.1***	4 641.3***
βM	2.79***	4.80**	0.59	0.70	1.79***	6.87**
δN	18.87**	22.99	-2.59	6.13	14.16***	90.09***
θMN	-0.03***	-0.05	-0.01	-0.01	-0.01**	-0.03
ϕM^2	-0.001	-0.002	-0.0001	-0.0003	-0.002***	-0.003
λN^2	0.04	0.28	0.10	-0.03	-0.15**	-0.77
F-ratio	25.05***	11.68***	0.53	0.68	2.64**	11.47***

***, ** indicate statistical significance at 1 and 5% level, respectively.

Table 4 Economic optimum levels of N and M with the corresponding yields, cost of nutrients and net returns

	Rotation		
	Wheat →	Chickpea →	Tef
N (kg ha^{-1})	43.59	-	36.64
M (t ha^{-1})	6.85	-	4.53
Grain yield, Y_{ig} (kg ha^{-1})	1 930.44	2 557.59	2 279.01
Straw yield, Y_{is} (kg ha^{-1})	3 707.25	2 794.33	8 906.68
Gross benefit (USD ha^{-1})	941.86	1 366.37	1 751.79
Cost that vary (USD ha^{-1})	67.17	-	44.69
NPV (USD ha^{-1})		3 948.15	

Price information (USD kg^{-1}): wheat grain = 0.37; wheat straw = 0.06; chickpea grain = 0.54; chickpea straw = 0.03; tef grain = 0.56; tef straw = 0.08; nitrogen = 0.93; manure = 0.01.

Table 5 Benefit from application of N and M as compared to farmers' traditional practice

Farmers' practice	Rotation		
	Wheat →	Chickpea →	Tef
N (kg ha^{-1})	46	--	46
Grain yield, Y_{ig} (kg ha^{-1})	1 438.43	2 514.31	2 061.01
Straw yield, Y_{is} (kg ha^{-1})	2 966.43	2 762.45	7 156.11
Gross benefit (USD ha^{-1})	714.38	1 343.73	1 518.90
Cost that vary (USD ha^{-1})	42.56		36.82
NPV (USD ha^{-1})		3 497.63	
Comparison			
Marginal cost (USD ha^{-1})		32.48	
Marginal benefit (USD ha^{-1})		450.52	
Marginal rate of return (%)		1 387%	

earned from using optimum levels of M and N may encourage farmers to switch the use of manure from fuel or sell to crop production, so long as alternative energy sources are available at a price not more than the return generated from using manure as soil amendment. Under conditions where it is not possible to apply the optimum rate of M, a continued application of a sub-optimal rate of M could be significant as the required level may be attained by a prolonged application.

CONCLUSION

Integrating farm yard manure into the cropping system substantially reduced the nitrogen requirement for optimum yield of wheat and tef grown in a rotation. Together with the increased farm returns, this is believed to be a good reason for farmers to use manure for soil amendment than selling or using it as fuel. While disseminating this recommendation to the farmers after on-farm verification should be an urgent priority, a simultaneous provision of affordable alternative energy sources should be seriously taken. Analysing the enhancement in soil quality due to manure application can also substantiate the advantage of such integration. In the face of the alarming decline in soil quality on the one hand and a disquieting increase in the price of the imported inorganic fertilizers and continued increase in demand for foreign currency on the other, this finding is of paramount importance to the farmers, the government and the public at large. Therefore, a concerted effort needs to be exerted to exploit the potential economic and ecological benefits of this locally available resource.

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