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*A Spatiotemporal Analysis*

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# Exploring the Evidence for Inward Diffusion of Soil Practices among Farmers in Nigeria: A Spatiotemporal Analysis

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## Abstract

Soil erosion is one of the most devastating issues that farmers face in Nigeria and in many rural communities in the Global South. Studies on factors that affect soil conservation may, however, be biased in the absence of consideration of spatial effects, particularly over time. In this paper, we use data from three waves of the World Bank's Living Standards Measurement Survey for Nigeria to explore spatiotemporal patterns in farmers' soil conservation adoption practices (i.e., mixed cropping and cover crop farming with legumes) and determine whether current soil conservation behaviours are affected by earlier adoption behaviours of neighbours. We begin with exploratory spatial data analyses to identify significant spatial clustering in the relationship between farmers' soil conservation practices in 2015 and neighbours' practices in earlier periods (2010 and 2012). The findings suggest the presence of inward diffusion – that is, conservation behaviours in 2015 are positively and significantly correlated with the conservation behaviours of neighbours in 2010 and 2012. Although the strength of the relationship lessens unless we control for farm and farmer characteristics, the effects persist once we control for these factors. Evidence of sustained neighbourhood effects forms a basis for policies to promote the most effective information diffusion methods among farmers.

**Keywords**: spatiotemporal analyses; instrumental variable technique; soil conservation; agriculture; poverty; Nigeria

**JEL Codes**: Q18, Q24, C55

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## I. INTRODUCTION

According to the FAO (2015), approximately 12 million hectares of productive land are lost to soil erosion annually, and a third of all soils are degraded (UNCCD, 2017). The problem is worse in rural communities in the Global South, particularly areas that are presently undergoing transitions due to climate change, population growth, political upheaval, land tenure change, and migration. The unprecedented pressures on soils and natural resources require urgent intervention, given that continued unsustainable land management systems lead to higher rates of erosion that exceed natural soil production. Consequences of continued soil erosion and land degradation include reduced agricultural production, food insecurity (Pimental, 2006), and destruction of water bodies (Kondolf et al. 2014), among others.

In Nigeria, the situation is no different. Land is a vital but threatened resource in the country due to soil erosion and desertification (FMARD 2016). In Nigeria, soils in certain parts of the country are naturally prone to erosion (Oguike and Mbagwu, 2009) and deficient agricultural practices have exacerbated the high erodibility of the soils in these areas, leading to deep gully sites. The situation is particularly true in the South East geographical zones. Land degradation represents a real cost to society as well as to individual farmers as it reduces crop yields and raises the levels of inputs (and therefore costs) required to restore or increase productivity (Miheretu and Yimer 2017, Wolnni and Anderson 2014).

In Nigeria, 66% of the total land area is cultivable, but less than 37% (about 34 million hectares) is currently cultivated. According to the Federal Ministry of Water Resources, the most significant constraints to the use of the remaining cultivable land for agriculture are degradation, salinization, and water logging. These environmental problems can be addressed by use of conservation practices. To combat soil degradation, measures to minimize the impact of rainfall and wind by covering the soil, impeding run-off, and maintaining soil fertility and structure should be adopted. Such measures, variously termed soil conservation measures or conservation agriculture, have been increasingly implemented. Three key elements of conservation agriculture identified in the literature include zero tillage, cover cropping and crop diversification through rotation or intercropping instead of monocropping (Powlson et al 2016; Fisher et al, 2018; Oladimeji et al., 2020). Insight into the driving factors behind the adoption of conservation practices is of paramount importance for agricultural policy making in Nigeria.

The adoption of these practices by farmers has been traditionally linked to a set of farmers' socio-economic characteristics (see: Miheretu and Yima 2017; Belachew, Mekuria and Nachimuthu 2020; Teshome, Graaf and Kassie, 2016; Abebe and Sewnet, 2014). However, the role that location and neighbourhood effects play in farmer adoption of soil conservation practices cannot be ignored. Agglomeration economies have been identified as a major incentive for spatial clustering of soil conservation behaviours among farmers. As more farmers adopt a new technology, the more information about the new technology is available to other individuals in the social group. As a result, the fixed costs of learning can be substantially reduced and provide an incentive for individual farmers to also adopt these technologies (Lewis et al., 2011). The importance of this social learning is particularly critical in rural and remote parts of the country where information is relatively scarce. In addition to agglomeration economies which may occur from knowledge-sharing, the need for social conformity may also facilitate adoption decisions of farmers in developing countries (Moser and Barrett, 2006). In rural societies, for example, there is often strong social pressure regarding compliance with desired behaviours and cultural norms (Owoo and Lambon- Quayefio, 2013; Platteau, 2000).

In this study, the role of social networks in the diffusion and adoption of soil conservation practices is assessed in a spatiotemporal context. While existing studies have typically focused on contemporaneous neighbourhood effects in soil conservation practices (e.g., Lapple and Kelley, 2014; Tessema et al., 2016), less attention has been paid to how persistent these effects may be over time. Without a temporal evolution of these activities, investigating spatial patterns in soil conservation practices offers only a partial picture of these practices. Farmers are likely to develop their processes and practices through space and over time, and only by considering space and time together can a full and comprehensive understanding of these processes and activities be achieved. Spatiotemporal modelling enables the investigation of trends in soil conservation practices over time, whereas spatial modelling only captures information at a specific point in time. If the risk of soil erosion and therefore soil conservation practices show increasing or decreasing trends over time, then the use of spatiotemporal analyses is imperative. Spatiotemporal analyses therefore have the additional benefit over purely spatial or time-series analyses, of allowing a simultaneous examination of the persistence of spatial patterns over time.

The specific questions are as follows:

1. Are farmers' adoption of soil conservation measures spatially correlated with adoption behaviours of their neighbours in earlier time periods?
2. Are these neighbourhood effects sustained over time, controlling for a host of farm and farmer characteristics?

The first research question is explored using a series of exploratory spatial data analyses (ESDA) leading to visual illustrations of hot- and cold- spots of spatial correlations of farmers' soil conservation in 2015 and their neighbours' earlier conservation behaviours. The second research question is answered by the use of spatiotemporal regression models to determine whether neighbourhood effects persist once farm and farmer characteristics are controlled for. It is important to mention that the regression analyses are intended to untangle important associations between farmers' soil conservation practices and neighbour influences over time and not to identify causal links, even if they might exist. In this study, reverse causality is unlikely to be an issue of concern, as farmers in present periods cannot reasonably be expected to influence conservation behaviours of neighbouring farmers in the past.

This study contributes to the existing literature by not only reiterating the importance of accounting for interdependence in farmers' conservation decisions, but also emphasizing the persistence of these interdependencies over time. To best of our knowledge, no study has explored the evidence in this regard. The evidence for such inward diffusion can be critical to the formulation of agricultural policy in the country. Nigeria's current Agriculture Promotion Policy 2016-2020 has as one of its main objectives: "focusing policy instruments on the sustainability of the use of natural resources (land and soil, water and ecosystems) with the future generation in mind..." Study findings would be expected to feed into the knowledge base for directing actions and programmes to promote soil conservation in Nigeria.

The remainder of the paper is organized as follows: Section II discusses the relevant literature of social networks and soil conservation behaviours; Section III presents the data and methods while Section IV discusses results from the ESDA and empirical specifications. It also presents a brief discussion of research findings and relates it with the existing evidence on neighbourhood effects and conservation behaviours. Section V concludes with policy applications from this study.

## II. LITERATURE REVIEW

Many paradigms or models for the extension of innovation exist globally (de Janvry et al., 2016). Historically in the agricultural sector, extension of innovation was the sole purview of public extension systems (FAO, 2016), but more recently, particularly in developed countries, pluralistic systems involving many actors including farmer organisations, input suppliers and non-governmental organisations, have emerged (Davis, Babu and Ragasa 2020; FAO, 2016). In this model, multiple actors –either state, non-state, or jointly, use various approaches, diverse funding, and information streams to facilitate interaction and learning in a coordinated manner (Heenskerk and Davis 2012; Eastwood et al., 2019).

Social networks can foster agglomeration economies such as reductions in costs, easier access to information, skilled labour, and input supplies within the geographic concentration of agents pursuing similar activities (Wollni and Andersson, 2014). It can also arise from social conformity. As noted by Stok and de Ridder (2019), humans are social beings; therefore they are constantly influenced by other people. The attitudes, behaviours and emotions exhibited by an individual are influenced by the social groups they are a part of (Tsusakaa et al., 2015). Thus, the decisions of neighbouring individuals are likely to be interdependent.

In the presence of limited extension services in most developing countries, many scholars acknowledge the critical role that social learning and social networks play in information delivery and technology adoption within the agricultural space (Tessema et al 2016; Weyori et al 2018). Although studies have provided empirical evidence on peer learning in the technology adoption literature, the existing empirical support for social learning is far from conclusive, as noted by Bandiera and Rasul (2006). For instance, in Ethiopia, Krishnan and Patnam (2013) argued that although extension services initially encouraged high adoption and diffusion of technology, their effects dissipated over time in comparison with the effect of learning from neighbours. Also, evidence from their study showed that the neighbourhood effect is about three times as important as extension services. In northern Ghana, Abdulai and Huffman (2014) also found that the uptake of soil and water conservation practices was influenced by farmers' social networks, as well as other farmer level characteristics such as farmers' education level, capital, and labour constraints. In examining factors that affect farmers' decision to convert to organic farming in

Honduras, Wollni and Andersson (2014) also found positive and significant neighbourhood effects. In an extensive review, Liu et al (2018) provide ample evidence from empirical studies to conclude that social norms and peer pressure are important determining factors when it comes to farmers' decisions to adopt best farming management practices across most developed and developing countries. Roesch-McNally et al. (2017) and Läpple and Kelly (2014) used data from the United States of America and Ireland, respectively, to establish the impact of neighbourhood effects on adoption of soil management techniques and organic farming. In a few cases, however, the evidence is contrary. For example, among cocoa and coffee farmers in Indonesia, Matous (2015) used panel data to show weak neighbourhood effects in the adoption of soil management practices.

The measures of social learning or peer effects tend to vary in the growing literature on social network and technology adoption. Studies including Tessema et al (2016), Wollni and Andersson (2014) and Krishnan and Patnam (2013) have used geographical proximity based on GPS data. In these studies, Euclidean distance is calculated between farm households, and researchers decide on a specific number of farmers within the bandwidth to classify as 'neighbours'. The difficulty associated with this measure, however, is what appears to be the arbitrary nature of the assigned bandwidth actually may be context specific. Other studies such as Nakano et al (2018) employ the concept of 'key farmers' to trace a farmer's network. In this structure, key farmers are trained on cultivation technologies and are then expected to train their networks who have not received such 'formal' training. A more elaborate social network, as used by Matous (2015), traces information-sharing links based on very detailed questions among farmer groups where randomly selected farmers are able to identify other farmers from whom they learned about an agricultural practice. Through this method, the researcher is able to trace a web of links from within or outside the farmer groups. Similarly, Conley and Udry (2010) construct a measure of farmers' networks by asking direct questions about their sources of information on new technologies. Even though the tracing approach allows for a neater delineation of farmers' networks, the limitation of this approach, as noted by Maertens and Barrett (2013), is the arduous task of tracing the social networks of farm households, as well as the possibility of non-representative samples from the process which limits inference making.

## III. DATA AND METHODS

### a. Data

The study uses 2010/2011, 2012/2013 and 2015/2016 waves of the World Bank's Living Standards Measurement Survey Integrated Surveys on Agriculture (LSMS-ISA) for Nigeria; this is a nationally representative dataset of 5,000 households in each wave. Over 95% of plots in the sample are owned/operated by household heads and therefore the analyses are conducted at the household (head) level. The presence of longitude and latitude GIS information is critical for the exploratory spatial analyses of neighbourhood effects in the paper, in addition to the spatiotemporal empirical strategy.

### b. Methods

A combination of exploratory spatial data analyses (ESDA) and empirical regression specifications is used to examine the importance of neighbourhood effects to the adoption of soil conservation practices among farmers in Nigeria, and whether these spatial effects are sustained over time.

Descriptive maps from the ESDA are used to present a visualization of the bivariate spatial relationship between farmer's current conservation practices (i.e., in 2015) and neighbours' past practices (i.e., in 2010 and 2012). The bivariate Local Indicator of Spatial Analysis (LISA) technique allows a visual presentation of the distribution of hot spots (i.e., spatial clusters of high soil conservation practices) and cold spots (i.e., spatial clusters of low soil conservation practices) across the country. Given the availability of longitude and latitude coordinates at the Enumeration Area (EA) level, in order to conduct the household-level analyses, EA GIS coordinates are randomly assigned to households within the EA. It is important to mention that in an ideal situation, the spatial analyses for this study would be conducted at the plot-level. Lack of access to this plot-specific GIS information has meant that household-GIS information is adapted instead. To the extent that neighbours communicate with one another and share information on their farming practices and experiences, the present configuration of influence channels is still relevant and consistent with other recent works (Wollni and Andersson, 2014).

The ESDA is complemented with a regression approach, including controls for farm and farmer characteristics, in addition to agroecological controls. Consistent with our assumption that the decision to adopt soil conservation measures is generated by a spatiotemporal dependent process, (i.e., the choices observed in one location in a current time period are similar to the choices made by farmers in nearby locations in earlier periods,) the following spatiotemporal regression model is run:

$$SC_{it} = \alpha_0 + \beta_1 W_{ij} SC_{j,t-1} + \alpha_2 X_{it} + \varepsilon_{it} \quad (1)$$

Where $SC_{it}$ is farmer *i*'s soil conservation practices (i.e., total/average number of plots under mixed cropping; and legumes cultivation) at time, t. $SCM_{j,t-1}$ refers to soil conservation practices adopted by neighbours, $j$, at time *t-1*. $\beta_1$ is the spatial regressive parameter that indicates the presence and strength of positive autocorrelation or negative spatial autocorrelation between a farmer's soil conservation practice and his/her neighbours. Where no spatial relationship is present, $\beta_1$ is zero (LeSage et al., 2011).$W_{ij}$ refers to the spatial weight matrix that defines the neighbourhood structure. An inverse distance weight matrix is used, where farmers with a greater geographical proximity are assumed to have greater influences on each other's behaviours than farmers further apart. It is ensured that every observation has at least one neighbour. $X_{it}$ refers to other controls in the model (i.e., age, gender and education of household heads, household size, household expenditures, rural/urban residence, geographical zones, average provision of extension services to plots, land/plot acquisition, plot size and distance of plot to household). To account for agroecological conditions, controls such as plot slope, elevation and wetness index are included. $\varepsilon_{it}$ is the error term.

## IV. RESULTS AND DISCUSSION

### a. Descriptive Statistics

A table of summary statistics on the analytic sample is provided below in Table 1 and a brief description of study variables follows.

The use of cover crops and mixed cropping systems have been identified as key practices within conservation agriculture (Lahmar, 2010; Lizarazo et al., 2020) and are therefore adopted as conservation practices in this study. On average, about three quarters of the total plots in the survey are characterized by mixed cropping systems, and households have about three plots with mixed cropping being practiced on them. About half of households in the sample also report that they grow legumes on their plots.

The majority (90%) of households are headed by men and household heads are, on average, about 50 years of age. Slightly over 50% of household heads in the analytic sample report that they have ever attended school. The survey mainly includes rural households, with less than 10% of farmers reporting that they reside in urban areas.

The average expenditure of households in the sample is about 116,000 naira for 2012 and 2015, increased from 77,455 naira in 2010. Household sizes have also increased over time from 5 members in 2010 to 6.5 members in 2015.

**Table 1:** Summary Statistics of Study Variables, WB LSMS-ISA Nigeria (2010-2015)

| | 2010 | | 2012 | | 2015 | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| Mixed cropping (% of total plots) | 0.748 | 0.395 | 0.781 | 0.37 | 0.73 | 0.404 |
| Mixed cropping (total # plots) | 3.099 | 2.531 | 3.441 | 2.619 | 3.297 | 2.644 |
| Legume cultivation (% households) | 0.456 | 0.498 | 0.457 | 0.498 | 0.466 | 0.499 |
| Male-headed households | 0.900 | 0.300 | 0.900 | 0.300 | 0.901 | 0.299 |
| Age of households (years) | 48.792 | 14.06 | 51.044 | 13.998 | 53.945 | 13.878 |
| Household head ever attended school | 0.603 | 0.489 | 0.584 | 0.493 | 0.558 | 0.497 |
| Urban residence | 0.079 | 0.27 | 0.078 | 0.269 | 0.078 | 0.269 |
| Household expenditure (Naira) | 77455 | 55946 | 116182 | 93194 | 116182 | 93194 |
| Household size | 5.245 | 2.701 | 6.597 | 3.139 | 6.597 | 3.139 |
| Extension services to plots | 0.148 | 0.753 | 0.067 | 0.377 | 0.114 | 0.424 |
| Land- purchased | 0.069 | 0.24 | 0.040 | 0.184 | 0.049 | 0.194 |
| Land- rented | 0.069 | 0.244 | 0.072 | 0.252 | 0.057 | 0.22 |
| Land- acquired free of charge | 0.073 | 0.251 | 0.151 | 0.353 | 0.082 | 0.268 |
| Land- community allocation | 0.788 | 0.391 | 0.737 | 0.43 | 0.812 | 0.372 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Farm-household distance | 4.967 | 53.64 | 1.119 | 2.326 | 1.427 | 5.666 |
| Plot slope | 2.880 | 2.835 | 2.824 | 2.439 | 2.911 | 2.884 |
| Plot elevation | 298.00 | 192.00 | 298.00 | 191.00 | 299.00 | 191.00 |
| Plot wetness | 14.653 | 2.669 | 14.638 | 2.775 | 14.627 | 2.691 |
| North central | 0.186 | 0.39 | 0.186 | 0.39 | 0.186 | 0.39 |
| North east | 0.168 | 0.374 | 0.168 | 0.374 | 0.168 | 0.374 |
| North west | 0.306 | 0.461 | 0.306 | 0.461 | 0.306 | 0.461 |
| South south | 0.066 | 0.248 | 0.066 | 0.248 | 0.066 | 0.248 |
| South east | 0.230 | 0.421 | 0.23 | 0.421 | 0.23 | 0.421 |
| South west | 0.043 | 0.203 | 0.043 | 0.203 | 0.043 | 0.203 |
| Observations | 1,443 | | | | | |

Extension services appear to be falling over time. While 15% of farmers reported visits by extension officers to their plots in 2010, this fell to 7% in 2013, although it increased slightly to 11% by 2015. With respect to plot acquisition, the percentage of plots that have been acquired through outright purchases has fallen over time, from 7% in 2010, to 5% by 2015. Plot rentals also appear to be falling over time. The most common forms of land acquisition appear to be by community allocation. Variables for agroecological conditions (i.e., plot slope, elevation, and wetness), in addition to geographical zones, are also included in the study. Most households in the sample are found in the North West part of the country, while the smallest proportion of households are from the South West zone.

### b. Results from Exploratory Spatial Data Analyses (ESDA)

Bivariate LISA output in Figure 1a and Figure 1b below shows some early evidence of inward diffusion of farmers' total number of plots under mixed cropping between 2015 and 2012 (see Figure 1a) and between 2015 and 2010 (see Figure 1b). It is likely that farmers in 2015 are informed and influenced by farming outcomes of their neighbours' soil conservation behaviours in earlier time periods.

Red (blue) dots represent households with many (few) plots cultivated using mixed cropping in 2015, surrounded by other households with similarly many (few) plots cultivated under mixed cropping practices in an earlier period. Although there is some evidence of negative spatial autocorrelation as well (i.e., pink and purple dots), the positive global Moran's **I** statistic of 0.335 in Figure 1a and 0.249 in Figure 1b suggests that overall, positive spatial autocorrelation is more prevalent. Interestingly, the magnitude of the spatial autocorrelation in soil conservation practices between farmers in 2015 and their neighbours in 2012 is stronger than the correlation between neighbours in 2010, suggesting that over time, neighbourhood effects diminish in strength. Significance maps on the right show the significance of the observed spatial clustering, with darker shades of green indicative of more significant spatial clusters. Significant hot spots are observed in South East and North West zones of the country, while cold spots are observed across the country, particularly in the South West and North East zones.

**Figure 1a:** Cluster and Significance Maps for total # plots under Mixed Cropping (2015/12), Moran I=0.335***.

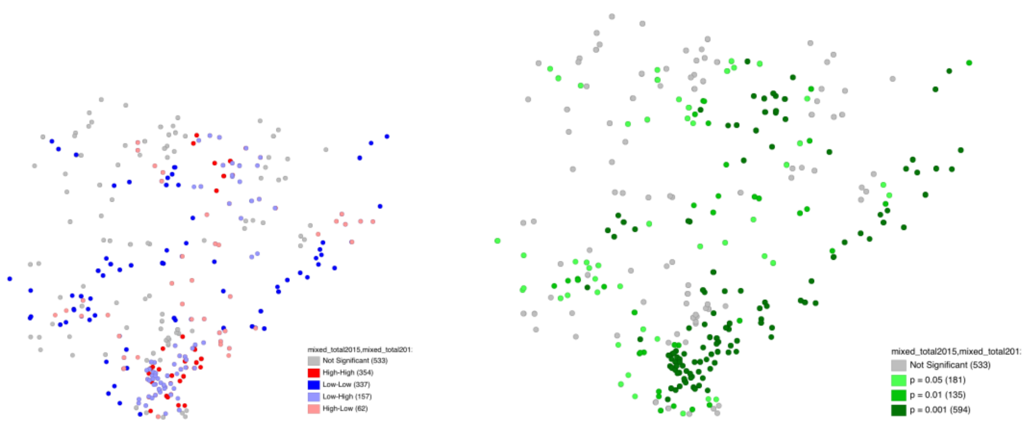
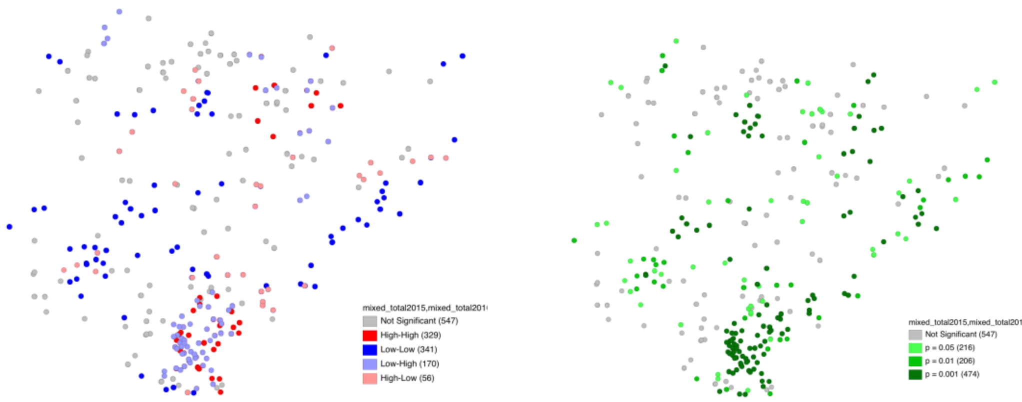



**Figure 1b:** Cluster and Significance Maps for total # plots under Mixed Cropping (2015/10), Moran I=0.249***.




*Authors' Constructions, WB LSMS Nigeria*

Similar patterns are observed for farmers' average percentage of plots cultivated under mixed cropping. Hot spots are observed in the South East and North West geographical zones of the country, with cold spots in the North East and North Central zones. Again, it would appear that neighbourhood effects diminish in strength over time.

**Figure 2a:** Cluster and Significance Maps for % of plots under Mixed Cropping (2015/12), Moran I=0.359***.

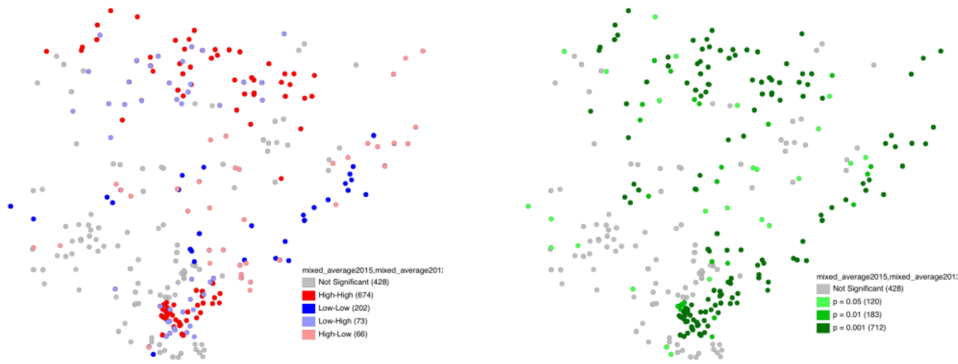
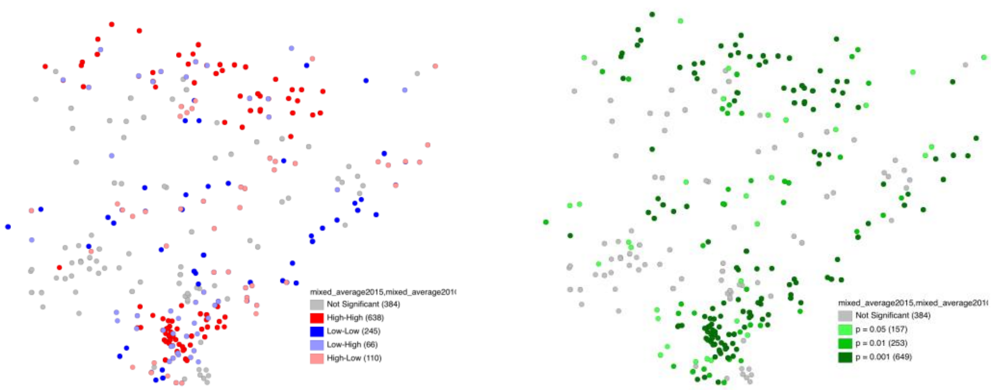



**Figure 2b:** Cluster and Significance Maps for % of plots under Mixed Cropping (2015/10), Moran I=0.326***.




*Authors' Constructions, WB LSMS Nigeria*

Figure 3a and Figure 3b show the bivariate spatial correlation between farmers' adoption of legumes cultivation in 2015 and the adoption behaviours of neighbours in earlier periods - 2010 and 2012. In Figure 3a, farmers with high (low) legumes cultivation in 2015 were surrounded by other farmers with similarly high (low) cultivation in 2012. In Figure 3b, farmers with high (low) legumes cultivation in 2015 were surrounded by other farmers with similarly high (low) cultivation in 2010. It is observed that a high spatial clustering or hot spots of legumes cultivation is observed in northern Nigeria, while cold spots are observed predominantly in the southern parts of the country. Despite the significance of neighbourhood effects, the strength of these associations also appears to diminish over time, as evidenced by the Global Moran I statistics.

**Figure 3a:** Cluster and Significance Maps for Legume Cultivation (2015/12), Moran I=0.515***.

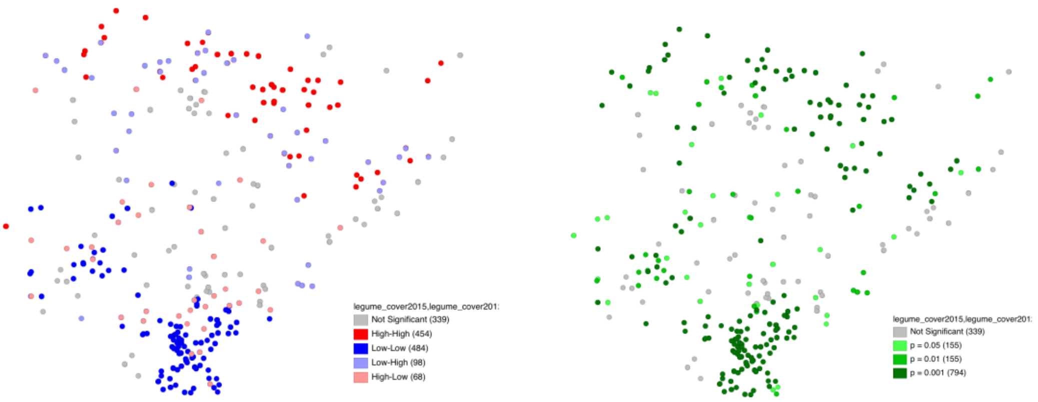
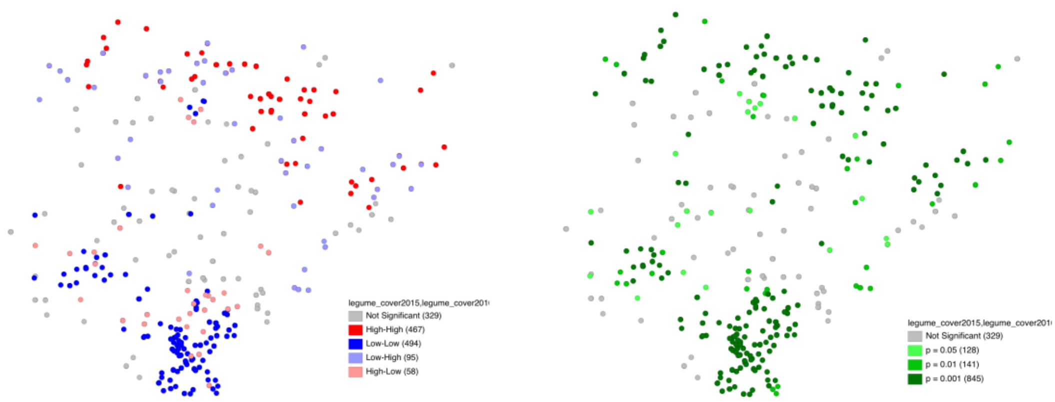



**Figure 3b:** Cluster and Significance Maps for Legume Cultivation (2015/10), Moran I=0.496***.




*Authors' Constructions, WB LSMS Nigeria*

Although the bivariate LISA highlights the presence and significance of spatial clustering in the country, it is not sufficient in providing conclusive evidence of inward diffusion of soil conservation practices of farmers over time (i.e., farmers' present conservation practices are determined by the adoption practices of neighbours in earlier periods). In order to draw closer to valid attributions of inward diffusion of information from farmers in earlier periods to farmers in recent periods, controls for potential unobservable factors are included by the use of a regression technique where a host of farm, farmer and agroecological characteristics are used.

A critical empirical challenge in the peer effects literature is the reflection problem (Manski, 1993), which is the problem of deciding whether one's outcome is affected by the outcomes of neighbours, or whether one's outcome affects one's neighbours. Given that the effects of past neighbours' conservations on a farmer's behaviour in 2015 is explored, it is unlikely that the relationship is bi-directional (i.e., a farmer's conservation behaviour in 2015 is unlikely to affect behaviour of his neighbours in 2010 and/or 2012). The presence of an endogenous effect can therefore be ruled out.

### c. Results of Spatiotemporal Regressions

Table 2 below presents the results from spatiotemporal regressions of farmers' soil conservation practices on practices of their neighbours in earlier time periods, controlling for a host of farm and farmer characteristics. The dependent variable is farmers' soil conservation practices (i.e., number of total plots under mixed cropping; proportion of total plots under mixed cropping; legume cultivation on plots) in 2015. The three main sets of independent variables are in bold in the table and comprise: Neighbours' soil conservation practices in 2012; Neighbours' soil conservation practices in 2010; and Neighbours' soil conservation practices in 2010 and 2012.

In specifications 1, 4, and 7, farmers' adoption of soil conservation practices in 2015 is correlated with the adoption behaviours of their neighbours in the 2012 farming period. In specifications 2, 5, and 8, farmers' adoption of soil conservation practices in 2015 is correlated with the adoption behaviours of their neighbours in the 2010 farming period as well. The magnitudes of the association here are smaller than observed under the earlier set of specifications, indicating that even after controlling for farm, farmer and agroecological factors, neighbourhood effects are strong but diminish over time, consistent with findings from the ESDA. Finally, in specifications 3, 6, and 9, farmers' adoption of soil conservation practices in 2015 is correlated with the adoption behaviours of their neighbours in both the 2010 and 2012 farming periods. Although the effects are smaller over time, consistent with what was observed in the ESDA above, adoption behaviours are persistent.

Other results are noteworthy: Male headed households were less likely to cultivate legumes compared to female headed households. Additionally, urban land cultivators were less likely to engage in mixed cropping in specification 2, while the presence of more household members encouraged the practice. The provision of extension services was related with mixed cropping in specification 3, although this finding was only marginally significant. With respect to land acquisition, land rentals (as compared to community allocations) were related with less adoption of mixed cropping in specification 2, although these findings were only marginally significant.

Plots situated on steep lands were related with a smaller number of plots adopting mixed cropping. These plots were also associated with lower legumes cultivation. Plots on higher ground were also associated with greater adoption of mixed cropping.

**Table 2:** Results from Spatial Autoregressive Regression models

| | *Dependent variable: Farmer adoption of soil conservation practices in 2015* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mixed cropping (# plots) | | | Mixed cropping (% plots) | | | Legumes cultivation | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Spatial lag Mixed | **0.53*** ** | **-** | **0.39*** ** | **0.49*** ** | **-** | **0.34*** ** | **0.46*** ** | **-** | **0.32*** ** |
| Cropping (total)- 2012 | **(15.42)** | | **(10.36)** | **(13.45)** | | **(8.77)** | **(13.71)** | | **(8.07)** |
| Spatial lag Mixed | **-** | **0.49*** ** | **0.31*** ** | **-** | **0.48*** ** | **0.35*** ** | **-** | **0.48*** ** | **0.29*** ** |
| cropping (total)- 2010 | | **(13.83)** | **(8.04)** | | **(13.85)** | **(9.35)** | | **(12.83)** | **(6.61)** |
| Male headed household | 0.13 | 0.12 | 0.12 | 0.02 | 0.01 | 0.01 | -0.08** | -0.08** | -0.08** |
| | (0.56) | (0.51) | (0.52) | (0.70) | (0.32) | (0.16) | (-2.13) | (-2.18) | (-2.27) |
| Age of Household head | 0.01 | 0.02 | 0.01 | -0.00 | -0.00 | -0.00 | -0.00 | 0.00 | -0.00 |
| | (0.17) | (0.63) | (0.30) | (-0.33) | (-0.17) | (-0.52) | (-0.14) | (0.23) | (-0.02) |
| Age squared | -0.00 | -0.00 | -0.00 | 0.00 | 0.00 | 0.00 | -0.00 | -0.00 | -0.00 |
| | (-0.10) | (-0.62) | (-0.30) | (0.27) | (0.02) | (0.39) | (-0.06) | (-0.46) | (-0.20) |
| Head ever went to school | 0.06 | 0.15 | 0.03 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 |
| | (0.46) | (1.15) | (0.23) | (1.13) | (0.95) | (1.14) | (1.45) | (1.47) | (1.31) |
| Urban residence | -0.33 | -0.72*** | -0.41* | -0.00 | -0.02 | -0.02 | -0.05 | -0.07* | -0.06 |
| | (-1.39) | (-3.05) | (-1.76) | (-0.02) | (-0.54) | (-0.47) | (-1.22) | (-1.85) | (-1.62) |
| Household | -0.00 | -0.00 | -0.00 | -0.00 | -0.00 | -0.00 | -0.00 | -0.00 | -0.00 |
| Expenditure (naira) | (-0.78) | (-0.91) | (-1.36) | (-0.05) | (-0.27) | (-0.43) | (-0.38) | (-0.42) | (-0.38) |
| Household size | 0.03 | 0.05** | 0.03 | -0.00 | -0.00 | -0.00 | 0.00 | 0.00 | 0.00 |
| | (1.32) | (2.15) | (1.52) | (-1.29) | (-0.05) | (-0.73) | (0.42) | (0.83) | (0.79) |
| Extension service to plots | 0.23 | 0.20 | 0.25* | 0.02 | 0.02 | 0.01 | -0.01 | -0.03 | -0.01 |
| | (1.62) | (1.38) | (1.75) | (0.70) | (0.71) | (0.53) | (-0.22) | (-1.25) | (-0.50) |
| Land- purchased (*community* | 0.28 | 0.23 | 0.25 | 0.04 | 0.04 | 0.05 | -0.00 | 0.03 | 0.02 |
| *allocation is base)* | (0.90) | (0.71) | (0.82) | (0.89) | (0.88) | (0.99) | (-0.06) | (0.50) | (0.40) |
| Land- rented | -0.29 | -0.48* | -0.34 | -0.02 | -0.04 | -0.03 | -0.05 | -0.05 | -0.05 |
| | (-1.00) | (-1.65) | (-1.19) | (-0.49) | (-0.98) | (-0.62) | (-0.98) | (-1.07) | (-1.07) |
| Land- acquired free of charge | -0.13 | -0.30 | -0.15 | 0.02 | 0.02 | 0.02 | -0.01 | -0.02 | -0.01 |
| | (-0.55) | (-1.31) | (-0.68) | (0.49) | (0.53) | (0.66) | (-0.21) | (-0.43) | (-0.24) |
| Farm-household distance | -0.01 | 0.00 | -0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | (-0.46) | (0.10) | (-0.10) | (1.09) | (0.84) | (1.20) | (1.39) | (0.87) | (1.05) |
| Plot slope | -0.04* | -0.07*** | -0.05** | 0.01* | 0.01* | 0.01** | -0.01** | -0.01* | -0.01** |
| | (-1.92) | (-2.83) | (-2.14) | (1.91) | (1.89) | (1.97) | (-2.37) | (-1.89) | (-2.38) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Plot elevation | 0.00** | 0.00*** | 0.00*** | 0.00 | 0.00*** | 0.00** | -0.00 | 0.00 | 0.00 |
| | (2.16) | (3.90) | (2.64) | (1.53) | (3.50) | (1.97) | (-0.43) | (1.27) | (0.29) |
| Plot wetness | 0.02 | 0.03 | 0.03 | 0.00 | 0.01* | 0.01* | -0.00 | -0.00 | -0.00 |
| | (0.97) | (1.03) | (1.15) | (1.14) | (1.94) | (1.76) | (-1.11) | (-0.94) | (-1.20) |
| North central (*North west is base)* | -0.47** | -0.74*** | -0.39** | -0.20*** | -0.21*** | -0.14*** | -0.16*** | -0.20*** | -0.13*** |
| | (-2.32) | (-3.64) | (-1.99) | (-6.26) | (-6.37) | (-4.28) | (-4.66) | (-5.72) | (-3.72) |
| North east | 0.05 | -0.43** | -0.03 | -0.16*** | -0.19*** | -0.12*** | 0.03 | -0.00 | 0.02 |
| | (0.28) | (-2.28) | (-0.18) | (-5.07) | (-6.28) | (-3.86) | (0.99) | (-0.02) | (0.61) |
| South east | 0.86*** | 1.29*** | 0.78*** | 0.06* | 0.08** | 0.06* | -0.41*** | -0.37*** | -0.29*** |
| | (3.57) | (5.38) | (3.29) | (1.66) | (2.30) | (1.80) | (-9.07) | (-7.56) | (-5.90) |
| South south | -0.41 | -0.40 | -0.21 | -0.14*** | -0.08 | -0.08 | -0.39*** | -0.34*** | -0.27*** |
| | (-1.29) | (-1.22) | (-0.67) | (-2.80) | (-1.59) | (-1.63) | (-6.83) | (-5.73) | (-4.54) |
| South west | -0.76** | -0.99*** | -0.61* | -0.23*** | -0.28*** | -0.22*** | -0.24*** | -0.20*** | -0.14** |
| | (-2.18) | (-2.82) | (-1.81) | (-4.39) | (-5.31) | (-4.18) | (-4.11) | (-3.28) | (-2.28) |
| Constant | 0.17 | -0.31 | -0.44 | 0.32** | 0.22 | 0.15 | 0.56*** | 0.45*** | 0.42** |
| | (0.16) | (-0.30) | (-0.44) | (2.04) | (1.39) | (0.97) | (3.37) | (2.63) | (2.54) |
| R-squared | 0.31 | 0.29 | 0.34 | 0.30 | 0.31 | 0.34 | 0.49 | 0.48 | 0.51 |
| Observations | 1,402 | 1,402 | 1,402 | 1,402 | 1,402 | 1,402 | 1,402 | 1,402 | 1,402 |

*Source:* Author calculations using NGHS 2010, 2013, 2015

*Notes: t* statistics in parentheses; $^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

Specifications 1, 2, 3 refer to inclusion of spatial lags in total plots under mixed cropping in 2012, 2010 and for both years (2010 and 2012), respectively

Specifications 4, 5, 6 refer to inclusion of spatial lags in percentage of plots under mixed cropping in 2012, 2010 and for both years (2010 and 2012), respectively

Specifications 7, 8, 9 refer to inclusion of spatial lags in legumes cultivation in 2012, 2010 and for both years (2010 and 2012), respectively

## d. Discussion of Results

It is well-known that differences in farmer productivity, particularly in developing countries, is largely correlated with differential access to information (Munshi, 2004; Jensen, 2007; Aker, 2010; Conley and Udry, 2010). Given limited access to extension services, peer learning can be an effective channel for information transfer among farmers. A number of mechanisms explain the transfer of information among peers (Oster and Thornton, 2012). First, farmers might simply choose to behave like their neighbours/peers. For example, adopting a soil conservation practice simply because their neighbours also adopt the practice. Second, one could learn about the benefits of a practice or technology from neighbours who have used these and experienced positive results. For example, farmers may adopt a conservation practice because their neighbours experienced increased yields after adopting the practice. Finally, farmers could learn how to use a technology from their neighbours' prior experience. For example, farmers may learn how to cultivate their farms using certain conservation practices from their neighbours' earlier experience. Existing studies have focused more on the first two channels. For example, Conley and Udry (2010) showed the presence of positive peer effects on fertilizer use among pineapple growers in Southern Ghana. Foster and Rosenzweig (1995) and Munshi (2004) also observed peer effects in land allocation among high-yielding variety (HYV) cotton farmers in India. In this paper, we focus on the third channel to determine whether farmers are influenced by earlier adoption behaviours of their neighbours.

Neighbourhood effects are indeed an important consideration in agriculture and soil conservation practices (Lapple and Kelley, 2014; Tessema et al., 2016). In this paper, we find additional evidence that these effects are persistent, although the strength of the relationships lessen over time. Results from the ESDA suggest that certain practices such as mixed cropping are more prevalent in the South East and North West zones of the country, while legumes cultivation is more dominant in northern zones. This suggests information flows and transfer of knowledge of soil conservation practices between farmers and neighbours over time. To draw closer to valid attributions of inward diffusion of information from farmers in earlier periods to farmers in recent periods, controls for a host of farm and farmer characteristics are used, including agroecological conditions, in the relationships between farmer adoption behaviours in 2015 and the adoption behaviours of their neighbours in 2010 and 2012. Sustained evidence of inward diffusion on farmers' conservation behaviours are observed.

As mentioned above, extension services are not widespread in Nigeria, likely as a result of staffing and funding challenges. Peer effects are therefore critical to the transfer of knowledge between farmers. This research shows that not only are these effects important, but they are also persistent over time.

A limitation of this study is that in the absence of data on network effects, it is difficult to decipher with actual certainly what particular neighbours are most critical to the transfer of soil conservation information over time. According to Tobler's First Rule of Geography that "everything is related to everything else, but near things are more related than distant things" (Tobler, 1970); this provides some rationale and justification for the use of our GIS-based approach. Using appropriate weighting matrices, evidence on the presence of neighbourhood effects and inward diffusion of soil conservation practices among farmers in Nigeria is presented. Controls are included for unobserved factors with the use of multivariate regression models.

# V. CONCLUSION AND POLICY RECOMMENDATIONS

In this research, the existing knowledge on the importance of neighbourhood effects to farmers' soil conservation adoption behaviours is extended by exploring the persistence of these effects. The study focused on Nigeria, a country characterized by high levels of erosion and soil degradation resulting in generally low agricultural production. Given the high involvement of Nigerians, particularly women, in the agricultural sector, the situation of low production has severe consequences, as many households are trapped in a vicious cycle of low agricultural productivity and poverty. Research has identified the adoption of soil conservation practices like mixed cropping and legumes cultivation as a likely approach to improving soil conditions, agricultural outcomes and therefore rural livelihoods.

There is an acknowledged dearth in the provision of information and extension services for farmers in many parts of rural Nigeria. In our analytic sample, only 10% of farmers reported receiving any extension officer visits to their plots. This suggests, therefore, that farmer-to-farmer interactions and knowledge transfers are critical to agricultural performance. It is deduced that knowledge transfers between farmers over time and across space are likely to be of particular importance in such a setting where access to information is limited. In this paper, results showed that farmer adoption of soil conservation practices and practices adopted by their neighbours are not random, but spatially clustered. This suggests that neighbourhood effects are present over time, and practices adopted by neighbours in one period are likely copied and adopted by farmers in subsequent time periods. These results persist even when farm, farmer and agroecological factors are controlled for.

A number of policy applications may be deduced from the analyses. In addition to its potential for improving agricultural productivity, research into factors that affect farmers' adoption of soil conservation have implications for poverty and gender inclusivity. In Nigeria, agriculture constitutes the single largest contributor to the well-being of the rural poor, providing livelihoods to 90% and 70% of the rural and total labour force respectively (Philip et al 2009), and yet agriculture has the highest poverty incidence rate (67%) among all occupational groups. Although the agricultural sector is dominated by men, women play significant roles across the agriculture value chain. At the national level, 48% of female headed households participate in the sector, while in rural areas about 70% of female headed households are involved in the sector (Bello et al., 2021) producing about 60-80 % of the food (FAO/ECOWAS, 2018). Enhancing the quality of farmer interactions, through joint neighbourhood initiatives, for example, is likely to have long and sustained effects on farmers' livelihoods with particular implications for women's well-being. Generally, this study emphasizes the importance of accounting for not just spatial, but also temporal interdependence in farmers' soil conservation decisions, as this has important implications for the policy formulation processes.

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