THE EFFECT OF INORGANIC FERTILIZER USE ON THE ADOPTION OF SOIL FERTILITY MANAGEMENT PRACTICES-EVIDENCE FROM MAIZE FARMERS IN NIGERIA

By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Agricultural, Food and Resource Economics—Master of Science

2019

ABSTRACT

EXPLORING THE EFFECT OF INORGANIC FERTILIZER USE ON THE ADOPTION OF SOIL FERTILITY MANAGEMENT PRACTICES IN NIGERIA

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Soil fertility management practices have been shown to improve soil health and have the potential to increase crop yield's response to inorganic fertilizer but this practice still remains scarcely adopted in Nigeria. Conversely, land intensification strategies like the application of inorganic fertilizer are largely adopted with about 60% of maize farmers using inorganic fertilizer. Thus, this paper explores the effect of inorganic fertilizer use on the adoption of four SFM practices; organic manure use, legume intercropping, water conservation techniques and reduced tillage. We find negative effects of inorganic fertilizer use on the adoption of organic manure and the share of plot used for legume intercropping. This suggests that farmers tend to treat inorganic fertilizer and organic farming practices as substitutes. This finding indicates a need for an information campaign about the complementary effect of inorganic fertilizer and SFM practices especially organic manure.

This thesis is dedicated to God, Dad and Mom.
I probably could not have done any of this without you all.
Thank you.

ACKNOWLEDGEMENTS

I will love to appreciate Dr. Saweda Liverpool-Tasie, Professor Robert Richardson, Dr. Veronique Theriault, Dr. Andrew Dillon, and Dr. Nicole Mason for their unwavering support and time in completing this thesis. You all came through for me most especially Dr. Saweda in no small measure and I could not be more grateful. Thank you so much. I also appreciate my sisters Temmy and Madesola for the calls and the moral support all through this challenging feat, you both are my bones. To my fiancée Ose, I appreciate you so much for being there for me and reading through with me for months. Thank you all.

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CHAPTER 1: INTRODUCTION

1. Background and Motivation

Over the last century, Africa has experienced an explosive growth in population. In the last 25 years alone, the annual growth rate of its population increased from 0.1% to 2.7% (World Bank Annual Report, 2018). To meet this expected demand, agricultural output has to more than double before 2050 (FAO, 2017). Among other factors, land degradation makes it increasingly challenging to increase smallholder production in many communities across Africa. This is largely attributed to the high rate of nutrient losses from the soils and the farming practices smallholders engage in (Smaling, Nandwa, & Janssen, 1997).

Although, there has been extensive focus on increasing agricultural productivity through land intensification strategies (typically the use of modern technologies such as improved seeds and inorganic fertilizer), there is increasing evidence that improving soil productivity will be necessary for these technologies to achieve this goal. Increasing soil productivity requires the use of both inorganic and organic inputs (S. Holden & Lunduka, 2010; Kamau, Smale, & Mutua, 2014; Levine & Mason, 2014; Marenya & Barrett, 2007; Ricker-Gilbert, Jayne, & Chirwa, 2011; Vanlauwe et al., 2010; Shamie Zingore, Delve, Nyamangara, & Giller, 2008). Soil scientists document that the incorporation of organic inputs (animal manure, crop residue) builds up the organic matter stock, replenishes soil carbon levels and subsequently increases the uptake of nutrients from mineral fertilizers (Palm, Gachengo, Delve, Cadisch, & Giller, 2007; Tittonell, Vanlauwe, Corbeels, & Giller, 2008). Organic inputs enhance the soil structure, improve the soil stability and increase the marginal productivity of fertilizer use (Palm et al., 2007; Tittonell, Shepherd, Vanlauwe, & Giller, 2008).

While there is evidence that farming practices such as legume intercropping, reduced tillage, water conservation techniques, herbicides, agroforestry, crop rotation, mulching and fallowing are being promoted (S Holden & Lunduka, 2010; Kamau et al., 2014; Koppmair, Kassie, & Qaim, 2017; Levine & Mason, 2014), there is still a very low rate of adoption of these practices relative to the use of inorganic fertilizer (World Bank LSMS[1], 2015) . Data from the most recent round of a nationally representative dataset on agricultural activities in Nigeria show that while 60.05% of farmers use inorganic fertilizer, only 23.05% of farmers use organic manure, 9.22% of farmers adopt reduced tillage, 5.59% of farmers adopt legume intercropping

[1] LSMS – Living Standard Measurement Survey

and 0.72% of farmers adopt at least 1 water conservation technique on their plots (World Bank LSMS, 2015). Furthermore, in the Northern zones (dominant cereal production areas), about 71.77% of farmers use inorganic fertilizer compared to 35.47% farmers that use organic manure in this zone.

A key approach national governments & donor-agency development programs in Sub-Saharan Africa have taken to increase farmer productivity is through the promotion of inorganic fertilizer use via input subsidy programs (IFDC, 2014). However, despite the huge cost of implementation, this has not been successful in increasing crop production (Liverpool-Tasie & Takeshima, 2013; Lunduka, Ricker-Gilbert, & Fisher, 2013) or improving soil fertility (Marenya & Barrett, 2009; Vanlauwe et al., 2010). Recent studies clearly reveal that the marginal returns (yield response) to inorganic fertilizer for key major cereals (rice, sorghum, maize) produced and consumed across sub Saharan Africa is low (Liverpool-Tasie, Omonona, Sanou, & Ogunleye, 2017). This is partly because of the limited adoption of complementary practices to inorganic fertilizer use thus limiting its marginal returns. Vanlauwe & Giller (2006) & S Zingore et al., (2006) document that the marginal returns to inorganic fertilizer & the marginal productivity of nitrogen depends on agro-ecological variables and the soil condition of farms (inter & intra).

There are many studies that document that both inorganic and organic fertilizers are important determinants of crop yield (Akighir & Shabu, 2011; Liverpool-Tasie & Takeshima, 2013; Marenya & Barrett, 2009; Sheahan, Ariga, & Jayne, 2016; Sheahan, Black, & Jayne, 2013; Sheahan & Barrett, 2014; Xu, Burke, Jayne, & Govereh, 2009). Other studies have demonstrated the potential complementary/substitutive relationship between inorganic fertilizer and organic inputs & by extension soil fertility management practices (Koppmair et al., 2017; Marenya & Barrett, 2009; Vanlauwe et al., 2015). However, only a handful of studies were found to have explicitly examined the relationship between inorganic fertilizer application and SFM practices. Stein Holden & Lunduka (2012) explored the effect of inorganic fertilizer use on organic manure in Malawi while Kamau et al. (2014) examined the joint decision to use inorganic fertilizer and other soil fertility management practices (particularly soil amendments and erosion control) in Kenya. (Levine & Mason, 2014) explored the extent to which household participation in a fertilizer subsidy program affected the adoption of land fallow, organic manure, minimum tillage, crop rotation & soil erosion control in Zambia. However, across West Africa, no studies were found to have explicitly examined the relationship between inorganic fertilizer application and a myriad of SFM practices. Consequently, this study contributes to filling this gap in the literature by examining the extent to which the use of inorganic fertilizer could affect the adoption (demand) of a suite of complementary SFM practices using plot level data of maize farmers in Nigeria, Africa's most populous country. Nigeria has a population growth rate of 3.2% and is expected to be the 3rd most populous country globally by 2050 (FAO, 2017). Limited growth in agricultural productivity in the country poses a huge food security challenge to the nation with implications across the continent and the world. However, as in SSA generally, there is recent evidence confirming the low marginal returns to inorganic fertilizer for the 3 major cereals (rice, sorghum, maize) in Nigeria. Liverpool-Tasie et al., (2017) document that the Marginal Physical Product (MPP) of applied nitrogen (i.e. additional cereal output gained from an additional unit of applied nitrogen) is about 8kg, 9kg and less than 2kg for rice, maize and sorghum respectively. Though the findings for Nigeria are still within the ranges that have been found in other studies across the continent, (often between 7 and 14 kg for maize and rice), they are at the low end of the range in Africa (Liverpool-Tasie et al., 2017). This indicates the importance of all efforts geared to support increased agricultural productivity in the country.

Using three waves of nationally representative data on maize producers in Nigeria, this study uses panel data methods to explore the extent to which the use of inorganic fertilizer crowds in (or out) the use of SFM practices that have scientifically been found to be complementary to inorganic fertilizer use in maize production. We derived reduced-form, input demand functions from the non-separable agricultural household model and estimated the decision to adopt these complementary SFM practices at both the extensive and intensive margin. The practices include organic manure use, legume intercropping, reduced tillage & water conservation techniques.

Consequently, the findings of this study are useful to policy makers and development practitioners geared to stimulate agricultural production across SSA through modern input use and particularly through sustainable agricultural intensification. Evidence of crowding out effects of inorganic fertilizer on the demand for SFM practices indicates the substitutive role of both technologies, which ultimately leads to reduced marginal productivity of inorganic fertilizer used. However, evidence of crowding in effects of inorganic fertilizer use on the demand for complementary SFM practices (in production) indicates additional benefits of management practices that might not have been captured and are not widely discussed.

2. Background

2.1 The complementarity of organic and inorganic inputs on soil organic matter

There is a complementary relationship between organic (manure, N-fixing legume, mulch, crop residues) & inorganic (fertilizer, improved seeds) inputs which builds up the soil's organic matter stock (Vanlauwe et al., 2015). Organic inputs improve the soil structure & increases the marginal returns obtained from using an additional unit of inorganic fertilizer (Vanlauwe et al., 2015). This in turn increases the availability of nutrients for crops without depleting the soil organic matter stock. This shows the complementarity of organic & inorganic inputs and the effect it has on the soil's organic matter stock.

This complementary relationship has been documented by Marenya & Barrett (2009) & Kimetu et al. (2008) where continuous cultivation of farmlands with no investment in organic inputs leads to soil degradation among farmers in Kenya. The adoption of both organic and inorganic inputs replenishes soil nutrients from excessive nutrient loss (leaching, erosion and harvest). This is very important as S. Holden & Lunduka (2012) estimate that about 30kg N and 20kg K of nutrient is lost per hectare in Sub-Saharan Africa because of excessive leaching and erosion. On maize plots in Kenya, about one third of the degraded plots had limited crop yield response to fertilizer, which made farmers unwilling to rationally purchase inorganic fertilizer (Marenya & Barrett, 2009).

The combination of rich soil organic matter content and inorganic nutrients is crucial because of the declining soil fertility that constrains subsistence farmers agricultural production in Sub-Saharan Africa (Marenya & Barrett, 2009). This declining soil fertility on the continent, if not managed will be a barrier to ending poverty and food insecurity (IFDC, 2006) which is in line with the contribution of this study. Despite the cost implications (in terms of labor & other resources with multiple alternative uses) associated with adopting both inorganic and organic soil investment practices, cultivation of degraded soils with only inorganic fertilizer will yield unprofitable marginal returns (S Zingore et al., 2006).

2.2 Soil Fertility Management (SFM) practices

SFM practices are soil management techniques that sustain soil fertility overtime. These practices range from land management practices such as minimum tillage, mulching dry leaves/shrubs, use of animal or plant based amendments, erosion control (soil conservation), water conservation and nitrogen-fixation techniques. The main purpose of SFM practices either minimum tillage, organic manure, mulching, earth bunds or legume intercropping is to provide nutrients (nitrogen, carbon) to lacking soils, such that these soils are able to deliver profitable yield to farmers.

Sanchez (2002) presented the second paradigm[2] for soil fertility management with a purpose of overcoming soil constraints by investing in biological processes (enhancing soil biological activity or optimizing nutrient cycling) to minimize the use of external inputs while maximizing the efficiency of the nutrients obtained from these inputs. Vanlauwe et al. (2010) defined ISFM as a comprehensive set of soil fertility management practices which includes integrating organic & inorganic inputs (including improved seed variety) combined with the knowledge of adapting to local conditions.

Integrated soil fertility management (ISFM) has been promoted for over three decades (Vanlauwe et al., 2010). In 2010, there was a launch of the Alliance for a Green Revolution in Africa with a focus on the use of inorganic fertilizer and maximizing the agronomic efficiency of its nutrients and value (cost ratio of fertilizer). Agronomic efficiency defined by (Vanlauwe et al., 2010) is the extra crop yield produced per unit of fertilizer nutrient applied and which is higher in soils with rich organic matter stock or rich carbon content (Marenya & Barrett, 2007). Therefore, farmers maximize the returns on the nutrients of inorganic fertilizer applied when there is adequate soil organic matter, which can be made available from the adoption of SFM (soil fertility management) practices (Tittonell, Vanlauwe, et al., 2008). In addition, maximizing the efficiency of external inputs like inorganic fertilizer minimizes the risk of inorganic fertilizer nutrients moving beyond the rooting zone into the environment and polluting water sources (Giller, Rowe, De Ridder, & Van Keulen, 2006), thus benefiting the environment overtime.

However, SFM practices require more time for adoption and take a longer period to deliver observed increases in yields. In addition, SFM practices often require relatively fewer external inputs but are largely laborious in nature thus requiring an increased demand for family and hired labor (Lee, 2005). For example, organic manure demands labor for its preparation, transportation and application and has lower concentration of nutrient than inorganic fertilizers (Stein Holden & Lunduka, 2012). Legume intercropping, mulching, minimum tillage and fallowing take a very long time to build up the soil organic matter stock (Marenya & Barrett,

[2] First paradigm relates to overcoming soil constraints and providing plant nutrients through purchased inputs

2009) and requires more time and labor to adopt compared to inorganic fertilizer application. Giller, Witter, Corbeels, & Tittonell (2009) found that farmers in the Zambezi valley of Zimbabwe had a lower adoption rate of crop rotation because of the demand for additional labor input. Duflo, Kremer, & Robinson (2011) also found that the time horizon for organic farming practices to yield results discourages farmers in SSA as they are more interested in immediate costs and benefits rather than future benefits. Marenya & Barrett (2007) show that Kenyan household's decision to adopt (or dis-adopt) SFM practices depends on their access to cash and labor. Thus, labor and liquidity constraints alongside time inconsistency have led to substitution of organic manure or legume intercropping for inorganic fertilizer whose time horizon for increased yields is shorter and requires less labor input.

2.3 Benefits of SFM practices

2.3.1 Animal Manure and Plant Compost

Compost is rich in nutrients as it benefits the land in many ways. It serves as a soil amendment, natural pesticide, erosion control and landfill cover. Excluding animal and plant compost, there are other forms of organic fertilizers, which include peat, guano, treated sewage sludge and many more. Peat and guano are mined materials but differ from mineral fertilizers. Peat improves the percolation of the soil to absorb water and air. Animal sources of organic fertilizer include blood meal, bone meal, horns, hides, hoofs, feather meal & fishmeal. Treated sewage sludge (animal sourced urea & urea-formaldehyde from urine) also known as bio solids serve as organic soil amendments. Blood meal, guano and animal sources of organic fertilizer release their nutrients over 3 to 6 weeks. The other forms of organic fertilizer like urea, fish emulsion and burned eggshells release their nutrients faster.

2.3.2 Legume Inter-cropping

Biological nitrogen fixation from grain legumes supplies about 300kg N/ha and about 600kg N/ha through tree legumes (Palm et al., 2007). The balance between the amount of nitrogen fixed into the soil and the amount removed during the production process are important factors in maintaining soil fertility. Grain legumes like cowpea add the highest amount of nitrogen into the soil with low harvest indices of nitrogen while high yielding varieties of soybean remove huge amounts of Nitrogen from the soil (Vanlauwe & Giller, 2006).

Maize-legume intercropping was found to boost the yield of component crops and enhance the fertility status of the soil in Ethiopia (Abera, Feyissa, & Yusuf, 2005). In addition, incorporating leaves from leguminous trees in Nigeria were found to reduce acidification from the excessive use of chemical fertilizer (Vanlauwe et al., 2015). Legume cereal inter-cropping is more beneficial to the soil than mono-cropping as the leguminous crops make more efficient use of the sun radiation which is due to the increased availability of nitrogen in the soil (Kermah et al., 2018).

2.3.3 Water Conservation technique

These are structures that conserve water and prevent soil run off. These structures are mostly created on steeper slopes and on soils susceptible to erosion from torrential rainfall or on land with very little vegetation. These techniques include terraces, ridges and barriers which help conserve water and prevent top soil run-off.

2.3.4 Reduced tillage

This technology relates to plowing of the farmland into basins or thin furrows. One main method of tilling common among smallholders is the hand hoe minimum tillage which relates to digging deep basins while tilling and placing seeds, fertilizer and other inputs within those basins to ensure maximum nutrients for the crops. In addition a specially designed plow "Magoye rippers" can be used to till and dig thin furrows while leaving the soil structure stabilized. Crops are placed in the thin deep furrows which allows for maximum growth.

This study focused on these four particular SFM practices; organic manure, legume intercropping, water conservation technique and reduced tillage. As mentioned earlier, these SFM practices were selected from the practices available in the Living Standard Measurement survey data for farmers in Nigeria because of their complementary relationship with inorganic fertilizer. Organic manure adds carbon or phosphorus especially to lacking soils and thus allows for increased matter stock which increases the absorption of nutrients from applied inorganic fertilizer. Legume intercropping combats soil acidification and increases the profitability of inorganic fertilizer (Abera et al., 2005; Vanlauwe et al., 2015). Water availability increases the returns from inorganic fertilizer use. Smaling et al. (1997) posited that one of the key reasons for the differential yield response of inorganic fertilizer in Asia relative to Africa was the difference in water use due to agro ecological conditions (such as annual rainfall rate) and the low adoption of irrigation. With regards to hand-hoe tilling into furrows or basins, this is complementary to inorganic fertilizer because it allows for very easy penetration of nutrients without disrupting the soil structure. The thin furrows or basins create room for maximum plant growth even if there is torrential rainfall, thus complementing the use of inorganic fertilizer.

2.4 Maize Production in Nigeria

Maize is the most important cereal crop in Sub-Saharan Africa. It is consumed as a staple food and used as feedstock as well as for the production of ethanol fuel and other industrial products. According to Umar, Ado, Aba, & Bugaje (2014), maize production increased from 4.1 million tons and 7.1 million tons between 2000 and 2006 respectively to 8 million tons and 10 million tons in 2010 and 2013 respectively. Nigeria is a leading maize producer on the continent; second to South Africa (FAO, 2017). While maize is grown in a range of agro-ecological environments across the country, majority of dry maize in the country comes from the Northern Guinea Savannah; known as the maize belt of Nigeria (Badu-Apraku, Fakorede, & Oyekunle, 2014; Iken, J.E. and Amusa, 2004; IITA, 2012; U. A. Umar, Muhammad, & Aliyu, 2015).

Maize production in Nigeria faces several challenges and maize yield in the country is quite low. Using the LSMS dataset for 2010 and 2012, Liverpool-Tasie (2017) document maize yields among farmers in the main cereal-root crop farming system of the country to be slightly over 1,000kg per hectare. This is much lower than the average yields in Asia, and USA of about 4,535kg and 8,164kg respectively (FAO, 2010). One important challenge is pests & diseases attack. It accounts for about 20-40% losses during cultivation and 30-90% loss after harvest (IITA, 2012). Another challenge is the poor quality of soils used for cultivation and the accompanied low yield response to inorganic fertilizer (Vanlauwe et al., 2015).

2.5 SFM Practices on maize plots in Nigeria

The benefits of SFM practices are numerous as explained above and overtime, its future benefit to the environment & the soil productive capacity outweighs its cost of adoption (labor, time and increased liquidity). Organic manure use has a relatively higher rate of adoption[3] among

[3] See Figure 1 & Table 1 for rate of technology adoption among maize farmers in Nigeria

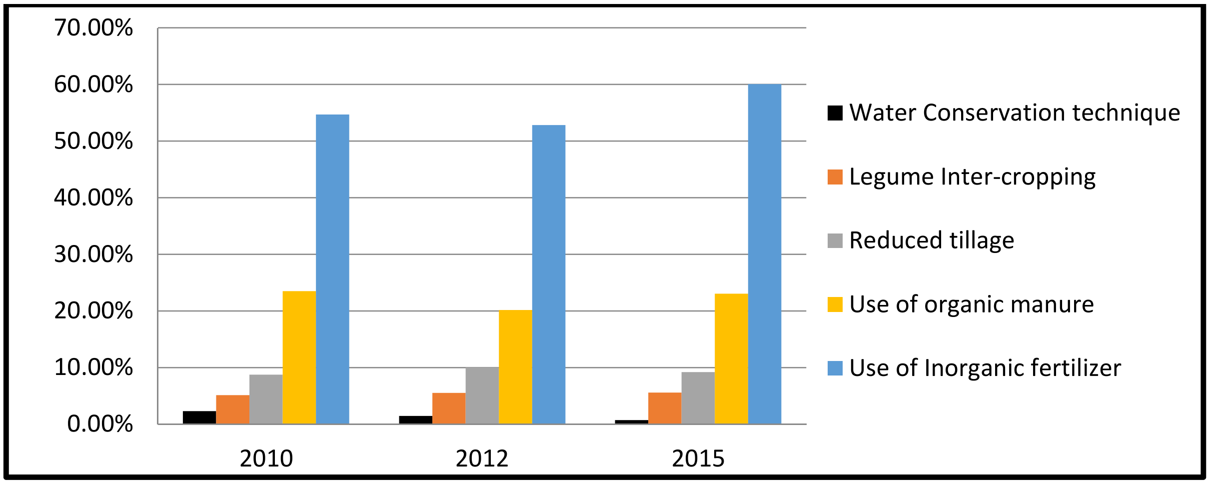
maize-farming households in comparison to other SFM practices. With about 23.52% of maize-farming households adopting SFM practices, it is about sixty-percent above the rate of adopting reduced tillage and water conservation techniques. One reason for this high demand could be the relative increased market access for organic manure and the availability of ready-to-go packages sold in the market which saves time and labor.

We find that maize-farming households have a lower rate of using reduced tillage for land preparation relative to the use of organic manure. Only about 9.22% of households adopt reduced tillage for maize cultivation. As stated overtime, the labor intensive nature could contribute to the low adoption rate. However, there is a significant difference in the adoption rate of reduced tillage across the Northern and Southern zones with 9.89% and 2.21% of farmers adopting in these zones respectively. This could arise from the high population density and relative less economic dynamism in the Northern zones in relation to the Southern zones, this allows farmers prioritize labor-using SFM practices like reduced tillage (Jayne, Snapp, Place, & Sitko, 2019).

Very few maize-farming households adopt legume intercropping; about 5.59% of them reported intercropping maize with legumes. However, we see that there is a higher rate of farmers adopting legume intercropping in the Northern zone relative to the Southern zone with 6.31% and 4.04% of them adopting in these zones respectively. We depict this relationship in Figure 2. This is likely because Northern zones are the major cereal dominant areas in Nigeria, thus, the increased rate of legume intercropping in these zones.

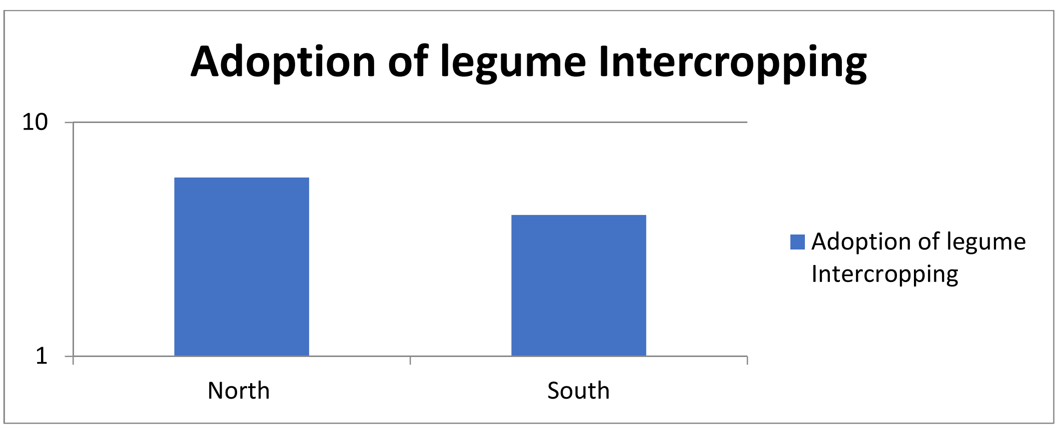
We also see that maize-farming households have a very low rate of adopting water-conservation techniques. Less than one percent (0.72%) of them adopted at least one water conservation technique in 2015. However, we see a higher adoption rate of water conservation practices in the Northern zones which is usually hotter during planting seasons. We find that 2.17% & 0.42% of maize farmers adopt at least one water conservation technique in the Northern and Southern zones respectively.

Figure 1: Rate of technology adoption on maize plots in Nigeria



Source: Author calculations from Living Standards Measurement Survey (2010-2015)

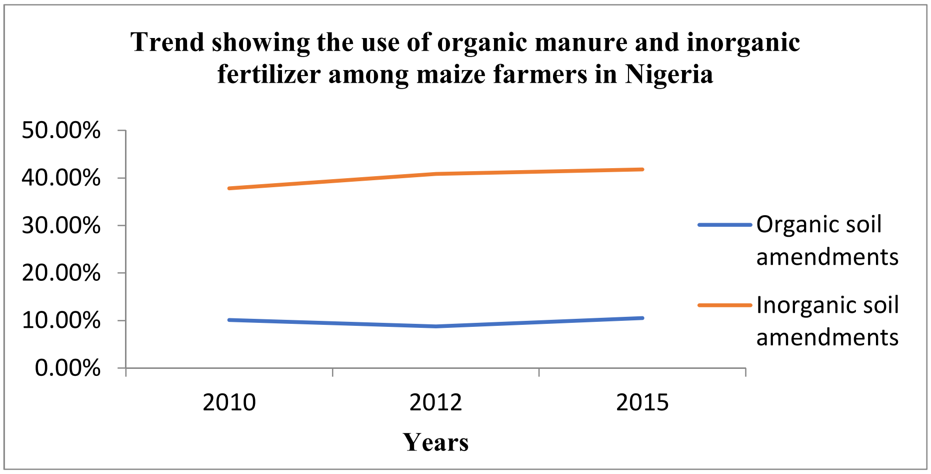
Figure 2: Adoption rate of legume intercropping among maize farmers in the Northern & Southern zones of Nigeria



Source: Author calculations from Living Standards Measurement Survey (2010-2015)

Comparing the use of organic manure and inorganic fertilizer over the years, we see an increased rate of inorganic fertilizer use in comparison to organic manure use, thus we show a trend in Figure 3 that captures the use of organic manure relative to the use of inorganic fertilizer overtime.

Figure 3: Trend showing the use of organic manure and inorganic fertilizer among maize farmers in Nigeria



Source: Author calculations from Living Standards Measurement Survey (2010-2015)

Table 1: Rate of technology adoption on maize plots in Nigeria

Year	2010 (%)	2012 (%)	2015 (%)
Water conservation technique	2.32	1.48	0.72
Legume Intercropping	5.14	5.52	5.59
Reduced Tillage	5.10	6.19	9.22
Use of Organic manure	23.52	20.15	23.05
Use of Inorganic fertilizer	54.68	52.84	60.05
No. of observation	2802	2973	3059

Source: Author calculations from Living Standards Measurement Survey (2010-2015)

2.6 Literature Gap

A strand of literature documents the complementary relationship of inorganic fertilizer & organic manure and their individual roles in boosting soil organic matter and productivity (Vanlauwe et al., 2010). To establish empirical evidence of substitution or complementarity, S. Holden & Lunduka (2012) explored the effect of receiving free or subsidized inorganic fertilizer on the adoption of organic manure using plot level data on farmers in Central & Southern Malawi. S. Holden & Lunduka (2012) also determined how participation of Malawi FISP affects farmers' decision to cultivate certain crops like nitrogen-fixing legumes using plot level data. Another strand of literature like Koppmair et al. (2017) and Levine & Mason (2014) went a bit further to determine the effect of receiving subsidized fertilizer on the adoption of a myriad of soil fertility and natural resource management techniques using household level data among farmers in Malawi and Zambia respectively.

In order to fully explore the low adoption of SFM practices across SSA, another strand of literature focused on the demand for soil fertility management practices to determine the factors responsible for its adoption. Kamau et al. (2014) explored this relationship using plot level data of Kenyan farmers while Marenya & Barrett (2007) explored the demand for soil fertility management practices using household level data of farmers in Western Kenya. In this same fashion; Ngoma , Mulenga & Jayne (2014) explored the determinants and the extent of adopting minimum tillage using household level data of Zambian farmers. However, we find limited studies exploring how inorganic fertilizer use crowds out a myriad of soil fertility management practices using plot level data among farmers in West Africa and none in Nigeria.

Therefore, this study explores how the demand for other soil fertility management practices is affected by the use of inorganic fertilizer in Nigeria. No studies were found (in the extensive literature search conducted) that explored this production relationship among farmers in Nigeria and how plot characteristics could affect the demand for SFM practices. Thus, this study estimates the extent to which farmer decisions to use inorganic fertilizer are correlated with their decision to adopt other SFM practices in Nigeria and if such SFM adoption decisions are jointly made by farmers. As stated earlier, evidence of crowding out effects of inorganic fertilizer use on the demand for SFM practices indicates the substitutive role of both technologies to farmers while evidence of crowding in effects of inorganic fertilizer use on the demand for complementary SFM practices (in production) suggest that farmers are aware of the benefits of adopting both technologies.

2.7 Study Objectives & Research Question

The objective of this study is to explore the relationship between the adoption of inorganic fertilizer and other soil fertility management (SFM) practices. With the important complementary relationship between SFM practices and inorganic fertilizer use, it is essential to understand how the use of inorganic fertilizer might inform farmer's decision to adopt other farming practices or not. Therefore, this study aims to achieve this objective by answering this research question and testing the following hypothesis.

- What is the effect of commercial inorganic fertilizer use on the adoption of organic manure, legume intercropping, water conservation techniques and reduced tillage among maize farmers in Nigeria?
- ***Hypothesis-***The purchase of commercial inorganic fertilizer crowds out the adoption of organic manure, legume intercropping, water conservation techniques and reduced tillage among maize farmers in Nigeria.

CHAPTER 2: CONCEPTUAL FRAMEWORK

In perfectly competitive and complete markets, households are price takers (prices determined by the market forces of demand & supply) and all traded products are at the prevailing market price. In this case, we can separately solve both production and consumption decisions of the household; the household determines its output supply based on prices of input & output, quasi-fixed factors and exogenous factors affecting production. The income derived from the household's production activity along with other sources of income becomes included in the household's consumption decision as a budget constraint (de Janvry & Sadoulet, 1995).

In Nigeria, poorly functioning credit and input markets make it impossible to assume separability of the households' decisions. Credit markets are not perfect as lenders regard it very risky to give out credit to farmers because of the inherent risk embedded in agricultural production and the limited presence of insurance. Households with better endowments have better access to finance relative to their less wealthy counterparts. There is information asymmetry between lenders and borrowers in Nigeria as there are usually poor records of credit standing of these borrowers; this makes it difficult for lenders to finance farmers especially the asset poor farmers. Credit institutions also have a very hard time laying claim to their finances because of the cost of enforcement; this can be very expensive and tasking as there are no laws governing repayment of loans especially informal loans in Nigeria and this increases the risk of providing finance to farmers.

Transaction and transportation costs pose significant challenges in the input market in Nigeria as many rural households face high transportation & transaction costs to secure their inputs and market their output. Market prices do not fully capture the real cost farmers incur to purchase inputs, extra cost incurred includes information and search costs needed to obtain inputs. This extra cost varies by households as resource endowed farmers with better social networks incur less search/information cost compared to farmers with less endowments. These market imperfections and failure make it necessary to assume non-separability of the agricultural household model in trying to understand production and input use decisions in rural Nigeria.

Therefore, to model the fertilizer decision-making process of maize farming households in Nigeria, we consider the maize enterprise of rural households in Nigeria and the trade-offs faced between the current planting season (k=0) and harvest season (k=1). Each household has an endowment of land (A), family labor (L^T), wealth (W), and education (E) that is employed into the production process; to maximize the stream of utility derived from the adoption of both organic and inorganic soil amendments. Thus, a farmer must choose the amount of endowments employed into the use of organic or inorganic farming practices. Households face a subsistence constraint such that in each season k and year t, each household must consume a minimum amount needed for survival denoted by C^{min}. Households also face a budget constraint, which binds the value of consumption (C) and savings (S) to the total income (Y^T) and other borrowings (B) from each season. They also face a labor constraint which requires that the labor allocated to on farm production of maize from the household (L^M) and non-farm employment (L^w) does not exceed the total family labor endowments (L^T).

Using a stylized model of household behavior, consider a household who aims to maximize utility derived from material consumption (C_{ikt}) which is subject to the budget, labor and subsistence constraint (Singh, Squire & Strauss, 1986). This utility maximization problem is set up below

$Max\ L^H, L^w\ \sum_{t=0}^{\infty}\sum_{k=0}^{1}\partial^{2t+k}\ U(C_{ikt})$………………………………….. (1)

Subject to

$C_{ikt+}\ S_{ikt}\ \leq\ Y_{ik}^T + \mathrm{E}$….. (2) ***Budget Constraint***

$L_{ikt}^M +\ L_{ikt}^w \leq\ L_{ikt}^T$……………………………… (3) ***Family Labor Constraint***

$C_{ikt} \geq C^{min}$…………..……………………….…….. (4) ***Subsistence Constraint***

Variable definitions;

$W_{ikt}\ =\ W_{i(1-k)(t+k-1)} +\ S_{ikt}\ \geq 0$...………..…………..……. (5) Household Wealth

$Y_{ikt}^T\ \equiv\ Y_{ikt}^m +\ w_{ikt}(E_i, w_{jt}, O_{ikt})L_{ikt}^w +\ B_{ikt}$……………. (6) Household total income

$Y_{ikt}^m\ \equiv\ P^m q_o(L_{ikt}^M, L_{ikt}^h, F_{ikt}, M_{ikt,}Seeds_{ikt}|A_{it}, M_{i(t-1)}, L_{i(t-1)}^M, L_{i(1-k)t}^h) -\ w_{jkt}L_{ikt}^h$
$-\,p^F F_{ikt}\ -\ p^o M_{ikt} -\ p^s Seeds_{ikt}$……………...……….…....… (7) Maize Income

The income accrued to each household comes from the production of maize, other crops (millet, sorghum, and legume), other non-farm activities they engage in, their borrowings & savings. Maize income is the value of the maize output produced in each planting season which is derived from the price of maize (P^m) times the quantity of maize produced (q_0) minus the cost of hired labor (w), fertilizer (p^F), manure (p^o) , maize and legumes seeds (p^s) used for household production. Thus, we assume land, labor, fertilizer, manure, maize & legume seeds are the only inputs employed in the production process. Land is a quasi-fixed input for few households with 25.67% of 8834 plots owned & 74.33% rented for cultivation. The household earns income from the sale of the output of maize produced (farm income) from which the cost of variable input is deducted. This is added to income from non-farm employment activities and exogenous income (E); this forms the total household income (Y^T) which is equal to the household's expenditure on consumption and savings.

Revenue derived from maize production accrues only in the harvest season (k=1) while revenue is not accrued in the planting season (k=0). Therefore, in the planting season, there is a cost incurred by households that must be covered by either savings, borrowings, exogenous income or other earnings from non-maize enterprises, which is determined by output from previous harvest season, level of education, and prevailing local labor market conditions. In addition, the labor constraint plays a crucial role in the allocation of labor for households who have limited time endowments at the onset of the season to offset the planting season loss through non-farm employment, collateral for borrowing or savings. Thus, households are constrained to allocate labor and other inputs to either technology choice in an efficient manner to maximize utility taking planting season loss into consideration.

Setting up the household's inter-temporal utility maximization problem with a full constraint is set up below;

$Max_{\ L^M,\,L^w}\ U(C_{ikt}) + \partial\ V\ (A_{ikt}, W_{ikt})$.. (8)

Subject to

$Y^m_{ikt} +\ w_{ikt\,(E_i, w_{jt}, O_{ikt})} L^w_{ikt} +\ B_{ikt} + E\ - S_{ikt} \geq\ C^{min}$ .... (9)

We incorporate the labor, budget and subsistence constraints into one major constraint that binds the choice variables of interest. Household's choices are made at the beginning of the planting season where (k=0) and setting t at an arbitrary value of 0, the Lagrange set up and the first order conditions to the constrained utility maximization problem of each household is written below;

$$\mathcal{L}=U(C_{i00}) + \partial\, V\,(C_{i10}) + \lambda_1 \{P^m q_0\big(L_{i00}^M, L_{i00}^h, F_{i00}, M_{i00}^h, Seeds_{i00},\ \big|A_{i0}, M_{i(-1)}, L_{i(-1)}^M, L_{i(-1)}^h\big) - w_{j00}L_{i00}^h - P^F F_{i00} - p^o M_{i00} - p^s Seeds_{i00}\} + w_{i00}(L_{i0}^T - L_{i0}^M) + B_{i00} + E - S_{i00} - C^{min} \text{..........} \quad (10)$$

$$\frac{\partial \mathcal{L}}{\partial L^M} = -\frac{\partial U(C_{i00})}{\partial C_{i00}}\, w_{i00} + \frac{\partial V(C_{i10})}{\partial C_{i10}}\, P^m - \lambda_1 w_{i00} \leq 0 \text{ ....} \quad (11)$$

$(\frac{\partial \mathcal{L}}{\partial L^M}) = 0$; L_{i00}^M is positive if the marginal net benefit of increasing the labor devoted to either organic or inorganic farming practices in the planting season is zero.

$(\frac{\partial \mathcal{L}}{\partial L^M}) < 0$; L_{i00}^M is zero if the marginal net benefit of increasing the labor devoted to either organic or inorganic farming practices in the planting season is negative.

$$\frac{\partial \mathcal{L}}{\partial L^w} = -\frac{\partial U(C_{i00,})}{\partial C_{i00}}\, w_{i00} + \frac{\partial V(C_{i10})}{\partial C_{i10}}\, w_{i00} + \lambda_1 w_{i00} \leq 0 \text{......................} \quad (12)$$

$(\frac{\partial \mathcal{L}}{\partial L^w}) = 0$: L_{i00}^w is positive if the marginal net benefit of increasing the labor devoted to non-farm enterprise in the planting season is zero. This increased labor for non-farm enterprise implies increased hired labor in the planting season to offset the low time endowment.

$(\frac{\partial \mathcal{L}}{\partial L^w}) < 0$: L_{i00}^w is zero if the marginal net benefit of increasing the labor devoted to non-farm enterprise in the planting season is negative. This decreased labor for non-farm enterprise implies decreased hired labor in the planting season.

$$\boldsymbol{\mathcal{L}_{\lambda_1}} = \boldsymbol{\lambda_1} \{P^m q_0\big(L_{i00}^M, F_{i00}, L_{i00}^h \big| A_{i0}, L_{i(-1)}^M, L_{i(-1)}^h\big) - w_{j00}L_{i00}^h - P^F F_{i00}\} w_{i00}(L_{i0}^T - L_{i0}^M) + B_{i00} + E - S_{i00} - C^{min} = 0 \text{...} \quad (13)$$

This conceptual model applies to the adoption of organic manure and inorganic fertilizer since both technologies are divisible with relatively similar application methods. We recognize that this conceptual model is not directly applicable for all soil fertility management (SFM) practices. Our other SFM practices; legume-maize intercropping, water conservation techniques and reduced tillage are land management practices, which require a different method to conceptualize their adoption. For example, reduced tillage is a pre-planting management practice; this less rigorous land-preparation technique requires a hand-hoe or a specially designed plow (Magoye rippers). This decision comes during the pre-planting season and is different from purchasing soil-amendments (inorganic fertilizer, organic manure) during the planting season or previous planting seasons. For legume intercropping, farmers decide to intercrop if the utility derived from adopting is higher than mono cropping (Maize). This decision to adopt depends on the net expected benefit derived from either technology, which is a linear combination of explanatory variables and the error term (Koppmair et al., 2017). Farmers also decide to adopt any water conservation practice if the utility derived from conserving water on plots outweighs the cost of purchasing irrigation pumps. Factors influencing this decision range from the prevailing ecological variables (rainfall) in farmers' zones to the liquidity and labor constraints faced by farmers. If the net expected benefit is positive, farmers are more likely to adopt at least one water conservation technique (terraces or earth buns) to conserve water.

Despite these conceptual differences in dealing with these different SFM practices, the factors that are important for the decision to adopt organic manure and inorganic fertilizer are likely to be similar to those that determine the adoption of the land management SFM practices that we consider. Consequently, we largely explore similar sets of explanatory variables in our empirical estimations of adopting all four SFM practices. From the solution to the constrained utility maximization problem above, we can express the household's decision to adopt organic farming practices as a function of the household characteristics (educational level, initial wealth, household endowments, and other income), community characteristics (ecological factors, prices of output & input, wage rate) and exogenous factors affecting production:

$$q_0 = f\left(E_i, W_{i0}, A_{i00}, I_{i00}, E_j, P^F, P^m, P^o, P^s, w_{j00}, w_{i00}, Z_{i0}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(14)}$$

CHAPTER 3: EMPIRICAL ESTIMATION & SAMPLING

3.1 Estimation techniques

Drawing from the conceptual framework, we estimate the adoption of SFM practices as a linear combination of the explanatory variables captured in equation 14. Our explanatory variable of interest is kilograms of inorganic fertilizer used, because we are particularly interested in the extent to which household decisions to adopt organic manure, legume intercropping, water conservation technique and reduced tillage are affected by their use of inorganic fertilizer. To estimate these effects, we specify the following linear unobserved effects panel data model:

$$Y_{ijt}^{*} = \beta_0 + \beta_1 \boldsymbol{P_{ijt}} + \beta_2 IF_{\boldsymbol{ijt}} + \beta_3 \boldsymbol{A_{ijt}} + \beta_4 \boldsymbol{X_{it}} + \beta_5 \boldsymbol{E_{jt}} + \beta_6 I_{it} + \beta_7 L_{it} + d_t + c_i + u_{it}$$

.... (15)

Where i index the household, j index the plot, t indexes the agricultural year. d_t is a year fixed effect while c_i and u_{it} are the household time invariant and time-varying error terms. This equation is estimated for each of the four SFM practices of interest. The four SFM practices of interest are

- Use of organic manure (defined as the use of urea/compost/manure combined into one question in the survey)
- Legume intercropping (defined as the alternation of cereal with soybean/groundnuts)
- Water conservation technique (defined as water harvesting facility which prevents top soil erosion) such as terraces, gabions, tree belts, water harvest bunds and dam
- Reduced tillage (defined as hand hoe land preparation which disturbs about 15% of top soil)

The adoption of SFM practices will first be estimated as a binary variable i.e. Y_{ijt} = 1 if at least one of the four SFM practices are adopted on plot j in time t and Y_{ijt} = 0 if none of the three SFM practices are adopted on plot j in time t. Secondly, the adoption of SFM practices will be estimated as a continuous variable showing adoption intensity measured as the kilograms of organic manure used & the share of households' plots with at least one SFM practice (Feder & Umali, 1993).

We define the explanatory variables as follows; IF_{ijt} represents the use of commercial inorganic fertilizer on plot j in time t. $\boldsymbol{P_{ijt}}$ is a vector of prices for inputs (seeds, labor, inorganic and organic fertilizer) used on plot j in time t. $\boldsymbol{A_{ijt}}$ is a vector of farm assets (land, tractors, farming equipment) used on plot j in time t. Households' assets are transformed into a standard unit (household asset index)[4] for uniformity. L_{it} index the livestock owned by household i in time t. $\boldsymbol{E_{jt}}$ index a vector of variables, which represent the ecological variation within zones & characteristics that affect plot j in time t (mean rainfall, mean temperature, slope, elevation, potential wetness index).

$\boldsymbol{X_{it}}$ is a vector of the socioeconomic characteristics affecting production and/or consumption decisions of household i in time t; household size, male-headship (indicator variable), age and educational level of plot manager and I_t is the earnings from non-farm activities and borrowings or savings for household i in time t. We estimate the $\beta's$ in the empirical model specified above in equation 15. Table A2 in the appendix has the summary statistics for the explanatory variables.

Y_{ijt}^* is the unobserved net benefit derived from adopting any of the four SFM practices on plot j in time t whereas Y_{ijt} represents the adoption of technology if the expected net benefit is greater than zero and the non-adoption if the net benefit is negative.. The main explanatory variable of interest is the use of commercial inorganic fertilizer. Coefficient β_2 measures the effect of inorganic fertilizer use as where a significant positive (negative) coefficient would indicate that the use of commercial inorganic fertilizer increases (decreases) the probability of adopting SFM practices while controlling for time varying and invariant household characteristics.

3.2 Estimation strategy

Our goal is to estimate the average partial effect (APE) of using commercial inorganic fertilizer on the adoption of each of the four SFM practices being studied. Thus, our main focus is on β_2 in equation 15. Wu & Babcock (1998) found that ignoring the inter-dependence between practices might over/under estimate the effect of exogenous variables on the decision to adopt. Farmers have to deal with several constraints that affect their production and consumption decisions and in this case, they face labor, budget and subsistence constraints. Thus, farmers may decide to use any combination of technologies to maximize their utility or profits. For example,

[4] See Gender, Livestock and Livelihood Indicators - International Livestock Research Institute for conversion factors (Njuki et al., 2011)

the adoption of multiple technologies can be complementary and benefit the farmers more than adopting one technology. This means that the adoption of any one SFM practice may not be independent of the decision to adopt other practices because farmers adopt some of these practices as complements or substitutes.

A modeling approach that takes this complementary or tradeoff decisions into consideration in technology adoption is the Multivariate Probit (MVP) model. In contrast to the standard Probit model with only one dependent variable or the multinomial probit and logit models (with multiple dependent variables), the MVP model explores multiple dependent variables (SFM practices) while accounting for potential relationships between the different practices that can lead to the correlation of unobserved factors and the error term in the equation (Greene 2012). Marenya & Barrett (2007), Kassie, Jaleta, Shiferaw, Mmbando, & Mekuria, (2013) & Koppmair et al. (2017) used the Multivariate Probit (MVP) model to estimate technology adoption, controlling for the interdependence between technology choices. We follow these studies to account for this potential interdependence between leaving land fallow, legume intercropping and organic manure use. We used an MVP model to explain the binary adoption decision for the four SFM practices, estimate the effect of inorganic fertilizer purchase in these decisions and explore any correlation between the three SFM practices from the variance-covariance matrix of the model (Kassie et al., 2013). However, we found insignificant coefficients for our matrix of complementarity/substitutability (arthro) which suggests that the decisions to adopt any SFM practice of interest are not jointly determined. We present the matrix for the diagnostic test of the MVP analysis in table 6.

Therefore, we estimate the binary choice of adopting three SFM practices using a standard probit model of the form;

$\boldsymbol{P(Y_{ijt} = 1|}$ $\mathbf{G}_{it}$, $c_i + u_{it}\boldsymbol{)}$ where $\mathbf{G}_{it}$ represents all the explanatory variables in equation 15

Where i index the household, j indexes the plot and t indexes the agricultural year. The error terms in the MVP model follows a multivariate normal distribution with zero conditional mean and variance normalized to unity. Similarly, for the continuous variables; kilograms of organic manure used & share of plot under each SFM practice; we adopt a Tobit model & fractional response logistic model analysis respectively. This model accounts for the non-adopters of SFM practices which piles up at the corner of the reduced form solution. The low rate of adoption leaves a greater proportion of households reporting zero as the quantity of organic manure used

& the share of plot used for SFM practices (Papke & Wooldridge, 1996). We estimated the average partial effects while controlling for unobserved heterogeneity.

We estimate the adoption intensity of the three SFM practices using a fractional response logistic regression model of the form;

$$\boldsymbol{E}\,[\boldsymbol{Y}_{\boldsymbol{ijt}} \vee \boldsymbol{X}_{ijt}] \; = [\frac{\boldsymbol{exp}\,(\boldsymbol{X}_{ijt}\boldsymbol{\beta}_{ij}\,)}{\boldsymbol{1}\, + \boldsymbol{exp}\,(\boldsymbol{X}_{ijt}\boldsymbol{\beta}_{ij}\,)}] \, + c_i \, + u_{it}$$

Where $\boldsymbol{Y}_{\boldsymbol{ijt}}$ index the dependent variables (share of plot used for SFM practices) explained by the four regression equations. $\boldsymbol{X}_{ijt}$ = the explanatory variables in the regression equations, $\boldsymbol{\beta}_{ij}$ index the coefficient associated with each $\boldsymbol{X}_{ijt}$. $c_i \, + u_{it}$ indexes the value of the random error component associated with each equation.

Our variable of interest (kilograms of inorganic fertilizer) is a choice variable and is potentially endogenous to the adoption of SFM practices. This potential endogeneity arises from unobserved factors that jointly affect the decision to use inorganic fertilizer and adopt SFM practices. For example, knowledgeable farmers are likely to use inorganic fertilizer and also adopt SFM practices because of the complementary role of both technologies. Another example, more progressive farmers or better connected farmers might be more likely to use commercial inorganic fertilizer but also more likely to be aware of the benefits of SFM practices and hence more likely to adopt them. Not accounting for this could yield inconsistent estimates of β_2 due to omitted variable bias. We us a rich set of control variables likely to jointly affect our explanatory variables of interest (inorganic fertilizer use) and our SFM adoption variables. These include assets, access to markets and a host of plot and farmer characteristics. In addition, to account for unobserved variables that might be correlated with our explanatory variable of interest (inorganic fertilizer use) and out outcome adoption variables, we estimate equation 15 using the panel correlated random effects (CRE) models. The advantage of the CRE model is that it allows us to account for time invariant unobserved characteristics that are likely to be correlated with the decision to use commercial inorganic fertilizer and the adoption of particular SFM practices. We focus on the CRE versus the panel Fixed effect (FE) which could also address the same issue of time invariant unobserved characteristics because the CRE allows us to obtain the coefficients of key control variables that don’t change over time in our study including the gender and educational status of plot managers.

The CRE model uses the special case of Mundlak 1978 (Chamberlain, 1982) correlated random effect (CRE) to model the relation between the unobserved time invariant heterogeneity parameter c_i and the explanatory variables X_{it}. The inclusion of averages of explanatory variables that change over time controls for other factors that might be responsible for these changes overtime but are not observable, this means that its inclusion controls the unobserved heterogeneity that might influence the decision to adopt any SFM practices. By doing this, we are able to imply that the decisions to use inorganic fertilizer after controlling for any heterogeneity like skill or social networks with distributors/sellers with time-varying average of explanatory variable, we can imply that the decision to use inorganic fertilizer is very independent (exogenous) from the decision to adopt any other SFM practice.

We estimate our adoption equations using the CRE models because they are simple and allow the estimation of APE and MPE on the distribution of heterogeneity. The time-invariant unobserved factors are a function of the household variable averages of the observed covariates.

$$C_i = \alpha + \beta \bar{X}_{it} + v_{it}$$

This suggests that optimizing households, who know their idiosyncratic factors (C_i), will adjust the other variables X_{it} (household and district) to respond to C_i when there are external drivers that change over time such as prices. To operationalize the CRE model, we include the means of all time varying covariates for each household. Since it is the calculated mean, it remains constant for each year but varies by household. We also compute robust standard errors clustered at the household level to control for serial correlation and heteroscedasticity.

One potential limitation of this study is the effect of time varying unobserved characteristics that are jointly correlated with inorganic fertilizer use and the adoption of SFM practices. With the CRE we are only able to account for the time-invariant unobserved factors. While we attempt to address this with a wide range for farm, farmer and regional control variables supplemented with the correlated random effects model (CRE), we recognize that this might not completely eliminate concerns about the endogeneity of inorganic fertilizer use. In addition, the low adoption rates of several of the SFM practices in our data gives us very limited variation of the dependent variables in our analysis.

3.3 Data

We draw data from the Living Standard Measurement Survey, which applies to about 5,000 households with information about their multiple agricultural activities, production and household consumption (National Bureau of Statistics, 2016). The first wave of this General Household Survey was conducted in two visits to these households (post-planting visit August-October 2010, post-harvest visit February-April 2011). The second wave was carried out in the same fashion to the same panel households (post-planting visit August-October 2012, post-harvest visit February-April 2013) and the third wave also followed suit (post-planting visit August-October 2014, post-harvest visit February-April 2015). (National Bureau of Statistics, 2016)

The design of the selected sample of 5000 households is representative at the national level as well as at the zonal level (urban and rural). The first stage of the sampling method was to select Enumeration Areas based on the probability proportional to size of these enumeration areas in each state and the total households listed in these enumeration areas. Therefore, they selected 500 EAs (Enumeration Area) using this method. The second stage of the sampling method randomly selected ten households in each EA; obtained systematically by dividing the total households listed in each EA by 10, which made up the Sampling Interval (S.I). To ensure the household selection process was random, a random start 'k' from the table of random numbers was the first selection; they obtained consecutive household selection by adding the sampling interval to the random start. The sample size of 10 at the household level was borne out of experience gained from previous rounds of the GHS survey in which 10 households per EA give robust estimates (National Bureau of Statistics, 2016).

The survey in total has 500 clusters (EAs) and 5000 households, selected in relation to the size of each state. The final number of households interviewed in both post-planting & post-harvesting seasons was 4407 for all three waves because of the attrition of data. For our analysis, we had a total number of 4041 maize-farming households with 8834 maize plots. For the first wave of survey, restricting our sample to households who own at least one maize plot in any survey year, we have 1253 farmers and 2802 maize plots in the survey. In the year 2012, our sample restricts us to 1370 maize farming households with 2973 maize plots and in the final survey year 2015, 1418 maize farming households with 3059 plots were reported in the survey. We find increased number of maize farming households in subsequent survey rounds as farmers with limited number of plots crop in and out of maize production annually. We find that 63.46% of maize-farming households have a maximum of two plots on which they rotate multiple crops in different planting seasons, thus the inconsistency in the number of maize farming households. In 2010, 3.72% of households who cultivated millet were reported to own at least one maize plot in the subsequent survey round while in 2012, 3.84% of households who cultivated guinea corn/sorghum were reported to own at least one maize plot in the year 2015.

CHAPTER 4: RESULTS & DISCUSSION

4.1 Adoption of Organic manure

We present the results of CRE probit, Tobit and logit models on the probability of organic manure use, the intensity of organic manure use and the share of plot on which organic manure is used in table 2. We find that inorganic fertilizer use & the intensity of inorganic fertilizer reduce the probability of organic manure use, the quantity of organic manure used and the share of plot on which organic manure is applied. On average, the probability that organic manure is used is approximately 11% less on a plot on which inorganic fertilizer is used. This negative effect of inorganic fertilizer use is consistent for the quantity and share of land on which organic manure is used. At the intensive margin, a 100% increase in the quantity of fertilizer applied on a maize plot reduces the probability of using organic manure by 0.8% points (at a 1% significance level) and reduces the quantity of organic manure applied by 0.63%. In addition, a 100% increase in fertilizer intensity reduces the share of plot on which organic manure is used by 1.25% points holding all other factors constant. With a mean application rate of 231.35kg per hectare on plots on which inorganic fertilizer is used, these effects are quite small. This crowding out effect of inorganic fertilizer use suggests that maize farmers in Nigeria appear to substitute the use of inorganic fertilizer & organic manure as hypothesized. As farmers increase their use of inorganic fertilizer, they are less likely to use organic manure and if used at all, use limited quantities on a small share of their plots. This compares to the limited use of organic manure on small share of plots in Central & Southern Malawi (S. Holden & Lunduka, 2012)

Organic manure is less likely to be applied (and in lower quantities) on plots with steeper slopes. A 10% increase in slope (according to the SRTM[5] data) reduces the probability of using organic manure by 3.4% points, reduces organic manure intensity by 4.4% & the share of plots on which organic manure is applied by 1.8% points holding all other factors constant. This is likely because steeper lands might be more susceptible to erosion. If they have a very high soil run-off (from torrential rainfall or wind) this could affect the ability to retain nutrients and thus reduce the value of applying organic manure on steeper farmlands. Similarly, we see that geographical variables like rainfall reduces the probability of adopting organic manure, intensity of use & share of plot used for organic manure holding all other factors constant. On average, a

[5] Derived from un-projected 90m SRTM using DEM Surface Tools https://pubs.usgs.gov/of/2007/1188/ (World Bank LSMS, 2015)SRTM - Shuttle Radar Topography Mission

100mm increase in the annual rainfall rate reduces the probability of using organic manure by 0.6% points, reduces the quantity of organic manure used by 0.5% & the share of plot on which organic manure is used by 1.0% points. With an average annual rainfall rate of 1354.4mm, these effects are very small in magnitude. This could mean that some plots susceptible to erosion are less likely to have increased quantity of organic manure applied albeit small in magnitude when there is increased rainfall. Conversely, we see that organic manure is more likely to be applied (in higher quantities and on larger shares of plots) on plots with higher potential wetness index. This is possible, because plots with higher water retention capacity liquidate chemicals applied on the soil. This could allow for easy percolation of nutrients into the soil and prevent soil acidity, thus the crowding in effect. A unit increase in the soils wetness index increases the probability of adopting organic manure by 0.24% points, the intensity of organic manure use by 0.19% & the share of plot on which organic manure is used by 0.26% points holding all other factors constant.

We also see that higher elevation maize plots have a higher probability of adopting organic manure, higher use rate of organic manure & larger shares of the plot on which organic manure is used. An additional 10m increase in the plots' elevation increases the probability of adopting organic manure by 0.2% points, increases the quantity of organic manure used & the share of plot on which organic manure is used by 0.1% points holding all other factors constant. We see that elevated plots significantly decrease the soil horizon depth which reduces the retention capacity of the soil from an agronomic perspective (He, Hou, Liu, & Wen, 2016). In addition, higher altitudes and elevation reduces the soil temperature and the concentration of organic matter in the soil (He et al., 2016). We also find that the distance of plot to the household reduces the probability of adopting organic manure & the share of plot on which organic manure is used ceteris paribus. A 100km increase in plot distance reduces the probability of adopting organic manure by 3.0% & the share of plot on which organic manure is used by 2.0% points holding all other factors constant. This suggests that proximity to maize plots is an important determinant of the adoption of organic manure. This could be because farmers who purchase or produce organic manure find it difficult to store their inputs because of the distance to their households. In addition, the difficulty of transporting bags of organic manure could decrease the demand for organic manure. In comparison, Isik & Khanna (2003) and S. Holden & Lunduka

(2012) found that farmers are more likely to apply organic manure closer to the homestead rather than farmlands farther from their household.

As expected, we find that households with livestock holding are more likely to adopt organic manure, increase the quantity of organic manure used and also increase the share of plot on which organic manure is used holding all other factors constant. On average, households with livestock holding have a higher probability of adopting organic manure by 4.4% points, and tend to use 8.4% more organic manure with a 4.38% higher share of their maize plot on which organic manure is used. This suggests that animal waste produced from livestock motivates farmers to apply this on their farmland which saves them the cost of purchasing, thus the crowding in effect of livestock ownership. This symbiotic production relationship has been reported in previous literature (Kristjanson, Okike, Tarawali, Singh, & Manyong, 2005; Marenya & Barrett, 2007) where Kenyan households with more livestock holding have an increased adoption of organic manure.

We find that access to extension services is positively associated with the adoption of organic manure, intensity of adoption & the share of plot used for organic manure. On average, the receipt of extension services increases the probability of adopting organic manure by 4.14% points, increases the quantity of organic manure used by 3.24% & the share of plot used for organic manure by 3.52% points holding all other factors constant. This suggests that households who are equipped with information are more likely to know the importance of building up the soil organic matter, and are more likely to adopt organic manure on their plots. This further indicates the potential for improved extension access to be a mechanism to stimulate the use of SFM practices such as organic manure use.

We find that being members of cooperatives reduces the quantity of organic manure used & the share of plot on which organic manure is used holding all other factors constant. On average, farmers in a cooperative are likely to reduce the quantity of organic manure used by 6.0% and the share of plot on which organic manure is used by 4.17% points ceteris paribus. This is not surprising if cooperatives tend to have better access to modern inputs (inorganic fertilizer, improved seed varieties) in their shared pool of resources thus encouraging their use to the detriment of organic manure for members.

As expected, higher manure price reduces the probability of adopting organic manure, reduces the intensity of adoption & the share of plot used holding all other factors constant. On average, a 10NGN[6] increase in the price of manure decrease the probability of its use by 2.0%, decreases the quantity of organic manure used by 1.4% and the share of the plot used for organic manure by 1.7% points ceteris paribus. This relates to the law of demand; the increase in price decreases the demand for the input as expected. We find that the price of inorganic fertilizer increases the share of plot on which organic manure is used holding all other factors constant. On average, a 100NGN increase in the price of inorganic fertilizer increases the share of plot on which organic manure is applied by 2.19% points holding all other factors constant. This strengthens the substitutive relationship of inorganic fertilizer use on the decision to use organic manure. A higher price of inorganic fertilizer increases the share of plot on which organic manure is used probably because farmers lack the ability (cost) to adopt both practices simultaneously especially poor farmers, hence, the crowding in effect of organic manure. This compares to (Stein Holden & Lunduka, 2012) where higher fertilizer prices increases the demand for organic manure among farmers in Central & Southern Malawi.

The price of labor increases the share of plot on which organic manure is used holding all other factors constant. One would expect that an increase in wages paid to workers decreases the adoption of labor intensive practices such as organic manure. However, we see that increased wages (which should reduce the use of labor and labor intensive technologies) still increases the share of plot on which organic manure is used. Given the average price of organic manure at N168/kg, it is possible that farmers are more likely to hire less labor and thus allocate more household labor to their maize plot. Lower labor hire costs might be associated with higher quantities of organic manure purchased, thus the increased share of plot for its adoption. On average, a 100 NGN increase in wages paid increases the share of plot on which organic manure is used by 1.79% points (at a 1% significance level) holding all other factors constant. At an average wage rate of N2800, this has a large effect on the extent of adopting organic manure, most importantly for the 92.5% of maize farmers who use own produced organic manure (rather than purchasing).

We also find that higher market prices of millet and sorghum increases the intensity of organic manure use & the share of plot on which organic manure is applied holding all other factors constant. On average, a 100NGN increase in the price of millet increases the quantity of organic manure used by 3.3% and the share of plot on which organic manure is used by 1.68%

[6] NGN- Nigerian Naira

points ceteris paribus. In addition, a 100NGN increase in the price of sorghum increases the quantity of organic manure used by 2.2% ceteris paribus. For farmers who make investment decisions that maximize their profits, an increased market price of millet or sorghum (maize substitute) in the previous planting season could motivate farmers to use relatively inexpensive organic manure for maize production since there are no incentives to increase yield. Conversely, higher market prices of maize reduce the quantity of organic manure used holding all other factors constant. On average, a 100NGN increase in the market price of maize in the previous planting season increases the quantity of organic manure used by 2.6% holding all other factors constant. This is possible if profit-maximizing farmers make decisions to invest in inputs that deliver immediate yield, thus the crowding out of quantity of organic manure.

We also find that male-headship & education increase the probability of using organic manure, intensity of adoption and the share of plot on which organic manure is used. On average, a maize plot managed by a male is 11% points more likely to use manure than a maize plot in a female headed household, use 10% more organic manure and apply manure on 7% increased share. This suggests that males (possibly with more control over household labor or other complementary resources) are more likely to adopt organic manure and intensify its use on very large areas of land. In addition, one more year of headship's education increases the probability of adopting organic manure by 0.2% points and the quantity of organic manure used by 0.12% ceteris paribus. This is likely because educated farmers know the importance of using organic manure on depleted soils, thus the increased probability of adopting organic manure and the intensity of organic manure use. This is consistent with (Kamau et al., 2014; Marenya & Barrett, 2007; Minot, Kherallah, & Berry, 2000) who all find that male headed households are very likely to adopt SFM practices.

We find that a higher asset index increases the probability of adopting organic manure, the intensity of adopting organic manure and the share of plot on which organic manure is used. On average, an additional asset owned increases the probability of adopting organic manure by 0.006% points, increases the quantity of organic manure used by 0.004% & the share of plot on which organic manure is used by 0.009% points (at a 10% significance level) holding all other factors constant. This suggests that endowed households are more likely to adopt organic manure & on large areas of land which compares to (Kamau et al., 2014; Minot, 2007) who found same effect. We also see that households with other income sources increases the share of plot on which organic manure is used holding all other factors constant. On average, households with other income source increases the share of plot on which organic manure is used by 3.81% points ceteris paribus. This is very logical as wealthier households are able to purchase inputs in large quantities and on very great share of their plots. Conversely, households without other income sources have a decreased share of plot on which organic manure is used.

We find that households who have non-farm enterprises are more likely to increase the adoption of organic manure, increase the intensity of organic manure used and the share of plot on which organic manure is used holding all other factors constant. On average, having a non-farm enterprise increases the probability of using organic manure by 2.47% points, increases the quantity of organic manure used by 2.33% and the share of plot on which organic manure is used by 2.04% points holding all other factors constant. This might reflect that households with alternative sources of income are better able to invest in their farms including the purchase and application of manure. Such households who are less dependent on agriculture might be better able to afford to adopt organic manure to buffer limiting nutrients in the soil at the expense of immediate increased yield. This could crowd in the use of organic manure, the intensity of organic manure use & the share of plot on which organic manure is used.

We also find that the receipt of subsidized fertilizer increases the probability of adopting organic manure, the intensity of organic manure use & the share of plot used for organic manure holding all other factors constant. On average, the receipt of subsidized fertilizer increases the probability of adopting organic manure by 23% points, increases the intensity of organic manure used by 20% & the share of plot on which organic manure is used by 18% points; this suggests that farmers who receive subsidized fertilizer are more likely to use organic manure to complement the cheaper input received. This finding compares to (Stein Holden & Lunduka, 2012) who find a crowding in of organic manure albeit small in magnitude from the receipt of subsidized fertilizer in Zambia & Malawi.

4.2 Adoption of Legume Inter-cropping

We present the results of the CRE probit and logit of the demand for legume intercropping and the share of plot with legume intercropping respectively in table 3. We find that an increased use of inorganic fertilizer is positively associated with the adoption of legume intercropping while increased intensity of inorganic fertilizer use decreases the share of plot with legume intercropping holding all other factors constant. On average, households who use inorganic fertilizer have an increased probability of adopting legume intercropping by 1.83% points while a 100% increase in fertilizer intensity reduces the share of plot with legume intercropping by 0.26% points holding all other factors constant. Although these effects are small in magnitude, it suggests that farmers may be aware of how legumes reduces soil acidity and increases the profitability of inorganic fertilizer use (Vanlauwe et al., 2015) thus the joint adoption of the practices. However, the reduction in the share of land intercropped as inorganic fertilizer use increase might indicate that increased inorganic fertilizer use is associated with maize specialization. This finding compares to (Kamau et al., 2014) who report that an increased probability of inorganic fertilizer use crowds out the adoption of legume intercropping thus suggesting a potential substitutive relationship.

An increased plot elevation increases the probability of adopting legume intercropping holding all other factors constant. On average, a 10mm increase in plots' elevation increases the probability of adopting legume intercropping by 0.1% points holding all other factors constant. This is likely because higher elevation might allow for proper aeration & adequate sunlight which is needed for maximum growth of both crops. We find that potential wetness index increases the share of plot with legume intercropping holding all other factors constant. On average, a 10.0 increase in plot's wetness index increases the share of plot with legume intercropping by 0.9% points. This is possible because soils with a higher retention capacity allows for easy percolation of nutrients, thus encouraging farmers to increase the share of plots intercropped with legumes and maximize yield.

We also find that being members of cooperatives increases the probability of adopting legume intercropping & the share of plot with legume intercropping holding all other factors constant. On average, being members of cooperatives increase the probability of adopting legume intercropping by 2.43% points (at a 1% significance level) & the share of plot with legume intercropping by 0.8% points. Having a social network with a pool of resources and information helps members adopt practices they are not familiar with or unable to afford, this could include the provision of modern inputs like legume seeds. Therefore these households benefit from such networks and are likely to adopt legume intercropping.

We also find that households with livestock holding are very likely to adopt legume intercropping holding all other factors constant. On average, households with livestock holding have an increased probability of adopting legume intercropping by 1.44% points ceteris paribus. As reported by (Kristjanson et al., 2005), livestock owned has a positive effect on the adoption intensity of legume intercropping in Nigeria. They suggest that wealthier households are very likely to own larger plots, have more livestock, have more labor endowment, use animal traction and have more credit. Thus, the adoption of leguminous crops serves as food and feed while livestock provides manure for the crop enterprise.

The price of maize output increases the adoption of legume intercropping & the intensity of legume intercropping holding all other factors constant. On average, a 100NGN increase in the price of maize increases the adoption of legume intercropping by 0.8% points & the share of plot with legume intercropping by 0.5% points (at a 5% significance level).This could arise from the complementary role of legumes in maize production in ameliorating soil acidity and ultimately increasing maize yield. This symbiotic relationship could increase the demand for legume and the share of plot with legume intercropping when market prices of maize increase.

However, we find that market prices of legume decrease the adoption of legume intercropping & the share of plot on which it is adopted holding all other factors constant. This is unexpected because one would expect that increased prices of legume will motivate farmers to increase production and maximize farm income. On average, a 100NGN increase in the price of legume reduces the probability of adoption of legume intercropping by 1.46% points ceteris paribus and the share of plot with legume intercropping by 0.48% points. For an average legume price of N1100/kg, this has a minimal effect on the probability of adopting legume intercropping. We also find that higher prices of millet reduce the share of plot with legume intercropping holding all other factors constant. On average, a 100NGN increase in the price of millet reduces the share of plot with legume intercropping by 0.6% points (at a 10% significance level). This is likely because higher market prices of millet in the previous planting season could inform farmers' decision to reduce their production of maize in the current planting season, thus the crowding out of the intensity of legumes intercropped as a complement to maize production.

We find that an increase in wage decreases the probability of adopting legume intercropping. On average, a 100NGN increase in wages decreases the probability to adopt legume intercropping by 1.2% points holding all other factors constant. The extra labor needed for intercropping, weeding, thinning, pesticides application and harvesting increases the cost of production (Kristjanson et al., 2005); this could reduce the demand for legume intercropping especially if the opportunity cost of time is very valuable for households.

However, households with non-farm enterprises are more likely to adopt legume intercropping and intensify its adoption holding all other factors constant. On average, households with non-farm enterprises have an increased probability of adopting legume intercropping by 2.20% points (at a 1% significance level) and increase the share of plot with legume intercropping by 0.86% points holding all other factors constant. According to Bennett's law, household's consumption of staples reduces as their income increase. Therefore, a change in dietary pattern could encourage households to intercrop with legumes for consumption and sale. On the other hand, the alternative source of income for farmers might lessen household dependence on maize income and enable them have a more long-term perspective on their soil health. This finding compares to (Kamau et al., 2014) who report that wealthier households are more likely to adopt SFM practices in Western Kenya because the additional earnings from other sources of income could serve as a pathway for farmers to invest in soil fertility management practices..

4.3 Adoption of Water Conservation technique

We present the results of the CRE probit and logit of the demand for water conservation techniques and the share of plot with water conservation techniques in table 4. We find that the intensity of inorganic fertilizer increases the share of plot with water conservation technique holding all other factors constant. On average, a 100% increase in fertilizer intensity increases the share of plot with water conservation techniques on them by 0.13% points holding all other factors constant. This effect albeit small in magnitude suggests that farmers complement inorganic fertilizer use with adequate water storage techniques (terraces, gabions, tree belts, water harvest bunds and dams), to reduce soil acidity and allow for easy percolation of nutrients. Thus, we see that an increased quantity of inorganic fertilizer is complemented with the share of plot with water conservation techniques on them.

Water conservation techniques are more likely to be adopted on plots with steeper slopes. On average, a 10% increase in plots' slope increases the allocation of water conservation techniques by 0.3% points ceteris paribus. This is logical because steeper slopes have a higher probability of water & soil run-off, thus the need to increase the share of plot with water conservation techniques. We find that the potential wetness index of soils increase the probability of adopting water conservation techniques holding all other factors constant. On average, a 10.0 increase in the plots' potential wetness index increases the probability of adopting at least one water conservation technique by 0.7% points (at a 5% significance level). This is likely because soils with higher retention capacity are likely to conserve water adequately; these soils are also very complementary to conservation techniques, thus the increase in its adoption. In addition, we find that members of cooperatives have an increased probability of adopting water conservation techniques. On average, being members of cooperatives increase the probability of adopting water conservation techniques by 0.82% points holding all other factors constant. These households benefit from social learning and are informed on practices that could increase their production overtime.

We find that the price of millet decreases the probability of adopting water conservation techniques holding all other factors constant. On average, a 100NGN increase in the price of millet decreases the probability of adopting at least one water conservation technique by 0.44% points ceteris paribus. This suggests that a higher market price of millet in the previous planting season could encourage farmers to reduce their investment on their maize plot in favor of millet in the current planting season, thus the crowding out of water conservation techniques on them. However, higher prices of maize increases the probability of adopting at least one water conservation technique holding all other factors constant. On average, a 100NGN increase in the price of maize increases the probability of adopting at least one water conservation technique by 0.56% points holding all other factors constant. This suggests that increased prices of maize in the previous planting season motivate households to increase maize production in the current planting season, thus the need to adopt water conservation techniques to improve plant growth and quality.

As expected, increased wages decreases the probability of adopting any water conservation technique holding all other factors constant. On average, a 100NGN increase in wages decreases the probability of adopting at least one water conservation technique by 0.59% points (at a 10% significance level) ceteris paribus. Adopting any water conservation technique requires extra labor for its execution; an increase in the cost of adoption reduces the demand for water conservation techniques, thus the crowding out of water conservation techniques.

We also find that the cost of maize seed increases the share of plot with water conservation techniques on them holding all other factors constant. On average, a 100NGN increase in the cost of maize seed increases the share of plot with water conservation techniques by 0.44points (at a 5% significance level). This is possible because high investments in the cost of inputs increase the need to conserve water and maximize crop yield, thus the need to conserve water on large hectares of land. We find that the price of inorganic fertilizer increases the share of plot with water conservation techniques on them holding all other factors constant. On average, a 100NGN increase in the price of inorganic fertilizer increases the share of plot with water conservation techniques by 0.54% points (at a 1% significance level). One would expect that increased prices of inorganic fertilizer would reduce the intensity of water conservation techniques as complements. However, the crowding in of water conservation techniques could arise from the fact that the higher external input costs and associated investment or reduction thereof might increase the adoption of water conservation practices to guarantee the return on this investment.

We find that the household asset index has a crowding out effect on the adoption of water conservation techniques holding all other factors constant. On average, a higher asset index unit owned by households decreases the probability of adopting at least one water conservation technique by 0.005% points ceteris paribus. We find that household asset index has a very small effect on the adoption of water conservation techniques; this suggests that households with more assets who could have irrigation pumps are less likely to adopt water conservation practice and are more likely to irrigate their farmland to provide water for their crops. This is in contrast to the findings in (Kamau et al., 2014), who report that wealthier households are more likely to adopt SFM practices in Western Kenya.

4.4 Adoption of Reduced tillage

We present the results of the CRE probit and logit of the demand for reduced tillage and the share of plot prepared with reduced tillage respectively in table 5. We find that the use of inorganic fertilizer does not significantly affect the adoption of reduced tillage among maize farmers in Nigeria. However, we find that households who are members of cooperatives tend to prepare lower shares of their maize plots with reduced tillage. On average, members of cooperatives reduce the share of plot cultivated with reduced tillage by 0.11% points holding all other factors constant. We also find that households in the urban sector are very likely to increase the share of plot tilled minimally holding all other factors constant. One would expect that urban households will use more labor-saving and capital-using techniques because of the economic dynamism (Jayne et al., 2019). However, the relative factor prices of tilling manually or using tractors could crowd in the share of plots prepared with reduced tillage.

We also find that the education level of households' head increase the share of the plot prepared with reduced tillage; this suggests that educated farmers are aware of the importance of reduced tillage and are likely to increase the intensity of adoption. On average, one more year of households heads' education increases the share of plot cultivated with minimum tillage by 0.01% points (at a 1% significance level) holding all other factors constant. Increased prices of manure also increases the share of plot cultivated with minimum tillage. On average, a 100NGN increase in the price of manure increases the share of plot by 0.19% points ceteris paribus. This could mean that farmers substitute either management practice to improve the health of their soil. Therefore, a decreased demand for organic manure increases the share of plot tilled minimally.

We find that rent-paying households are more likely to increase the share of plot cultivated with reduced tillage holding all other factors constant. On average, a 100NGN increase in the rent paid increases the share of plot cultivated with reduced tillage by 0.10% points. One would expect that households who cultivate rented land are less likely to adopt reduced tillage on large hectares of their land. This could arise if these farmers have limited options of preparing their farmland before cultivation, thus limiting them to prepare their land with reduced tillage and on very large hectares as well.

Households who receive subsidized fertilizer are more likely to increase the share of plot prepared with reduced tillage holding all other factors constant. The receipt of subsidized fertilizer increases the area of land prepared with this practice, thus suggesting that farmers are likely to adopt reduced tillage which complements the inexpensive or free inorganic fertilizer received. On average, the receipt of free inorganic fertilizer increases the probability of adopting reduced tillage by 0.24% points holding all other factors constant. This finding is consistent with (Levine & Mason, 2014) who find that the receipt of subsidized inorganic fertilizer increases the adoption of minimum tillage among Zambian farmers.

4.5 Conclusion and Policy Recommendation

The profitability of inorganic fertilizer use on cereals in Africa is generally low and this is partly due to challenges with poor soil quality. However, there continues to be a lot of emphasis (by governments and development practitioners) on programs and strategies to increase the use of inorganic fertilizer. These programs pay little attention to soil fertility management despite the fact that the efficiency of inorganic fertilizer use on cereals improves with soil quality (Vanlauwe et al., 2010). As part of an effort to understand the low adoption rates of SFM practices in Africa, this research study focuses specifically on the role that inorganic fertilizer use plays on the adoption of SFM practices. We draw on evidence from maize farmers in Nigeria using a nationally representative panel data covering a six year period (2010-2015). We estimated the effect of the use of inorganic fertilizer on the adoption of organic manure, legume intercropping, water conservation technique and reduced tillage. We use a standard probit model (confirmed with a multivariate probit analysis) to explain the adoption of all four management practices. This is supplemented with a Tobit model to explain the quantity of organic manure used and the fractional regression model to explain the share of land allocated to these SFM practices. The Chamberlain Mundlak correlated random effect model was used to control for the endogeneity of the main explanatory variables due to time invariant unobserved household characteristics.

One key finding of this paper is the negative effect of inorganic fertilizer use on the use of organic manure, the quantity of organic manure used and the share of plot on which organic manure is applied for maize farmers. This reveals that maize farmers in Nigeria treat organic manure & inorganic fertilizer as substitutes rather than complements. This finding contrasts with Levine and Mason who found no effect of inorganic use on manure use among maize farmers in Zambia. It also contrasts with (Stein Holden & Lunduka, 2012) who found a limited but positive effect of inorganic fertilizer use on organic manure on very small shares of plots in Central & Southern Malawi. We see positive effects of increased prices of fertilizer on the share of plot on which organic manure is adopted; thus strengthening our finding that farmers tend to treat inorganic fertilizer and some SFM practices as substitutes. In addition, we see the same effect in (Stein Holden & Lunduka, 2012) where higher inorganic fertilizer prices increases the use of organic manure showing possible substitution between both inputs. However, we do see some complementarity between the use of inorganic fertilizer and the adoption of legume intercropping and water conservation practices. Plot characteristics also play a huge role on the adoption of SFM practices, plots with higher topographic wetness index & elevation increases the probability of adopting organic manure, legume intercropping and water conservation techniques while plots with steeper slopes and less proximity to the household decreases the probability of adopting these practices.

The findings of this paper suggest a need for an information campaign to farmers about the importance of adopting more soil management practices and the complementary role of both organic and inorganic inputs, particularly organic manure. Sustainable intensification requires both fertilizer-intensive and management-intensive techniques. Therefore, the use of organic manure in adequate proportions alongside inorganic fertilizer should be encouraged because of their different functions in the soil and to increase the profitability of external inputs used. Programs that ensure availability and accessibility of organic manure in large amounts should be encouraged as the lack of incentives to invest in SFM practices slow adoption rate and limits the intensity of adoption (small share of plot with SFM practices).

The possible inclusion of manure as part of regular fertilizer subsidy programs might also encourage their joint use. Mechanisms that reduce the labor and time requirement of adopting SFM practices should be sought out. Considering the relatively lower nutrients in organic manure, length of time needed for organic inputs to deliver observable returns and the present-bias nature of farmers, these inputs need to be distributed at little or no cost to farmers to build up the soil organic matter stock and repair degraded soils overtime. Minimizing the cost of these inputs will serve as incentives for farmers to achieve sustainable land intensification. Increasing the availability of organic manure at inorganic fertilizer depots might encourage farmers to purchase both inputs in similar quantities. Legume seeds could be provided to farmers at a discounted price as well. These among other strategies to expand knowledge and access to SFM practices are important and likely necessary to see a significant improvement in soil quality & low yield of inorganic fertilizer in cereal production in Nigeria and generally in Africa

Table 2: Probit, Tobit & Logit models for the adoption of organic manure

Explanatory variables	PROBIT Dependent variable Indicator=1 if organic manure is adopted on at least 1 plot	TOBIT Dependent variable Log Quantity of organic manure used per ha	LOGIT Dependent variable Share of plot on which organic manure is used	PROBIT Dependent variable Indicator=1 if organic manure is adopted on at least 1 plot	TOBIT Dependent variable Log Quantity of organic manure used per ha	LOGIT Dependent variable Share of plot on which organic manure is used
	APE	APE	APE	APE	APE	APE
=1 if inorganic fertilizer is applied	-0.1092***	-0.0899***	-0.1600***	-	-	-
Log fertilizer applied (kg/ha)	-	-	-	-0.0080**	-0.0063*	-0.0125***
Plot distance (km)	-0.0003*	-0.0001	-0.0001	-0.0003**	-0.0001	-0.0002*
Plot slope (%)	-0.0031**	-0.0042***	-0.0023**	-0.0034**	-0.0044***	-0.0018*
Plot elevation (m)	0.0001***	0.0001***	0.0001***	0.0002***	0.0001***	0.0001***
Plot potential wetness index	0.0025**	0.0020**	0.0030***	0.0024**	0.0019**	0.0026***
Annual Rainfall (mm)	-0.00005**	-0.00007***	-0.0001***	-0.00006**	-0.00005***	-0.0001***
Annual Temperature (^{o}C)	0.0015**	0.0010**	0.0001	0.0016**	0.0010**	0.0005
Livestock holding	0.0442***	0.0799***	0.0464***	0.0440***	0.0811***	0.0438***

Table 2 (cont'd)

=1 if HH is a member of a cooperative	-0.0234	-0.0541***	-0.0331**	-0.0277	-0.0584***	-0.0417***
=1 if HH received extension services	0.0365*	0.0289	0.0339**	0.0414**	0.0324*	0.0352**
=1 if HH is in the urban sector	-0.0304*	-0.0199	-0.0253*	-0.0302*	-0.0197	-0.0258*
Log Maize price (NGN/kg, t-1) (district median)	-0.0043	-0.0258***	0.0073	-0.0047	-0.0261***	0.0076
Log Legume price (NGN/kg, t-1) (district median)	0.0006	-0.0069	0.0053	-0.0012	-0.0090	0.0029
Log Millet price (NGN/kg, t-1) (district median)	0.0099	0.0305***	0.0118*	0.0123	0.0326***	0.0168***
Log Sorghum price (NGN/kg, t-1) (district median)	0.0021	0.0212***	-0.0083	0.0029	0.0223***	-0.0091
Log Wage per ha of maize (weeding, planting)	0.0035	-0.0065	0.0156*	0.0068	-0.0048	0.0179**
Log Land rental rates (NGN/hectares)	-0.0033	-0.0005	-0.0037*	-0.0035	-0.0005	-0.0031
Log Maize seed cost (NGN/100kg)	-0.0050	-0.0056	-0.0000	-0.0111*	-0.0102	-0.0080

Table 2 (cont'd)

Log Legume seed cost(NGN/100kg)	0.0050	0.0021	0.0114	-0.0277	-0.0584***	-0.0417***
Log Price of fertilizer (N/100kg)	0.0121	0.0121	0.0191**	0.0130	0.0126	0.0219**
Log Price of manure (N/100kg)	-0.2114***	-0.1440***	-0.1736***	-0.2089***	-0.1424***	-0.1702***
Male headship (1/0)	0.1112***	0.0988***	0.0696***	0.1130***	0.0991***	0.0669***
Headship education (years)	0.0017***	0.0012***	0.0005*	0.0018***	0.0012***	0.0005
Asset Index (endowments)	0.00004	0.0000***	0.00008**	0.00006**	0.00004***	0.00009***
Other income sources (borrowings & savings)	0.0193	-0.0212	0.0404**	0.0193	-0.0217	0.0381*
Non-farm enterprises (1/0)	0.0248***	0.0225***	0.0249***	0.0247***	0.0233***	0.0204***
Fertilizer subsidy (1/0)	0.2338***	0.2015***	0.2032***	0.2307***	0.1984***	0.1880***
North	0.0743***	0.0838***	0.0291***	0.0741***	0.0815***	0.0273**
South	-	-	-	-	-	-
2010	-0.0149	-0.0129	0.0449***	-0.0130	-0.0156	0.0490***
2012	-0.0007	0.0462	-0.0108	-0.0013	0.0047	-0.0137*
Time-varying averages included	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*

Table 2 (cont'd)

Constant	10.118***	6.5807***	16.703***	9.9640***	6.5218***	15.0637***
Observations	8,834	8,834	8,834	8,834	8,834	8,834

APE= Average Partial Effect. HH= Household. NGN= Nigerian Naira.
** Indicates APE significance level of 10% ** Indicates APE significance level of 5%*
**** Indicates APE significance level of 1%*
Source: Authors calculation based on the LSMS General Household Survey data (2010/2011, 2012/2013, 2014/2015)

Table 3: Probit & Logit models for the adoption of legume intercropping

Explanatory variables	PROBIT Dependent variable Indicator=1 if legume intercropping is adopted on at least 1 plot	LOGIT Dependent variable Share of plot with legume intercropping	PROBIT Dependent variable Indicator=1 if legume intercropping is adopted on at least 1 plot	LOGIT Dependent variable Share of plot with legume intercropping
	APE	APE	APE	APE
=1 if inorganic fertilizer is applied	0.0183**	-0.0017	-	-
Log fertilizer applied (kg/ha)	-	-	-0.0019	-0.0026**
Plot distance (km)	0.00003	0.00005*	0.00006	0.00002
Plot slope (%)	-0.0007	-0.0004	-0.0008	-0.0004
Plot elevation (m)	0.0001**	-0.00003	0.0001**	-0.0000
Plot potential wetness index	-0.0001	0.0010***	-0.0001	0.0009***

Table 3 (cont'd)

Annual Rainfall (mm)	-0.00001	0.00002	-0.00005	0.00002
Annual Temperature (ºC)	0.0007	-0.0006***	0.0007	-0.0005**
Livestock holding	0.0144*	0.0064	0.0144*	0.0075
=1 if HH is a member of a cooperative	0.0239***	0.0063	0.0243***	0.0077*
=1 if HH received extension services	0.0150	0.0018	0.0154	0.0654
=1 if HH is in the urban sector	0.0062	0.0060	0.0067	0.0056
Log Maize price (NGN/kg, t-1)	0.0088**	0.0050**	0.0084**	0.0049**
Log Legume price (NGN/kg, t-1)	-0.0145***	-0.0051*	-0.0146***	-0.0048*
Log Millet price (NGN/kg, t-1)	-0.0059	-0.0063*	-0.0053	-0.0060*
Log Sorghum price (NGN/kg, t-1)	0.0015	0.0034	0.0014	0.0033
Log Wage per ha of maize	-0.0110*	-0.0046	-0.0116*	-0.0036
Log Land rental rates (NGN/hectares)	0.0037**	0.0006	0.0040**	0.0009
Log Maize seed cost (NGN/100kg)	0.0027	0.0014	0.0034	0.0021
Log Legume seed cost(NGN/100kg)	-0.0033	-0.0051	-0.0041	-0.0047
Log Price of fertilizer (N/100kg)	-0.0058	0.0028	-0.0059	0.0022

Table 3 (cont'd)

Log Price of manure (N/100kg)	-0.0015	0.0011	-0.0016	0.0014
Male headship (1/0)	0.0045	-0.0053	0.0047	-0.0035
Headship education (years)	0.0002	-0.00004	0.0002	0.00005
Asset Index (endowments)	0.00005	0.00002	0.00003	0.00008
Other income sources (borrowings & savings) (1/0)	-0.0158	-0.0015	-0.0150	-0.0019
Non-farm enterprises (1/0)	0.0213***	0.0079***	0.0220***	0.0086***
Fertilizer subsidy (1/0)	-0.0321	-0.0144	-0.0295	-0.0145
North	-0.0248**	-0.0213***	-0.0225**	-0.0181***
South	-	-	-	-
2010	-0.0072	-0.0109**	-0.0075	-0.0107**
2012	0.0052	-0.0079**	0.0055	-0.0074**
Time-varying averages included	*Yes*	*Yes*	*Yes*	*Yes*
Constant	-0.9236	9.1297***	-0.5688	7.5602**
Observations	8,834	8,834	8,834	8,834

APE= Average Partial Effect. HH= Household. NGN= Nigerian Naira.

Table 3 (cont'd)
** Indicates APE significance level of 10% ** Indicates APE significance level of 5%*
**** Indicates APE significance level of 1%*
Source: Authors calculation based on the LSMS General Household Survey data (2010/2011, 2012/2013, 2014/2015)

Table 4: Probit & Logit models for the adoption of water conservation techniques

Explanatory variables	PROBIT Dependent variable Indicator=1 if water cons. technique is adopted on at least 1 plot	LOGIT Dependent variable Share of plot with water cons. technique	PROBIT Dependent variable Indicator=1 if water cons. technique is adopted on at least 1 plot	LOGIT Dependent variable Share of plot with water cons. technique
	APE	APE	APE	APE
=1 if inorganic fertilizer is applied	-0.0052	0.0025	-	-
Log fertilizer applied (kg/ha)	-	-	-0.0014	0.0013**
Plot distance (km)	-0.0004	0.00002	-0.0004	0.00007
Plot slope (%)	-0.0005	0.0004***	-0.0006	0.0003***
Plot elevation (m)	-0.00002	-0.00001	-0.00004	-0.0000
Plot potential wetness index (%)	0.0007**	0.0001	0.0007**	0.0001
Annual Rainfall (mm)	-0.00005	-0.00003*	-0.00003	-0.00008

Table 4 (cont'd)

Annual Temperature (ºC)	-0.0002	-0.0001	-0.0003	-0.0001
Livestock holding	0.0034	-0.0003	0.0045	-0.0002
=1 if HH is a member of a cooperative	0.0072	0.0016	0.0082*	0.0019
=1 if HH received extension services	0.0011	0.0017	0.0010	0.0019
=1 if HH is in the urban sector	0.0067	0.0013	0.0076*	0.0015
Log Maize price (NGN/kg, t-1)	0.0055***	-0.0011	0.0056***	-0.0012
Log Legume price (NGN/kg, t-1)	-0.0013	-0.0021	-0.0010	-0.0021
Log Millet price (NGN/kg, t-1)	-0.0046*	0.0007	-0.0044*	0.0005
Log Sorghum price (NGN/kg, t-1)	-0.0014	-0.0014	-0.0019	-0.0013
Log Wage per ha of maize (NGN/ha)	-0.0061*	0.0023	-0.0059*	0.0025
Log Land rental rates (NGN/ha)	-0.0010	-0.0006	-0.0008	-0.0007
Log Maize seed cost (NGN/100kg)	0.0007	0.0042**	0.0007	0.0044**
Log Legume seed cost(NGN/100kg)	-0.0023	-0.0016	-0.0018	-0.0017
Log Price of fertilizer (N/100kg)	0.0049	0.0055***	0.0049	0.0054***
Log Price of manure (N/100kg)	0.0058	-0.0002	0.0060	-0.0002

Table 4 (cont'd)

Male headship (1/0)	0.0091	0.0001	0.0099	0.0002
Headship education (years)	0.0002	-0.00003	0.0002	-0.00004
Asset Index (endowments)	-0.00006***	-0.00005	-0.00005**	-0.00007
Other income sources (borrowings & savings) (1/0)	-0.0152	0.0043	-0.0156	0.0044
Non-farm enterprises (1/0)	-0.0003	-0.0016	0.0005	-0.0012
Fertilizer subsidy (1/0)	-0.0023	0.0025	-0.0013	0.0029
North	0.0081	0.0038	0.0083	0.0038
South	-	-	-	-
2010	0.0002	0.0089**	0.0187***	0.0086**
2012	-0.00008***	0.0035	0.0103***	0.0035
Time-varying averages included	*Yes*	*Yes*	*Yes*	*Yes*
Constant	-5.7900**	-2.5232	-4.6979*	-1.3086
Observations	8,834	8,834	8,834	8,834

APE= Average Partial Effect. HH= Household. NGN= Nigerian Naira.
** Indicates APE significance level of 10% ** Indicates APE significance level of 5% *** Indicates APE significance level of 1%*
Source: Authors calculation based on the LSMS General Household Survey data (2010/2011, 2012/2013, 2014/201

Table 5: Probit & Logit models for the adoption of reduced tillage

Explanatory variables	<u>PROBIT</u> Dependent variable Indicator=1 if reduced tillage is adopted on at least 1 plot	<u>LOGIT</u> Dependent variable Share of plot cultivated with reduced tillage	<u>PROBIT</u> Dependent variable Indicator=1 if reduced tillage is adopted on at least 1 plot	<u>LOGIT</u> Dependent variable Share of plot cultivated with reduced tillage
	APE	APE	APE	APE
=1 if inorganic fertilizer is applied	0.0006	-0.0015	-	-
Log fertilizer applied (kg/ha)	-	-	0.0016	-0.0002
Plot distance (km)	0.00001	0.00006	0.0001	0.00005
Plot slope (%)	-0.0020	-0.0001	-0.0021	-0.0001
Plot elevation (m)	0.00005	0.00006	0.0001	0.00009
Plot potential wetness index (%)	-0.0008	0.00006	-0.0010	0.00005
Annual Rainfall (mm)	0.00004	0.00002	0.00002	0.00007
Annual Temperature (^{o}C)	0.0015	0.00009	0.0013	0.00006
Livestock holding	-0.0081	-0.0123***	-0.0706	-0.0114***

Table 5 (cont'd)

=1 if HH is a member of a cooperative	0.0015	-0.0017*	0.0197	-0.0011*
=1 if HH received extension services	0.0010	0.0005	-0.0021	0.0001
=1 if HH is in the urban sector	0.0455	0.0021**	0.0335	0.0023***
Log Maize price (NGN/kg, t-1)	-0.0020**	-0.0002	-0.0035	-0.0001
Log Legume price (NGN/kg, t-1)	-0.0006	0.0006	0.0090	0.0007
Log Millet price (NGN/kg, t-1)	0.0025	0.0009	-0.0112	0.0008
Log Sorghum price (NGN/kg, t-1)	0.0033	0.0014	-0.0003	0.0008
Log Wage per ha (NGN/ha)	-0.0003	0.00005	0.0124	0.0001
Log Land rental rates (NGN/ha)	-0.0007	0.0010**	0.0042	0.0010**
Log Maize seed cost (NGN/100kg)	-0.0002	-0.0008	-0.0055	-0.0009
Log Legume seed cost(NGN/100kg)	-0.0022	-0.0002	0.0199	-0.0006
Log Price of fertilizer (N/100kg)	-0.0015*	-0.0007	-0.0008	-0.0009
Log Price of manure (N/100kg)	-0.0019	0.0027**	0.0035	0.0019*
Male headship (1/0)	0.0050	-0.0004	-0.0014	-0.0004
Headship education (years)	0.0002	0.0001***	0.0003	0.0001***

Table 5 (cont'd)

Asset Index (endowments)	0.00001	-0.00007	0.00006	0.00004
Other income sources (borrowings & savings)	-0.00008	-0.0004	-0.0200	0.0002
Non-farm enterprises (1/0)	0.0004	-0.0005	0.0027	-0.00006
Fertilizer subsidy (1/0)	-0.0029	0.0017**	0.0241	0.0024***
North	0.1569	0.0010	0.0261	0.0008
South	-	-	-	-
2010	-0.0112	-0.0175***	-0.0245	-0.0158***
2012	-0.0116	-0.0181***	-0.0233	-0.0172***
Time-varying averages included	*Yes*	*Yes*	*Yes*	*Yes*
Constant	-14.763***	-65.812*	-14.649***	-55.404
Observations	8,834	8,834	8,834	8,834

APE= Average Partial Effect. HH= Household. NGN= Nigerian Naira.
** Indicates APE significance level of 10% ** Indicates APE significance level of 5% *** Indicates APE significance level of 1%*
Source: Authors calculation based on the LSMS General Household Survey data (2010/2011, 2012/2013, 2014/2015)

Table 6: Predictions from the Multivariate Probit Model for SFM practices (simulated maximum likelihood)

Diagnostic tests of Multivariate Probit Model for SFM practices

	Maize plots	
	Coefficient	P-value
Adoption of water cons. technique and organic manure (atrho 21)	0.0164 (0.050)	0.741
Adoption of legume intercropping and organic manure (atrho 31)	0.0034 (0.031)	0.914
Adoption of reduced tillage and organic manure (atrho 41)	0.0064 (0.049)	0.898
Adoption of legume intercropping & water cons. technique (atrho 32)	0.0122 (0.045)	0.784
Adoption of reduced tillage and water cons. technique (atrho 42)	0.0074 (0.074)	0.921
Adoption of reduced tillage & legume intercropping (atrho 43)	-0.0479 (0.065)	0.464
Chi-square for LR test of rho (ρ) = 0	0.7433	0.994

Source: Authors calculation based on the LSMS General Household Survey data (2010/2011, 2012/2013, 2014/2015). Standard error in parentheses
Standard errors in parentheses (). Indicates APE significance level of 10% ** Indicates APE significance level of 5% *** Indicates APE significance level of 1%*
***atrho** represents the Fisher's Z transformation of correlation, which is also known as the arc-hyperbolic tangent.1 represents the adoption of organic manure on at least 1 field, 2 represents the adoption of legume intercropping on at least 1 field, 3 represents the adoption of water cons. technique on at least 1 field and 4 represents the adoption of reduced tillage on at least 1 field.. Therefore, 21, 31, 41, 32, 42 and 43 refer to the correlation between the three different choices of adoption.*

APPENDIX

Table A1: Multivariate Probit Analysis on the adoption of SFM practices

Explanatory variables	Dependent variable Indicator=1 if organic manure is applied on at least 1 plot	Dependent variable Indicator=1 if legume intercropping is adopted on at least 1 plot	Dependent variable Indicator=1 if water conservation techniques are adopted on at least 1 plot	Dependent variable Indicator=1 if reduced tillage is adopted on at least 1 plot
	APE	APE	APE	APE
Log fertilizer applied (kg/ha)	-0.0381**	-0.0435	-0.0236	0.0606**
Plot distance (km)	-0.0013	-0.0124	0.0008	0.0095**
Plot slope (%)	-0.0154**	-0.0205	-0.0041	-0.0442**
Plot elevation (m)	0.0007***	-0.0004	0.0007***	0.0010**
Plot potential wetness index	0.0119***	0.0251***	0.0009	-0.0338***
Annual Rainfall (mm)	-0.0002**	-0.0002	0.0000	0.0003
Annual Temperature (^{o}C)	0.0069**	-0.0085*	0.0075	0.0255***
Livestock holding	0.2214***	0.1463	0.1629*	-0.8620***
=1 if HH is a member of a cooperative	-0.1474**	0.2794**	0.2469***	0.1477
=1 if HH received extension services	0.1864**	0.0247	0.1701*	0.0258
=1 if HH is in the urban sector	-0.1462**	0.2223	0.0978	0.7847***
Log Maize price (NGN/kg, t-1)	-0.0201	0.1789**	0.0784*	-0.2489***
Log Legume price (NGN/kg, t-1)	-0.0020	-0.0241	-0.1258**	0.1264
Log Millet price (NGN/kg, t-1)	0.0557	-0.1357	-0.0429	0.0547

Table A1 (cont'd)

Log Sorghum price (NGN/kg, t-1)	0.0097	-0.0650	0.0097	0.2373**
Log Wage per ha of maize (weeding, planting)	0.0305	-0.1786	-0.1143*	0.0208
Log Land rental rates (NGN/hectares)	-0.0153	-0.0275	0.0443**	0.1208***
Log Maize seed cost (NGN/100kg)	-0.0482	0.0248	0.0360	-0.1328
Log Legume seed cost(NGN/100kg)	0.0460	-0.0577	-0.0271	0.1227
Log Price of fertilizer (N/100kg)	0.0556	0.1425	-0.0458	0.0259
Log Price of manure (N/100kg)	-0.9548***	0.1909	-0.0279	0.1198
Male headship (1/0)	0.5009***	0.3172	0.0392	0.0621
Headship education	0.0086***	0.0061	0.0016	0.0037
Asset Index (endowments)	0.0001	-0.0011**	0.0000	0.0007***
Other income sources (borrowings & savings)	0.1016	-0.4590	-0.1131	-0.6543**
Non-farm enterprises	0.1369***	0.0143	0.2407***	-0.0714
Fertilizer subsidy (1/0)	1.0494***	-0.0447	-0.3403*	0.5216**
North	0.3091***	0.2628	-0.2543***	0.6513***
South	-	-	-	-
2012	0.0706	-0.2561*	0.1154	21.8975
2015	0.0716	-0.5721***	0.0633	29.0484
Constant	8.5896***	-3.0575	-0.7476	-43.5693

Table A1 (cont'd)

Observations	8,834	8,834	8,834	8,834

APE= Average Partial Effect. HH= Household. NGN= Nigerian Naira.
** Indicates APE significance level of 10% ** Indicates APE significance level of 5%*
**** Indicates APE significance level of 1%*
Source: Authors calculation based on the LSMS General Household Survey data (2010/2011, 2012/2013, 2014/2015

Table A2: Summary Statistics of Explanatory Variables

Explanatory variables	Description	Mean	SD
Household characteristics			
=1 if inorganic fertilizer is used on at least 1 plot	Inorganic fertilizer was used on at least 1 plot during the planting season (dummy 1= Yes, 0= otherwise)	0.4152	0.4927
Kilograms of inorganic fertilizer purchased by HH	Quantity of inorganic fertilizer purchased by household during the last season	231.35	296.54
Age of HH head	Household head age (years)	52.387	14.971
=1 if male headed HH	Household head male (dummy 1=male, 0=otherwise)	0.8811	0.3236
Years of education of HH head	Household head education (years)	25.675	9.8285
Resources			
Household Asset Index (endowment)	Total value of major farm and household equipment including livestock (Index)	103.50	599.94
Landholding size in hectares	Total farm size owned (hectares)	6.8372	118.88
=1 if HH has other sources of income	Household has other sources of income like borrowings & savings (dummy 1=Yes, 0=otherwise)	0.0765	0.2658
=1 if HH has non-farm enterprises	Household has own business income (dummy 1=Yes, 0=otherwise)	0.5800	0.4935

Table A2 (cont'd)

Social Capital			
=1 if HH is a member of a cooperative	Household has a social network that they are involved in (dummy 1=Yes, 0=otherwise)	0.1211	0.3263
Access to Services			
Mean distance from HH to plot	Average plot distance to households in kilometers	2.0396	20.026
=1 if HH received extension services	Household received training from extension agents (dummy 1=Yes, 0=otherwise)	0.0891	0.2849
=1 if HH is in the urban sector	Household is in the urban part of the community (dummy 1=Yes, 0=otherwise)	0.0952	0.2935
District Input Prices			
Log Maize price (NGN/kg, t-1) (district median)	Price of maize at household's district level (Naira)	5.1356	1.2462
Log Legume price (NGN/kg, t-1) (district median)	Price of legume at households district level (Naira)	5.5324	1.0777
Log Millet price (NGN/kg, t-1) (district median)	Price of millet at households district level (Naira)	5.7498	1.2448
Log Sorghum price (NGN/kg, t-1) (district median)	Price of sorghum at households district level (Naira)	5.5203	1.2930
Log Wage per ha of maize (weeding, planting)	Price of labor at the district level (Naira)	8.0024	0.6475
Log Land rental rates (NGN/hectares) (district level)	Rent of land at district level (Naira)	8.3304	2.2985
Input Prices			
Log Maize seed cost	Price of maize seed purchased by	6.8625	0.9515

Table A2 (cont'd)

(NGN/100kg)	household (Naira)		
Log Legume seed cost(NGN/100kg) (mean)	Price of legume seed purchased by household (Naira)	7.7819	0.4904
Log Price of fertilizer (N/100kg)	Price of fertilizer at the household level (idiosyncratic cost- Naira)	9.1295	0.8231
Log Price of manure (N/100kg)	Price of manure at the household level (Naira)	9.4376	0.4396
Plot characteristics			
Slope (%)	Slope of plot derived from unprojected 90m SRTM using DEM surface tools	2.8999	2.9926
Elevation (m)	Elevation of plot in meters	300.83	261.60
Topographic wetness index	Moisture retention capacity derived from modified 90m SRTM.	12.751	5.0025
Ecological variables			
Rainfall	Average of the yearly rainfall January-December (mm)	1354.4	380.52
Temperature	Annual Mean temperature (0C)	261.34	11.163
Household dummy			
North Central	Household is in the North Central zone (dummy 1=Yes, 0=otherwise)	0.1968	0.3977
North East	Household is in the North Eastern zone (dummy 1=Yes, 0=otherwise)	0.2745	0.4463
North West	Household is in the North Western zone (dummy 1=Yes, 0=otherwise)	0.1868	0.3899
South East	Household is in the South Eastern zone (dummy 1=Yes, 0=otherwise)	0.2677	0.4428
South South	Household is in the South Southern zone (dummy 1=Yes, 0=otherwise)	0.0236	0.1519

Table A2 (cont'd)

South West	Household is in the South Western zone (dummy 1=Yes, 0=otherwise	0.0504	0.2188
Time dummy			
2010	Year reported is 2010 (dummy 1=Yes, 0=otherwise)	0.3172	0.4654
2012	Year reported is 2012 (dummy 1=Yes, 0=otherwise)	0.3365	0.4725
2015	Year reported is 2015 (dummy 1=Yes, 0=otherwise)	0.3463	0.4758

REFERENCES

REFERENCES

Abera, T., Feyissa, D., & Yusuf, H. (2005). Effects of Inorganic and Organic Fertilizer on Grain Yield of Maize-Climbing Bean Intercropping and Soil Fertility in Western Oromiya, Ethiopia, (1995), 1–10.

Akighir, D. T., & Shabu, T. (2011). Efficiency of Resource use in Rice Farming Enterprise in Kwande Local Government Area of Benue State , Nigeria. *International Journal of Humanities and Social Science*, *1*(3), 215–220. Retrieved from http://www.ijhssnet.com/journals/Vol._1_No._3;_March_2011/30.pdf

Badu-Apraku, B., Fakorede, M. A. B., & Oyekunle, M. (2014). Agronomic traits associated with genetic gains in maize yield during three breeding eras in West Africa. *Maydica*, *59*(1), 49–57.

Chamberlain, G. (1982). Nber working paper series arbitrage, factor structure, and mean-variance analysis, (October).

de Janvry, A., & Sadoulet, E. (1995). Household Modeling for the Design of Poverty Alleviation Strategies. *Revue d'Economie Du Developpement*, *3*, 3–23.

Duflo, E., Kremer, M., & Robinson, J. (2011). Nudging farmers to use fertilizers: theory and experimental evidence from Kenya. *American Economic Review*, *101*(6), 2350–2390. https://doi.org/10.1257/aer.101.6.2350

Feder, G., & Umali, D. L. (1993). The adoption of agricultural innovations. A review. *Technological Forecasting and Social Change*, *43*(3–4), 215–239. https://doi.org/10.1016/0040-1625(93)90053-A

Food and Agriculture Organization of the United Nations - FAO. (2017). CGIAR. Consortium of International Agricultural Research. *Leveraging Food Systems for Inclusive Rural Transformation*. *The State of Food and Agriculture*. Retrieved from http://www.fao.org/3/a-i7658e.pdf

Giller, K. E., Rowe, E. C., De Ridder, N., & Van Keulen, H. (2006). Resource use dynamics and interactions in the tropics: Scaling up in space and time. *Agricultural Systems*, *88*(1), 8–27. https://doi.org/10.1016/j.agsy.2005.06.016

Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research*, *114*(1), 23–34. https://doi.org/10.1016/j.fcr.2009.06.017

He, X., Hou, E., Liu, Y., & Wen, D. (2016). Altitudinal patterns and controls of plant and soil nutrient concentrations and stoichiometry in subtropical China. *Nature Publishing Group*, (January), 1–9. https://doi.org/10.1038/srep24261

Holden, S., & Lunduka, R. (2010). Too poor to be efficient? Impacts of the targeted fertilizer subsidy programme in Malawi on farm plot level input use, crop choice and land productivity. *Noragric Report*, (55), iii-pp. Retrieved from http://www.nlh.no/noragric

Holden, S., & Lunduka, R. (2012). Do fertilizer subsidies crowd out organic manures? The case of Malawi. *Agricultural Economics*, *43*(3), 303–314. https://doi.org/10.1111/j.1574-0862.2012.00584.x

Iken, J.E. and Amusa, N. A. . (2004). Maize research and production in Nigeria. *African Journal of Biotechnologyournal of Biotechnology*, *3*(6), 302–307.

Isik, M. & Khanna, M. (2003). Stochastic Technology , Risk Preferences and Adoption of Site-specific technologies, *85*(May), 305–317.

Jayne, T. S., Snapp, S., Place, F., & Sitko, N. (2019). Sustainable agricultural intensi fi cation in an era of rural transformation in Africa. *Global Food Security*, *20*(January), 105–113. https://doi.org/10.1016/j.gfs.2019.01.008

Kamau, M., Smale, M., & Mutua, M. (2014). Farmer demand for soil fertility management practices in Kenya ' s grain basket, 793–806. https://doi.org/10.1007/s12571-014-0398-5

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., & Mekuria, M. (2013). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological Forecasting and Social Change*, *80*(3), 525–540. https://doi.org/10.1016/j.techfore.2012.08.007

Kermah, M., Franke, A. C., Adjei-Nsiah, S., Ahiabor, B. D. K., Abaidoo, R. C., & Giller, K. E. (2018). N2-fixation and N contribution by grain legumes under different soil fertility status and cropping systems in the Guinea savanna of northern Ghana. *Agriculture, Ecosystems and Environment*, *261*(December 2016), 201–210. https://doi.org/10.1016/j.agee.2017.08.028

Kimetu, J. M., Lehmann, J., Ngoze, S. O., Mugendi, D. N., Kinyangi, J. M., Riha, S., … Pell, A. N. (2008). Reversibility of soil productivity decline with organic matter of differing quality along a degradation gradient. *Ecosystems*, *11*(5), 726–739. https://doi.org/10.1007/s10021-008-9154-z

Koppmair, S., Kassie, M., & Qaim, M. (2017). The influence of farm input subsidies on the adoption of natural resource management technologies. *Australian Journal of Agricultural and Resource Economics*, *61*(4), 539–556. https://doi.org/10.1111/1467-8489.12220

Kristjanson, P., Okike, I., Tarawali, S., Singh, B. B., & Manyong, V. M. (2005). Farmers' perceptions of benefits and factors affecting the adoption of improved dual-purpose cowpea in the dry savannas of Nigeria. *Agricultural Economics*, *32*(2), 195–210. https://doi.org/10.1111/j.0169-5150.2005.00338.x

Lee, R. David. (2005). Agricultural Sustainability And Technology Adoption : Issues And Policies For Developing Countries, *American Journal of Agricultural Economics 87*(5), 1325–1334.

Levine, K., & Mason, N. M. (2014). Do input subsidies crowd in or crowd out other soil fertility management practices? Evidence from Zambia. *Prepared for Presentation at Agricultural*

& Applied Economics Association's 2014 Annual Meeting, Minneapolis, MN, July 27-29, 1–34. https://doi.org/10.1017/CBO9781107415324.004

Liverpool-Tasie, L. S. O. (2017). Is fertiliser use inconsistent with expected profit maximization in sub-Saharan Africa? "Evidence from Nigeria." *Journal of Agricultural Economics*, *68*(1), 22–44. https://doi.org/10.1111/1477-9552.12162

Liverpool-Tasie, L. S. O., Omonona, B. T., Sanou, A., & Ogunleye, W. O. (2017). Is increasing inorganic fertilizer use for maize production in SSA a profitable proposition? Evidence from Nigeria. *Food Policy*, *67*, 41–51. https://doi.org/10.1016/j.foodpol.2016.09.011

Liverpool-Tasie, L. S. O., & Takeshima, H. (2013). Input promotion within a complex subsector: Fertilizer in Nigeria. *Agricultural Economics (United Kingdom)*, *44*(6), 581–594. https://doi.org/10.1111/agec.12075

Lunduka, R., Ricker-Gilbert, J., & Fisher, M. (2013). What are the farm-level impacts of Malawi's farm input subsidy program? A critical review. *Agricultural Economics (United Kingdom)*, *44*(6), 563–579. https://doi.org/10.1111/agec.12074

Marenya, P. P., & Barrett, C. B. (2007). Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. *Food Policy*, *32*(4), 515–536. https://doi.org/10.1016/j.foodpol.2006.10.002

Marenya, P. P., & Barrett, C. B. (2009). State-conditional fertilizer yield response on Western Kenyan Farms. *American Journal of Agricultural Economics*, *91*(4), 991–1006. https://doi.org/10.1111/j.1467-8276.2009.01313.x

Minot, N. (2007). Are Poor Remote Areas left behind in Agricultural Development. The Case of Tanzania. *Journal of African Economies 17*(2) 239-276. (August). https://doi.org/10.1093/jae/ejm018

Minot, N., Kherallah, M., & Berry, P. (2000). Ferilizer market reform and the determinants of fertilizer use in Benin and Malawi, (40), 62.

Njuki, J., Poole, J., Johnson, N., Baltenweck, I., Pali, P., Mburu, S., … Poole, J. (2011). GENDER , LIVESTOCK AND LIVELIHOOD INDICATORS, (August).

Organización de las Naciones Unidas para la Alimentación y la Agricultura. (2010). *The State of Food Insecurity in the World Addressing food insecurity in protracted crises 2010 Key messages*. *Notes*. https://doi.org/10.1519/JSC.0b013e3181b8666e

Palm, C. A., Gachengo, C. N., Delve, R. J., Cadisch, G., & Giller, K. (2007). Organic inputs for soil fertility management in tropical agroecosystems Organic inputs for soil fertility management in tropical. *Agriculture, Ecosystems & Environment*, *83*(January 2001), 27–41.

Papke, L. E., & Wooldridge, J. M. (1996). Variables With an Application To 401 (K) Plan Participation Rates. *Journal of Applied Econometrics*, *11*(February), 619–632.

Report, A. (2018). The World Bank Annual Report 2018. https://doi.org/10.1596/978-1-4648-1296-5

Ricker-Gilbert, J., Jayne, T. S., & Chirwa, E. (2011). Subsidies and crowding out: A double-hurdle model of fertilizer demand in Malawi. *American Journal of Agricultural Economics*, *93*(1), 26–42. https://doi.org/10.1093/ajae/aaq122

Sanchez, P. A. (2002). Soil fertility and hunger in africa.pdf. *Science*, *295*(March 2002), 2019–2021.

Sheahan, M., Ariga, J., & Jayne, T. S. (2016). Modeling the Effects of Input Market Reforms on Fertiliser Demand and Maize Production : A Case Study from Kenya, *Journal Of Agricultural Economics 67*(2), 420–447. https://doi.org/10.1111/1477-9552.12150

Sheahan, M., & Barrett, C. B. (2014). Understanding the Agricultural Input Landscape in Sub-Saharan Africa Recent Plot , Household , and Community-Level Evidence, (August).

Sheahan, M., Black, R., & Jayne, T. S. (2013). Are Kenyan farmers under-utilizing fertilizer? Implications for input intensification strategies and research. *Food Policy*, *41*, 39–52. https://doi.org/10.1016/j.foodpol.2013.04.008

Smaling, E. M. A., Nandwa, S. M., & Janssen, B. H. (1997). Soil fertility in Africa is at sake. *Replenishing Soil Fertility in Africa.*, *SSSA Spec.*(51), 47–62.

Squire, L. Y. N., & Jof, L. (1986). Agricultural Household Models, 354.

The International Fertilizer Development Center. (2006). Annual Report (2016). Growing Food and Changing Lives. https://doi.org/10.1007/978-1-4020-4975-0

The International Institute of Tropical Agriculture. (2011). CGIAR. Consortium of International Agricultural Research. Annual Report 2014. *American Psychologist*, *66*(6), 573–573. https://doi.org/10.1037/a0024795

The International Institute of Tropical Agriculture. (2012). Annual Report 2012, 18. Retrieved from http://www.statkraft.no/globalassets/1-statkraft-public/05-investor-relations/4-reports-and-presentations/2004-2013-reports-and-presentations/2012/statkraft-annual-report-2012_tcm9-27539.pdf

Tittonell, P., Shepherd, K. D., Vanlauwe, B., & Giller, K. E. (2008). Unravelling the effects of soil and crop management on maize productivity in smallholder agricultural systems of western Kenya-An application of classification and regression tree analysis. *Agriculture, Ecosystems and Environment*, *123*(1–3), 137–150. https://doi.org/10.1016/j.agee.2007.05.005

Tittonell, P., Vanlauwe, B., Corbeels, M., & Giller, K. E. (2008). Yield gaps, nutrient use efficiencies and response to fertilisers by maize across heterogeneous smallholder farms of western Kenya. *Plant and Soil*, *313*(1–2), 19–37. https://doi.org/10.1007/s11104-008-9676-3

Umar, U. A., Muhammad, M. B., & Aliyu, A. S. (2015). Maize production and yield improvement in nigeria (1994-2013), 5.

Umar, U. U., Ado, S. G., Aba, D. A., & Bugaje, S. M. (2014). Estimates of Combining Ability and Gene Action in Maize (Zea mays L .) Under Water Stress and Non-stress Conditions, *4*(25), 247–254.

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K. E., Merckx, R., Mokwunye, U., … Sanginga, N. (2010). Integrated soil fertility management Operational definition and consequences for implementation and dissemination. *Outlook on Agriculture*, *39*(1), 17–24. https://doi.org/10.5367/000000010791169998

Vanlauwe, B., Descheemaeker, K., Giller, K. E., Huising, J., Merckx, R., Nziguheba, G., … Zingore, S. (2015). Integrated soil fertility management in sub-Saharan Africa: Unravelling local adaptation. *Soil*, *1*(1), 491–508. https://doi.org/10.5194/soil-1-491-2015

Vanlauwe, B., & Giller, K. E. (2006). Popular myths around soil fertility management in sub-Saharan Africa. *Agriculture, Ecosystems and Environment*, *116*(1–2), 34–46. https://doi.org/10.1016/j.agee.2006.03.016

What Explains Minimal Usage of Minimum Tillage Practices in Zambia ? Evidence from District-Representative Data by Hambulo Ngoma , Brian P . Mulenga , and T . S . Jayne Working Paper No . 82 March 2014 Indaba Agricultural Policy Research Institute (IAPRI. (2014), (82).

World Bank Living Standard Measurement Survey. Basic Information Document Nigeria General Household Survey panel. (2016).

World Bank Living Standard Measurement Survey Metadata. Survey-panel, G. H. (2015). General household survey-panel.

Xu, Z., Burke, W. J., Jayne, T. S., & Govereh, J. (2009). Do input subsidy programs “crowd in” or “crowd out” commercial market development? Modeling fertilizer demand in a two-channel marketing system. *Agricultural Economics*, *40*(1), 79–94. https://doi.org/10.1111/j.1574-0862.2008.00361.x

Zingore, S., Delve, R. J., Dimes, J. P., Herrero, M., Murwira, H. K., & Giller, K. E. (2006). Evaluation of Resource Management Options for Smallholder Farms Using an Integrated Modelling Approach.

Zingore, S., Delve, R. J., Nyamangara, J., & Giller, K. E. (2008). Multiple benefits of manure: The key to maintenance of soil fertility and restoration of depleted sandy soils on African smallholder farms. *Nutrient Cycling in Agroecosystems*, *80*(3), 267–282. https://doi.org/10.1007/s10705-007-9142-2