

Is Increasing Inorganic Fertilizer Use in Sub-Saharan Africa a Profitable Proposition?

Evidence from Nigeria

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Abstract

Inorganic fertilizer use across Sub-Saharan Africa is generally considered to be low. Yet, this belief is predicated on the assumption that it is profitable to use rates higher than currently observed. However, there is little rigorous empirical evidence to support this notion. Using a nationally representative panel data set, and with due recognition of the role of risk and uncertainty, this paper empirically estimates the profitability of fertilizer use for maize production in Nigeria. The analysis finds that inorganic fertilizer use in Nigeria is not as low as conventional wisdom suggests.

Low marginal physical product and high transportation costs significantly reduce the profitability of fertilizer use. The paper finds evidence that strategies to reduce transportation costs are likely to have a much larger effect on the profitability of fertilizer use than fertilizer subsidies. Apart from reduced transportation costs, other constraints such as timely access to the product; availability of complementary inputs such as improved seeds, irrigation, and credit; as well as good management practices are also necessary for sustained agricultural productivity improvements.

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Introduction

Inorganic fertilizer use is considered low in Africa and many reasons have been invoked to explain this. These include limited or untimely availability of the input (Carlsson, et al., 2005; World Bank, 2006), imperfect markets (Abrar, Morrissey, and Rayner, 2004), lack of agronomic knowledge (Asfaw and Admassie, 2004), riskiness and credit constraints (Croppenstedt, Demeke and Meschi, 2003) and economies of scale in supply – which have all been invoked to give rise to “market smart subsidies”. While there are signs of an increase in fertilizer use, especially in those countries with subsidy programs (Nigeria, Malawi and Zambia) or other concerted support (Ethiopia), fertilizer use generally remains low (Sheahan and Barrett, 2014; Sommer et al., 2013; Montpellier, 2013; Banful et al., 2010; Liverpool-Tasie and Takeshima, 2013).

Importantly, the notion that fertilizer use is low is predicated on the assumption that it is profitable to use higher rates than is currently the case. However, there is little rigorous empirical evidence to support this notion. While various studies have explored the yield response of fertilizer in crop production, (Adedeji et al., 2014 ;Sommer et al., 2013; Omonona et al, 2012; Offodile, 2010; Akighir and Shabu, 2011; Xu et al., 2009), there are few studies that have actually explored the profitability of fertilizer use. Moreover, most studies on profitability are either outdated or largely based on case study areas; not nationally representative (Wopereis-Pura et al., 2002; Poussin, et al., 2003; Becker and Johnson, 1999; J.L.Adedeji et al., 2014 ; Omonona et al, 2012; Offodile, 2010; Akighir and Shabu, 2011; Dadi, Burton, and Ozanne, 2004).

Examination of the profitability of fertilizer use requires an understanding of 1) fertilizer agronomics, i.e. the yield response, and 2) fertilizer economics (the output/input price ratio as well as quantities and costs of inputs such as seed, chemicals, labor and transportation. This requires detailed information on agricultural practices and input costs. The Nigeria Living Standard Measurement Study-Integrated Survey on Agriculture (LSMS-ISA) data set provides a unique opportunity to explore the profitability of fertilizer use in Nigeria. It is a nationally representative panel data set with detailed agricultural information at the plot level. This makes it possible to specifically address the profitability of fertilizer use in a production function framework.

Furthermore, while various studies have explored the yield response of fertilizer in crop production, very few address the fact that there are likely unobserved characteristics that affect

fertilizer application rates that also affect yields¹ (Offodile, 2010; Akighir and Shabu, 2011; Adedeji et al., 2014). This paper uses this rich national representative panel data set with plot level information (The LSMS-ISA) to provide empirical evidence on the profitability of fertilizer use for maize production across Nigeria, addressing the endogeneity of the input use decision. We exploit panel data estimation techniques to estimate expected profit maximizing quantities of applied nitrogen for maize production across agro ecological and market conditions. Then we compare these expected optimal rates (adjusted to account for the riskiness of fertilizer use for smallholder farmers) to the actual rates used by maize farmers. We explore if fertilizer use pays at current prices and if not always, under which circumstances it does.

Thus, this paper addresses two gaps in the literature. First we are able to more consistently identify the yield response to fertilizer application by accounting for unobserved time invariant household characteristics likely to affect fertilizer application and yields. Second we are able to address a key gap in the fertilizer use literature which believes fertilizer use is low in SSA, even though it is profitable. As a result of this assumption, the literature generally looks to other constraints to its adoption, such as financial market imperfections (credit/insurance/savings), knowledge, or lack of demand and thus the realization of economies of scale on the supply side (agro-dealer network), or lack of access to markets to sell the produce, but these all link again to profitability issues. This paper rather focusses on the profitability of fertilizer use as a likely explanatory factor for observed fertilizer use rates.

The rest of this paper is organized as follows: Section 2 describes fertilizer use generally, and within major maize producing farming systems across Nigeria while Section 3 presents our conceptual framework and empirical methods. We present the production function estimates, marginal (and average) products of applied nitrogen and the analysis of the profitability of nitrogen application for maize across various categorizations in section 4. Section 5 concludes.

2. Fertilizer use across Nigeria

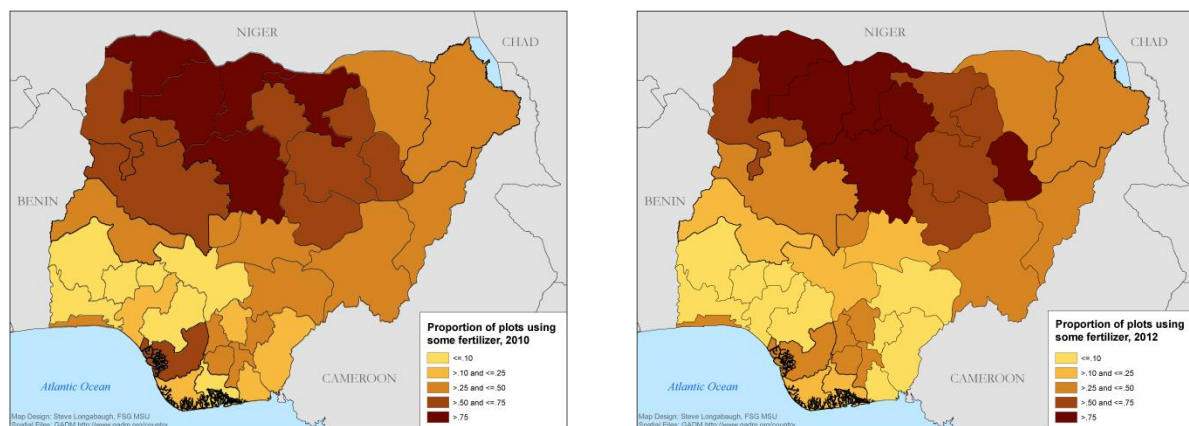
Since the 1940s, Nigerian governments have generally perceived that fertilizer use in the country was low. By the 1960s, population density had started rising and the government became increasingly concerned about farmers' awareness of fertilizer's benefits (Whetham 1966), and

¹ Liverpool-Tasie (2014) is the only paper found in Nigeria while Sheahan et al (2013) and Xu et al (2009) are examples for maize in Kenya and Zambia respectively.

the effects of credit constraints (Ogunfowora and Norman, 1973). Since the 1970s, Nigerian governments have tried to stimulate fertilizer demand, grow the commercial fertilizer sector and lower fertilizer prices. Strategies used to stimulate fertilizer use include subsidies, using extension to develop soil fertility management technologies and programs to increase farmers' access to credit. These programs were said not to have significantly raised fertilizer demand (Nagy and Edun, 2002). Though programs continue to be developed, there is limited evidence that fertilizer use has increased substantially through even more recent programs such as the National Fadama Development Programs, National Special Program for Food Security, and Presidential Initiatives on Agriculture (Liverpool-Tasie and Takeshima, 2013).

Despite the numerous factors cited as responsible for low fertilizer use, there is limited empirical evidence on the nature and rationale for the actual patterns of observed fertilizer use rates across Nigeria's diverse farming systems and cropping patterns. Fertilizer use and needs will naturally vary depending on agro ecological and market conditions, government policies, cropping systems and fertilizer responsiveness. Fertilizer use in the Northern states is typically higher than in the southern states (Figure 1). This is partly attributed to lower soil fertility (FFD, 2011; Smith et al. 1997), larger area cultivated and the growth of high value crops such as cereals and vegetables in the region (Eboh et al., 2006). Additionally, Northern states have traditionally provided greater fertilizer subsidies since the colonial era when administrations provided support for fertilizer use out of concerns over soil depletion and desertification (Mustapha, 2003).

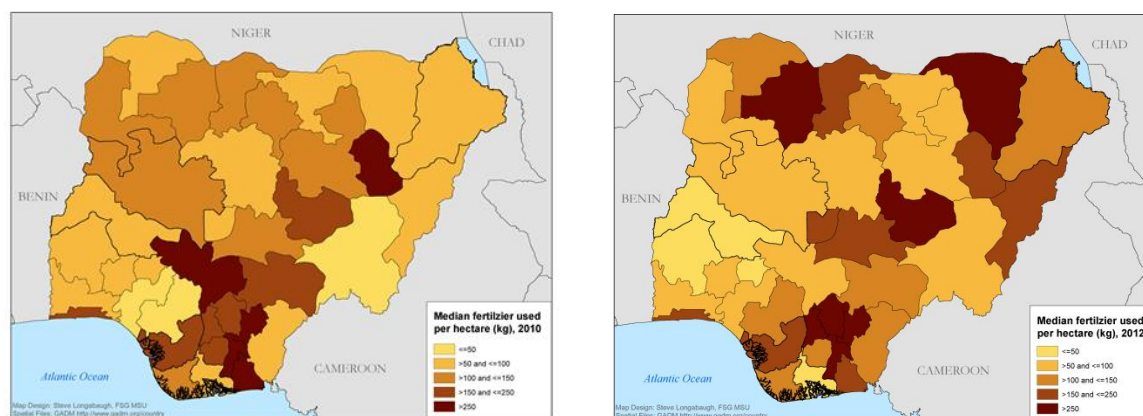
Figure 1: Fertilizer use across Nigeria 2010 and 2012- The proportion of plots on which inorganic fertilizer is applied



Source: Data generated by authors from the 2010 and 2012 Living Standard Measurement Study – Integrated Survey on Agriculture (LSMS) data and Map generated by Longabaugh, S. 2014

Contrary to conventional wisdom, figure 2 indicates that fertilizer use is quite common in Nigeria. Many Nigerian smallholder farmers use some inorganic fertilizer and in many states, some inorganic fertilizer is applied on over 70% of plots. Fertilizer use rates across all plots (including zeros) vary significantly across space and time and are often greater than 100kg per hectare. This is consistent with Sheahan and Barrett (2014) who find unconditional and conditional fertilizer use rates in Nigeria to be about 130kg/ha and 310kg/ha respectively.

Figure 2: Fertilizer use across Nigeria 2010 and 2012: Median quantity of fertilizer applied per hectare of land (including zeros)



Source: Data generated by author from the 2010 and 2012 Living Standard Measurement Study – Integrated Survey on Agriculture (LSMS) data and Map generated by Longabaugh, S. 2014

2.1 Fertilizer use in maize production in Nigeria

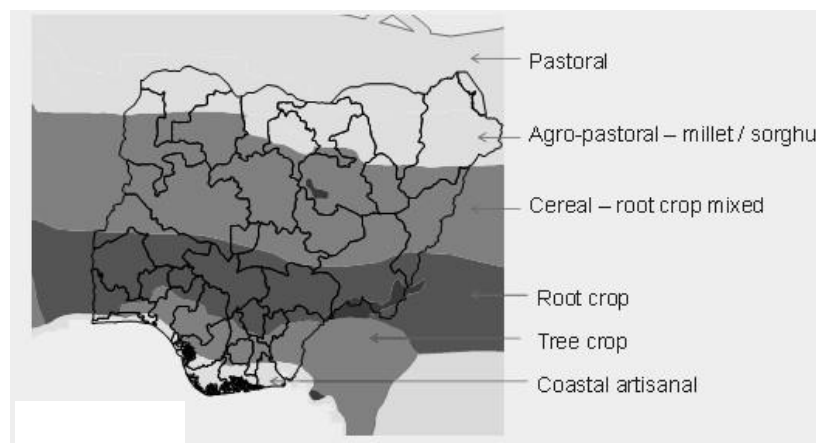
This paper uses information extracted from the LSMS-ISA data for Nigeria. This data set is nationally representative and includes detailed agricultural information collected at the plot and household level across Nigeria. The LSMS-ISA data set includes geo-referenced plot locations and Global Positioning System (GPS)-based plot areas. It also includes plot-level information on input use, cultivation and production. The information was collected over two visits per household per year in 2010/2011 and again in 2012/2013. The first visit each year collected information on planting activities of the households while the second collects information on post-harvest outcomes. For this analysis, we extract all plots on which maize was grown in the main agricultural season in each survey year. Thus we have information on the size of maize plots, the amount of fertilizer and other inputs used and the maize yields for about 2,000 plots over the two survey

periods.

Maize is the third most important cereal grown in Nigeria after sorghum and millet (USAID, 2010). It is also a versatile crop; grown across a wide range of agro ecological zones (IITA, 2001). Every part of the maize plant has economic value: the grain, leaves, stalk, tassel, and cob can all be used to produce a large variety of food and non-food products. In Nigeria, the growing demand for maize is also partly attributed to its use for poultry feed (IITA, 2008). To understand the heterogeneity of fertilizer use and profitability across Nigeria's agro ecological and market conditions, we adopt the categorization of maize farmers in Nigeria by farming systems as defined by Dixon et al (2001). A farming system refers to a group of individual farm organizations that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate (Dixon et al, 2001). Thus a farming systems classification is based on available natural resource base (e.g. water, land, grazing areas and forest), climate, landscape and the consequent dominant pattern of farm activities and household livelihoods.

Maize producers in our sample were categorized into 3 of the 7 farming systems found in Nigeria (see figure 3). They are the Cereal – root crop mixed farming system (C-RCFS), Root crop farming system (RCFS) and the Tree crop farming system (TCFS).

Figure 3. Farming systems in Nigeria



Source: Dixon et al (2001)

Though maize is grown all across Nigeria, the majority of maize production takes place in

three farming systems; the C-RCFS, RCFS and TCFS². The C-RCFS, found in the dry sub humid agro ecological zone is characterized by relatively lower population density, higher temperatures and lower altitude. Almost half (44%) of the maize plots in this farming system (in our sample) use animal draught and intercropping is relatively common; practiced on about 75% of maize plots³. The RCFS is found in the moist sub humid and humid agro-ecological zones. This zone has a favorable average length of growing period (LGP)⁴; between 180- 270 days LGP (Harvest Choice, 2010). Since the RCFS generally enjoys a continuous or bimodal rainfall pattern, risk of crop failure is considered low (Dixon et al, 2001). The TCFS is found in the humid agro ecological zone and maize production occurs with minimal livestock input as draught or source of manure⁵. Tree crops and off farm activities serve as sources of cash and other food crops are grown in addition to tree crops; often in between the trees (Dixon et al, 2001).

Table 1 reveals the extent and magnitude of fertilizer use for maize across Nigeria. Fertilizer use is prevalent among maize farmers; applied on above 60% of plots in the C-RC farming system. However, there is variation in the extent of use. Though fertilizer use on maize is generally above 100kg per hectare, we find consistently higher rates (over 300kg/hectare) of fertilizer application on maize plots in the TCFS. Higher fertilizer use in the TCFS (a portion of the country where population densities are higher) might reflect the more intense use of modern inputs associated with high population density as proposed by Boserup (1965). Binswanger and Savastano (this volume) do not find evidence of Boserup's hypothesis in their sample of African countries (including Nigeria). Though their analysis is based on a cross section, this might indicate that there are other factors correlated with population density that are driving the observed high levels of fertilizer use in our sample.

2 These three farming systems account for about 90% of maize growing plots in our sample.

3 One other crop apart from maize is being grown on about half of our maize plots while over 30% grow more than two crops

4 The length of the growing period refers to the time which both moisture and temperature are conducive to crop growth

5 In our sample of maize farmers, no farmers in the tree crop farming system used manure or animal draught. While manure use is generally low, animal draught use is more common in the C-RCFS, APFS, PFS where 44%, 64% and 46% of maize plots use animal draught power respectively.

Table 1: Fertilizer use rates and maize yield by farming systems

Farming system	Mean fertilizer use per hectare (2010)*	Proportion of plots using fertilizer (2010)	Mean fertilizer use per hectare (2012)*	Proportion of plots using fertilizer (2012)	Mean maize output per hectare (kilograms)	Mean maize output per hectare for fertilizer users (kilograms)	Number of observations
Tree crop	322.2	0.36	463.0	0.33	1,179	1,491	150/203
Root crop	160.8	0.23	187.6	0.15	1,190	1,087	197/278
Cereal-root crop	197.8	0.64	211.0	0.67	1,143	1,232	584/637

**These mean values are conditional on use*

Table 1 reveals that fertilizer use across the survey years is relatively consistent across farming systems⁶. For example, fertilizer use in the TCFS is consistently high (more than 300kg/hectare) over the two survey rounds. Similarly, fertilizer application rates are similar over time for the RCFS and the C-RCFS. In all farming systems, there appears to have been an increase in the average fertilizer rates between 2010 and 2012. Despite the huge difference in fertilizer use across the farming systems, it appears that there is relatively little difference in yields. Furthermore, there does not appear to be a significant difference in yields between fertilizer users and the average sample. This likely reflects that there are other important factors explaining maize productivity and the effect of fertilizer use on maize yields besides fertilizer use. These could include the quality of the soil, input and output costs, the availability of fertilizer and other complementary inputs (such as water, seed, and organic manure) or other management practices.

3. Conceptual framework and empirical approach

Agricultural production constitutes a key source of income for most rural households; alongside non-farm or off-farm activities. Households optimize, not only over all these activities, but also at the plot level. Farmers need to decide the amount of risky inputs (such as fertilizer) to be applied on each plot. Modern inputs such as fertilizer typically increase both the mean and the variance of the net returns to production (Just and Pope, 1979). Generally, the amount of fertilizer

⁶ This likely indicates that measurement error is not big in our panel data set or that the same measurement error is observed over time which can be picked up in a model such as the fixed effects model.

use has to be decided before the rains have come or output price is known for sure and in the presence of imperfect credit and insurance markets.

Consequently, we model the fertilizer use decision of a farmer as a constrained utility maximization problem as in Singh, Squire and Strauss (1986). As described in Sadoulet and de Janvry (1995), the solution to the constrained maximization problem of an agricultural household yields reduced form specifications of demand for inputs and technologies and supply of outputs. We follow previous studies to base our analysis on the quadratic production function which is viewed as a good approximation to the underlying functional form and is widely used in crop yield response analysis (Traxler and Byerlee, 1993; Kouka et al., 1995 Sheahan et al., 2013).

We can express the effect of input use on output as:

$$Yield_{ijt} = f(\mathbf{X}_{kijt}, \mathbf{Z}_{kijt}) \quad (1)$$

Where $Yield_{ijt}$ refers to the output per hectare (in kilograms) of maize on plot i for household j in time t which is a function of several vectors of endogenous and exogenous factors:

$\mathbf{X}_{kijt}$, refers to a vector of inputs a farmer applies (including the quantity of fertilizer) per hectare for maize production, $\mathbf{Z}_{kijt}$, is a vector of controls that are also likely to affect crop yields such as agronomic conditions or household characteristics

Our primary interest is in estimating the extent to which nitrogen use affects maize productivity. The conceptual model above can be specified as:

$$Yield_{ijt} = \mathbf{X1}_{kijt}\boldsymbol{\beta} + \delta Nitrogen_{ijt} + \mathbf{Z}_{kijt}\boldsymbol{\gamma} + c_i + \varepsilon_{ijt} \quad (2)$$

Where $Yield_{ijt}$ remains as defined earlier. $Nitrogen_{ijt}$ refers to the quantity of nitrogen applied per hectare for plot i of household j in time t . Farmers use different types of fertilizers on their plots and these fertilizers have different nutrient contents. Thus, rather than consider all inorganic fertilizer to be the same, we isolate the nitrogen and phosphorus nutrient component of the applied fertilizer. These are the two nutrients limiting in most soils in Sub-Saharan Africa (Stoorvogel and Smaling, 1990; Sanchez et al., 1997).⁷

$\mathbf{X1}_{ijt}$ is a vector of input choices. It includes a subset of $\mathbf{X}_{kijt}$ such as irrigation, pesticides, labor

⁷ The two major fertilizers used in Nigeria are NPK and Urea. NPK typically has about 27% Nitrogen and 13% phosphorus while Urea is about 46%. For this analysis, we multiply those percentages by the total amount of each fertilizer applied to the maize plot to arrive at the total quantity of applied nitrogen and phosphorus.

and other equipment. Z_{kijt} is a vector of controls that affects crop production such as soil quality, rainfall, access to markets, household characteristics including gender and education of the farmer, likely labor availability⁸ as well as household wealth. Finally, $\varepsilon_{ijt} + c_i = u_{ijt}$ is a composite error term comprising time invariant (c_i) and time varying unobserved characteristics ε_{ijt} of our production system while, δ and γ are parameters to be estimated.

A key problem in estimating the effect of fertilizer on yields is the endogeneity of the decision to use fertilizer and the quantity of fertilizer applied on a maize plot. It is likely that fertilizer application is correlated with other farmer and plot specific characteristics (such as unobserved variation in soil characteristics, managerial skill or ability) that are also likely to drive farmer yields and this restricts any causal interpretation to the coefficient on fertilizer use in a yield response model. This correlation between the unobserved individual effect in the error term c_i and the rate of application of fertilizer would cause a bias in ordinary least squares (OLS) estimators (Hausman and Taylor 1981). Consequently, our method of identification of the effects of fertilizer on yields is largely based on a fixed effects model. The fixed effects method attenuates potential biases that can threaten our ability to consistently estimate the effects of fertilizer by using variation in fertilizer use within a household over time to identify the causal effect of fertilizer on yields (Wooldridge, 2010).

While the fixed effects model addresses bias caused by time invariant factors (such as farmer ability that is crucial for production function estimates), it does not deal with any bias caused by time-varying unobservable factors that may be correlated with yields and also correlated with the household's fertilizer use. One unique feature of this study is the availability of plot level characteristics which we include in our production function estimates. This addresses some of the usually absent but important time varying unobserved characteristics of concern when using fixed effects model in yield response estimations by accounting for factors such as the plot wetness potential index and the slope and elevation of the plot. Another limitation of the fixed effects model is that we are unable to recover the coefficients on any time invariant observable characteristics as well. Given that our main concern is on fertilizer use, we do not consider this a major limitation. However, because of time invariant factors such as some dimensions of soil quality

⁸ We recognize that farm decision making at the household level is important when thinking about cost minimization or profit maximization. Though we focus on the maize enterprise, we recognize the importance of other household characteristics in this process and capture that with household characteristics like proximity to markets and labor availability.

(our soil nutrient content) and locational (distance to markets and towns⁹), administrative factors that might affect farmers fertilizer application rate and yields, we also explored the Correlated Random Effects (CRE) model which enables us to address time invariant unobserved household characteristics and still recover the coefficients on time invariant variables (Sheahan et al., 2013)¹⁰

To address challenges associated with extreme outliers, both the input and output variables were winsorized at 99% (or 95% where values at 99% still seemed very large). This involves replacing extreme outlier values beyond the 99th percentile with the value at the 99% percentile rather than dropping the variable. However, where fertilizer use per hectare was still larger than 1 ton after winsorizing, such observations were replaced with a cap value of 700 kilograms per hectare¹¹. Due to challenges associated with using the labor data for the first wave of data, household adult equivalency units were used as a proxy for available labor¹². We also use a dummy to account for whether a farmer uses a chemical (herbicide or pesticide) because of problems encountered with the units of measures of the quantity of herbicides and pesticides used by farmers,. To control for the fact that improved seed varieties are often a complementary input to inorganic fertilizer, we include whether seed used was commercially purchased. This assumes that most improved seed is hybrid which needs to be purchased each year and not open pollinated varieties. We also include measures of the plot's slope (measured in degrees), plot elevation measured in meters above sea, the tropical wetness index /plot wetness potential index and length of growing period (Wilson et al., 2007). A dummy variable is used to distinguish farmers who planted maize as a sole crop on the plot versus those engaged in intercropping. While monocropping could be a sign of specialization in maize production for commercial purposes, intercropping of crops such as maize with legumes is also commonly used to diversify risk and increase maize yields because of the nitrogen fixing effect of legumes. As a source of additional nutrients likely to affect maize yields as well as response of nitrogen application, we control for

⁹ These do not vary over the short duration covered and are indicators of access to extension agents and also indicate likely differences in transportation and other transactions costs

¹⁰ The full results from the CRE models are not included due to space considerations but are available from the authors. We find that our key output of interest (the MPPs) in the main maize farming systems (where effects are significant) are similar for both the FE and CRE even though the CRE model does indicate that some time invariant characteristics are important. As expected both soil quality and administrative factors appear to be important determinants of maize yields.

¹¹ This follows Sheahan and Barrett (2014) as 700kg/hectare represents an upper-bound limit associated with inorganic fertilizer use in the United States under irrigated corn conditions .

¹² For this same reason we are not able to explore other dimensions of nitrogen application as the likely role labor availability plays in the effectiveness and profitability of nitrogen application

organic manure use and the number of other crops grown on the plot. While growing more crops on a plot might indicate competition for nutrients, the kind of crops grown (e.g. if they are leguminous crops that fix nitrogen) could also indicate differential effects of applied nitrogen and consequent maize yields. We also control for plot ownership defined as whether the plot was purchased or distributed by community or family¹³. Finally we control for the geopolitical zones to account for any region specific characters or policies that could affect maize yields. In all specifications, standard errors are clustered at the household level to make them robust to serial correlation and to account for non-constant variance (Wooldridge, 2010).

We then use the estimates from our production function to calculate the expected marginal and average physical products of nitrogen in maize production; EMPPs and EAPPs respectively. The EMPP of applied nitrogen (which describes how much extra maize output can be produced by using one additional unit of applied nitrogen, all else held constant) is gotten by taking the first derivative of the production function with respect to applied nitrogen. We conceptualize and calculate the average physical product as the gain in maize yield per unit of applied nitrogen relative to not using any applied nitrogen (Sheahan et al, 2013). These EMPPs and EAPPs are then used to calculate our partial profitability measures; the expected marginal value cost ratio (EMVCR) and the expected average value cost ratio (EAVCR) as follows:

$$E(MVCR_{nijt}) = \frac{E(p_{mt}) * E(MPP_{nijt})}{p_{nijt}} \quad (3)$$

$$E(AVCR_{nijt}) = \frac{E(p_{mt}) * E(APP_{nijt})}{p_{nijt}} \quad (4)$$

where p_n is the price of nitrogen and p_m is the price of maize. When $MVCR_{nijt}$ is greater than one, it means that a risk neutral household could increase its income by increasing its nitrogen application rate. When $AVCR_{nijt}$ is greater than 1, it implies that a risk neutral household could increase its income by using fertilizer. Consequently, we expect risk neutral households to use fertilizer if $E(AVCR_{nijt}) > 1$ and their nitrogen application rate to be determined by $E(MVCR_{nijt})$

¹³ We follow Sheahan and Barrett (2014) to use this definition but recognize that this might be an overestimation (for the purposes of capturing tenure as an indicator of likely willingness to make various agricultural investments) as in many communities in Nigeria where land is distributed by the community, this occurs yearly with no guarantee for the same plot being assigned yearly.

As mentioned above, fertilizer use is risky and rural households in Nigeria are likely to be risk averse. Consequently we incorporate a risk premium of δ into our analysis (Sheahan et al., 2013; Anderson et al., 1977). As has been done in the literature, we use a risk premium of 1 to factor in risk and uncertainty and approximate for the rate at which nitrogen application is going to be profitable enough for rural farmers to be willing to use it (Xu et al., 2009; Sauer and Tchale, 2009; Bationo et al., 1992; Sheahan et al., 2013; Kelly, 2005).

In this framework, rather than $AVCR_{nijt} > 1$ and $MVCR_{nijt} > 1$ being used as the decision rule guiding farmers in their decision to use fertilizer, a higher MVCR of 2 is considered to be necessary for a risk averse farmer to find nitrogen application profitable. In line with Sheahan et al (2013) we consider MVCR and AVCR values greater than 2 to be an adequate indicator of profitability of nitrogen application for maize production.

Nigeria is a country with a significant fertilizer subsidy program. There are multiple layers of subsidy possible and when received, the subsidy rate could range between 25% and 100% (Liverpool-Tasie and Takeshima, 2014). Consequently it would be ideal to compare profitability of nitrogen application under subsidized and non-subsidized scenarios. We do not have information on the receipt of subsidized fertilizer in the LSMS-ISA data for our survey years. However, there is information on whether a farmer received some of their fertilizer for free to those who did not.¹⁴ In both survey years, only about 2% of maize plots recorded that some of the fertilizer applied on the plot was received for free. Consequently, we restrict our consideration of the profitability differences across market purchased and subsidized fertilizer to simulations based on the expected price differences provided in recent studies on fertilizer subsidy programs in Nigeria.

4. Results

Our descriptive statistics indicate that maize production is largely a smallholder activity in Nigeria. The average maize plot is between 1 and 1.5 hectares, managed by a middle aged male with limited use of irrigation and mechanization. While only about 20% of maize plots use purchased seed, almost 50% of farmers use some chemicals (herbicides and pesticides) in maize production and the average fertilizer use is between 36 and 38kg of applied Nitrogen This figure is

¹⁴ In our study sample from the LSMS-ISA data, only 1.2% of plots on which maize is grown did not pay in full for their fertilizer.

not conditional on use (e.g. table 1) and translates to between 133kg and 140kg/ha of fertilizer¹⁵. This is almost identical with Sheahan and Barrett (2014) who find unconditional fertilizer use for Nigeria to be 130kg/ha using the 2010/11 data. As Table 2 suggests, the average nitrogen application per hectare (as well as most input use variables) among maize farmers is relatively consistent across years lending credibility to the data. Maize prices vary widely across the different states of Nigeria; likely reflecting state level differences such as proximity to the port (for fertilizer) and local consumption and production of maize. Average state level prices generally have a standard deviation less than 15.

Table 2: Descriptive statistics for key study variables

Variables	2010		2012	
	Mean	Std. Dev.	Mean	Std. Dev.
Household adult equivalency units (units)	5.237	2.699	5.522	2.883
Area planted (hectares)	1.543	1.728	1.322	1.342
Nitrogen applied (kilograms per hectare)	38.08	73.62	36.62	68.66
Seeding rate (kilograms per hectare)	19.52	30.21	18.56	24.15
Organic Fertilizer (1/0)	0.0190	0.136	0.0173	0.130
Farmer purchased seed (1/0)	0.229	0.421	0.159	0.365
Male plot manager (1/0)	0.845	0.362	0.832	0.374
Mechanization (1/0)	0.0664	0.249	0.0331	0.179
Animal traction use (1/0)	0.277	0.448	0.268	0.443
Irrigation (1/0)	0.0227	0.149	0.0165	0.128
Agro chemical use (1/0)	0.424	0.494	0.423	0.494
Distance to central market (kilometers)	73.08	40.35	70.19	43.04
Topographic wetness index (units)	14.42	2.710	14.28	2.501
Slope (percent)	3.582	2.578	3.421	2.483
Annual Mean Temperature (°C*10)	257.9	13.76	259.7	12.63
Annual Precipitation (mm)	1,335	454.0	1,363	501.2
Any household member could sell land (1/0)	0.757	0.429	0.780	0.415
Plot elevation (meters)	380.0	255.7	400.1	291.7
No other crop planted (1/0)	0.207	0.405	0.159	0.366
One other crops planted (1/0)	0.402	0.491	0.356	0.479
Two other crops planted(1/0)	0.239	0.427	0.264	0.441
Three or more other crops planted(1/0)	0.153	0.360	0.221	0.415

¹⁵ This translates to about 150kg of fertilizer per hectare assuming the nutrient content of NPK fertilizer is 27:13:13 while that of Urea is 46% of the fertilizer quantity.

Legume grown on plot (1/0)	0.177	0.382	0.198	0.398
Maize yield per hectare (kilograms)	1,154	1,649	1,282	1,718
Age of plot manager (years)	48.29	14.63	50.36	14.94
Phosphorus per hectare (kilograms)	10.28	22.11	11.93	23.38
Owned Household Assets (Thousand Naira)	140.9	548.2	93.55	147.5
Maize price (Naira per kilograms)	79.2	61.83	104.37	70.49
Fertilizer price (Naira per kilograms)	115.68	153.5	102.20	41.76

All prices are adjusted to 2012 prices using the cpi from the Nigerian National Bureau of Statistics

4.1 Production function estimates and marginal physical product of nitrogen

The production function estimates are presented for each farming system in Table 3. The results from a chow test (Chow, 1960) indicate that a pooled production function across farming systems is inadequate to explore the yield effects of nitrogen application in Nigeria¹⁶. Consequently we run separate production functions for each of the 3 farming systems under consideration. We present the pooled OLS and Fixed effects results for comparison. Table 3 indicates that applied nitrogen significantly affects maize yields in the Cereal- Root Crop Farming system (C-RCFS) and Tree Crop farming system (TCFS). The negative squared terms imply decreasing returns to applied nitrogen and indicate that the quadratic functional form used is likely appropriate. Only in the TCFS do we find evidence of increasing returns from the use of applied nitrogen alongside commercially purchased seed (likely to be improved varieties). This is in line with our expectation that improved varieties of seed and applied nitrogen are complementary inputs¹⁷. The general insignificance across other systems might reflect the poor quality of commercially purchased seed; often a problem in Nigeria (Ajeigbe et al., 2008). The seeding rate appears to be a major determinant of maize yields in Nigeria and this holds across all farming systems. The coefficients range between 14 and 40 and are significant at 1%. Higher labor supply, the use of a tractor or other mechanical equipment and animal traction tend to increase maize yields in the C-RCFS¹⁸. Where significant, maize plots on which two other crops (apart from maize) were grown had better yields than those on which 3 or more other crops apart from maize. This likely indicates that while mixed cropping (with a leguminous crop for

¹⁶ With $F(51, 1927) = 2.5$, we reject the null that the reduction in the residual sum of squares from running separate regressions is not significant at 1 %.

¹⁷ We also tried to interact the applied nitrogen variable with irrigation but were unable to due to collinearity problems.

¹⁸ Whether a household member received advice on agricultural information (likely endogenous) was also considered and found not to be significant.

example) could improve soil nutrient content (and consequently fertilizer application) and thus yields, higher number of crops also leads to more competition for nutrients¹⁹.

Maize production in Nigeria appears to exhibit the inverse relationship between farm size and physical yield. The plot size variable and its square are negative and positive respectively with both coefficients significant at 1%. This is in line with a similar study on rice in Nigeria and several other studies feeding into the long debate on this relationship (Liverpool-Tasie et al., 2013; Sheahan et al., 2013; Chayanov, 1966; Sen, 1962; Berry and Cline, 1979; Barrett, 1996).

Table 3 also shows the importance of addressing the effects of unobserved household specific characteristics when estimating nitrogen yield response functions. The difference between the pooled OLS and Fixed Effects results indicate the presence of some time invariant unobserved factors that are likely correlated with nitrogen application as well maize yields.

¹⁹ We run specifications that include a control for whether a leguminous plant is grown on the maize plot but this did not yield significant results and was highly correlated with the number of crops grown. Thus we focused on the number of crops grown. We also tried interacting the number of crops grown on the plot with applied nitrogen but these were not significant; probably partly due to multicollinearity.

Table 3: Production function estimates

	Cereal-Root Crop Farming system		Tree Crop Farming system		Root Crop Farming system	
	Pooled OLS coefficients	Fixed Effects coefficients	Pooled OLS coefficients	Fixed Effects coefficients	Pooled OLS coefficients	Fixed Effects coefficients
Nitrogen	4.286*	8.732**	33.436***	16.039	0.993	14.726
Nitrogen squared	-0.000	-0.005	-0.071*	-0.094**	0.043	-0.041
Nitrogen*Phosphorus	0.036*	-0.018	-0.088	0.152	-0.089	-0.308
Seed rate (kg/hectare)	14.701***	14.236***	40.693***	39.068***	35.053***	30.919**
Labor (adult equivalency units)	1.787	154.480+	92.792	681.492	69.831	445.483
Mechanization (1/0)	133.406	33.697	6,411.498*	29.141	2,429.232	924.351
Irrigation (1/0)	394.784*	88.806				
Animal traction use (1/0)	234.310**	281.889+			193.436	
Chemicals (1/0)	155.566*	88.050	2,308.792	3,647.580	124.142	-615.047
Organic fertilizer (1/0)	247.631	330.152			3,142.838	5,176.077
Commercial seed	340.636*	79.101	1,093.81	1535.231	307.544+	1009.473
Commercial seed*Nitrogen	-2.839*	-0.790	0.451	9.757*	-16.518***	-26.543
Sex (1/0)	629.837***	23.987	35.025	431.291	908.289*	238.767
Age (years)	5.204*	10.491	8.245	-17.551	9.730	36.740
Assets ("000 Naira)	-0.018	-0.013	0.317	-6.910	-0.451	0.202
Plot area (hectares)	-615.184***	-600.999***	-6,332.303***	-9,241.305**	-1,805.749***	-2,221.989***
Squared plot area (hectares)	65.622***	61.498***	760.432***	1,329.332+	200.227***	231.537**
Topographic wetness index (units)	-20.632	-29.721	-29.209	-97.284	71.733	110.140
No other crop planted	175.051	64.777			-308.579	-273.237
One other crop planted	202.466	239.031	-673.275	684.865	-289.589	175.176
Two other crop planted	-42.636	218.495	147.816	1,302.021*	877.233**	1,698.545**
Three or more other crop planted	-	-	-	-	-	-
Plot elevation (m)	0.573**	0.771	-3.118	6.731	2.357	-8.397
Plot slope (percent)	-5.792	-45.692	-130.074	-13,610.466	67.741	-1,379.519
Annual Precipitation (mm)	-0.205	-4.303	-2.347	-3,372.297	-3.497**	-95.809
Any household member could sell land (1/0)	-61.775	-221.211	-195.704	-645.518	-179.401	1,044.760

Moderate nutrient constraint	474.136***		-3,951.444***		1,268.295***	
Severe nutrient constraint	265.427		-4,180.699***		922.046	
North east	-420.139**	14,988.698			2,196.389***	
North west	-580.688***					
Year	-149.064	-64.466	2,074.295***	2,799.376***	-482.444	-798.215*
South south			-1,035.603		-434.767	
South west			-810.804		2,330.586***	
South East					3,657.806***	
Constant	702.385	540.232	1,951.064***	7,380.450	4,707.881	1,428.990
Number of observations	1,084	1,084	339	339	427	427
R-squared	0.306	0.764	0.254	0.879	0.431	0.891

. *, ** and *** are significant at 10, 5 and 1 percent respectively. + is significant at 15% or less.

4.2 MPPs and APPs of applied nitrogen in Nigeria

The MPPs of applied nitrogen are estimated as the derivative of the production function with respect to our applied nitrogen variable. The MPPs were estimated using the “margins” command in Stata and represent the average partial effects of nitrogen on maize yields (See Table A1 in the appendix for the APEs of all variables). We also calculate the APP as the change in output due to the use of applied nitrogen. This captures the gain in yield per unit of nitrogen compared to not applying any nitrogen. We manually calculate the APPs at the field level using the coefficient estimates of our production function.

Table 4: MPPs and APPs of applied nitrogen across farming systems in Nigeria

	MPP of applied Nitrogen	APP of Applied Nitrogen
Cereal-root crop farming system	7.98**	7.79
Tree crop farming system	12.38+	8.76
Root crop farming system	11.15	19.37

, ** and * are significant at 10, 5 and 1 percent respectively. + is significant at 15% or less.*

The marginal physical product (MPP) for applied nitrogen in Nigeria appears to be quite low. The average MPP of nitrogen across farming systems ranges between about 8 and 13kg. Though usually focused on a very specific location, many studies in Nigeria indicate relatively wide variation in fertilizer yield responses from about 0.2 to 2 (Onuk et al., 2010; Gani and Omonona, 2009) with cases of negative APP (Kehinde et al., 2012). Studies on fertilizer yield response in Mfantseman Municipality in the Central Region of Ghana yielded an MPP value of 0.12. This is quite different from what has been found in East and Southern Africa. Sheahan et al. (2013) estimate an overall MPP of nitrogen for maize production to be about 17 (though this varies across space and time). Matsumoto and Yamano (2011) found marginal products ranging between 11 and 20 across the western and higher potential regions of Kenya while Marenja and Barrett (2009) found the marginal product of nitrogen to be 17.6 for Vihiga district (Western Province) of Kenya. The low MPPs of applied nitrogen in maize production indicate that increasing fertilizer use alone might not be sufficient to increase maize yields to desired levels in Nigeria. Furthermore, given high fertilizer

costs, low maize yield response to nitrogen application is likely to also affect the profitability of its use.

4.3 Profitability of applied nitrogen for maize production

To estimate the expected profitability of applied nitrogen, the MPPs and APPs that were calculated from the FE model are combined with the price of maize and the acquisition price for nitrogen to estimate the marginal value cost ratios (MVCRs) and average value cost ratios (AVCRs). As mentioned earlier, the application of nitrogen is considered to be profitable where the marginal value product of nitrogen (MPP*price of maize) exceeds its market price (Marennya and Barrett, 2009). This is equivalent to saying where the MVCR or AVCR is greater than 1 (see equations 3 and 4). With an AVCR greater than one, a risk neutral farmer can increase his income with fertilizer use. However, with a MVCR of greater than one, a risk neutral farmer can increase his income by increasing his rate of fertilizer application. To capture the fact that smallholder farmers in rural Nigeria are likely to be risk averse we consider AVCR and MVCR need to be 2 or more to be profitable for these farmers as our base scenario.

The output price used for this analysis was the median community selling price of maize per kilogram. While it is likely that a farmer's decisions to use fertilizer during the planting season is driven by expected prices of maize rather than the actual price at post planting or post-harvest, the unavailability of good price information at the community or local government area (LGA)²⁰ level precluded our ability to explore options to generate such expected prices as described in Muyanga (2013) and used by Sheahan et al. (2013). By using the selling price we are assuming farmers had a good sense of those prices at planting time. We replace missing maize price values with local government medians and then state medians when LGA medians are unavailable.

The majority of fertilizer used for maize production in Nigeria is either NPK or Urea. Consequently, the price used for nitrogen is a simple average of the market price of the nitrogen components of Urea and NPK converted to a one kilogram equivalent (Xu, 2008; Sheahan et al. 2014). We consider both the acquisition and the market price of nitrogen to account for the role of high transportation costs in the profitability of nitrogen application. The market prices were calculated as the value paid for fertilizer divided by the quantity purchased. In communities where

²⁰ Local government authorities are administrative units below the state. There are 776 LGAs across Nigeria's 36 states.

the resulting price of fertilizer was less than N50²¹ per kilogram of fertilizer or missing, the local government average (gotten from the data) was used and where that was not available, a state level average fertilizer price was used. To address persistently extreme values (beyond N1000/kg), fertilizer prices were winsorized at 95%. Extreme values after winsorizing (greater than N250/kg) were also replaced with the local government or state average.

We compare the profitability of plot level nitrogen application (determined by the MVCRs) to observed nitrogen application to see if observed use patterns are in line with that indicated from expected profitability. We consider how the profitability of nitrogen application varies when the acquisition cost is used to calculate expected profit versus the market price and when farmers are considered to be risk averse or risk neutral. We also consider how fertilizer profitability varies across different levels of fertilizer subsidy.

4.4 Fertilizer acquisition costs and the profitability of nitrogen application for maize production in Nigeria

With few community level input suppliers and poor infrastructure in rural areas, market prices do not always adequately reflect the cost of acquiring fertilizer. Transactions cost more generally (and transport costs more particularly) have been shown to play a key role in farmers' decisions to use modern inputs (Winter-Nelson and Temu, 2005; Morris et al., 2007; de Janvry et al., 1991; Key et al., 2000; Bellemare and Barrett, 2006). Thus we calculate the fertilizer acquisition cost to be the market price for nitrogen plus the cost of transportation from the market to the farm gate (Sheahan et al. 2013). Transportation costs to acquire fertilizer are very high in Nigeria (Table 5). The average price paid per kilogram of NPK fertilizer in 2010 was about N105. However, when we factor in the average transportation cost to acquire the fertilizer, the acquisition cost in 2010 was about N425²². This indicates that about 70% of the actual cost incurred by farmers using fertilizer is

²¹ According to the data from the Nigerian agricultural markets information system, the price for fertilizer in 2010 generally ranged between N4500 (for a 50kg bag) and N6000 which amounts to between N90/kg and N120. Our data exhibits wide variation thus extreme values were winsorized at 95% and then all fertilizer price values greater than N200 per kg were replaced with N200.

²² As the common mode of transporting fertilizer was motorcycle, closely followed by mini bus, transportation costs in this paper also replaces any transportation costs (after winsorizing) that exceed N700 with N700 to exclude the effect of transportation costs for cars and pickups. However anecdotal evidence from extension agents in rural Nigeria indicates that transportation cost even by motorcycle ranges between N200-N2,000 depending on many factors such as the region of the country, the season and quality of the road.

²² We use both total winsorized (at 95%) transportation costs and winsorized transportation costs with a cap of N700. While the uncapped transportation costs gives us much larger values (with transportation being up to 70% of total

due to transportation costs. This echoes the findings of other studies that transportation costs account for 20-25% of the urban retail prices at regional hub cities in Nigeria (Liverpool-Tasie and Takeshima, 2013). This effect is likely exacerbated at rural markets and (even further in remote villages) to capture the costs of getting the fertilizer to more remote areas with poorer road networks²³.

Table 5: Share of total fertilizer acquisition prices due to transport costs in Nigeria

	2010	2012
Market price for fertilizer (per kilogram)	104.55	100.62
Total acquisition cost	425.57	450.21
Share of total acquisition cost of fertilizer that is due to local transportation cost*	0.70	0.71

*Prices are adjusted to 2012 prices using the CPI from the Nigerian National Bureau of Statistics.**

Transportation cost is the difference between the total acquisition cost and the market price. The share represents the proportion of the acquisition cost that goes towards transport

With the low MPP of nitrogen for maize production in Nigeria, the proportion of maize plots for which nitrogen application is profitable (for a risk averse farmer) at the observed fertilizer acquisition prices and maize price is quite low. In the C-RCFS, it is only profitable for about 16% of all maize plots. This farming system is the largest farming system in our sample (comprising over 60% of all maize plots) and likely most representative of maize production in Nigeria. Even in the TCFS where the MPP of fertilizer application was about 13kgs of maize per kg of nitrogen applied, nitrogen application is only profitable in expectation for about 35% of maize plots (Table 6)²⁴.

acquisition costs) we present the more conservative estimates (at about 50% of the cost) that still enable us to make our point about the effect of high transportation costs on fertilizer profitability.

²³ We use both total winsorized (at 95%) transportation costs and winsorized transportation costs with a cap of N700. While the uncapped transportation costs gives us much larger values (with transportation being up to 70% of total acquisition costs) we present the more conservative estimates (at about 50% of the cost) that still enable us to make our point about the effect of high transportation costs on fertilizer profitability.

²⁴ We do not lay too much emphasis on the results for the RCFS because they were never statistically significantly different from zero in the production function estimates and this was consistent across all methods; fixed effects, pooled OLD and correlated random effects.

To explore the effects of transportation costs on the profitability of nitrogen application, we simulate how reducing transportation costs affect the number of plots on which nitrogen application is profitable. We find that reducing the transportation costs associated with securing fertilizer by 50% increases the percentage of plots on which nitrogen application would be profitable in the C-RCFS by 56%. Within that farming system alone, a further reduction of transportation costs by 75% would double the number of plots on which nitrogen application would be profitable. This indicates that while the low profitability of nitrogen application in the C-RCFS is partly driven by the low MPP of nitrogen, reducing the cost of fertilizer acquisition can significantly affect the profitability of nitrogen application for maize production in this farming system. This profitability increasing effect of reduced transportation costs on nitrogen application for maize production in Nigeria cuts across all farming systems. Even in the TCFS where nitrogen application is profitable on about 35% of plots at current acquisition costs, reducing these costs by 25% and 50% could increase the number of plots on which nitrogen application is profitable by about 40 and 60% respectively. These are really large effects and we consider these conservative estimates²⁵.

Table 6: Transportation costs and the profitability of fertilizer use

Proportion of maize plots for which fertilizer use is profitable for a risk averse farmer (MVCR$\geq$2)				
Farming system	Full acquisition cost	Transportation cost reduced by 50%	Transportation costs reduced by 75%	Fertilizer available in the village
Cereal-root crop	0.16	0.25	0.32	0.45
Tree crop	0.35	0.48	0.57	0.68
Root Crop	0.38	0.51	0.58	0.65

These results are gotten from a simulation of fertilizer profitability with different transportation cost.

Table 7: Transportation costs and the profitability of fertilizer use when risk neutrality is assumed

Proportion of maize plots for which fertilizer use is profitable for a risk neutral farmer (MVCR$\geq$1)				
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²⁵ Using the winsorized but uncapped transportation costs we find that a 50% reduction in transportation costs could increase the percentage of plots for which fertilizer use is profitable by much larger fractions than presented in table 7

	Full acquisition cost	Transportation cost reduced by 50%	Transportation costs reduced by 75%	Fertilizer available in the village
Cereal-root crop	0.39	0.57	0.69	0.78
Tree crop	0.64	0.75	0.77	0.80
Root Crop	0.60	0.64	0.65	0.68

These results are gotten from a simulation of fertilizer profitability with different transportation cost.

We see a large difference in the distribution of plots on which nitrogen application is profitable when risk aversion versus risk neutrality is assumed. While nitrogen application (at full acquisition costs) is profitable for less than 20% of maize plots in the former (for the C-RCFS) this increases to almost 40% for the latter (See table 7 vs. table 6). Similarly reducing transportation costs by 75% increases the number of plots for which nitrogen application is profitable to almost 70% in the C-RCFS compared to about 45% when risk aversion is assumed. With risk neutrality, these transport cost reductions increases the number of plots on which nitrogen application is profitable from just under 60% (in the TCFS) to closer to 80%. With these large variations in profitability when risk neutrality is assumed versus risk aversion, it is important to see if farmers observed behavior is more in line with one assumption more than another.

4.5 Fertilizer profitability and observed use rates

Next, we compare actual observed fertilizer use rates on maize plots in Nigeria with the expected profit maximizing levels. Following Sheahan et al. (2013) we use the estimates from the production function to derive the amount of nitrogen that should be applied for the marginal value cost ratio to be equal to 2 (for a risk averse farmer) and 1 (for a risk neutral famer) given the full acquisition price of fertilizer and the market price.

Comparing table 8 and table 6 we see that the percentage of plots on which nitrogen is actually applied in the TCFS (35%) is almost identical to the percentage of plots for which the application of nitrogen is considered profitable for a risk averse farmer (i.e. $MVCR > 2$); which is 34%. Over 70% of these households for which nitrogen application is profitable actually use some of the input. However, for the C-RCFS, while fertilizer use is only profitable in expectation for about 16% of plots, we have over 65% of maize plots using some fertilizer. This likely indicates that

fertilizer use is not purely driven by observed market prices and MPP. For example, for food security concerns, (particularly when faced with poor quality soils), the shadow price of maize might be much higher than the observed market prices. Some of these factors might be correlated with the true decision prices for farmers not observed in our study.

Comparing actual nitrogen application rates on maize plots to expected profit maximizing rates indicates that fertilizer use for maize is often higher than expected profit maximization for risk averse farmers would indicate. Table 8 reveals that the mean observed application rate of nitrogen for farmers (assuming they are risk averse) is consistently higher than the mean expected profit maximizing level. At the plot level we see that only 16% of farmers in the C-RCFS apply less than the amount of nitrogen one would expect a profit maximizing risk averse farmer to apply. Though the mean observed application rates lie between the expected amounts for risk averse and risk neutral farmers, the means of the actual application rates of maize farmers in our sample are much closer to those predicted assuming risk aversion. More importantly, at the plot level, we see that if risk neutrality was assumed then many more farmers would be considered to be under-using fertilizer; almost 45% versus 16% (for farmers in the C-RCFS) and almost 70% versus about 35% in the TCFS. This indicates that the observed nitrogen application rates in our sample are much closer to what is predicted by the expected optimal allocation rates for risk averse farmers than risk neutrality. These findings demonstrate the importance of acknowledging risk preferences when studying the profitability of the use of modern inputs that are risk increasing such as fertilizer.

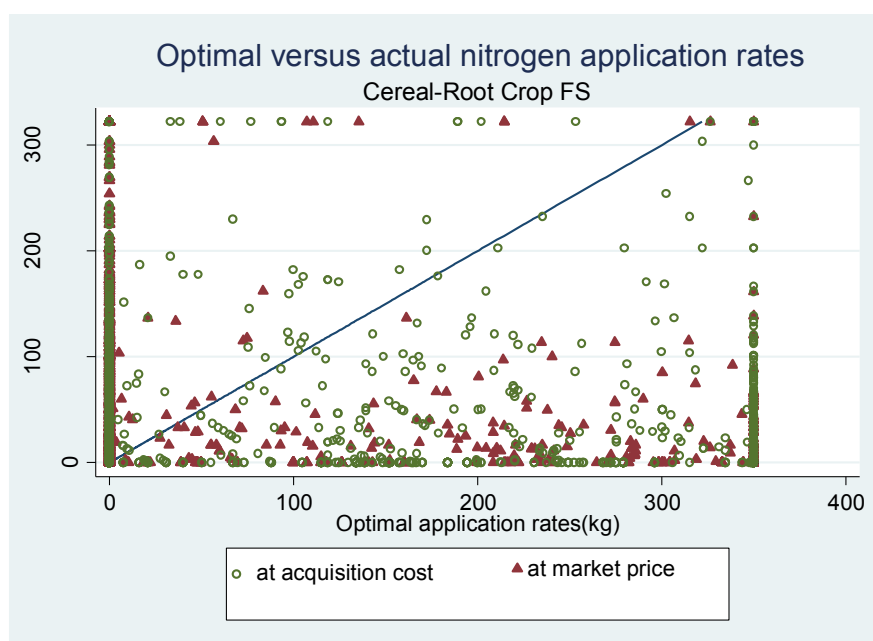
Table 8: A comparison of actual and expected profit maximizing nitrogen application rates for maize in Nigeria for risk averse farmers

	Percentage of plots using fertilizer	Mean of the Actual applied Nitrogen (kg/ha)	Mean of the estimated expected profit maximizing level of Nitrogen application (kg/ha) at acquisition cost	Percentage of plots whose application rate is less than optimal (%)	Mean of the estimated expected profit maximizing level of Nitrogen application (kg/ha) at market price	Percentage of plots whose application rate is less than optimal (%)
Cereal-root crop farming system (C-RCFS)	67.16	76.01	37.75	16.71	103.2	44.76
Tree crop farming system (TCFS)	34.18	49.59	28.95	35.51	60.07	67.94
Root crop farming system (RCFS)	18.07	45.13	39.03	38.67	83.09	62.03

Source: Authors estimations from the LSMS-ISA data. Values are means over the two survey years

We also compare the effect of taking into account full acquisition costs versus the market price. Table 8 shows how using the market price without consideration for transportation costs would lead to much higher optimal rates of nitrogen application. Properly reflecting the high acquisition costs reveals optimal rates closer to the application rates than when using the observed market price. Figure 4 supports Table 8 and indicates that there is a better correspondence between observed nitrogen application rates when full acquisition costs are used compared to when market prices are used. This is seen by the tighter fit around the 45 degree line when acquisition cost is considered.

Figure 4.



Source: generated by authors using STATA

4.6 Fertilizer subsidies and fertilizer profitability

Throughout most of Nigeria's recent history, fertilizer subsidies have been a dominant component of agricultural input programs; accounting for substantial shares of government capital spending on agriculture (Mogues et al., 2012). In 2012 (when our second round of data was collected) the Nigerian government began a new fertilizer program. Prior to 2011 (and when our first round of data was collected), the subsidy program in existence was called the Federal Market Stabilization Program (FMSP). Under the FMSP, each Nigerian state government would submit a request to the federal government for a certain quantity of subsidized fertilizer it wanted to procure. Depending on the federal agricultural budget, the federal government then determined the total amount of subsidized fertilizer to be allocated to each state (Takeshima and Nkonya, 2014). The federal government then procured and sold fertilizer to the state governments with a 25 percent subsidy. States, as well as LGAs often added their own subsidies to the 25% provided by the federal government. This amount varied across states and often ranged between 0 and 50 percent (Banful et al. 2010). Consequently depending on a farmer's state and local government of origin, the rate for subsidized fertilizer under the FMSP typically ranged between 25 and 75 percent. Anecdotal evidence indicates that a substantial portion of subsidized fertilizer leaked into commercial markets

and was sold as unsubsidized fertilizer. Thus, the amount of subsidized fertilizer that actually received by farmers accounted for only a relatively small fraction of the intended quantity (Liverpool-Tasie and Takeshima, 2013).

In contrast to the previous subsidy system (implemented from 1970s to 2011) in which the government directly procured and distributed subsidized fertilizer, the new system (called Growth Enhancement Support [GES]) scaled up a previously piloted paper voucher-based program to the national level, delivering vouchers electronically to registered farmers with mobile phones, while leaving procurement and distribution to the private sector. Under the current scheme, farmers are restricted to receiving 2 bags of subsidized fertilizer (typically subsidized at 50% of market price) in contrast with the FMSP where no quota existed.

Our data set does not have any information about whether farmers received some subsidized fertilizer or not. The only indication is the response to a question on if some fertilizer applied on the plot was gotten for free and only about 2% of our sample responds affirmatively to this. Consequently we simulate the likely effect of subsidized fertilizer on the profitability of nitrogen application for maize farmer using the typical range of 25% to 75%. It should be noted that our simulated profitability effects overestimate the likely impact of subsidies since we assume that all farmers would receive these subsidies and don't restrict the quantity of subsidized fertilizer each farmer can receive.

Table 9: Fertilizer subsidies and the profitability of fertilizer use for a risk averse farmer

Farming system	Full price	25% subsidy on fertilizer price	50% subsidy on fertilizer price	75% subsidy on fertilizer price
Cereal-root crop	0.17	0.22	0.25	0.34
Tree crop	0.35	0.39	0.47	0.52
Root Crop	0.38	0.43	0.48	0.53

These results are gotten from a simulation of fertilizer profitability with different levels of fertilizer subsidy

Table 9 above reveals that reducing the price of fertilizer increases the number of plots on which nitrogen application is profitable across the farming systems. However, the effect of subsidizing fertilizer is much less than the effect of reducing the transportation costs paid to acquire

fertilizer. If the current fertilizer program was to reach all maize farmers with a 50% subsidy, this would only increase the number of plots on which nitrogen application was profitable from 17% of total maize plots to 25% in the main maize farming system, C-RCFS. This compares to making nitrogen application profitable for 32% of plots by reducing transport costs by 50%. Given that less than 20 percent of applied fertilizer is likely to be subsidized (Takeshima and Liverpool-Tasie, 2015), the effect of the 50% subsidy (depicted in table 9) will be much lower than 25%. Consequently, attempts to reduce the transportation costs for fertilizer acquisition (such as infrastructure improvements or programs to encourage the setup of retail depots within communities or in smaller towns) are likely to have a larger effect. Besides, such improvements in infrastructure and access to fertilizer benefit all farmers in the community compared to a fertilizer subsidy for which access is less likely to be universal.

In the absence of information about subjective expectations about rainfall and yields, these results suggest that there are a good number of maize farmers in Nigeria whose nitrogen application rates are higher than what one would expect of a risk averse farmer maximizing his expected profit. This is particularly true in the dominant maize farming system in Nigeria. It appears that while expanding nitrogen application for maize production in Nigeria is necessary (with application currently on about half of maize plots in the sample), some farmers (for which fertilizer use is profitable) could potentially reduce their application levels. While high transportation costs are partly responsible for the low optimal nitrogen application rates for maize production, the low MPP of applied nitrogen for maize in Nigeria is also a key factor.

This study's results indicate that further studies are necessary to understand why and how maize yields can better respond to fertilizer use for maize production. Access to and use of complementary inputs is one area to explore further. Currently, only about 20%, 5% and 3% of maize farmers are using hybrid seed, mechanization (tractors or other equipment) and irrigation respectively; all of which are complementary inputs to applied nitrogen.

5. Conclusions

This paper looked at the effect of nitrogen application for maize production across the main maize farming systems in Nigeria. Accounting for the endogeneity of nitrogen application

when estimating a maize production function, we find that the marginal physical product of nitrogen in Nigeria is quite low. We also find that the profitability of nitrogen application for maize production is quite marginal for the main cereal-root crop farming system. Though this is partly driven by the relatively low MPP of nitrogen, high transportation costs are another factor that significantly reduces the profitability of nitrogen application.

We find that while both subsidizing the price of fertilizer and reducing transportation costs in rural Nigeria could increase the profitability of using the input, reducing transportation costs will likely have a much larger impact. This is largely due to the fact that the benefits of improvements in infrastructure and access to fertilizer (at the community level) are more universally spread among rural farmers relative to fertilizer subsidies. Reducing transportation costs by half or three-quarters could increase the percentage of plots in the main cereal farming system (C-RCFS) for which fertilizer use is profitable by about 40% and 65% respectively. Innovative schemes by the private sector which use industrious farmers within communities to serve as village promoters (teaching farmers about new technologies and also selling inputs) could further reduce transportation costs and increase the expected profitability of fertilizer use for many rural farmers (Liverpool-Tasie et al., 2014). In the case of the TCFS, this could lead to increases in the percentage of plots on which fertilizer use is profitable by about 90%. Significant reforms are underway in the Nigerian agricultural sector; particularly with regards to fertilizer. These reforms (including improvements in infrastructure and increased access to fertilizer and seed for smallholder farmers) might change these results. Consequently these findings could provide a basis for the evaluation of such programs in the near future.

Our results indicate that the application of nitrogen could be expanded for certain farmers in Nigeria. There are likely opportunities for expansion in fertilizer use in both the tree crop farming system and the cereal-root crop farming system. In addition to transportation costs, improving the response to nitrogen through complementary practices (such as irrigation facilities, good quality seed and other more efficient methods of fertilizer use or crop management practices) could also play a significant role. For farmers in the root crop farming system of Nigeria, we find that only about 20% of maize producers in this farming system currently use fertilizer even though they represent over 20% of maize plots in our sample. This is not surprising since the yield response to nitrogen application is not significant. Efforts to understand and improve the likely yield response of applied nitrogen are necessary to expand fertilizer use in this area.

Generally, this study confirms that fertilizer use which is clearly evident in maize production in Nigeria can be profitable²⁶. However, at current input and output prices, this remains a reality for only a subset of maize farmers. Our study finds farmer observed practices to be closer to that expected of risk averse farmers and demonstrates the importance of accounting for risk preferences in modern input profitability considerations. Expanding the number of maize farmers that use fertilizer (and for which it is economically profitable at acquisition price) is still necessary in Nigeria. Currently only about 50% of maize plots use fertilizer. However, we find that many maize farmers in Nigeria are already applying nitrogen beyond levels considered economically optimal. While this is partly driven by low optimal rates given the high transportation costs, this indicates the need for further studies on fertilizer profitability in Sub-Saharan Africa. This study only focusses on maize but indicates issues that are likely to affect fertilizer use for other crops. See Liverpool-Tasie (2014) and Liverpool-Tasie et al. (2015) for the cases of rice and sorghum in Nigeria. More effort is needed to understand the rationale for the current nitrogen application rates across smallholder farmers and to increase the profitability of fertilizer use by addressing transportation costs and other factors (such as timeliness of availability and management practice) currently mitigating the yield and profitability effects of fertilizer use.

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²⁶ A full scale profitability would be necessary to make this claim as fertilizer use has other dimensions such as increased labor demand for application and consequent weeding and this has not been taken into account yet.

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Appendix

Table A1. Marginal effects

	Cereal-Root Crop Farming system		Tree Crop Farming system		Root Crop Farming system	
	Pooled OLS coefficients C-RCFS	Fixed Effects coefficients C-RCFS	Pooled OLS coefficients TCFS	Fixed Effects coefficients TCFS	Pooled OLS coefficients RCFS	Fixed Effects coefficients RCFS
Nitrogen	4.311***	7.988***	21.390***	12.387+	-3.120	11.152
Phosphorus	1.661*	-0.849	-3.883	6.027	-0.764	-2.645
Seed rate (kg/hectare)	14.701***	14.236***	31.719***	39.068***	35.053***	30.919***
Labor (adult equivalency units)	-1.787	154.480+	149.104	681.492	69.831	445.483
Mechanization (1/0)	133.406	33.697	4,078.191	29.141	2,429.232	924.351
Irrigation (1/0)	394.784*	88.806				
Animal traction use (1/0)	234.310**	281.889+			193.436	
Chemicals (1/0)	155.566*	88.050	1,515.494	3,647.580	124.142	615.047
Organic fertilizer (1/0)	247.631	330.152			3,142.838	5,176.077
Commercial seed	-131.632*	-36.620	-139.436	386.797	-141.917***	-228.047
Sex (1/0)	629.837***	-23.987	96.539	-431.291	908.289*	238.767
Age (years)	5.204*	10.491	-0.428	-17.551	9.730	36.740
Assets ("000 Naira)	-0.018	-0.013	0.244	-6.910	-0.451	0.202
Plot area (hectares)	-615.184***	-600.999***	-4,947.313***	-9,241.304**	-1,805.749***	-2,221.989***
Squared plot area (hectares)	65.622***	61.498***	582.874***	1,329.332	200.227***	231.537**
Topographic wetness index (units)	-20.632	-29.721	-47.172	-97.284	71.733	110.140
No other crop planted	175.051	64.777			-308.579	-273.237
One other crop planted	202.466	239.031	-5.248	684.865	-289.589	175.176
Two other crop planted	-42.636	218.495	534.431	1,302.021*	877.233**	1,698.545**
Three or more other crop planted	-	-	-	-	-	-
Plot elevation (m)	0.573**	0.771	-3.590	6.731	2.357	-8.397
Slope (percent)	-5.792	-45.692	-38.286	-13,610.466	67.741	-1,379.519
Annual Precipitation (mm)	-0.205	-4.303	-0.240	-3,372.297	-3.497**	-95.809
Any household member	-61.775	-221.211	-124.231	-645.518	-179.401	1,044.760

could sell land (1/0)						
Moderate nutrient constraint	474.136***		-4,510.164***		1,268.295***	
Severe nutrient constraint	265.427		-4,403.066***		922.046	
North east	-420.139**	14,988.698			2,196.389***	
North west	-580.688***					
Year	-149.064	-64.466	1,603.823**	2,799.376***	-482.444	-798.215*
Number of observations	1,084	1,084	339	339	427	427

Source: Authors estimations from the LSMS-ISA data. *, ** and *** are significant at 10, 5 and 1 percent respectively. + is significant at 15% or less.