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Is Fertilizer Use Inconsistent With Profitability? Evidence From Sorghum Production In Nigeria

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Abstract
This article contributes to a limited but growing literature challenging a core assumption that it is profitable for smallholder farmers in sub-Saharan Africa to use more fertilizer than currently obtains. Using panel data from Nigeria, Africa's largest economy, we empirically estimated the effect of applied nitrogen on sorghum yields. We explored if fertilizer use was profitable for sorghum farmers and the conditions that could facilitate profitable use of the input. We found that while input subsidies or reducing the high transportation costs for securing inputs could increase the profitability of fertilizer use for sorghum farmers, increasing the yield response rate of applied nitrogen is a more effective approach to improve the profitability of fertilizer application for these farmers. This involves addressing key challenges smallholders' face including poor fertilizer and soil quality, limited use of complementary inputs and management practices.

Key words: Sorghum, Yield response, Marginal physical product, Fertilizer profitability.

Introduction

While there is increasing evidence that fertilizer use has risen in countries with large-scale fertilizer promotion programs (including Ethiopia, Zambia, Malawi and Nigeria), there is still a general concern that fertilizer use in sub-Saharan Africa (SSA) is low and needs to be increased. This low use of fertilizer is considered to be a key factor explaining lagging agricultural productivity growth in Africa (Morris *et al..,* 2007; Africa Fertilizer (2012).While increasing quantities of fertilizer is actively being promoted among smallholders, there is limited empirical evidence to indicate that it is profitable for smallholder farmers. This paper contributes to the limited (but growing) literature that empirically explores the profitability of applied fertilizer for crop production in SSA. We follow recent studies by Sheahan *et al.* (2013); Liverpool-Tasie *et al.* (2017); Liverpool-Tasie (2016) to explore the agronomics and economics of fertilizer use in crop production to inform if fertilizer use (and at current rates) is profitable for smallholder farmers.

Unlike previous studies that have focused on maize (or rice), we focus on another very important, but largely overlooked cereal crop, sorghum. Sorghum (*Sorghum bicolor*) is one of the most important cereals in the world and the fifth largest cereal in terms of hectares cultivated. It serves as a staple food crop for many, particularly in SSA, and a key ingredient for various industries such as feed, breweries etc. (FAO, 2015). Sorghum production in most of SSA is characterized as traditional, subsistence and small-scale with low yields, whereas in industrialized countries such as the USA, production is mechanized, large scale and with high-input use (CGIAR, 2015). An understanding of the current rate of use of key inputs such as fertilizer for a key staple, sorghum, and how profitable the use, is highly important. Of high importance is also the identification of factors that can make the use of fertilizer, a key input, more profitable.

This study used panel data (Living Standard Measurement Survey – Integrated Survey on Agriculture (LSMS –ISA 2010/2011 and 2012/2013) from a nationally representative sample of smallholder sorghum producers in Nigeria to explore the profitability of fertilizer use. We used a fixed effect stochastic frontier panel analysis to explore the yield response of sorghum to applied fertilizer with the recognition that there is a likely deviation from the optimal yield attainable by smallholder farmers (as is assumed in production theory) and their actual yields. We employ panel estimation techniques to address time invariant unobserved factors (such as farmer ability) that are likely correlated with input use and productivity. The specific objectives of the study were to identify the determinants of sorghum yield, to identify the level of fertilizer profitability among sorghum farmers and identify the conditions under which fertilizer use is likely to be more profitable.

Fertilizer use and sorghum production in Nigeria:
Sorghum is a staple cereal food crop for more than 500 million people across the globe (Mundia *et al.* 2019, Prasad and Staggenborg, 2011). Nigeria is the largest producer of sorghum in West Africa accounting for around 71% of total output in the sub-region (Ogbonna, 2011). In the Northern States of Nigeria, about 73% of the total calories' intake and 52.3% of the per capita protein intake are contributed by sorghum alone (Samm, 2009). Sorghum stover and stems are used as animal feed and wall board for house building, respectively (Mohammed *et al.*, 2011).

Though dependable, sorghum yields in Nigeria (and most of SSA) are low and relatively constant. According to Atokple (2010), the area harvested to sorghum in Africa has nearly doubled, but yields averaging 800 kg/ha have not increased. Sorghum is suited to a wide range of soil types, from light loams to heavy clay soils. While best results can be expected from free-working, well-drained soils of high fertility, useful returns are frequently obtained from second-class agricultural land. Results of research have confirmed that sorghum (particularly the improved varieties) responds to nutrient application. According to Ajeigbe *et al.* (2008), the nutrient recommendations for sorghum are 64kg/ha of nitrogen and 32kg/ha of phosphorus (P_2O_5). For very sandy soil, especially in the Sudan and the northern Guinea savanna zones that are known to be deficient in potassium, 30kg K_2O/ha are recommended in addition to nitrogen and phosphorus. A combination of compound fertilizer 15-15-15 and urea could be used to meet these requirements; 5–10t/ha of manure could also be applied. Table 1 shows that the average nitrogen application rates among sorghum farmers who use fertilizer in Nigeria is not so far from the recommended use rates. However, the mean applied phosphorus rate is less than half of the recommended rate.

Table 2 shows that there was a rise in the proportion of plots where fertilizer was applied in wave 2 compared to wave 1 in cereal/root crop farming system, while the reverse was the case in the agro-pastoralist farming system. Similarly, while the yield for fertilizer users is slightly higher than non-users in the cereal-root crop farming system, it is lower in the agro-pastoralist farming system.

Methodology

Analytical framework:
Rural households in SSA are typically engaged in the production of multiple crops alongside any off-farm or nonfarm activities its members are engaged in. Farmers have to decide on level of input use (across plots and crops on plots) before the rains or output price is known for sure, and this decision is usually taken in the presence of imperfect credit and insurance markets. Consequently, the decision and extent of improved input use is typically derived from the input demand function from the solution to the household's constrained utility maximization problem in a non-separable framework (Singh *et al.* 1986 and Strauss, 1986; Sadoulet and deJanvry, 1995). Once the decision on inputs is made, the benefit of input use is captured by the production function (or yield response model), which is largely driven by agronomic principles.

The general form for a yield function is expressed as:

Y_{it}= f (X_{it},Z_{it},ε) (1)

Where sorghum yield (Y) on field i in time t depends on a vector of physical inputs and other factors that may affect yield. In (1) above, X is a vector of inputs used on the plot in time t such as seed, fertilizer, chemicals and labour; Z is a vector of other factors that influence yields such as plot, farmer and household characteristics. ε is the error term that captures unobservable characteristics in the production function that may affect yield.

Recognizing that there is a likely gap between the optimal yield attainable by sorghum farmers and what they actually obtain due to factors beyond their immediate control, we relax the traditional production theory assumption that farmers are producing the maximum possible output with the given combination of inputs they use. We use a Stochastic Frontier Approach (SFA) to estimate (1) above. We use a panel approach given that there are likely unobserved farmer characteristics (including motivation and ability) that affect input choices and yield effects of applied nitrogen in sorghum production. Coelli *et al.*. (2005) document the advantages of panel approach within the stochastic frontier framework. For example, some of the distributional assumptions to differentiate statistical noise and inefficiency terms are relaxed in a panel model which enables us to obtain more consistent estimators of inefficiencies and examine the change in inefficiencies over time (which could indicate technological progress). Panel approaches also enable us to model the inefficiency term in different ways. A key decision in panel stochastic frontier analysis is whether to treat the inefficiency term as time variant or invariant. Time-invariant inefficiency models are estimated either by fixed effects or random effects approach. Alternatively, time-variant inefficiency supposes that firms learn from their experiences to enhance efficiency levels incrementally. In this study, we run the Greene (2005) true fixed effect model of Stochastic Frontier Model. With the short timeframe of our panel (2 years), we assume that any heterogeneity across farmers is going to be largely driven by the time-invariant unobserved factors such as farmers' ability. Furthermore, the True Fixed Effects specification allows us to disentangle time-varying inefficiency from unit-specific time-invariant unobserved heterogeneity.

Consequently, our model specification under the stochastic frontier is as follows:

$$Y_{it} = \alpha_{it} + X_{it}\beta + \varepsilon_{it} \quad (2)$$
$$\varepsilon_{it} = v_{it} - u_i \quad (3)$$
$$v_{it} \sim N(0, \sigma_v^2) \quad (4)$$
$$u_i \sim N^+(0, \sigma_u^2) \quad (5)$$

Where Y, X and ε are as defined earlier. The error term ε is divided into a random component and an inefficiency component which varies across farmers and is time invariant.

Farmers use different types of fertilizers with varying nutrient contents on their plots. The two most commonly available fertilizers in Nigeria are the compound fertilizer (NPK) and Urea fertilizer which is 46% Nitrogen. Rather than consider all inorganic fertilizer to be the same, we isolate the nutrient component of the applied fertilizer. NPK typically has about 27% Nitrogen, 13% Phosphorus and 13% Potassium, while Urea is about 46% Nitrogen. For this analysis, we multiply those percentages by the total amount of each fertilizer applied to the sorghum plot to arrive at the total quantity of applied nutrients.

The two commonly used functional forms for the Greene (2005) true fixed effect stochastic frontier panel model for are the Cobb-Douglas (CD) and trans-logarithmic production functions. While the CD in its simplicity allows marginal products of inputs to vary with use, the translog is more flexible and allows for second order approximations. To determine the appropriate functional form for this analysis, we conduct a likelihood ratio (LR) test since the CD is nested within the translog model. The Null hypothesis of that LR test is that a CD specification is an adequate representation of the data. Based on the result from the test, we failed to reject this for both farming systems at 5% or less. This indicates that the Cobb Douglas model is generally preferred for our data. We estimate a Cobb-Douglas production function as follows:

$$ln\,(Y_{it}) \;= \beta_0 + \sum_{i}^{n} \;\beta_i lnX_{it} + \; v_{it} + u_i \qquad (6)$$

The MPP of applied nitrogen was derived using the coefficient from our estimated Cobb-Douglas production function. We estimate the production function as well as the determinants of the technical inefficiency. In the determinants of the inefficiency, the composite error term $v_{it} + u_i$was disaggregated into its different technical efficiency part (U) and the idiosyncratic error component (V). For both U and V, we imposed heteroskedastic assumptions, i.e. both U and V are heteroskedastic. In the first stage, wherein we estimate the production function, we include a year dummy to control for unobserved time-dependent variation in yield—for example rainfall, pests or other weather effects.

The model specification for the sorghum yield response to applied nitrogen is shown below:

$$LnY_{it} = \beta_0 + \beta_1 lnS_{it} + \beta_2 lnN_{it} + \beta_3 lnP_{it} + \beta_4 lnAE_{it} + \beta_5 T + \mu_{it} + v_i \qquad (7)$$

LnY_{it}= natural logarithm of sorghum yield for the i-th farmer in year t
LnS_{it} = natural logarithm of sorghum seed used per hectare for farmer i in year t
lnN_{it} = natural logarithm of nitrogen used per hectare for the i-th farmer in year t
lnP_{it}= natural logarithm of phosphorus used per hectare for the i-th farmer in year t
$lnAE_{it}$ = natural logarithm of adult equivalence for the i-th farmer in year t
T= the year dummy (1 if wave equals 2, 0 otherwise)
β_0 toβ_5 are the parameters estimated.

For the determinants of technical inefficiency and idiosyncratic error, the model specification is given as:

$$U_{it} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots\ldots \beta_4 X_4 \qquad (8)$$
$$V_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots\ldots \beta_4 X_4 \qquad (9)$$

Where V_i = Idiosyncratic error score of the ith household, U_i= Inefficiency score of the ith household,
X_1 = Household Size
X_2 = Agricultural advice dummy (1 if agricultural advice was received, 0 otherwise)
X_3 = Age of household head in years
X_4 = Plot Acquisition method dummy (1 if owned/purchased, 0 otherwise)

Profitability in this study is based on the marginal value cost ratio of applied nitrogen. We followed Sheahan *et al.,* (2013), Liverpool-Tasie *et al.* (2016) and Liverpool-Tasie (2016) to use the estimates from our production function to calculate the expected marginal physical products (EMPP) of nitrogen in sorghum production at the plot level. The EMPP of applied nitrogen (which describes how much extra sorghum output can be produced by using one additional unit of applied nitrogen, all else held constant) was obtained by taking the first derivative of the production function with respect to applied nitrogen. These EMPPs were then used to calculate the partial profitability measures. The expected marginal value cost ratio (EMVCR) as follows

$$E(MVCR_{nijt}) = \frac{E(p_{rt}) * E(MPP_{nijt})}{p_{nijt}} \qquad (3)$$

Where p_n is the price of nitrogen and $p_s$is the expected price of sorghum at harvest.

In this analysis, we built an auxiliary model for price expectations following Nerlove and Fornari's (1998) quasi-rational expectations model. We assume price expectations are formed using predictions from an optimal linear projection autoregressive model. The order of the auto-regression varies from 1 to 4 for the 18 States[1] included in our analysis and for each State takes the form:

$$P_t = a_0 + \sum_{i=1}^{k} \quad a_i p_{t-i} + \upsilon_t \qquad (4)$$

When $MVCR_{nijt}$ is greater than one, it means that a risk neutral household could increase its income by increasing its nitrogen application rate. Thus, we expect the nitrogen application rate for risk neutral households to be determined by $E(MVCR_{nijt})$.

Fertilizer use comes with some risks including weather uncertainty and consequently crop failure, and rural households in Nigeria are likely to be risk averse. Liverpool-Tasie *et al.* (2016) and Liverpool-Tasie (2016) find farmer behaviour in rural Nigeria to be consistent with the implications of this assumption. Consequently, we incorporate a risk premium of δ into our analysis (Bationo *et al..,* 1992; Sauer and Tchale, 2009; Sheahan *et al..,* 2013). Thus, in this analysis, rather than $MVCR_{nijt} > 1$ was used as the rule guiding farmers in their decision to use fertilizer. A higher MVCR is considered necessary for a risk averse farmer to find nitrogen application profitable. We consider 2 (which has traditionally been used in the literature (Kelly, 2005; Sauer and Tchale, 2009; Sheahan *et al.*., 2013) and 1.5, since we deliberately factor in the effect of transportation costs in our analysis; something that was not done in most of the literature that used a higher value of 2 (Burke *et al.*, 2014).

We equally calculated Nitrogen: Sorghum price ratio which shows the number of kilograms of sorghum a farmer needs to purchase one kilogram to capture the market orientation side of fertilizer use.

Data:
The data used for this analysis were extracted from the Nigeria Living Standard Measurement Survey – Integrated Survey on Agriculture (LSMS –ISA data) panel dataset collected for the primary agricultural seasons in 2010/2011 and 2012/2013, respectively. It is implemented by National Bureau of Statistics in collaboration with the World Bank Living Standards Measurement Study (LSMS) team as part of the Integrated Surveys on Agriculture (ISA) program. Its objectives include the development of an innovative model for collecting agricultural data, inter-institutional collaboration, and comprehensive analysis of welfare indicators and socio-economic characteristics. The dataset includes agricultural production information at both household and plot level for 2010/2011(wave1) and 2102/2013(wave2). We extracted information from all plots on which sorghum was planted in the main agricultural season for the two waves. 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 99th percentile rather than dropping the variable. Due to challenges associated with using the labour data for the first wave of data, household adult equivalency units were used as a proxy for available labour[2]

Results and Discussion

Yield response of Sorghum:
Table 3 shows the correlates of sorghum yield. For cereal-root crop farming system, all the included variables except phosphorus per hectare have a significant positive effect on the sorghum yield, while the year 2012 dummy has a significant negative effect on the sorghum yield. Since the coefficients of the Cobb-Douglas production function represent the elasticity, for cereal-root crop farming system results indicate a 100% increase in quantity of seed used per hectare, quantity of nitrogen per hectare, and adult equivalence there is an approximately 11%, 14% and 83% rise in sorghum yield. The observed positive effect of seed per hectare

[1] The table of autocorrelations and the selected number of lags per state are included in the appendix

[2] 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

on yield is in line with Baiyegunhi (2010) for sorghum and other cereals but contradicts Sani *et al.* (2013). The positive effect of nitrogen used per hectare is in line with Ahmed *et al.* (2005), Baiyegunhi (2010), Wakali (2012) and Sani *et al.* (2013) and the positive effect of adult equivalence, which is proxy for our labour, is similar to the positive effect of labour on sorghum yield observed in Baiyegunhi (2010) and Sani *et al.* (2013).

The wave 2 dummy for cereal-root crop farming system leads to about 62% reduction in yield relative to wave 1. This implies that sorghum yield declined in wave 2 relative to wave 1. This is likely due to poor weather conditions in 2012. According to FEWS NET (2013), the heavy rainfall and release of water from several dams led to unusually widespread flooding from July-October 2012, which destroyed crops and livestock. Before the floods, national crop production levels (including cereals) were forecasted to be about two percent higher than 2011 levels (a bumper year) and about six percent higher than the five-year average. However, significant crop damage due to the floods eroded these good prospects, and instead crop production, sorghum inclusive was below-average. Additionally, civil insecurity relating to *Boko Haram* continued in northern areas, with states such as Borno, Yobe, Adamawa and Kano which play a significant role in sorghum production being worst affected. In 2012, about 1,510 people were killed by *Boko Haram*-related attacks and 205 bombings were recorded. This violence led to the continued displacement of populations and disruption of normal activities, especially abandonment of farms. For the agro-pastoralist farming system, nitrogen per hectare is the only variable with significant positive effect on sorghum yield. The result for agro-pastoralist farming system shows that 100% increase in the quantity of Nitrogen applied per hectare will result in about 14% rise in sorghum yield, and this is consistent with the findings of Ahmed *et al.* (2005), Baiyegunhi (2010), Wakali (2012) and Sani *et al.* (2013) who found a positive effect of applied nitrogen on yield per hectare.

The marginal physical product (MPP) of applied nitrogen among sorghum producers in Nigeria:
Table 4 shows the distribution of MPP values for sorghum farmers in Nigeria. The median MPP in the cereal-root crop farming system is 0.69, while it is 1.05 in the agro-pastoralist farming system. Even at the top end of the distribution, the MPP in both systems is relatively low at 7.3 and 11.2 for the C-RCFS and APFS respectively. This indicates that while one additional unit of applied nitrogen engenders an approximate 0.69kg rise in sorghum yield in the cereal-root crop farming system, it results in a 1.05 rise in yield from the agro-pastoralist farming system. These values are similar to the findings of other studies; for example Baiyegunhi *et al.* (2010) obtained MPP value of 2.65 for fertilizer use in sorghum production and Abubakar (2014) obtained MPP of 1.63 in economic analysis of millet-based cropping system.

Profitability of applied nitrogen for sorghum production:
Like for maize and rice farmers, we found that transportation costs are a major fraction of the total acquisition cost of fertilizer for rural farmers (Table 5). While lowering transportation costs by 50% increases the proportion of sorghum farmers on whose plots fertilizer use is profitable in the cereal and agro-pastoral farming systems by 25% and 33% respectively, making fertilizer available in farmers' villages will only make it worthwhile for about 20% of sorghum farmers to increase the quantity of nitrogen applied in the cereal farming system. Likewise, in the agro-pastoral farming system, making fertilizer available in farmers' rural communities would only make it profitable for about 25% of sorghum farmers to expand their input use.

We found similar magnitude of effects for reducing input costs. We follow Liverpool-Tasie *et al.* (2016) to consider the effect of Nigeria's subsidy program on the profitability of nitrogen application. When received, the subsidy rate for fertilizer in Nigeria could range between 25% and 100% (Liverpool-Tasie and Takeshima, 2013). We explored using simulation how differences across market-purchased and subsidized fertilizer is likely to affect the profitability of fertilizer use. Table 6 shows that providing input subsidy such as fertilizers has an even smaller effect on the profitability of expanding nitrogen application. With a 50% subsidy as is currently provided by the government fertilizer subsidy program, it will only be profitable for about 12% and 17% of sorghum farmers in the cereal-root crop and agro-pastoral systems.

Table 7 clearly shows that one way to expand fertilizer use profitably would be with higher yield response to nitrogen application, as captured by the marginal physical product of applied nitrogen. Just increasing the MPP of all farmers to about 15 kilograms of sorghum per kilogram of applied nitrogen, this made fertilizer use profitable for about 30% of farmers in the cereal- root crop farming system and about 40% in the agro-pastoralist system. Moving higher to MPP of 25 makes the expansion of fertilizer use profitable for almost 75% of farmers in both systems.

Further Considerations:
Another important factor is the market orientation of sorghum farmers. Compared to crops like rice and maize, where households typically engage with the market in sales, sorghum production appears to be largely for home consumption (FAO, 2013). Takeshima and Liverpool-Tasie (2015) show that less than 20% of sorghum producers in Nigeria sell some of their produce, compared to almost 60% and 30% for rice and maize producers respectively. This might explain why changes in sorghum prices do not appear to affect probability as much as increasing the MPP of applied nitrogen. This implies that strategies for reducing farmers' inefficiency and increasing the sorghum yield response to nitrogen are key for any fertilizer expansion efforts among sorghum producers. Better connection between farmers and industries that use their cereal as input could potentially improve the price received by farmers. Table 9 reveals that at typical prices in rural communities, the Nitrogen: Sorghum price ratio which shows the number of kilograms of sorghum a farmer needs to purchase one kilogram of fertilizer is high. Comparing this to earlier studies, Yanggen *et al.* (1998) carried out a review of empirical evidence on fertilizer profitability for period covering 1970 to 1995. The results reported for urea/sorghum price for the considered countries are as follows: In Burkina the highest urea: sorghum price ratio was 15.7 obtained in 1974 and the lowest was 1.8 in the year 1984 with an average of all the years put at 4.1. In South Africa, the highest ratio was 7.6(1989) and the lowest 3.4(1974) with the average being 5.5, In Malawi, the ratio was as high as 17.4 in 1974 and lowest in 1985 with 3.2 value and the average was 7.6. The highest for Togo and Zimbabwe are 3.2(1994) and 8.4(1993 and 1984) and lowest ratio are 0.4(1977) and 4.7(1981) respectively. The average for Togo and Zimbabwe over the years are 1.4 and 6.5 respectively. Other countries considered in the review of Yanggen *et al.* (1998) were India and Pakistan with average Urea: sorghum price put at 3.7 and 3.0 respectively. In a more recent study, Yamano and Arai (2010) obtained a DAP/sorghum price ratio of 1.4 and 3.0 for period 2003/2004 and 2005/2007 respectively in Kenya, and 2 and 1.6 for 2003/2004 and 2005/2007 respectively in Ethiopia. This observed ratio is lower compared to this study where the least ratio is 4.11 for cereal-root crop farming system in year 2012.

Within the framework of subsistence production that characterizes sorghum production in Nigeria, the areas of further study which we could not capture in this study as a result of lack of data include role of information and extension. This includes efforts to strengthen farmers' access to better management practices that can improve the organic content of their soils to improve the yield response to applied nitrogen. It also involves farmers' access to other complementary inputs such as improved seeds and water. Equally not addressed in this paper but worthy of attention (and difficult to demonstrate in the absence of samples), is the issue of fertilizer quality. The low-yield response of applied nitrogen and the profitability of its use might also be driven by poor-quality fertilizer.

Conclusion and Recommendations

This paper looked at the profitability of fertilizer use for sorghum production in Nigeria. We found that typically over 50% of sorghum farmers in Nigeria use some fertilizer and the average quantity used is over 150kg. At current sorghum prices and fertilizer costs, expanding fertilizer use among sorghum producers in Nigeria is only profitable for a small subset of farmers. While reducing transportation costs and input subsidies could expand the proportion of plots on which using fertilizer is profitable, the largest impact appears to be from increasing the yield response of sorghum to applied nitrogen. While fertilizer use is important, the issue of fertilizer use profitability goes beyond the use and subsidy as yield response tend to drive profitability more than the use or the reduced cost of use.

This indicates that rather than promoting expanded use of fertilizer, keen attention needs to be paid to the factors that drive the low MPP of applied nitrogen in Sorghum production in Nigeria. Understanding the amount of organic matter present in Nigerian soils, the extent of micronutrient availability and other soil properties are key factors to better understand how the yield response to inorganic fertilizer use in Nigeria can be improved. The findings of this study support the recent call for a more holistic approach to input intensification strategies in Nigeria and SSA more generally.

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Table 1: Nutrient application rates for sorghum production in Nigeria

Farming system	**Mean nitrogen application per hectare (kilograms- (2010)**	**Mean phosphorus application per hectare (kilograms- 2010)**	**Mean nitrogen application per hectare (kilograms- (2012)**	**Mean phosphorus application per hectare (kilograms-2012)**
Cereal-root crop	57.90	15.33	64.30	20.93
Agro-pastoral	43.05	8.53	39.43	7.63

Source: Authors estimations from the LSMS-ISA data. (Wave 1- 2010/2011 and Wave 2 -2012/2013)

Table 2 Fertilizer use rates and sorghum yield by farming systems

Farming System	**Proportion of plots using fertilizer (2010)**	**Proportion of plots using fertilizer (2012)**	**Average sorghum output per hectare among non-fertilizer user (kilograms)**	**Average sorghum output per hectare for fertilizer users(kilograms)**
Cereal-root crop	0.49	0.60	1342.58	1412.85
Agro-pastoralist	0.62	0.58	1373.77	1240.24

Source: Authors estimations from the Living Standard Measurement Survey – Integrated Survey on Agriculture (LSMS –ISA 2010/2011 and 2012/2013 data)

Table 3: Determinants of sorghum yield for cereal-root crop and agro-pastoralist farming systems

	Cereal-root Crop Farming System		**agro-pastoralist Farming System**	
Sorghum yield per ha	Coefficient	Z	Coefficient	Z
Lnseed	0.1069	4.65***	0.0104	0.12
LnNitrogen/ha	0.1403	4.15***	0.1411	2.17**
lnPhosphorus/ha	-.0093	-0.33	-0.0297	-0.28
Ln Adult Equivalence	0.8254	37.26***	3.7008	1.23
Year 2012 dummy	-0.6151	-8.15***	-0.0711	-0.15

*** Significant at 1%, ** significant at 5%, * significant at 10%

Source: Authors estimations from the LSMS-ISA data.

Table 4: The distribution of MPPs of applied nitrogen across sorghum farmers in Nigeria

Farming system	**Median**	**75th percentile**	**90th percentile**	**95th percentile**
Cereal-root crop	0.61	2.81	7.29	12.12
Agro-pastoralist	1.05	4.54	11.2	17.11

Source: Authors estimations from the LSMS-ISA data.

Table 5: Transportation costs and the profitability of fertilizer for sorghum production

Proportion of sorghum plots for which fertilizer use is profitable for a risk averse farmer				
Farming system	**Full acquisition cost**	**Transportation cost reduced by 50%**	**Transportation costs reduced by 75%**	**Fertilizer available in the village**
Cereal-root crop	0.082	0.102	0.127	0.198
Agro-pastoral	0.124	0.161	0.197	0.264

Source: Authors estimations from the LSMS-ISA data. These results are got from a simulation of fertilizer profitability with different transportation cost.

Table 6. The effect of subsidizing fertilizer on the profitability of fertilizer use for sorghum production

	Full price	**25% subsidy on fertilizer price**	**50% subsidy on fertilizer price**
Cereal-root crop	0.082	0.094	0.124
Agro-pastoral	0.124	0.15	0.168

Source: Authors estimations from the LSMS-ISA data and based on production function estimates

Table 7. The effect of increasing the yield response (marginal physical product-MPP) of applied nitrogen

The proportion of sorghum plots for which fertilizer use is profitable for a risk averse farmer					
	Current MPP	**MPP of 15**	**MPP of 20**	**MPP of 25**	**MPP of 30**
Cereal-root crop	0.082	0.297	0.49	0.638	0.77
Agro-pastoral	0.124	0.427	0.652	0.76	0.84

Source: Authors estimations from the LSMS-ISA data. These results are gotten from a simulation of fertilizer profitability with different transportation cost.

Table 8 Sorghum/Nitrogen price ratios across major sorghum farming systems

Farming system	**Nitrogen/Sorghum (2010)**	**Nitrogen/Sorghum (2012)**
Cereal-root crop	6.00	4.11
Agro-pastoral	5.39	4.08

Source: Authors estimation from LSMS-ISA (2010/2011 and 2013/2013)

Appendix

Number of lags used per state

State	Number of lags
Abuja	1
Adamawa	1
Bauchi	4
Borno	4
Gombe	4
Jigawa	4
Kaduna	1
Kano	4
Katsina	1
Kebbi	4
Kwara	1
Nasarawa	1
Niger	1
Plateau	3
Sokoto	2
Taraba	3
Yobe	4
Zamfara	4