The profitability of inorganic fertilizer use in sorghum production: Evidence from Nigeria

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Synopsis:

This brief summarizes the empirical findings from a study on the profitability of fertilizer use for sorghum production in Nigeria. Using a representative panel dataset with rich agricultural information, the study examines if fertilizer application is currently profitable for sorghum production. Mindful of risk and uncertainty, we first estimate how much more sorghum a farmer gets from applying one additional kg of nitrogen using a production function. Then we explore if the value of this additional output in the market is sufficient to cover the cost of fertilizer.

Highlights:

- ✓ While there is a higher fertilizer application rate among sorghum farmers in the cereal root crop farming system compared to those in the agro pastoralist farming system, the Marginal physical Product (MPP) of the applied fertilizer is generally low across both farming systems.
- ✓ Consistent with the findings from similar studies for maize and rice, transportation cost remains a major share of the acquisition cost for fertilizer in Nigeria
- ✓ The study finds that while subsidizing the price of fertilizer and reducing transportation costs have significant and positive effects on the level of profitability, **increasing the sorghum yield response has the greatest potential to increase the profitability of fertilizer use.**
- ✓ At current fertilizer prices and sorghum selling price, the nitrogen/sorghum price ratio is high and level of profitability is low for sorghum production in Nigeria.

Policy Implication:

- ✓ Strategies to increase yield response of sorghum to applied fertilizer appear to be the most effective way of raising profitability level for sorghum production.
- ✓ Conscious effort aimed at reducing transport cost and the cost of the input can reduce the current high level of Nitrogen/sorghum price ratio.
- ✓ Further research into value addition of sorghum is required for higher commercialization of sorghum and better market orientation among sorghum farmers.

Background

With the challenges of increasing food demand alongside limited supply of land, intensification through the use of modern inputs such as improved seeds and inorganic fertilizers has gained prominence. According to Naseem and Kelly (1999), chemical fertilizers are key productivity-enhancing inputs. As a result, the promotion of chemical fertilizers has been on the increase in Sub Saharan Africa (Sheahan et al., 2013; Liverpool-Tasie et al (2015)). In Nigeria, recent government programs (e.g. the Agricultural Transformation Agenda (ATA) have emphasized the use of these technologies to increase smallholder productivity and consequently reduce poverty and food insecurity. While increasing the quantity of fertilizer that African smallholder farmers use is actively being promoted, there is limited empirical evidence to indicate that higher quantities of fertilizer application are profitable for these 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. (2015); and Liverpool-Tasie (2016) to explore the agronomics and economics of fertilizer

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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 and or rice, we focus on another important cereal crop, sorghum.

Why Sorghum?

Sorghum is one of the most important cereals in the world. It is the fifth largest cereal in terms of area of production. Sorghum is a staple cereal food crop for more than 500 million people across the globe (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). At the global level, Nigeria is the third highest producer after United States and India (FAOSTAT, 2012). Sorghum is a key cereal consumed by the majority of the Nigerian population (NAERLS, 1997). In the Northern States, about 73% of the total caloric intake and 52.3% of the per capita protein intake are contributed by sorghum alone (Samm, 2009). As important as sorghum is, its yields in Nigeria (and most of Sub Saharan Africa (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. In this study, we focus on two major farming systems; namely the Cereal-Root Crop (C-RC) and Agro pastoralist (AP) farming systems.

The data

The data used for this analysis was extracted from the Living Standard Measurement Study – Integrated Surveys on Agriculture (LSMS –ISA data) panel dataset collected for the primary agricultural seasons of 2010/2011 and 2012/2013 respectively. The dataset includes information on agricultural production at both household and plot levels. We extracted information on all plots on which sorghum was planted in the main agricultural season for the two waves. 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 labor.

Estimation of Yield Response and Profitability

We first estimated the yield response of sorghum to key production inputs. A stochastic frontier approach was adopted to estimate the yield response of sorghum to production inputs and the determinants of the efficiency among the sorghum farmers. (See details in the box below). From the production function estimates, we then calculated the Expected Marginal Physical Product (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) is gotten by taking the first derivative of the production function with respect to applied nitrogen. These EMPPs are then used to calculate our partial profitability measures; the Expected Marginal Value Cost Ratio (EMVCR) as follows:

$$E(MVCR_{nijt}) = \frac{E(p_{st}) * E(MPP_{nijt})}{p_{nijt}}$$

where p_n is the price of nitrogen and P_s is the expected price of sorghum at harvest. In this analysis, we build 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 included in our analysis and for each state takes the form:

$$P_t = a_0 + \sum_{i=1}^{k} a_i p_{t-i} + \upsilon_t$$

The study adopts the following criteria in determining profitability of fertilizer use:

- ✓ for *risk-neutral* farmers, the MVCR should be equal to or greater than 1;
- ✓ for *risk-averse* farmers, MVCR will need to be higher. Thus we consider 1.5 and 2 as possible thresholds but also consider the distribution of MVCRs

Box 1: Understanding the challenges of estimating the sorghum production function

The general form for a yield function is expressed as:

$Y_i = f(X_i, Z_i)$ (1)

Where sorghum yield (Y) on field i is dependent on a vector of physical inputs and other factors that may affect yield. In (1) above, X is a vector of inputs used such as seed, fertilizer, chemicals and labor; Z is a vector of other factors that influence yields such as farmer and household characteristics. ε is the error term that captures unobservable characteristics in the production function that may affect yield. We recognize 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. Thus we relax that traditional assumption in production theory that farmers are producing the maximum possible output with the given combination of inputs they use. We use a stochastic frontier approach to estimate (1) above and explore some of the determinants of inefficiency among sorghum farmers. Recognizing that there are likely unobserved farmer characteristics (like motivation and ability) which could affect their efficiency in production, we use panel stochastic frontier models to estimate the yield effects of applied nitrogen in sorghum production. Coelli et al. (2005) enumerates additional advantages of panel approaches 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 to examine the change in inefficiencies over time (which might be a good indication of technological progress). Panel approaches also enable us 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. On the other hand, 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. 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:

$Y_{it} = \alpha_{it} + X_{it}\beta + \varepsilon_{it}$ (2)

$\varepsilon_{it} = v_{it} - u_i$ (3)

$v_{it} \sim N(0, \sigma_v^2)$ (4)

$u_i \sim N^+(0, \sigma_u^2)$ (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. We estimate the Greene (2005) true fixed effect stochastic frontier panel model to estimate the yield response of sorghum to applied nitrogen. We estimated the two commonly used functional forms the Cobb-Douglas and translogarithmic production functions. To determine the appropriate functional form for this analysis, we conducted a likelihood ratio test based on the fact that the Cobb-Douglas model is nested within the more flexible translog model. The null hypothesis of that LR test is that a Cobb-Douglas specification is an adequate representation of the data. We fail to reject this for both farming systems at 5% or less. This indicates that the Cobb Douglas model is generally preferred for our data. Consequently, we estimate a Cobb-Douglas production function as follows:

$\ln(Y_{it}) = \beta_0 + \sum_i^n \beta_i \ln X_{it} + v_{it} + u_i$ (6)

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

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

For the i^{th} farmer in year t, LnY_{it}= natural logarithm of sorghum output per hectare (yield), lnS_{it} = natural logarithm of sorghum Seed used per hectare, lnN_{it}= natural logarithm of Nitrogen used per hectare, lnP_{it}= natural logarithm of phosphorus used per hectare, $lnAE_{it}$ = natural logarithm of Adult equivalence, T= the year dummy (1 if year is 2012,0 otherwise)

$\beta's$ are parameters to be estimated.

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

$U_{it} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4$ (8)

$V_{it} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4$ (9)

Definition of variables: V_i=Idiosyncratic error score, U_i= = Inefficiency score

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)

Key findings

The yield response to applied Nitrogen is low

Estimates of production function show that applied nitrogen has significant positive effect on sorghum yield across the two farming systems. However, the derived MPPs of 0.69 and 1.05 for cereal root crop and agro pastoralist farming systems are low. This implies that 1kg additional applied nitrogen gives an additional 0.69kg and 1.05 kg of sorghum for cereal root crop and agro-pastoralist Farming systems respectively, holding all other factors constant.

Reducing transportation costs has the potential to improve profitability

Similarly to maize and rice farmers, we find that transportation costs are a major fraction of the total acquisition cost of fertilizer for rural farmers. It constitutes over 70% of the acquisition cost. We carried out a simulation of the transport cost to see the effect of transport cost reduction on the profitability level .Lowering transportation costs increases the proportion of sorghum farmers for which fertilizer use is profitable in the cereal and agro pastoral farming systems. However, even making fertilizer available to farmers in their villages will only make it worthwhile for about 20% (25%) of sorghum farmers in the cereal-root crop farming system (agro pastoral farming system) 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 actually only make it profitable for about 25% of sorghum farmers to expand their input use.

The distributional impact of a subsidy on fertilizer is low

Following Liverpool-Tasie et al (2015), we considered the effect of Nigeria's subsidy program on the profitability of nitrogen application. When received, the subsidy rate for fertilizer in Nigeria during the survey years could range between 25% and 100% (Liverpool-Tasie and Takeshima, 2013). Thus, we explore how differences across market purchased and subsidized fertilizer is likely to affect the profitability of fertilizer use. We find 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 cereal root and agro pastoralist farming systems respectively.

Increasing the yield response of sorghum is important for improved profitability

The Sorghum yield response of applied Nitrogen is important in the profitability of fertilizer use. One way to expand the profitability of fertilizer use would be with a higher yield response to nitrogen application (i.e. a higher MPP of applied nitrogen). Consequently, we explored the effect of increasing the MPP of applied nitrogen on the profitability of fertilizer use. If the MPP of all farmers is increased to just about 15 kilograms of sorghum per kilogram of applied nitrogen, we are able to make the expansion of fertilizer use profitable for about 30% of farmers in the cereal- root crop farming system and about 40% for the agro pastoralist system. Moving to a higher MPP of 25 makes the expansion of fertilizer use profitable for almost 75% of farmers in both systems.

Improved market access can also improve fertilizer profitability

Another important factor about sorghum is the market orientation of sorghum farmers. Compared to crops such as rice and maize where households typically engage with the market in terms of 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 actually sell some of their produce, compared to almost 60% and 30% for rice and maize producers respectively. Better connection between farmers and industries that use their cereal as input could potentially improve the price received by farmers. We observed 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.

Policy agenda

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. This indicates that rather than only promoting expanded use of fertilizer, keen attention needs to be paid to the factors that drive the low MPP of applied nitrogen in cereal production in Nigeria. Farmer practices and use of complementary inputs is one important factor. Understanding the amount of soil organic matter present in Nigerian soils, the extent of micronutrient availability and other soil properties are also key factors to better understand how the yield response to inorganic fertilizer use in Nigeria can be improved.

Going forward, strategies to enables farmers assess the nutrient level of their soils based on an understanding of the specific nutrient need of each plot can go a long way to increase the efficiency of fertilizer use rather than a blind application of fertilizer to all soil types. Furthermore, strategies to increase the use of some complementary technologies such as mechanization, irrigation and use of improved seed varieties rather than just applying fertilizer in isolation are key. Improved farm management practices are likely additional strategies required. Finally, in addition to increasing the yield response of sorghum, conscious effort and research into value addition of sorghum could lead to higher commercialization of sorghum and better market orientation among sorghum farmers which will lead to a reduction in the Nitrogen/sorghum price ratio.

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