Is Fertilizer use Inconsistent with Expected Profitability for Rice Production in Nigeria?

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Synopsis:

This brief presents empirical results that revisit a conventional wisdom that inorganic fertilizer use across sub-Saharan Africa is too low. This expectation that more farmers should be using inorganic fertilizer and at higher rates implies it is profitable to use rates higher than observed if farmers are rational expected profit maximizers. This study exploits the political economy of fertilizer access in Nigeria to get consistent estimates of the effects of applied nitrogen on rice production.

Key findings

- We find the yield response to applied nitrogen to be low in the main rice growing farming system in Nigeria. On average, each additional kilogram of applied nitrogen yields about 8kg of rice.
- The behavior of rice farmers in Nigeria is not inconsistent with expected profitability which is limited by a low yield response to applied fertilizer, high transportation costs and low selling prices for rice in rural areas
- At the observed fertilizer acquisition prices and rice selling price, the profitability of nitrogen application is low for both risk averse and risk neutral farmers.

Policy implication:

- It is important to understand and improve the yield response of applied fertilizer.
- Actions are needed to increase the profitability of fertilizer use in rural Nigeria.
- Link farmers to input suppliers and making the product more available in rural communities
- Improve rice quality and design mechanism to increase the fraction of the retail price of rice in rural areas

Research question: Is fertilizer use profitable for rice production in Nigeria?

The notion that the use of fertilizer is low, despite limited empirical evidence that using rates higher than observed is indeed profitable, has defined the research questions in the literature pertaining to this topic. Rigorous empirical evidence to determine whether fertilizer use is inconsistent with expected profitability is limited. Thus, this paper contributes to the limited literature by exploring the profitability of nitrogen application for rice production in Nigeria.

A survey of the existing literature revealed that many profitability studies are dated or based on particular case study areas. Furthermore, few address the endogeneity of the fertilizer use decision or have compared actual farmer fertilizer use behavior to those expected of profit maximizing rural households while taking risk preferences and transportation costs into consideration. This paper takes advantage of recent nationally representative data in Nigeria to tackle three gaps in the literature. First it tests the popular notion that fertilizer use is too low in SSA, even though it is profitable. Second, it identifies more consistently the yield response to fertilizer by accounting for both time invariant and time varying unobserved characteristics likely to affect fertilizer application and rice yields. Third, it focuses on a different crop; rice, since most of the current literature has focused on maize.

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The Nigerian context
Rice farmers in Nigeria commonly use fertilizer and not as low as conventional wisdom suggests
There is limited empirical evidence testing whether it is profitable to use fertilizer at rates higher than is currently observed. While fertilizer use rates among rice farmers in Nigeria has traditionally been considered low from studies focused on particular areas (Ezui et al., 2010; Manyong et al., 2001; Ezui et al., 2008), more recent studies based on nationally representative data indicate that fertilizer use is quite common in Nigeria and not as low as conventional wisdom suggests (Liverpool-Tasie et al., 2015; Sheahan and Barrett, 2014).

Why rice?
Rice is an extremely important crop serving as the staple food for over half the world's population (IRRI, 2013). In SSA alone, rice consumption among urban dwellers has consistently grown, doubling since 1970 (Muthayya et al., 2014). Nigeria is a major importer of rice. This is driven by population growth, urbanization and a preference for rice, which have seen rice demand grow faster than domestic supply. Heavily dependent on imports, recent spikes in global cereal prices have led to expanded efforts to promote national self-sufficiency in rice. Given the prevailing conventional wisdom, these efforts have been focused on the dissemination and adoption of modern technologies like seeds and fertilizer (FMARD, 2011). However, average rice yields in Nigeria are quite low (said to be between 1 and 2.5 tons per hectare against potential yields of 5-6 tons per hectare) and rice farmers still rely on traditional practices (Cadoni and Angelucci 2013; Nwilene et al 2008). This occurs even though Nigeria is endowed with favorable ecologies for rice cultivation. Though rice is grown all across Nigeria's varied agro ecological conditions, majority of rice production takes place in the Cereal-Root Crop Farming System (C-RCFS) found in Central and Northern Nigeria. This paper focusses solely on the C-RCFS for the productivity analysis.

The analysis: Estimating rice yields response to applied nitrogen and profitability in Nigeria

The profitability of fertilizer use requires an understanding of:
- ✓ *fertilizer agronomics*, that is the yield response to applying it under different circumstances (such as soil quality, water availability and so on.); and

- ✓ *fertilizer economics*, which involves 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) provides a rare opportunity to estimate both yields and 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 address specifically the profitability of fertilizer use in a production function framework. 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, while the second collected information on post-harvest outcomes. The paper focuses on all plots on which rice was grown in the main agricultural season in each survey year. It therefore draws on information on the size of rice plots, the amount of fertilizer and other inputs used and the rice yields for the cereal-root crop farming system. It is the only farming system where there is consistently over 100 rice plots in each survey period.

From production function to profitability

The paper deals first with the agronomics, measuring the relationship between rice output and the relevant factors of production (including inorganic fertilizer). The production function estimates (see Box) are used to calculate the expected marginal and average physical products of nitrogen in rice production (EMPPs and EAPPs respectively). The EMPP of applied nitrogen (which describes how much extra rice output can be produced by using one additional unit of applied nitrogen, all else held constant) is obtained by taking the first derivative of the production function with respect to applied nitrogen. The EAPP is the gain in rice yield per unit of applied nitrogen relative to not using any nitrogen. These EMPPs and EAPPs are then used to calculate partial profitability measures. These are defined as the expected marginal value cost ratio (EMVCR) and the expected average value cost ratio (EAVCR) as follows:

Expected marginal value cost ratio: $(MVCR_{nijt}) = [E(p_{rt})*E(MPP_{nijt})]/p_{nijt}$
Expected average value cost ratio: $(AVCR_{nijt}) = [E(p_{rt})*E(APP_{nijt})]/p_{nijt}$
where p_n is the price of nitrogen and p_r is the price of rice.
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 should be equal to or greater than 1.5 or 2.

The findings:

Using an instrumental variable approach within a panel data framework to address endogeneity of nitrogen when estimating a rice production function, the paper explores the agronomics of fertilizer use in rice production (rice yield response to applied fertilizer). Next it explores the economics of fertilizer application by analyzing observed input and output prices as well as transportation costs. The study finds that farmer behavior is not inconsistent with expected profitability. In fact, the profitability of fertilizer is limited by a low yield response to applied nitrogen, high fertilizer costs and low selling prices for rice in rural areas.

What are the main factors that drive the profitability of fertilizer use?

The yield response to applied nitrogen is low in the main rice growing farming system

The production function estimates indicate that applied nitrogen has a significant effect on rice yields. Furthermore, the average marginal effect of applied nitrogen is about 8.9 and the MPP for farmers in this farming system range between about 3 and 15. This means that an additional kilogram per hectare of applied nitrogen increases rice yields per hectare by about 8.9 kilograms, all other things being held constant. These findings appear to be in line with other Nigerian studies. Akighir and Shabu (2011) estimate the MPP for fertilizer in Kwande Local Government Area of Benue State, Nigeria to be 10.7. Oniah et al (2008) in a study on swamp rice production in Cross Rivers State found marginal products of fertilizer to be much lower; about 3.7kg. Omonona et al (2012) actually find negative marginal product for fertilizer among Ofada rice producers in Ogun State in South West Nigeria.

Box: Understanding the challenges of estimating the rice production function

To understand the effect of fertilizer use on rice yields, we use a yield response (production function) model for rice that is driven by agronomic principles. Here the yield on a rice plot for a farmer is a function of several factors and can be expressed as follows:

$$Yield_{ijt} = X_{kijt}\beta + \delta QNitrogen_{ijt} + Z_{hijt}\gamma + u_{ijt}$$

Where $Yield_{ijt}$ refers to the yield per hectare (in kilograms) of rice on plot i for household j in time t which is a function of several vectors of endogenous and exogenous factors. X_{kijt}, refers to a vector of determinants of rice yields controlled by the farmer, including his use of other inputs apart from fertilizer. $QNitrogen_{ijt}$ captures the quantity of applied nitrogen on the plot while Z_{hijt} is a vector of controls that affects crop production such as soil quality, access to information and markets, the level and distribution of rainfall (Tolk, Howell and Evett 1999). Z_{hijt} also includes household characteristics including the age and gender of the plot manager, household wealth. Finally, $u_{ijt} = \varepsilon_{ijt} + c_i$ is a composite error term comprising time invariant (c_i) and time varying unobserved characteristics ε_{ijt} of our production system while β, δ and γ are parameters to be estimated.

One key issue is the endogeneity of the quantity of nitrogen applied on a rice plot. It is likely that nitrogen application is correlated with other farmer and plot specific characteristics that are also likely to drive farmer yields and restrict any causal interpretation to the coefficient on fertilizer use in a yield response model. For example, a positive correlation between the unobserved individual effect in the error term c_i and the rate of application of nitrogen would cause an upward bias in ordinary least squares (OLS) estimators of the effect of applied nitrogen on rice yields (Hausman and Taylor 1981).

A Fixed Effects (FE) model or a Correlated Random Effects (CRE) model can be used to address the endogeneity due to unobserved time invariant characteristics. The FE method attenuates potential biases by using variation in fertilizer use within a household over time to identify the causal effect of fertilizer on yields (Wooldridge, 2002). One limitation of the FE model is that we are unable to recover the coefficients on any time invariant observable characteristics as well. This can be an issue when important variables affecting yields such as soil type are time invariant. One way to address this is with the Correlated Random Effects (CRE) model. The CRE model addresses endogeneity due to unobserved time invariant factors but still makes it possible to recover the coefficients on time invariant observed variables (Wooldridge, 2010; Sheahan et al., 2013).

While the FE and CRE models potentially address bias caused by time invariant factors (such as farmer ability that is crucial for production function estimates), they do not deal with any bias caused by time-varying unobservable factors that may be correlated with yields and also correlated with the household's nitrogen application rate. Furthermore, the amount of fertilizer applied is usually determined by the farmers expected profit maximizing objective which in turn depends on the production function, and hence ε_{ijt} (Burke, 2014). Thus, there could also be unobserved time varying factors that could affect both fertilizer application and yields, which (if not accounted for) could also lead to a bias on the estimated yield response to applied nitrogen.

To address this potential problem, we use a Control Function Approach (CFA) which is largely an instrumental variables (IV) method (Imbens and Wooldridge 2007, Wooldridge, 2013). We adopt the CFA rather than the typical Instrumental Variables (IV) or Two-Stage Least Squares approaches (2SLS) because our potentially endogenous explanatory variable, nitrogen application is a corner solution (i.e., many households apply zero kilograms of nitrogen). This is important because fertilizer use represents an observable outcome by a farmer where the use variable takes a zero value with positive probability but is largely continuous over strictly positive values.

The estimates of this production function show the importance of addressing the effects of both the time invariant and time varying unobserved factors when estimating nitrogen yield response functions. While the CRE model which only accounts for time invariant unobserved factors appears to control for some of the endogeneity of nitrogen application (when compared to the pooled OLS), the difference between the CRE and the CF specification indicates the importance of correcting for time varying unobserved factors that are likely correlated with nitrogen application as well as rice yields. Using the CF specification estimates, the paper calculates the marginal physical product of using nitrogen by taking the derivative of the production function with respect to applied nitrogen for each plot. We also calculate the average physical product as the change in output due to the use of applied nitrogen. This captures the gain in rice yield per unit of nitrogen compared to not applying any nitrogen.

Significant variation between the selling price of rice and the retail price hurts profitability

The output price is key for any profitability analysis. Though nitrogen application was only profitable for about 18% of rice plots in 2010, this number is slightly higher in 2012 at 23% (see figure 1). This 27% difference in the percentage of plots on which nitrogen application is profitable may be partly driven by the increase in the price of rice over the two years. Using data on rice prices over time from the National Bureau of Statistics, the average price for local rice increased by about 19% between 2010 and 2012. The change in the mean price of rice in our study sample over the two survey rounds is similar at 21%. This indicates the importance of the price of rice in the profitability of rice production in Nigeria. The paper runs various simulations to see how the profitability of fertilizer use would change if the community prices were what farmers received. We find that with the retail price in the community (more than double the selling price), the percentage of plots on which nitrogen application is profitable tripled in 2012 from 16% to about 75 for risk averse farmers maximizing expected profit (see Figure 2).

Figure 1: Fertilizer application is profitable for some farmers

Percentage of rice plots on which fertilizer application is profitable for risk averse farmers
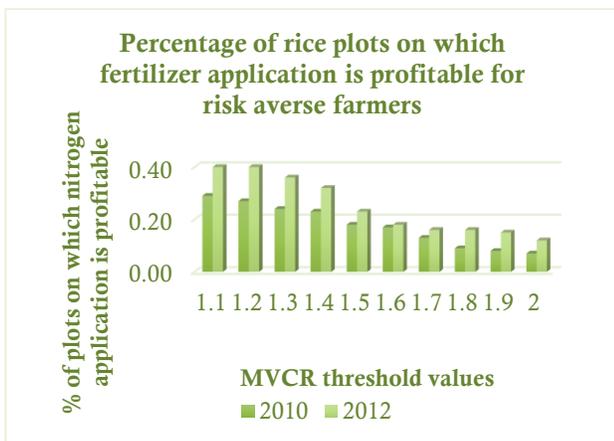
Figure 2: The selling price for local rice is low

Profitability of nitrogen application across different rice prices
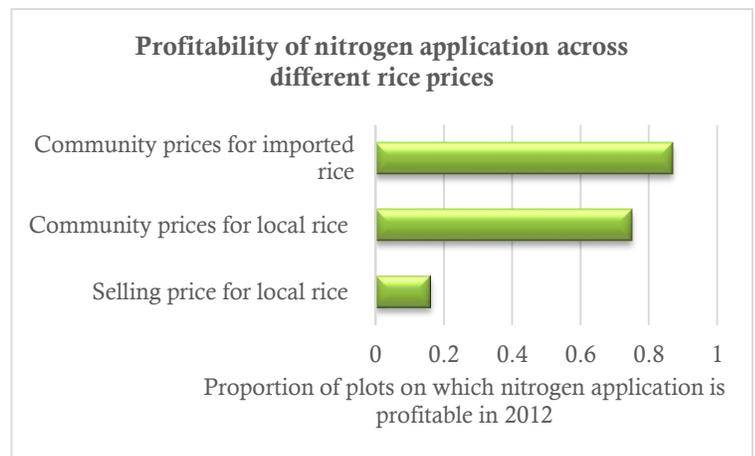
High transportation costs significantly reduce the profitability of fertilizer use
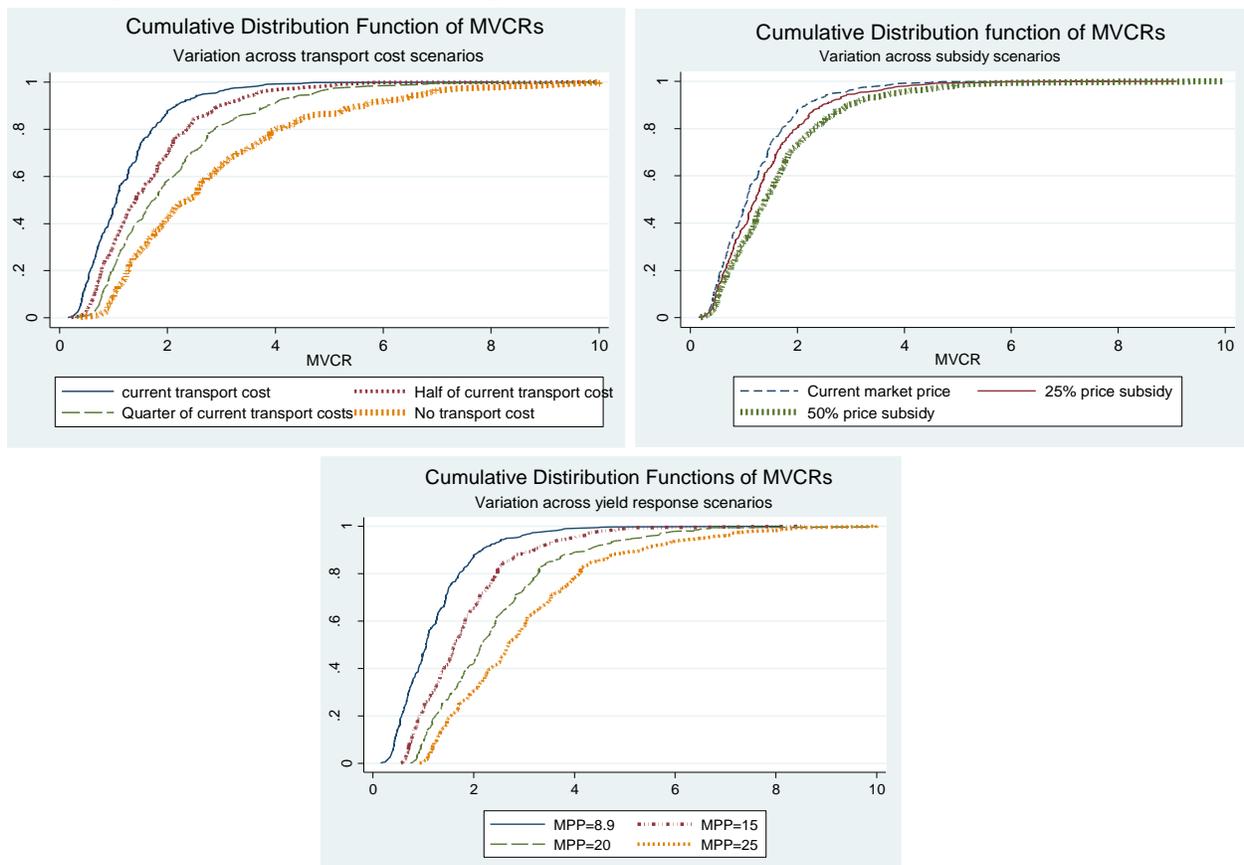
Generally, transportation costs to acquire fertilizer are very high in Nigeria. Liverpool-Tasie et al (2015) found that about 70% of the total acquisition cost for fertilizer is due to transportation cost. To explore the effects of transportation costs on the profitability of nitrogen application, we 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% more than doubles the percentage of plots on which nitrogen application would be profitable in the C-RCFS; from 18% to 42% in 2010 and from 23% to 52% in 2012. A further reduction of transportation costs by 75% would just about triple the percentage of rice plots on which nitrogen application would be profitable in both years. This indicates that while the low profitability of nitrogen application in the main C-RCFS is partly driven by the low MPP of nitrogen, reducing the cost of fertilizer acquisition can significantly improve the profitability of nitrogen application for rice production in this farming system. These are really large effects which we consider to be conservative estimates.

Fertilizer subsidies are not as effective as reducing transportation costs

Subsidizing fertilizer is a longstanding key component of Nigeria's agricultural support programs. Consequently, we now consider the effect of reducing input prices with a fertilizer subsidy. The paper simulates the likely effect of receiving subsidized fertilizer on the profitability of nitrogen application for rice farmers using the 25% to 50% that is associated with recent government subsidy programs in Nigeria. The simulations reveal that reducing the price of fertilizer increases the number of plots on which nitrogen application is profitable in the C-RCFS. If the fertilizer program was to have reached all rice farmers with a 25% subsidy, this would have increased the number of plots on which nitrogen application was profitable by about 30% from 18% to 24% in C-RCFS in 2010 and from 23% to 37% in 2012. If a 50% subsidy was provided for all rice farmers, this would further increase the proportion of plots on which nitrogen application was profitable to 34% and 40% for 2010 and 2012 respectively.

While these are significant effects, since only a small fraction of farmers typically receive subsidized fertilizer, the true profitability effect will be much lower. This idea is further reinforced by additional simulations (see figure 3) directly juxtaposing the effect of subsidies versus transportation costs. It appears that reducing the transportation costs farmers face to secure fertilizer will have a larger effect on the profitability of fertilizer use than using fertilizer subsidies. Since transportation costs are such a high portion of the total acquisition cost for fertilizer, it is not surprising that 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 closer to farmers) 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 effect, we find evidence that the proximity to the local government of origin of the state governor increases access to fertilizer.

Figure 3: A reduction in transport costs is more effective than fertilizer subsidies

Cumulative Distribution Function of MVCRs
Variation across transport cost scenarios

— current transport cost ······· Half of current transport cost
– – Quarter of current transport costs ||||||| No transport cost

Cumulative Distribution function of MVCRs
Variation across subsidy scenarios

– – Current market price —— 25% price subsidy
||||||| 50% price subsidy

Cumulative Distiribution Functions of MVCRs
Variation across yield response scenarios

—— MPP=8.9 ·–·–· MPP=15
– – MPP=20 ········ MPP=25

The rice yield response of applied Nitrogen is important in the profitability of fertilizer use

At the observed fertilizer acquisition prices and rice selling price, the yield response to fertilizer application in Nigeria is quite low. Recall that the marginal physical product of applied nitrogen for rice production was about 8.9 kilograms of rice per hectare for each kilogram of applied nitrogen per hectare. that at the observed acquisition costs and selling price of rice, if the MPP of applied nitrogen was higher at 15kg per hectare of rice for each kilogram per hectare of applied nitrogen, this would increase the percentage of plots on which applied nitrogen was profitable for a risk averse farmer; from 18 percent to 53 percent in 2010 and from 23 to 64% in 2012. If the MPP was higher at 25kg the application of nitrogen would be profitable for about 80% of rice plots, even at the current high acquisition costs of fertilizer. While the range of MPP values in our sample of rice farmers is between 3 and 15, response rates of 25 and higher are feasible based on field trials and studies in West Africa (Haefele and Wopereis, 2005).

On average, farmer behavior is not inconsistent with expected profitability

The paper compares actual observed fertilizer use on rice plots in Nigeria with expected profit maximizing behavior. We consider a MVCR>=1 as an indication that a risk neutral farmer would gain from using fertilizer. A risk neutral farmer would require a MVCR threshold greater than 1 to make it profitable to use fertilizer. We find that nitrogen is applied on over 50% of rice plots and the mean application rate is about 60kg per hectare. The mean application rates are significantly higher among farmers for which the MVCR is greater than 1 compared to those for which it is not profitable (based on expected profit maximization) but on which fertilizer is being used. This mean difference is statistically significant at 5% or below. Furthermore, among farmers who are currently not applying any nitrogen on their rice plots, there are no plots on which fertilizer application would be profitable. This result remains consistent irrespective of the profitability threshold (MVCR value considered necessary to indicate profitability) used. On the contrary, it appears that there are plots on which fertilizer use 7 would not be considered profitable but on which fertilizer is being applied.

The way forward:

Generally, this study confirms that fertilizer use which is clearly evident in rice production in Nigeria can be profitable. However, at current input and output prices, this remains a reality for only a subset of rice farmers. Expanding the number of rice farmers that use fertilizer (and for which it is economically profitable at acquisition price) is still necessary in Nigeria.

Policy agenda:

Historically, Nigerian governments have tried to improve the affordability of fertilizer and increase its use with the aim to increase productivity. One such strategy are fertilizer subsidies which often account for more than 30% of total federal government spending on agriculture (Mogues et al., 2008). The positive returns of these programs are yet to be seen. This study indicates that it is necessary to put the profitability of fertilizer use at the forefront of the policy agenda. Promising reforms are already underway in the Nigerian agricultural sector. To address the challenges associated with the trend of increasing rice imports, the Nigerian government recently introduced several policies to stimulate local rice production. Alongside the usual trade restrictions, other policy reforms have been introduced to deregulate sub sectors like fertilizer and seed and to better coordinate demand and supply of rice. These reforms alongside others geared to improve infrastructure might change some of our findings which could serve as a basis for evaluating such programs.

Key policy recommendations:
- ✓ There is a need to understand and improve the yield response of applied nitrogen to expand fertilizer use in this area. This could be through complementary practices (such as irrigation facilities, good quality seed and other more efficient methods of fertilizer use or crop management practices).
- ✓ Reallocate subsidy funds to address the high transport cost to improve universal access to fertilizer
- ✓ To address the low selling prices, it is important to facilitate the processing of the local paddy rice
- ✓ Further studies on the soil organic matter and other micronutrient availability for cereal farmers is necessary.
- ✓ There is also likely a significant role for extension and other innovatively structured mechanisms to disseminate agronomic best practices to rural farmers

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