Is it Profitable for Smallholder Rice Farmers to Use Inorganic Fertilizer? Evidence from Tanzania

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ABSTRACT

Increase inorganic fertilizer use is crucial for rice farming's sustainable productivity, particularly for smallholder farmers. However, there was limited empirical evidence on the economic return of inorganic fertilizer and its impact on farm income. This study used the National Sample Census of Agriculture (NSCA) 2019-20 survey and an empirical model that account for sample selection bias and unobserved heterogeneity at the household level. Study found that rice's average response to inorganic fertilizer uses ranges from 4 kg/ha to 7.4 kg/ha. Furthermore, though the use of inorganic fertilizer is profitable, the current inorganic fertilizer application rate lies below the optimal economical level. Furthermore, the study found that, use of inorganic fertilizer increases farm income for farmers. This study suggests that reducing the costs of inorganic fertilizer is likely to significantly increase the use of inorganic fertilizer and farm income among smallholder rice farmers. This will enable farmers to improve their living conditions and, in general reduce their income poverty. Moreover, increasing inorganic fertilizer use coupled with the provision of extension services, off-farm income generation opportunities, and development of irrigation infrastructure will sustainably increase rice farming productivity.

Keywords: Inorganic fertilizer, Rice farming, SDG 1

INTRODUCTION

Rice stands out as a common crop among primary agricultural products, exhibiting significant potential for economies in sub–Saharan Africa (SSA) to attain the Sustainable Development Goal (SDG 1) of ending poverty (Ouatarra, 2022). Africa ranks as the second-largest contributor to world rice production, accounting for around 5% of the total output, behind the Asia continent (FAO, 2021). The demand for rice in Africa had an annual growth rate of 6% due to population growth, urbanization, and dietary preferences. In 2018, Africa imported around 15.5 MT of rice, which is equivalent to 33.3% of the global rice trade (Arouna et al., 2021). This was due to the fact that rice consumption exceeded region's production. It is possible to enhance rice productivity and close the gap in regional consumption by utilizing improved technologies in farming.

Tanzania is one of Africa's leading rice producers, with an annual production of over 3.4 MT. This production volume positions Tanzania as the fourth-largest rice producer in Africa. Rice occupies nearly 22% of the total cereal crop planted area, and around 25% of the agricultural households grow rice (URT, 2021). The average annual rice consumption per capita is around 25 kg, nearly six times below that of Madagascar, at 140 kg per person per year (URT, 2019). The rice sub-sector in Tanzania significantly influences the livelihood of around two million people, contributes to 3% of the GDP, and serves as a crucial source of dietary energy for the Tanzanian population (Jamwal et al., 2021; URT, 2019).

Despite the benefits of the Tanzanian rice subsector, productivity remains low, with a recorded average of 2.3 t/ha, which is half the global average of 4.6 t/ha (URT, 2021). According to the National Sample Census of Agriculture (NSCA) for 2019-20, identified low soil fertility as one of the constraints on increasing productivity. One evident approach to address poor soil fertility is to increase inorganic fertilizer use (Chinasa, 2022). However, the NSCA 2019-20 shows the use of inorganic fertilizer among smallholder farmers is low, with only 23.9% of farmers use inorganic fertilizer. Moreover, the observed fertilizer application rate in rice production was 104 kg/ha, which is below the agronomist's prescribed range of 125-250 kg/ha (Nakano & Kajisa, 2013). Farmers are reluctant to use inorganic fertilizer because of uncertainty about its return.

The profitability of inorganic fertilizer, among other factors, is a key consideration for sustainable use among smallholder farmers in rice production (Kulyakwave et al., 2019). However, there is limited knowledge on the profitability of using inorganic fertilizer under heterogeneity conditions for smallholder farmers. Yanggen et al., (1998) asserts that yield response, inorganic fertilizer price and rice price determined the profitability of inorganic fertilizer.

To estimate yield response, inorganic fertilizer use might correlate with farmer and plot characteristics such as managerial skill or ability or soil quality. Hence, this results in an inconsistent parameter estimate. We refer to this problem as endogeneity (Wooldridge, 2012). While there are several approaches to address endogeneity, none of the studies in Tanzania used the control function approach (CFA) which is more appropriate and produce more precise estimate (Yu, et al., 2013).

Along these lines, this study follows the lead of Yu et al., (2013) by using the CFA to look at (i) how rice yield changes when inorganic fertilizer is used, (ii) how profitable inorganic fertilizer is, and (iii) how using inorganic fertilizer affects farm income. Findings from these study objectives will provide valuable insight to inform policies such as the Agricultural Sector Development Program II (ASDP II) and the National Rice Development Strategy II (NRDS II) that aim to achieve sustainable productivity and increase smallholder farmers' income.

Theoretical framework

This study's theoretical background is based on the firm's theory. The theory postulate that the ultimate objective of any farm enterprise is to maximize profit. Farm managers make decisions in accordance with one of economics' fundamental marginal rules. The decision rules state that the use of the input should be increased until the point is reached whereby the last shilling spent on input return exactly its incremental cost (Nicholson, 2007).

METHODOLOGY

Description of the study area

This study used data collected in the Mbeya and Morogoro regions. We choose these regions because they comprise approximately 26% of Tanzania's harvested area. In addition, the regions contribute to around

29% of the country's rice output and have the largest number of households reported to use inorganic fertilizer.

Data sources and sampling procedure

This study used secondary data obtained from the NSCA 2019-20 dataset, provided by the National Bureau of Statistics (NBS). Data were collected using multistage sampling, a two-stage design. The first stage entails identifying and selecting urban and rural enumeration areas from the 2012 population and housing census frame. The second stage was the identification and inclusion of agricultural farming households from the selected enumeration areas. NSCA 2019/20 is a nationally representative data set including farm-level agricultural statistics. The main purpose of NSCA is to help high-level decision-making bodies, plan and create actions by filling the information gap.

Analytical framework

The following empirical model (quadratic functional form) was chosen to estimate the effect of yield response to inorganic fertilizer.

$$Y_i = \beta_0 + \beta_{1j}X_{1j} + \beta_2 X_{1j}^2 + \ldots \beta_{ij}X_{ij} + e_i \qquad (1)$$

Where Y_i is the rice yield, X_1 is the amount of inorganic fertilizer applied per hectare. Study expect β_1 to have positive sign, and β_2 to have negative sign because it represents the quadratic effect of inorganic fertilizer. The inorganic fertilizer squared term captures the fact that increasing inorganic fertilizer increases yield up to a point, and then any increase in inorganic fertilizer decreases yield (Ricker-Gilbert et al., 2009). The rest of the independent variables that was used to estimate equation (1) are continuous variables age, farm size, education, seed, household size, farm income, price of inorganic fertilizer and dummy variables sex, land ownership, improved seed use, use of tractor, extension service, herbicide use, off farm income, irrigation, farmers group, market and road distance.

We used CFA to address endogeneity and sample selection bias. CFA provides three-step procedures, first it use the Heckman sample selection technique to obtain a probit estimate of the inverse mills ratio (IMR). Second, estimate reduced-form equation of inorganic fertilizer to generate the general residual. Third, we include IMR and general residual as explanatory variables in equation (1) as explanatory variables. Therefore, following the CFA procedures, equation (1) assumes the following form:

$$Y_i = \beta_0 + \beta_{1j}X_{1j} + \beta_2 X_{1j}^2 + \ldots \beta_{ij}X_{ij+}\ m_1\widehat{v_1} + k_1\widehat{\varphi_1} + e_i \qquad (2)$$

Where, $\widehat{v_1}$ is IMR and $\widehat{\varphi_1}$ is general residual. The IMR controls sample selection bias, while general residual controls inorganic fertilizer endogeneity. As a result, the obtained parameters are more precise.

Estimating profitability of inorganic fertilizer

Value-cost ratios often assess the profitability of inorganic fertilizer in the absence of full production costs (Mather et al., 2016). We used two ratios: marginal value cost ratio (MVCR) and the average value cost ratio (AVCR).

The MVCR tells us how close the farmer is to achieve the economically optimal level of use of inorganic fertilizer. MVCR = 1 signifies the level of inorganic fertilizer use that maximizes profit, MVCR > 1 signifies underutilization of inorganic fertilizer and MVCR < 1 signifies above optimal inorganic fertilizer use. For underutilization, farmers can increase their income by increasing the application rate of inorganic fertilizer. For above optimal case, farmers can increase income by reducing the application rate of inorganic fertilizer.

Equation (3) shows that we obtain the MVCR by taking the marginal physical product (MPP) of inorganic fertilizer, multiplying by the rice price, and then dividing by the price of inorganic fertilizer. MPP is obtained by taking the first derivative of equation (2) with respect to inorganic fertilizer. The MPP tells us the additional quantity of rice produced (kg/ha) by the last unit of fertilizer applied (kg/ha).

The AVCR gives a sense of overall profitability. AVCR = 1 means farmer breakeven; the additional unit cost of the inorganic fertilizer is equal to the additional value of the rice produced. AVCR > 1 implies that inorganic fertilizer use is profitable; AVCR < 1 indicates that inorganic fertilizer use is not profitable.

To calculate the AVCR, we first estimated the average physical product (APP) by dividing the quantity of rice produced by the quantity of fertilizer applied. Next, we took the average median value, multiplied it by rice price, and divide it by the price of inorganic fertilizer, as shown in equation (4). Liverpool et al., (2014) express the MVCR and AVCR as follows:

$$AVCR=\frac{(APP_f*P_r)}{P_f} \qquad (3)$$

$$MVCR=\frac{(MPP_f*P_r)}{P_f} \qquad (4)$$

Where P_r is average price of rice per kg and P_f average price of fertilizer per kg. The rule of thumb requires that, for inorganic fertilizer to be profitable, the MVCR and AVCR must be equal to or greater than two (Yanggen et al., 1998).

Examine impact of inorganic fertilizer use on farm income

We used propensity score matching (PSM) to estimate the impact of inorganic fertilizer on farm income. PSM use statistical techniques to construct an artificial comparison group of farmers without inorganic fertilizer that has similar observable characteristics to the group of farmers who use inorganic fertilizer (Gertler et al., 2007).

Let G_i denote a dummy variable such that $G_i = 1$ if the i^{th} farmer adopts inorganic fertilizer and $G_i = 0$ otherwise. Similarly let Y_{1i} and Y_{2i} denote potential observed farm income for adopter and non-adopter groups respectively. Then

$$\Delta=Y_{1i}-Y_{2i} \qquad (5)$$

Following the Rosenbaum and Rubin (1983) PSM assumptions of condition independence and common support, the average treatment effect on the treated (ATT) can be estimated as:

$$\tau_{ATT}^{PSM} = E[E\{Y_{1i}|G_i = 1, p(X)\} - E\{Y_{2i}|G_i = 0, p(X)\}] \qquad (6)$$

Equation (6) shows that the PSM estimator is simply the mean difference in farm income of the two groups, inorganic fertilizer user and non-user over the common support area.

RESULTS AND DISCUSSION

Descriptive statistics of sampled rice farmers

Table 2 presents the descriptive statistics of the key study variables for 119 households in Mbeya and 184 households in Morogoro.

In the Mbeya region, the average rice yield was around 3.1 t/ha, greater than the national average of 2.3 t/ha, and around 75.6% of the farmers are male. Males dominate rice production due to their ownership of resources and greater exposure compared to females (Rashid, 2020).

Moreover, on average, the inorganic fertilizer application rate was around 209.05 kg/ha. The observed inorganic fertilizer application rate is within the appropriate level recommended by agronomist of 125-250 kg/ha (Nakano & Kajisa, 2013). In addition to that, the average age of farmers was 47 years and number of years spent in schooling was around 6.2 years. The average age of rice farmers is within active labour force age that range between 15-64 years.

Furthermore, the average farm size was around 0.71 ha and average household size per family was 4 members. Household member can be source of labour if and only if most of the members are of productive age; otherwise, they can add household expenses, particularly food expenses. Additionally, around 9.2% of the farmers belong to farmer groups and nearly 3.4% of the farmers received extension advice. Herbicide use was prevalent, around 59.7% of farmers used herbicide, while improved seeds, tractor and irrigation were used at 16.8%, 12.6%, 17.6% respectively.

In the Morogoro region, the average rice yield was around 1.9 t/ha which is below the national average of 2.3 t/ha and the average farm size was around 0.93 ha. The average farm size in the Morogoro region aligns with the findings, indicating that significant numbers of rural households have farms ranging from 0.5 to 3 ha (URT, 2019).

Furthermore, the rate of inorganic fertilizer application was around 96.9 kg/ha, falling short of the agronomist's recommended rate of 125-250 kg/ha (Nakano & Kijisa, 2013). The average age of farmers was 49 years, and the average household size was around 4 members per family.

In addition to that, the average number of years spent in school was about 6.2 years. The number of years spent in education reflects the quality of the work force. It is anticipated that a farmer with more schooling years will have enhanced capabilities to incorporate modern inputs and achieve the higher levels of efficiency in their production processes (Rashid, 2020). Nearly 77.2% were male household heads, and around 3.3% of rice farmers belong to farmer groups. Farm groups serve as the primary resource for farmers seeking to acquire knowledge about production technology as well as enable farmers to enjoy economies of scale by reducing procurement cost of inputs when ordered in bulk.

Table 1: Description Statistics for Key Study Variables

Variable	**Mbeya**		**Morogoro**	
	Mean	**Std. dev.**	**Mean**	**Std. dev**
Yield (kg/ha)	3121.02	1668.825	1981.79	714.69
Inorganic fertilizer (kg/ha)	209.05	139.29	96.9	69.3
Quantity of seed (kg/ha)	50.49	14.29	33.7	28.4
Age of household head (years)	47.9	15.78	49.51	14.3
Farm size (ha)	0.71	0.92	0.93	0.92
Household size (member)	4.62	2.41	4.01	2.21
Education (years spent in school)	6.2	3.95	6.1	3.76
Price inorganic fertilizer per kg (TZS)	1079.82	332.15	1085.71	185.164
Sex of household head (1=male, 0=female)	75.6%		77.2%	
Land ownership (1= owner, 0= otherwise)	75.6%		78.3%	
Farmer groups (1=yes, 0= no)	9.2%		3.3%	
Off farm income (1=yes, 0= no)	45.4%		48.4%	
Road distance (1 < or = 3km, 0 otherwise)	47.1%		59.2%	
Market distance (1 < or = 3km, 0 otherwise)	20.2%		15.2%	
Extension (1= receive advice, 0= no)	3.4%		4.3%	

Use of tractor (1 = yes, 0 = no)	**12.6%**		**6%**	
Irrigation (1 = irrigated, 0 = no)	17.6%		1.1%	
Improved seed (1= yes, 0 = no)	16.8%		5.4%	
Herbicide (1 = yes, 0 = no)	59.7%		59.8%	
Source: Author estimations using NSCA 2019-20 data				

Herbicide use was widespread, around 59.8% of farmers used herbicide. The use of improved seed (5.4%), irrigation (1.1%), and use of tractor (6%) were low in comparison to Mbeya region. Moreover, around 4.3% of farmers received extension advice.

Control function estimates

Table 2 shows the results of control function estimate from CFA procedure. For the Mbeya region, key factors that determine rice yield are inorganic fertilizer, irrigation, off farm income, farm income and price of inorganic fertilizer. Inorganic fertilizer, irrigation, off farm income and farm income had statistically significant positive effect on the rice yield, while the price of inorganic fertilizer had a statistically significant negative effect on the rice yield.

The quadratic functional form is likely to be appropriate, as indicated by the squared negative sign in the quantity of inorganic fertilizer which implies decreasing returns to applied inorganic fertilizer. The presence of squared and interaction terms in the model prevents the inorganic fertilizer parameter from providing an immediate interpretation of the effects. Therefore, we utilized, the margins command in STATA for analysis.

Table 3 results show an estimated rice yield response to inorganic fertilizer of around 4 kg/ha, which is statistically significant at the 5% level. This finding implies that the additional unit kg/ha of inorganic fertilizer leads to a corresponding increase of around 4 kg/ha in rice output, keeping all other variables constant. This result confirms the findings of previous studies that there is positive relationship between inorganic fertilizer use and rice yield (Rashid, 2020; Liverpool et al., 2014).

In addition to inorganic fertilizer, irrigation is another factor that influences rice yield. On average, rice farmers who irrigate obtained about 2237.349 kg/ha more than farmers who did not. Having access to irrigation improves investment in rice enhancing inputs by reducing the risk of moisture stress leading to output failure. This result had a resemblance of that by Rashid (2020), who found that irrigation had a significant positive effect on the rice yield.

Furthermore, farmer who reported having off farm income activities obtained an average of 233 kg/ha more than those who did not, and the increase in farm income led to an increase in rice yield around 103 kg/ha. This could suggest that farmers use the income from crop sale and off-farm activities to invest in modern farming technology, like purchasing inorganic fertilizer, thereby, increasing rice yield.

Table 2: Control Function Estimate

Variables	**Morogoro**		**Mbeya**	
	coefficients	**Std. error**	**coefficients**	**Std. error**
seed	-5.036	5.465	-14.544	9.799
Fertilizer	13.886**	6.818	5.017*	2.772
fertilizer squared	-0.031	0.025	-0.005	0.005
improved seed	416.847	411.578	-1320.782	825.481

Herbicide	-136.252	563.865	353.386	931.979
Irrigation	2237.349*	1199.069	656.733	840.493
household size	32.603	26.394	6.556	67.907
extension	306.605	259.358	1658.844**	733.613
distance to market	-130.889	147.09	-398.887	318.714
Tractor	81.888	218.673	-487.761	589.468
Age	3.28	4.525	6.124	10.225
Sex	192.486	150.12	1.372	293.55
Education	-5.817	19.099	-31.572	37.479
Farmer groups	-306.855	288.771	-385.333	408.58
off-farm income	233.669*	128.56	113.083	297.585
farm size	-11.345	93.281	-311.785	295.555
land ownership	23.224	139.688	-427.057	470.517
farm income	103.147***	22.649	274.709***	30.388
Price of fertilizer	-1.94**	0.937	369.665	284.873
general residual	-11.199	7.13	1.95	4.521
inverse mills ratio	86.641	2051.628	1336.012	3624.514
fertilizer*farm size	-6.456*	3.531	-0.198	1.208
fertilizer*improved seed	5.084	3.634	0.481	2.211
Observation	184		119	
R square	0.302		0.58	

Source: Author estimations using NSCA 2019-20 data. *, ** and *** are significant at 10%, 5% and 1% levels respectively.

Additionally, an increase in price of inorganic fertilizer by one Tanzania shilling resulted in a decrease in rice yield of about 1.94 kg/ha. This result bears a resemblance to that of Rashid (2020), which found that when inorganic fertilizer is expensive for smallholder rice farmers, they do not use it, reducing rice yield.

In the Morogoro region, the key factors that determine rice yield are inorganic fertilizer, extension and farm income. Inorganic fertilizer, extension and farm income had statistically positive effect on the rice yield.

Again, the squared negative sign in the quantity of inorganic fertilizer implies decreasing returns to applied inorganic fertilizer. The presence of squared and interaction terms in the model prevents the inorganic fertilizer parameter from immediately providing an interpretation of the effects. Therefore, we utilized the margins command in STATA for analysis.

Table 3 result estimates the rice yield response to inorganic fertilizer at around 7.4 kg/ha, which is statistically significant at the 10% level. This finding implies that the additional unit of inorganic fertilizer leads to a corresponding increase of around 7.4 kg/ha in rice yield, keeping all other variables constant.

Moreover, farmers who received extension service had a rice yield average of 1658.3 kg/ha greater than farmers who did not receive extension advice. This could mean that farmers receive information that enables them to increase rice yield.

In addition to that, an increase in farm income results in a rice yield of 274.709 k/ha. This could suggest that, the income from crop sales provides them with capital to buy improved technology, leading to an increase in yield.

The observed yield response to inorganic fertilizer for both regions Morogoro and Mbeya, are below the rule of thumb established by Yanggen et al., (1998), that a kilogram of inorganic fertilizer produces 10 or more kilogram of output. Therefore, we can enhance the yield response by increasing inorganic fertilizer use together with crop management practices such as timely weeding, adequate pest control, timely harvest and proper post-harvest techniques.

Profitability of inorganic fertilizer

Table 3 shows the results of AVCR and MVCR that were estimated using equations (3) and (4). We used the farmer's selling price of rice for analysis. We obtained the inorganic fertilizer price per kg by dividing the value of the inorganic fertilizer by the quantity purchased.

We found the AVCR in the Morogoro region to be around 11 suggesting that using inorganic fertilizer in the study area is profitable. Furthermore, we found the MVCR to be 3.7. This suggests that farmers could increase their profit by using more inorganic fertilizer, as the current rate does not maximize profit.

Similarly to the Mbeya region, we found the AVCR equal to 10 suggests that using inorganic fertilizer in the study area is profitable. Furthermore, we found the MVCR equal to 2.2 suggesting that farmers could increase their profit by using more inorganic fertilizer.

Table 3: MPP, APP and Profitability of Inorganic Fertilizer

Yield (kg/ha)	MPP	APP	MVCR	AVCR
Morogoro	7.4*	22	3.7	11
Mbeya	4**	18.666	2.2	10.2

Source: NSCA 2019-20. * and ** are significant at 10% and 5% levels respectively.

The MVCR values obtained in Morogoro and Mbeya regions are greater than two, within the cutoff point suggested by Yanggen et al., (1998) for the inorganic fertilizer to be considered profitable for farmers. This implies that the increase in yield attributable to inorganic fertilizer have a value at least double the cost of acquire the inorganic fertilizer. However, some suggested that a potential return greater than four is desirable, serving as a type of "insurance premium" to protect against undesirable eventualities.

Impact of inorganic fertilizer use on farm income

Table 4 presents the estimated results using the PSM procedure. In this study, we define farm income as revenue from rice production after subtracting various expenses. These expenses include land preparation, planting, irrigation, weeding, harvesting, transportation costs from the farm to the storage location as well as expenditure on seeds, inorganic fertilizer, herbicide, fungicide, insecticide and any other costs. We calculated the impact estimate using nearest neighbor (NN) and kernel matching (KM). The analysis used psmatch2 command in STATA.

Farmers have proven that using inorganic fertilizer positively impacts their farm income. For example, Table 4 shows that rice farmers in Morogoro who use inorganic fertilizer gain a mean increase in their farm income within a range of TZS 280,591 to TZS 575,685. This result was statistically significant at the 1% level for NN, but not significant for the KM matching method.

Similarly, the use of inorganic fertilizer increases farmer income in the Mbeya region. Farmers using inorganic fertilizer have a mean average farm income ranging from TZS 467,588 to TZS 756,603. The NN method yielded statistically significant results at the 5% level.

Table 4: Impact of inorganic fertilizer use on farm income

Regions	Treated	Control	ATT	T-stat
Outcome variable crop income				
Method 1: Nearest neighbor matching				
Morogoro	978225.158	402540	575685.158	2.74***
Mbeya	1394066	637462.051	756603.949	2.33**
Method 2: Kernel matching				
Morogoro	978225.158	697633.951	280591.207	1.22
Mbeya	1394066	926477.096	467588.904	1.24

Source: NSCA 2019-20 data. ** and *** are significant at 5% and 1% levels respectively.

These results indicate the potential direct role of inorganic fertilizer use in improving smallholder rice farmers' welfare, as higher farm incomes obtained translate into lower poverty income.

Conclusion

This study aimed to estimate profitability of inorganic fertilizer and the impact of inorganic fertilizer use on farm income. The results showed that the yield response to inorganic fertilizer was around 4 kg/ha in Mbeya and 7.4 kg/ha in Morogoro region. In addition to that, a study found that the use of inorganic fertilizer in rice production is profitable, though the current inorganic fertilizer application rate is not profit maximizing. This suggests that rice farmers are underutilizing inorganic fertilizer, and increasing the application rate of inorganic fertilizer could increases profit. Furthermore, farmers who uses inorganic fertilizer earn more income than those who did not use it in rice production.

This study advocates increasing fertilizer uptake in rice production as a means to enhance profitability for smallholder farmers, improve their living conditions and in general reduce their income poverty situation. Similarly, to increase rice productivity the government should put more efforts in investment in irrigation infrastructure. Additionally, existing extension system needs to be well equipped and adequately staffed to cover large number of farmers. In addition to that, extension agents should receive regular training so that they can transfer appropriate location and crop specific knowledge to farmers. Furthermore, the government should promote off farm income generation opportunities such as petty trade, livestock keeping and carpentry because the income obtained invested in rice farming hence result to increase yield.

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