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Complementarity between Irrigation and Fertilizer Technologies – A justification for increased Irrigation Investment in the Less-Favored Areas of SSA

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Abstract

There is a downward spiral of declining soil fertility, low crop yield and increasing poverty in the less-favored areas of SSA. The semi-arid tropics of northern Ghana share this episode. The soils in this part of the country are naturally less endowed, have little organic matter content and farmers use very little inorganic fertilizer. Existing studies indicate that the erratic nature of rainfall in the area increases risk and constrains farmers' investment on inorganic fertilizer. However, agronomic studies suggest that promotion of sustainable use of inorganic fertilizer is indispensable at least in the short to medium term to break the downward spiral. Therefore, promoting sustainable use of inorganic fertilizer use remains to be a policy challenge. This paper argues that in spite of observed disinvestment on irrigation both by governments and donors there is significant complementarity between irrigation and inorganic fertilizer use in the less-favored areas of northern Ghana. This implies that increased irrigation investment in the semi-arid tropics of SSA can be justified given its importance in reducing rainfall risk and boosting inorganic fertilizer use.

JEL: Q15, Q16, Q18

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1. Introduction

There are about 3 billion rural people in the developing world of which 1.2 billion (42%) live in Less Favored Areas (LFAs), defined as areas with a limited agricultural potential because of low soil fertility, steep slopes or insufficient water resources, and usually with poor infrastructure and services (Ruben et al. 2003). LFAs account for about 40% of the total agricultural area in developing countries, including most of the more fragile soils and nearly all the available rangelands (Ruben et al. 2003). Sub-Saharan Africa (SSA) in general and its LFAs in particular have yield levels much lower than the world average. According to a World Bank estimate, meeting increasing demand for food in SSA requires a minimum of 3 % increase in land productivity (World Bank 1993). Nevertheless, many SSA farmers are not engaged in activities that promote land productivity, they either unsustainably intensifying (i.e., mining their soils and degrading the resource base) or extensifying onto fragile margins because they cannot meet needs on existing croplands.

The unsustainable paths are taken due to inappropriate policies that reduce farmers' incentives and capacity to pursue sustainable use of land. Economic liberalization measures that removed public support for farming, thus increasing input prices and market risk, without concomitant public investments in institutional or physical infrastructure to induce sustainable intensification by smallholders played significant role (Reardon and Barrett 1999). The future of agricultural productivity and its resilience to cope up with increasing population rests on a sustainable use of organic and inorganic fertilizers and the construction of soil and water conservation measures (Anani-Sakyi et al. 1993).

The increased use of organic fertilizer will help to stabilize the soil structure and increase in yield response to inorganic fertilizers (Anani-Sakyi et al. 1993). However, pursuing pure organic fertilization has major limitations. Low nutrient concentration in organic fertilizer also limits its wide use, for example to provide 100 kg of N, 20,000 kg of leaf biomass or manure (with 80 % moisture and 2.5 % N concentration) would have to be applied, in contrast to only 217 kg of urea (Sanchez et al. 2002). Arid and semi-arid agro-ecologies in general do not have the potential to produce large amount of biomass for organic fertilizer production. The cost of transporting bulky biomass to the plots is also another limitation, not mentioning the labor cost required to apply it on the plots. It also has serious scaling up problem if everybody in a community wants to adopt it (Reardon and Barrett 1999). In general, nutrient depletion in the semi-arid tropics of SSA exceeds replenishment rate and the traditional ways of organic fertilization alone will not suffice under current conditions to restore soil nutrients to levels needed to achieve steady increases in crop and animal production (Ryan and Spencer 2001 and Larson 1993).

Therefore, investment in soil fertility is central in increasing agricultural productivity in LFA of SSA and there is sufficient soil science evidence that shows sustainable use of inorganic fertilizers is one of the most important components in the improvement of land productivity. Elsewhere, as much as 75 percent of crop yield increases since the mid-1960s are directly or indirectly attributable to fertilizer use (Viyas 1983, cited in Reardon and Barrett 1999; Bumb 1995). For example, in India fifty percent of the increase in grain production is attributable to inorganic fertilizer (Hopper 1993, cited in Bumb 1995). In SSA, too existing evidences show that inorganic fertilizer can substantially increase yields (Larson and Frisvold 1996; Reardon et al. 1999).

So far, the use of inorganic fertilizer by African farmers is insignificant as compared to other continents and as compared to the amount of soil nutrients required to replenish the soils. For example, in 1993, African farmers used 10 kgs per hectare and as compared to 83 kgs per hectare in all developing areas in 1993 (Heisey and Muwangi 1997; Weight and Kelly 1998) and we do not think that this gap has closed over the past decade. The low use of chemical fertilizer is a major worry from both the environmental and food production perspectives (Reardon and Barrett 1999). Many factors limited the sustainable use of inorganic fertilizer in SSA by either limiting farmers' incentives or their capacity to invest in fertilizer.

A secured supply of soil moisture is one of the most important incentives because rainfall variability is a critical factor determining farmer's fertilizer use efficiency and risk aversion strategy (Feder, Just and Zilberman, 1985). There are not enough published results on the direct link between fertilizer response and soil moisture technologies in LFAs but existing evidences show that fertilizer responds better (and farmers are more likely to adopt it) in zones where rainfall exceeds 700 mm per year or in other words where there is better soil moisture supply (Lele and Stone 1989; Matlon 1990; Jha and Hojjati 1993; and Thompson 1987). For example, in Burkina Faso combining tied ridges with moderate levels of inorganic fertilizer increased sorghum yields by 90 to 440% (Sanders, Shapiro, and Ramaswamy 1996). Although there are some challenges in pursuing irrigation-driven agricultural development in Africa, in this paper we used an empirical data from a semi-arid region of Ghana, to argue that there is still enough justification for increased irrigation investment in SSA one of which is its significant impact on household fertilizer use. The article is organized as follows: Section II gives background into the study area and tries to show the need for increased use of inorganic fertilizer. Section III describes the empirical model. Section IV discusses the result and section V concludes.

2. The Study Area

This paper is based on empirical data collected from the Upper East Region (UER) of Ghana, which is a typical LFA. The soils of the region have low organic matter content because of high temperature, which causes rapid decomposition of organic matter. In addition to that, the traditional burning of vegetative cover reduced the amount of available organic matter in the area. About 85% of the soils in the region are grouped as class IV of FAO/UNESCO soil classification, and are suitable for pastures, tree crops and for sustained annual crop cultivation, provided adequate measures are taken to maintain soil structure and fertility (Anani-Sakyi et al. 1993). However, most of these soils are put under annual crop cultivation without fertility maintenance measures resulting in very low agricultural productivity (Terbobri and Albert 1993). Inorganic fertilizer use is also very low and varies significantly across farm households. As is also observed in other African countries (Savadogo et al. 1998 for Burkina Faso; Semgalawe 1998 for Tanzania; Clay et al. 1998 for Rwanda) farmers in the study area tend to apply inorganic fertilizer only to cash crops (tomato, other vegetables, rice) and not on the subsistence food crops (millet, and sorghum) (al Hassan, Kyyd and Warner 1996). Overall fertilizer use in Ghana is very low; however, the northern part of Ghana in spite of its high level of poverty uses more fertilizer (Table 1). The main reason for this gap is the presence of two relatively big irrigation schemes in this part of the country (FAO 2005).

TABLE 1: Average sales of fertilizer by region

Region	1997	1998	1999	2000	2001
			(tonnes)		
Ashanti	5 167	3 893	2 023	4 046	7 438
Brong Ahafo	7 582	5 712	2 969	5 937	10 914
Central	1 629	1 229	638	1 275	2 345
Eastern	1 011	762	396	792	1 455
Greater Accra	1 236	931	484	967	1 779
Northern	15 220	11 467	5 960	11 917	21 910
Upper Regions	15 501	11 679	6 070	12 137	22 314
Volta	8 481	6 390	3 321	6 640	12 208
Western	337	254	132	264	483
Total	56 164	42 317	16 593	43 975	80 846

Source: FAO 2005.

3. Empirical Specification

3.1 Analytical Model

A model depicting the impact of irrigation (*Irri)* on a farm household's inorganic fertilizer use (f_i) decision can be represented by:

$$f_i = f(Irri, Z) \qquad (1)$$

More generally, we can write the fertilizer use equation as;

$$f_i = \beta' X + \varepsilon , \qquad \varepsilon \sim N\left[0, \sigma_\varepsilon^2\right] \qquad (2)$$

Where f_i is measured in Kg. per hectare of cultivated land, X represents a vector of explanatory variables including irrigation, which determine fertilizer application decision, β' is a vector of parameters to be estimated and ε_i is the disturbance term.

Seventy percent of the sample households reported that they have not used any fertilizer during the 2003/04 cropping season. Under such conditions estimating the parameters with the conventional OLS regression method fails to account for the qualitative differences between zero observations and continuous observations (Greene 2003). In addition, restricting the analysis only on those households, who applied fertilizer, will yield a biased and inconsistent parameter estimates because it ignores the process that generated the observed fertilizer use (Maddala 1983).

Tobit and Heckit regression models are the most commonly used approaches in cases when the empirical observation includes both continuous and zero dependent variable. Confusion reigns, however, about the proper use of these models and the appropriate interpretation of their estimates. The standard Tobit model is applicable only if the underlying dependent variable can take negative values, but has been censored to zero in the empirical realization of the variables (Maddala 1992). This theoretical base is ignored many times and Tobit model is used when it is known that the dependent variable cannot take negative values for example in fertilizer use. The Heckit model has emerged as a de facto default alternative to Tobit when values are clustered at zero due to selection bias rather than censoring (Sigelman and Zeng 1999) like the case of fertilizer use estimation. Therefore, the Heckit model can better capture fertilizer decision model with zero observations than the Tobit model.

A Heckit specification of the fertilizer use decision above will be:

$$Z_i^* = \gamma' w + \mu \qquad (3)$$

$$f_i = \beta' X + \varepsilon \qquad \text{Observed only if} \qquad Z_i^* > 0 \qquad (2')$$

Where the error terms μ_i ε_i are assumed to follow a bivariate normal distribution with means 0, variances $\sigma_\mu = 1$ and σ_ε, and correlation coefficient ρ. Given the joint distribution of μ_i ε_i, the likelihood of the observed f_i can be derived. Maximum-likelihood estimation is computationally cumbersome and sometimes fails to converge and this problem can be solved by employing a two-stage estimation procedure (Heckman 1979). Under the two-stage procedure, the estimator is based on the conditional expectation of the observed *f*:

$$E(f / z^* > 0) = \beta' X + \rho\sigma_\varepsilon \lambda(-\gamma' w) \qquad (4)$$

Where $\lambda(-\gamma' w) = (\phi(-\gamma' w)) / (1 - \Phi(-\gamma' w))$ is the inverse Mills ratio. Equation (4) implies that the conditional expectation of *f* is $\beta' X$ only if the errors of Equations (3) and (2') are uncorrelated; otherwise, it is affected by variables in the selection equation as well. Equation (4) also suggests that consistent estimates of β can be obtained via OLS regression of the observed *f* on X and λ (.); the unknown coefficients in λ (.), γ, can be obtained from a probit estimation of z on w, with z=1 if $z^* > 0$ and 0 otherwise. Therefore, the probit specification of the fertilizer use decision can be specified as:

$$z_i = \gamma_0 + \sum \gamma_{ij} w_j + \mu_i \qquad (3')$$

Where, W_j's are variables determining fertilization decision. Farmer's choices of agricultural technologies and factor proportions- including the choice to extensify or intensify so as to increase output, and if to intensify, what sort of intensification- turns fundamentally on the *incentives* and *constraints* they (Reardon and Barrett 1999). Factors found to be important in determining farmers' fertilizer adoption included price factors, risk, access to market, farm and farm characteristics and liquidity/credit (Abdoulaye and Sanders 2003). In this paper in order to account for the impact of household characteristics on inorganic fertilizer use decision the sex (SEXHEAD) and age (AGEHEAD) of the household head were used to measure the impact of household head characteristics. On the other hand, family labor endowment (FAMLAB), proportion of household labor engaged in off-farm (PROPOFF), the logarithm of farm equipment in monetary terms (LNFARMEQ), and a dummy variable measuring household manure use (MANURE) were used to account for the impact of household resource endowments. The impact of social capital was measured by two dummy variables measuring whether a household head is currently a community leader (LEADER) or was once a community leader (EXLEADER) this differentiation can help to capture if there is accumulation of social capital. The impacts of spatial effects on fertilizer use were measured by two district dummies (BOLGA) and (KASSEN), which measure whether a household is located in Bolgatanga, Kassenanaken or Bongo districts and a variable measuring the logarithm of distance from the market (LNDISMKT). The impact of irrigation is proxied by a variable indicating whether a household is located near irrigation sites or not (IRRIVILA). Finally, to account for the crop choice on fertilizer use a dummy variable measuring whether a household has cultivated rice or not was included (RICE):

A model estimating the amount of fertilizer used that incorporates the inverse Mills ratio, λ, as an instrument variable to account for any selection bias was specified as:

$$f_i = \alpha_0 + \sum \alpha_{ij} X_j + \theta_i \lambda_i + \varepsilon_i \qquad (2')$$

Where: X_j's are factors determining amount of fertilizer used (Kg. per ha.). Those variables include, as per the preceding definition, SEXHEAD; AGEHEAD, IRRIVILA, LNFARMEQ, BOLGA, KASSEN, RICE, MANURE, and square of household age (AGESQU), number of female members engaged in off-farm (NUFEOFF), number of male adult household members (NUMALAD), and a dummy measuring household head education level (EDUCA). ε_i is the error term while α's are parameters to be estimated, and θ_i is the parameter associated with the inverse Mills ratio.

At this point it is important to note that only the non-zero observations on f_i were used in the second-stage estimation. The marginal effect of the k^{th} element of X on the conditional expectation of *f* will be calculated as:

$$\frac{\partial E(f/z^* > 0, X)}{\partial X_k} = \beta_k - \gamma_k \rho \sigma_\varepsilon \delta(-\gamma' w) \tag{5}$$

Equation (5)[2] shows that the effect of X is a compound of its effect on both the selection and the outcome equations. When the errors in the selection and the *f* regression equations are correlated ($\rho \neq 0$), it is incorrect to interpret β_k as the marginal effect of X_k on *f*, unless X_k does not enter the selection equation (in which case $\gamma_k = 0$).

3.2. Results and Discussion

The analysis is based on a sample of 197 households from the UER of Ghana. Table 2 presents some descriptive statistics of the sample households.

Table 2: Descriptive statistics of sample households

Variables	Mean	Std. dev
Age of household head	44.8	13.96
Sex of household head (1=male, 0= female)	0.84	0.36
Education (Literate=1, Illiterate=0)	0.22	0.42
Labor Endowment (Man Days)	5.4	3.1
Proportion of family working in off-farm	0.19	0.19
Credit ('000 Cedis)	111.5	481.9
Fertilizer Use (Kg/ha)	63	164.5
Manure Use (Yes=1, No=0)	0.74	0.44
Irrigation Use (Yes=1, No=0)	0.34	0.47
Access to Irrigation (leave near irrigation project Yes=1, No=0)	0.29	0.46

[2] $\delta(\alpha) = \lambda(\alpha)(\lambda(\alpha) - \alpha)$ and $\lambda(\alpha) = \phi(\alpha)/(1 - \Phi(\alpha))$ and $\alpha = -(\gamma' \omega)$ (Sigelman and Zeng 1999)

Two empirical models were estimated to evaluate the consistency of estimated parameters. The parameters remained consistent both in sign and in magnitude between the two models. McFadden R^2 and the percentage of observations correctly predicted (Table 3) indicate that the model is a good representation of the empirical observation. The variable directly measuring a household's irrigation use is highly correlated to most of the explanatory variables included in the models. To account for this multicollinearity a proxy variable IRRIVILA, a dummy variable measuring whether a household is located near irrigation projects or not, was used. The IRRIVILA was the most significant variable both in the fertilization decision (Table 3) and intensity of fertilizer use models (Table 4).

Table 3: Maximum Likelihood Estimates of Fertilizer Use Decision Models

Variables	Model 1		Model 2	
	Coefficients	Marginal Effect	Coefficients	Marginal Effect
CONSTANT	-3.2^{***} (1.3)	-0.75^{***}(0.30)	-6.7^{***} (2.29)	-1.56^{***} (0.54)
SEXHEAD	-2.03^{***} (0.74)	-0.47^{***}(0.14)	-1.4^{**} (0.67)	-0.34^{***}(0.15)
AGEHEAD	-0.03^{*} (0.02)	-0.001^{*}(0.004)	-0.03^{*} (0.02)	-0.01^{*}(0.004)
FAMLAB	0.1 (0.09)	0.02 (0.02)	0.15^{*} (0.09)	0.03^{*}(0.02)
PROPOFF	3.65^{***} (1.38)	0.85^{***}(0.31)	3.8^{***} (1.30)	0.88^{***}(0.30)
LNLANDOP	1.49^{***} (0.50)	0.35^{***}(0.12)		
LNFARMEQ			0.31 (0.21)	0.07 (0.05)
MANURE	1.70^{***} (0.65)	0.33^{***}(0.104)	1.64^{***} (0.63)	0.33^{***}(0.102)
IRRIVILA	4.1^{***} (0.92)	0.76^{***}(0.08)	3.4^{***} (0.80)	0.69^{***}(0.10)
LNDISMKT	-0.73^{*} (0.44)	-0.17^{*}(0.103)	-0.5 (0.40)	-0.12 (0.095)
EXLEADER	1.42^{***} (0.59)	0.34^{***}(0.133)	1.4^{***} (0.58)	0.33^{***}(0.13)
LEADER	-0.44 (0.76)	-0.10 (0.161)	-0.07 (0.72)	-0.02 (0.17)
BOLGAT	-1.32^{*} (0.79)	-0.28^{**}(0.14)	-1.3^{*} (0.78)	-0.28^{**}(0.14)
KASSNAK	1.82^{***} (0.71)	0.40^{***}(0.15)	1.6^{***} (0.69)	0.36^{***}(0.145)
RICE	1.3^{***} (0.59)	0.28^{***}(0.114)	1.8^{***} (0.57)	0.37^{***}(0.098)
Log Likelihood	-59.6		-63.7	
Predicted (%)	86.8		84.3	
McFadden R^2	0.55		0.52	
χ^2	147.0^{***}		138.6^{***}	

Model 1: A Logit Model with Farm Equipments as a measure of asset and Model 2: A Logit Model with Operated Land as a measure of assets Level of Significance: * 10 %, ** 5 % & *** 1%, numbers in parenthesis are standard errors.

This implies that the risk associated with rainfall variability was the most important determinant of fertilizer use. In addition to its direct effect, irrigation has significant indirect effect on inorganic fertilizer use through its compounding effect on other variables. The indirect effect can be seen from the impacts of farm equipment asset and family labor endowment on the probability of fertilizer use conditional on the irrigation condition (Figures 1 and 2) fertilizer use.

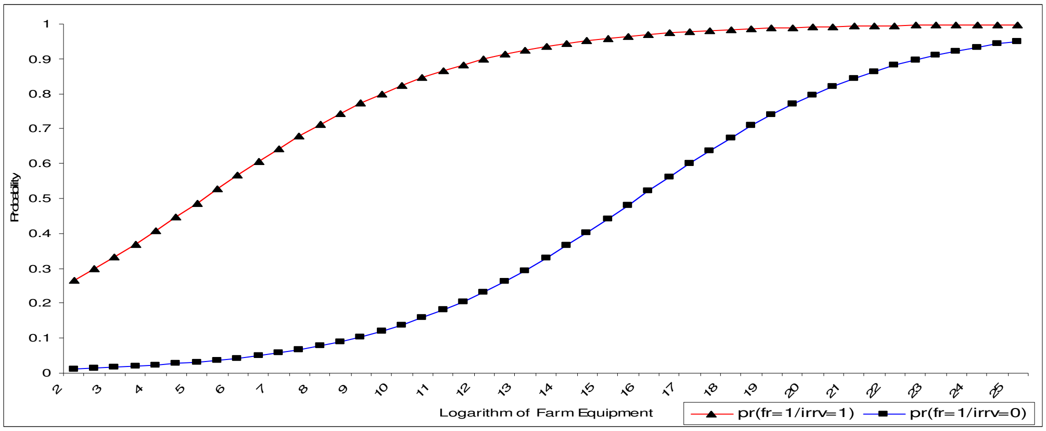

Figure 1: The conditional effect of farm equipment asset on fertilizer use

From figure 1 it can be seen that on the average for a given level of farm equipment asset the average probability of fertilizer use increased from a mere 0.41 in the case of non-irrigators to a probability of 0.82 to the irrigating households. Figure 1 also shows that the conditional impact of irrigation decreases only at a higher level of farm equipment. Likewise, Figure 2 shows that the average probability of fertilizer use increased by almost a factor of 300 percent, from a level of 0.37 for non-irrigators to a level of 0.92 for irrigators. This implies that, for the same level of family labor the probability of fertilization varies significantly depending on whether the household is living in irrigation areas or not.

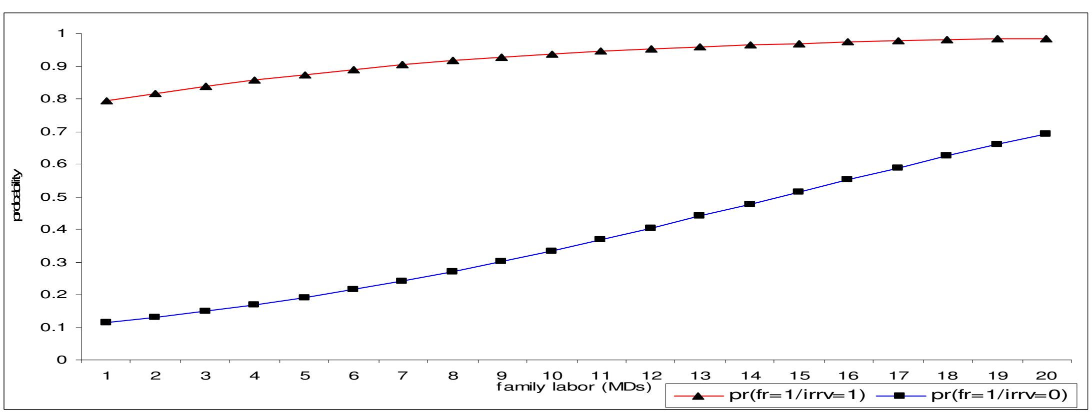

Figure 2: The conditional effect of family labor endowment on fertilizer use

Female household heads have higher probability of fertilizer adoption than male household heads. Given the important role women have in African agriculture, the result boosts the need for additional emphasis on gender issues in technology promotion and development in SSA. The size of operated land, measured in the logarithm of hectare of operated land, LNLANDOP, has significantly and positively determined inorganic fertilizer use. MANURE is used as a proxy for household livestock endowment and it has positively determined the inorganic fertilizer use and was significant at 1 %. The household liquidity status is another important determinant of inorganic fertilizer use. Most farmers in the semi-arid tropics of West Africa are very poor to finance inputs such as inorganic fertilizer (Abdoulaye and Sanders 2003). For example, about 75 percent of the sample households did not obtain credit in the cropping season 2002/2003 and cash income from sources like off-farm labor play crucial role in filling the gap left by the absence of credit markets. Farmers in the study area generate off-farm income both from temporary migration to the southern part of Ghana, where there are more employment possibilities, and from employment on other farmers' fields in the same locality and doing petty trades. The variable measuring the proportion of household labor engaged in off-farm, PROPOFF has positive and significant impact on inorganic fertilizer use. The parameter of off-farm variable was the second largest in magnitude next to the irrigation access variable. Therefore, there is significant implication on the role of off-farm employments in financing agricultural technologies in the LFA of Ghana.

Variables measuring the spatial location of a household also determine fertilizer use significantly. This implies that investment in complementary infrastructure facilities such as road boost farmers' inorganic fertilizer use. Likewise, the social capital of the head, here measured by dummy variables indicating whether a household head had previous formal or informal social responsibilities, EXLEADER, and whether the head is currently holding any position, LEADER, added important information on fertilizer use decision. The signs and significance level of the two social capital variables indicated that the probability of inorganic fertilizer use by those household heads that are currently holding social responsibilities is less than those who do not have those responsibilities. Household heads' previous social responsibility has a positive and significant effect on their inorganic fertilizer use decision. The combined effect of these results imply that while in office household heads may not have enough time to use fertilizer but when they leave their responsibilities they leave with experience and networks that increase their inorganic fertilizer use.

Table 4: A Selection Model of Fertilizer Use in the UER of Ghana

Variables	Coefficients
CONSTANT	-0.19 (1.43)
SEXHEAD	-0.81** (0.37)
AGEHEAD	0.07 (0.05)
AGESQU	-0.00 (0.00)
NUFEOFF	0.33** (0.17)
NUMALAD	0.08* (0.51)
EDUCA	0.47** (0.23)
IRRIVILA	2.11*** (0.46)
LNFARMEQ	-0.01 (0.09)
BOLGAT	0.83 (0.55)
KASSNAK	1.17*** (0.31)
RICE	0.91** (0.46)
MANURE	-0.04 (0.29)
DISTMKT	-0.04 (0.03)
Inverse Mills	0.23 (0.47)
Observations	80
Adjusted R^2	0.55
F-test	7.89***

Dependent Variable: logarithm of fertilizer use per hectare. Values in Bracket are standard errors. Level of Significance: *** 1%, ** 5 % and * 10 %.

5. Conclusions

In the less-favored areas of SSA, there is a downward spiral of declining soil fertility, low yields and increasing poverty. Soil productivity is low because soil nutrient levels are low, and little inorganic fertilizer is applied. Irrigation expansion in addition to its direct effect on crop yield can indirectly boost agricultural production by decreasing the risk of applying inorganic fertilizer in the LFAs. In this paper, it is shown that irrigation increases both the probability of inorganic fertilizer use and the amount of inorganic fertilizer used per hectare. In addition, it is shown that irrigation also has a compounding effect on the effect of other factors (such as household equipment asset and labor endowment) on fertilizer use decision. This implies that the direct and indirect positive impacts of irrigation on fertilizer use serve as additional justification for promoting irrigation investment in the LFA of SSA. Therefore, the effect of irrigation on agricultural productivity through improving inorganic fertilizer use need to be given due attention in analyzing or appraising irrigation investments in LFAs of SSA.

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