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Soil Fertility Management Choice in the Maize-Based Smallholder Farming System in Malawi

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Abstract: The paper analyses the factors that affect smallholder farmers' choice of soil fertility management options in Malawi using a two-stage maximum likelihood estimation procedure. Using results from the Double-Hurdle model, the paper estimates the probabilities and intensities of fertilizer application conditional on choice of inorganic fertilizer. The findings indicate that relative wealthy indicators, human capital, credit and market access, food security index and land pressure are the main factors that greatly influence farmers' choice and intensity of input investment. Although there is a high and positive correlation between probability of adoption and intensity of application, factors that influence adoption are not necessarily the same as those that influence the intensity of application, conditional on adoption. The paper concludes with policy and research implications aimed at informing the debate on enhancing sustainable soil fertility management among smallholder farmers in Malawi.
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Keywords: soil fertility management, smallholder farmers, Double-Hurdle model, Malawi

1. Introduction

Improving soil fertility management among smallholder farmers is widely recognized as a critical aspect in addressing food insecurity and poverty, especially in Sub-Saharan Africa, where up to 90% of the population in most countries earns their livelihood as smallholder farmers (Donovan and Casey 1998; Freeman and Omiti 2003). Sustained soil fertility management has been an important factor in increasing productivity, but this has been a challenge to Sub-Saharan Africa where on average, the rate of input intensity is estimated at between 8-12 kg ha^{-1} compared to over 83 kg ha^{-1} for all developing countries (see for example Stoorvogel and Smaling 1990; Mwangi 1997).

Due to many compelling reasons, which manifest themselves in increasing the relative cost of inorganic fertilizers, a number of traditional low-cost soil fertility management options have emerged, especially targeted at smallholder farmers[1]. In Malawi, over the last six agricultural seasons, government policy has seemingly been promoting the integration of inorganic fertilizers and grain legumes within the traditional maize-based farming systems. This has been seen, for example, through the distribution of inorganic fertilizer and grain legume seeds through the Targeted Inputs Programme (TIP) implemented since 1998. Promotion of integrated soil fertility management stems from the realization that smallholder farmers do not have the capacity to apply either option in optimal quantities. Besides, there are obvious disadvantages associated with either option when used independently, even in the less likely event of farmers being able to apply optimal quantities.

Despite government support, research results still indicate dismal adoption of the options that have been developed (Kumwenda et al. 1996). One attributing factor is that the technical feasibility of such options is not consistent with the actual farm conditions. Moreover, the development process of the options has not

[1] Government supported the development of best-bet soil fertility options through the Maize Productivity Task Force starting from the second half of the 1990s. Soil fertility options developed through this programme included, but not limited to: groundnut (*Arachis hypogea*), velvet beans (*Mucuna pruriens*), soybeans (*Glycine max.*) and pigeonpea (*Cajanas cajan*) incorporation either in rotation or intercrop with maize. Technical results from research show that these technologies improve maize yield significantly (see for example the work of the Soil Fertility Network in Eastern and Southern Africa in Waddington et al. 2004).

adequately incorporated socio-economic and livelihood conditions which are at the core of farmers' decision-making. As such, effective policy support in soil fertility management requires knowledge of the factors that compel farmers to arrive at the choices they make. Thus, the objective of this study is to assess the factors that determine smallholder farmers' choice of soil fertility management options. This study focuses on integrated soil fertility management options involving inorganic fertilizer and grain legumes, but more especially the former, because whether or not farmers adopt the low-cost soil fertility options, significant yield effects are obtained with application of inorganic fertilizers. Thus inorganic fertilizer is still the key input that would increase the incentive for adoption of other options because even the biological nitrogen fixation function associated with grain legumes is greatly reduced when some nutrients are deficient.

While other studies have approached a similar problem using the Heckman procedure (Minot et al. 1999), logistic analysis (Green and Ng'ong'ola 1993) and input demand analysis (Reardon et al. 1999), this paper compares the results from a joint Tobit and a Double-Hurdle models because we assume that factors that affect farmers' choice of an option should not necessarily be the same as those that affect the intensity of application. This is because the decision to choose a particular soil fertility option is obviously associated with some threshold effects. Although the Heckman model has been widely used to analyze such type of selectivity bias, it is not the most efficient estimator and Kennedy (1998) refers to it as a second best alternative to the full information maximum likelihood (FIML) approach. Furthermore, Davidson and MacKinnon (1993) recommend using the Heckman procedure only to test for the presence of selectivity bias. In terms of policy relevance, our analysis clearly shows that adoption and intensity may be different decisions and that estimation of intensity on the basis of factors affecting adoption, as implied by other approaches, may be liable to error.
The rest of the paper is arranged as follows: the next section reviews related research and this is followed by the theoretical and empirical specification of the model. Section three describes the data used in the analysis followed by the model diagnostics and discussion of results. The final section draws some conclusions and policy implications from the results.

2. Farmers' Choice of Soil Fertility Management Technologies: Review of Related Research

A review of the literature on adoption of both inorganic and organic soil fertility management inputs among smallholder farmers in Malawi reveals very low and inconsistent uptake rates (Green and Ng'ong'ola 1993; Kumwenda et al. 1995; Minot et al. 2000).[2] With the disruption of hybrid maize and fertilizer uptake, which occurred in the late 1980s and early 1990s, fertilizer use on maize has been continuously low. Both demand and supply constraints have contributed towards the low fertilizer uptake and have reinforced a spiral of low agronomic productivity, which results in reduced effective input demand. The situation has also been aggravated by the stagnant aggregate fertilizer supply and less effective distribution mechanisms.

From the demand side, the major factor that depresses fertilizer uptake is the increase in the domestic fertilizer price relative to output price. Because all fertilizers in Malawi are imported, domestic prices are invariably sensitive to devaluation.[3] The effect has been further compounded because Malawi depreciated its foreign exchange regime at roughly the same time when the country's agricultural policy seriously embarked on full liberalization of the input and output market, which necessitated the removal of input subsidies.[4] Supply side constraints point to structural problems related to importation due to the country's land-locked position. The bulk of smallholder fertilizer is still handled through the parastatal institutions: Smallholder Farmers Fertilizer Revolving Fund of Malawi (SFFRFM) and Agricultural Development and Marketing Cooperation (ADMARC), because even though the market is liberalized, private traders are few and often find it difficult to gain an increasing share of the market due to the poor state of development of

[2] This is in spite of the donor-funded programmes that distributed free seed and interest free input credit with the aim of stimulating input use among smallholder farmers. The major programmes included: The Drought Recovery Input Programme (from 1995/96); The Agricultural Productivity Investment Programme (from 1996/97) and The Starter Pack Scheme now called the Targeted Inputs Programme (from 1998/99).
[3] The Malawi Kwacha has been depreciated so many times since 1994, from as low as MK9/US$ to MK45/US$ in 1999 and nearly MK110/US$ as of the present. As such the average price of a 50kg bag of high analysis fertilizers such as 23:21:0+4s, Urea and CAN have increased nearly fifteen-fold from an average of MK100 in 1994/95 to over MK1500 at present.
[4] The input subsidies were gradually reduced from 11% in 1994 to zero in 1995/96 (Ng'ong'ola 1996).

the rural infrastructure (Kherallah and Govindan 1999; Ng'ong'ola et al. 1997). As such, the input retail price is substantially higher thus making the product highly unaffordable by the majority of the smallholder farmers. Relatively low maize: nitrogen price ratios have been experienced since the 1990s because even though both the maize and fertilizer markets are deregulated, the rate at which fertilizer price increases is higher relative to that of maize.

Apart from the price related variables, socio-economic variables such as wealth status, human and physical capital endowment, institutional support and location specificity i.e. access to markets (product, input and capital), are some key variables that largely explain the choice of soil fertility management options (Green and Ng'ong'ola 1993; Minot et al. 2000). Natural causes, such as moisture stress due to drought also result in low responses to inputs, which further depresses the relative profitability of soil fertility inputs. Given all these constraints, the yield response of low cost soil fertility options is often so low making such inputs effectively costly, especially when used without inorganic fertilizer.

3. Theoretical and Empirical Model

Traditional models that empirically assess agricultural household behaviour are largely based on the ideas portrayed in the original peasant household models of Chayanov (1966) and Singh et al (1986), among others. The basic idea is that agricultural households aim at maximizing their consumption or reducing the variation of consumption possibilities. In most developing countries, where it is assumed that some or all markets are dysfunctional, most agricultural household models assume that utility maximization is constrained, first by the resources with which to satisfy consumption, and second by the consideration of the safety-first principle which requires that consumption should not fall below certain minimum subsistence level (see Roy 1952; Thorner et al. 1986; de Janvry et al. 1991).

Thus we assume a representative household that maximizes an intertemporal utility from own production, expressed as a concave function of consumption and leisure:

$$Max\ U_t = U\left(c_a, c_m, c_l; z^{hh}\right) \quad \mathbf{1}$$

Where c_a, c_m and c_l are, respectively, quantities consumed of own produced agricultural commodity, a manufactured commodity and leisure; z^{hh} is a combination of household characteristics that influence consumption patterns. This equation implies that in highly agrarian societies where off-farm sources of income are an insignificant share of total household income, the intertemporal utility U is essentially a function of own production of crops whose proceeds are used to finance the purchase of other essential commodities not produced on the farm.

This utility function is attained subject to two conditions: the households' intertemporal resource endowment, which is given as a standard budget constraint and the production technology. These are expressed as:

$$p_a q_a + S = p_x q_x + p_m q_m \quad 2$$

Where p_a, p_m and p_x are the farm-gate prices for agricultural commodity, manufactured commodity and variable production inputs, respectively, q_a, q_m and q_l are the respective quantities and S represents exogenous income transfers. The production technology is expressed as:

$$q_a = q(q_x, q_l, z^q) \quad 3$$

Where z^q are farm household characteristics that influence production. The equilibrium condition implies that the time a household allocates to own production is the difference between total time endowment and leisure. Thus:

$$c_l = T - q_l \quad 4$$

Where T is the total time endowment for the household. Likewise quantity consumed of the agricultural commodity should be equal to the quantity produced plus purchases (including carryover stocks), q_p minus sales, q_s.

$$c_a = q_a - q_s + q_p \quad 5$$

Combining the utility maximization equation (1) and the constraints (2-5) yields the following Lagrangean function:

$$Max\ U = \left[U + \lambda\left(p_a q_a + S - p_m q_m - p_x q_x\right) + \phi q_a + \mu_a(v) + \mu_T(T - q_l - c_l)\right] \quad 6$$

Where $v = q_a - q_s + q_p$

The first order conditions from the Lagrangean equation (6), include, but not limited to:

$$\frac{\partial U}{\partial \phi} = q_a = 0 \text{ (technology constraint)} \quad 7$$

$$\frac{\partial U}{\partial \lambda} = p_a q_a + S = p_m q_m + p_x q_x \text{ (cash income constraint)} \quad 8$$

$$\frac{\partial U}{\partial \mu_a} = v = c_a = q_a - q_s + q_p \text{ (equilibrium condition for food)} \quad 9$$

$$\frac{\partial U}{\partial \mu_l} = c_l = T - q_l \text{ (equilibrium condition for labour)} \quad 10$$

The first order condition (7) implies that the attainment of the household utility depends very much on the production function because c_a is one of the arguments in the utility function, but also that farmers mainly finance the purchase of manufactured goods c_m and external inputs q_x through the sale of agricultural commodities as shown in the cash income constraint (2). As such the choice of the soil fertility management option that maximizes production and net income becomes critical in the intertemporal utility maximization decision. The theoretical framework implies that the decision to chose a given soil fertility management option will not only depend on the marginal benefit and marginal cost criterion, but will also depend on the household's ability to satisfy its own consumption, given the soil fertility management option. Thus:

$$q_a = q(p_a, p_x, q_x, p_m, z^q, z^{hh}, T, S) \quad 11$$

When farmers make joint production and consumption decisions, production is influenced by factors specified in equation 11. This forms the basis for the specification of the empirical model of soil fertility management choice.

A lot of empirical models have been specified to explain farmers' technology choice decisions. However, as Morris and Adelman (1998) argue, there is no single theory of causation that can fully embrace the different facets of farmers' decision-making process. Tolman (1967) defines adoption as a function of socio-economic and environmental factors and that it is endogenous to the interaction of these factors. Düvel (1994) and Adesina et al. (1995), among others, argue that adoption is governed by a set of intervening variables, which include individual and technology attributes and the way these attributes interact within a given socio-economic environment. Following Feder, Just and Zilberman (1985), Rogers (1995) and Thangata et al. (2003), we define adoption as a decision to make use of an innovation as an optimal course of action in the long-run equilibrium after the decision maker is fully aware of the technology and its attributes.

The most commonly used analytical models in adoption studies are based on the attribute theory of Lancaster (1966; 1971) and Gorman (1980), which are an extension of the earlier theoretical work on discrete choice by Quandt and Baumol (1966). These models analyze the rational decision making process in choosing among alternatives characterized by attributes that may be unobserved by the analyst but are assumed to be observed and acted upon by the decision-makers. Examples of the most commonly used rational choice models include but not limited to; Linear Probability models (LPM), Probit and Logit Models (Maddala, 1988; Baidu-Forson, 1999). However**,** Gujarati (1988) reported that the Linear Probability Models are not an attractive modeling option because they tend to be affected by a number of problems including heteroscedasticity, generally lower R^2 values, and possibility of the predicted value lying outside the 0-1 (the expected range of a probability).

The discrete decision of whether to use inorganic fertilizers and how much to apply is estimated using two models: a censored Tobit model (Just and Zilberman 1984; Freeman and Omiti 2003) and a Double-Hurdle model (Cragg 1971). The observed data on farmers' use of inorganic fertilizers contain a cluster of zeros and some very low application rates.[5] Thus inorganic fertilizer use data is censored from the lower tail by specifying the level of intensity below which a farmer is not regarded as having adopted, in order to control for the smallholder farmers that have been benefiting from the Targeted Inputs Programme (TIP) for the past six seasons. Thus the Tobit model assumes a latent variable x_i^* that is generated by the following function:

$$x_i^* = \beta_x' z_i + \varepsilon_{xi} \qquad 12$$

Where x_i^* is the latent variable that truncates the inorganic fertilizer use, z_i is a vector of farmer household characteristics and inorganic fertilizer attributes perceived by the farmer, β_{xi} is a vector of coefficients and ε_{xi} is a vector of error terms, assumed to be independently and normally distributed with mean zero and constant variance σ^2. Given this function, the specification of the farmers' inorganic fertilizer adoption will be expressed as:

$$x_i = x_i^* \text{ if } x_i^* \geq d \text{ and}$$
$$x_i = 0 \text{ if } x_i^* < d \qquad 13$$

Where d is an established threshold that distinguishes inorganic fertilizers adopters to non-adopters. The probability function for the non-adopters is:

$$p(x_i^* < d) = \Phi\left(\frac{\beta_x' z_i}{\sigma}\right) \qquad 14$$

and the density for the adopters is given as:

$$f(x_i \mid x_i^* \geq d) = \frac{f(x_i)}{p(x_i^* \geq d)} = \frac{\frac{1}{\sigma}\Theta\left(\frac{x_i^* - \beta_{x_i^*}' z_i}{\sigma}\right)}{\Phi\left(\frac{\beta_{x_i^*}' z_i}{\sigma}\right)} \qquad 15$$

Where $\Phi(.)$ and $\Theta(.)$ are the standard normal cumulative and probability density functions (cdf and pdf), respectively. The density function represents the truncated regression model for those farmers whose observed inorganic fertilizer intensity is greater than the threshold i.e. the adopters.

The log-likelihood function for the Tobit model is given as a summation of the probability functions for both adopters and non-adopters.

$$\ln L = \sum_{x_i^* < d} \ln\left(1 - \Phi\left(\frac{\beta_{x_i^*}' z_i}{\sigma}\right)\right) + \sum_{x_i^* \geq d} \ln \frac{1}{\sigma}\Theta\left(\frac{x_i^* - \beta_{x_i^*}' z_i}{\sigma}\right) \qquad 16$$

The issue of whether or not to estimate a joint Tobit model in adoption studies arises when one assumes that the z_i that affect a farmers' decision to chose to apply inorganic fertilizers also increase the mean amount to be applied (e.g. Lin and Schmidt 1984; Kachova and Miranda 2004). In the case of smallholder agriculture, the decision to apply fertilizer is likely to be influenced by some threshold effects, such as cash constraints and other resource endowments, thus, we hypothesize that the decision process is rather comprised of two stages. Other researchers have relaxed the assumption inherent in the joint Tobit model

[5] This was observed to be the case mostly because of the Targeted Inputs Programme that distributed small packs of inorganic fertilizer and seed to farmers.

by specifying a Double-Hurdle model in which the adoption and determination of the level of intensity of application are seen as a two-step procedure (see for example Cragg 1971). In this specification, the decision model treats adoption separately from the level of intensity, and implies the estimation of separate equations in 17 and testing if there is any significant difference in the likelihood ratios. Cragg (1971) observed that in cases where adoption decisions are influenced by threshold effects, the decision to adopt might in fact precede that on intensity of adoption. To test this assumption we chose to compare the results of the two models.

Based on the specification by Cragg (1971) and Moffat (2003), the Double-Hurdle model essentially contains two equations:

$$y_i^* = \begin{Bmatrix} 1 \text{ if } x_i^* \geq d \\ 0 \text{ if } x_i^* < d \end{Bmatrix} = z_i\beta^* + \varepsilon_i \text{ and } y_i^{**} = z_i\beta^{**} + u_i$$

$$\textit{where} \quad \begin{pmatrix} \varepsilon_i \\ u_i \end{pmatrix} \sim N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & 0 \\ 0 & \sigma^2 \end{pmatrix}\right] \qquad 17$$

Where y_i^* is a dependent dichotomous choice variable, taking on value of 1 if the rate of inorganic fertilizer x_i^* is equal or greater than the threshold rate, d or 0 if it is less than the threshold rate. y_i^{**} is dependent variable for the intensity equation conditional on $y_i = 1$. β^* and β^{**} are the parameters for the first and second hurdles, respectively. The estimated form for both stages and the expected parameter signs is specified as:

$$\begin{aligned} y_i = \beta_o &+ \beta_1 SEX + \beta_2 AGE + \beta_3 EDUC - \beta_4 DEPRATIO \\ &+ \beta_5 LHSCAP - \beta_6 PLM + \beta_7 PHYV + \beta_8 BTOB \\ &+ \beta_9 YMIN + \beta_{10} LSU + \beta_{11} MXCESS + \beta_{12} CREDIT \\ &+ \beta_{13} EXT + \beta_{14} FSI - \beta_{15} INPCOST - \beta_{16} LNLB + \varepsilon_i \end{aligned} \qquad 18$$

Where β's are the parameters to be estimated, *SEX, AGE, EDUC* are respectively, the sex, age and educational level of the household head, *DEPRATIO* is the dependency ratio within the household, *LHSCAP* is the per capita land holding size, *PLM, PHYV* and *PTOB* are respectively, the proportion of land allocated to local maize, hybrid maize and tobacco, *YMIN* is the minimum income requirement for basic livelihood, *LSU* is the livestock units, *MXCESS* is dummy variable measuring the household's access to an output and input market, *CREDIT* is a variable which indicates the amount of agricultural credit the household obtained within the season, *EXT* is the frequency of extension contact, *FSI* is the food security index, *INPCOST* is the proportionate cost of soil fertility management in total household expenditure, *LNLB* is the land to labour ratio and ε_i is a normally distributed error term. Measurement units for these variables are provided in Table 1.

4. Data

The study is based on data collected from a household and plot level data conducted in three agro-ecological zones in Malawi from May to December 2003. The data was collected using a structured questionnaire administered to a random sample of about 390 households.

The characteristics of the variables across all farmer groups differentiated by the choice of the soil fertility management option are presented in Table 1. The socio-economic characteristics include the human capital aspects such as age, sex and educational level of the household head, the dependency ratio within the household as well as the household's wealth status indicators such as the food security index, the minimum subsistence requirement and the asset endowment (proxied by amount of livestock units and land: labour ratio)[6]. The land: labour ratio is particularly important because of the need to test the assumption that as land pressure increases, farmers are likely to intensify their soil management efforts so as to improve productivity.

Table 1: Explanatory variables in the model

Variable	Acronym	Summary statistics		
		Inorganic fertilizer only	Integrated Organic	Total
Total count (%) N=376		42.9	57.1	100.0
Sex (dummy 0,1)	SEX			
Male		27.2	38.0	65.2
Female		15.7	19.1	34.8
Age (years)	AGE	43.4 (15.6)	43.8(15.6)	43.6(15.7)
Education (years)	EDUC	5.2(1.0)	3.1(1.1)	4.1(1.0)*
Dependency ratio (%)	DEPRATIO	63.1(15.4)	59.7(17.6)	61.2(16.8)*
Land holding size (ha/capita)	LHSCAP	0.30(0.3)	0.29(0.26)	0.299(0.26)*
% local maize area	PLM	18.5(16.6)	30.5(13.1)	25.3(14.0)***
% hybrid maize area	PHYV	23.3(22.2)	9.2(2.7)	16.9(12.0)*
% burley tobacco area	PTOB	16.3(14.0)	4.4(11.9)	10.2(12.9)
Minimum Income (MK/year)	YMIN	13319.84(6628.97)	12052.45(6430.57)	12598.78(6541.32)
Livestock units (LSU)	LSU	0.56(0.08)	0.16(0.04)	0.33(0.06)***
Market access (km)	MXCESS	4.50(1.0)	4.86(0.6)	4.70(0.8)*
Credit access (MK/year)	CREDIT	1733.94(3681.67)	874.80(3793.08)	1214.08(3742.87)
Extension access (No. of visits per month)	EXT	0.61(0.9)	0.43(0.8)	0.51(0.9)*
Food security Index (%)	FSI	68.2(27.3)	33.4(26.1)	48.4(31.7)***
Input investment cost (%)	INPINV	36.1(35.4)	44.2(47.6)	39.3(38.2)*
Soil fertility indices				
% Nitrogen	TOTALN	0.12(0.08)	0.09(0.07)	0.11(0.07)**
% soil organic matter	ORGANM	1.04(0.4)	1.08(0.5)	1.06(0.5)
P^H	SFI_3	5.82(0.75)	6.34(0.73)	6.11(0.79)***
Bulk density (g cm^{-3})	SFI_4	1.65(0.3)	1.62(0.3)	1.64(0.3)
Land: Labour ratio	LNLB	0.0196(0.027)	0.020(0.016)	0.020(0.022)

Figures in parenthesis are standard deviations. *Sig. at 10%; ** sig. at 5%; *** sig. at 1%.

We also include variables that define the cropping pattern of the households such as the proportion of total land allocated to main smallholder crops: local maize, hybrid maize and burley tobacco as well as access to

[6] The food security index is calculated as the percentage of total Calorific requirements satisfied from its own production, or using income generated from own production.
The minimum subsistence requirement is derived as the minimum calories per capita per year multiplied by the number of consumption units within the household.
A livestock unit for tropical species is equivalent to 250 kg live-weight (De Leeuw and Tothill 1990). Input investment cost is calculated as the proportion of total input cost in total farm income.

credit and extension. Attributes of the soil fertility option include the input cost as a proportion of the net farm income as well as the soil fertility indices (defined by the percentage of N and percentage of soil organic matter).

We expect all resource endowment and wealth proxy variables to be positively related to the likelihood and level of fertilizer uptake because wealthier farmers are capable of taking risks since they are more likely to have additional resources to fall back on (see Feder et al. 1985; Clay et al. 1998; Freeman and Omiti 2003). Similarly, farmer education level and frequency of extension contact are likely to positively influence farmers' demand for inorganic fertilizers because exposure to technical information may make farmers more adept to acquire, interpret and use technical advice. Access to credit is also expected to increase the likelihood as well as the intensity of applying inorganic fertilizers because it relaxes the liquidity constraint.

The cropping pattern is also likely to influence uptake of soil fertility management options. In most cases experience has shown that farmers that decide to grow input intensive crops such as hybrid maize and burley tobacco are more likely to apply inorganic fertilizer and at relatively higher rates than those that do not grow these crops.

Food security index is included on the premise that a higher food security index implies that the household is more self-sufficient in food and such households are likely to be better off smallholders that are likely to apply higher levels of inorganic fertilizer. Otherwise, households with lower food security index are for most part of the year pre-occupied with survival or coping mechanisms and have less time to manage their own farms. We also anticipate an inverse relationship between share of subsistence income in total income and input use.

The technology attributes are meant to assess whether farmers' perception of the profitability of the soil fertility options as well as the fertility of their plots do influence their choice of an option and the level of intensity once the choice has been made. The profitability variable is expected to be positively related to input use while the effect of the soil fertility indices depends on their impact on yield.
Because of the impact of transactions costs on the input budget, we expect farmers who are close to input and output market to be more likely to adopt and use higher levels of inorganic fertilizers compared to those in remote areas.

5. Results and Discussions

The results for both the joint Tobit and Double-Hurdle model are presented in Table 2. Comparison of these results confirms our hypothesis that factors affecting the decision to adopt inorganic fertilizer might not necessarily influence (by same magnitude and direction) the intensity of inorganic fertilizer application.

In the joint Tobit model, the Log Likelihood ratio, given by the Chi-square statistic test is highly significant at 1% level indicating that the chosen independent variables fit the data reasonably well. The R-squared value is also acceptable given the cross-section data we used for the analysis. In the diagnosis, we noted some moderate level of skewness, especially given the censoring of the dependent variable. Thus we chose to use the Box-Cox transformation in order to avoid violating the normality assumption (Moffat 2003).

The results from the joint Tobit model indicate that level of education, farmers' age, per capita land holding size, the percentage of land allocated to hybrid maize and burley tobacco, market access, number of extension visits, credit access, food security index have a positive and significant influence on farmers' level of intensity of inorganic fertilizer. Other variables that are positively related to intensity of use of inorganic fertilizer, but are not significant are the asset status (proxied by livestock units LSU); the degree of land pressure (proxied by the land to labour ratio); the soil fertility indices (plot level % soil organic matter and total nitrogen) and the location specific dummies. As expected, the proportion of input cost in total household expenditure is negative and significantly related to intensity of input use.

Most of the results confirm our a priori expectations and are consistent with other research findings. For example, it is plausible that educated or experienced farmers are more likely to opt for inorganic fertilizers because as other research findings have reported, education increases farmers' productivity by improving the level of understanding which makes them able to effectively process technical information relatively faster than uneducated farmers. In the absence of higher education, it is experience that makes a difference (Kabede et al. 1990; Freeman and Omiti 2003; Jagger and Pender 2003; Adesina 1996; Adesina and Zinnah 1993 and Adesina et al. 2000). Per capita land holding size is also an important variable that explains farmers' ability to apply inorganic fertilizers because this enables the household to diversify its cropping patterns into cash crops such as burley tobacco. This is supported in this study by the positive and significant effect of the proportion of land under hybrid maize and burley tobacco. However, when land is considered relative to the available labour, we see that land pressure is also positively (although not significant) related to intensity of inorganic fertilizer. This confirms that smallholder households facing land pressure are more likely to adopt improved soil fertility management technologies as a means to intensify productivity to meet their consumption needs (Adesina 1996). Improvements in market access and provision of seasonal agricultural credit are more likely to increase farmers' intensity of applying inorganic fertilizers because they all reduce the relative cost of fertilizers, the former through the reduction in transactions costs which invariably reduce the retail price of fertilizers and the later through its effect of reducing the farmers' liquidity constraints (Mwangi 1997). In this analysis, we controlled for the input cost as a proportion of farmers' total expenditure, and this variable comes out highly significant as a disincentive for farmers to increase the level of inorganic fertilizers. The other variable that influences inorganic fertilizer intensity is the food security index. Farmers' that are food insecure are less likely to apply higher levels of inorganic fertilizers. This is the key variable that perpetrates the food insecurity trap because without any external intervention, a chronically food insecure household is less likely to break out of the trap.

The results from the Double-Hurdle regression on the decision to adopt inorganic fertilizer indicate that education, land holding, cropping patterns, credit, land pressure and food security significantly explain the variation in the decision to invest in soil fertility management through inorganic fertilizer application. Unlike in the joint Tobit model, land to labour ratio is highly positive and significantly related to inorganic fertilizer uptake, confirming the hypothesis that as land pressure increases, farmers resort to more productive ways of intensification. Market access and food security are also significantly related to the decision to apply inorganic fertilizer. Although the extension variable is positive, it is not significant. The finding that extension is not significant in explaining inorganic fertilizer adoption may suggest that extension in itself does not increase farmers' chances of adopting inorganic fertilizer. This may not at all be surprising because in the case of Malawi, since the demise of the Smallholder Agricultural Credit Administration (SACA) in the early 1990s, the provision of public extension service has been completely de-linked from credit services. Also, there is research evidence of mixed performance of public extension systems in disseminating technical information, especially due to budget cuts towards the provision of public extension services (Barrett et al. 2002). We also note that the first hurdle is negatively affected by the input cost, implying that most farmers are not able to afford inorganic fertilizer largely due to the cost element. The significance of credit supports conventional wisdom that, other factors being equal, it is the cash constraint that would compromise farmers' ability to finance the purchase of fertilizers and this has justified the provision of seasonal agricultural credit. In terms of the area-specific dummies, the results indicate that smallholder farmers in Mzuzu agro-ecological zone are more likely to apply inorganic fertilizers than those of Lilongwe. Among other reasons, Mzuzu is located in the northern region where average poverty levels are lower than those of other regions (Government of Malawi 2000).

In the case of the intensity equation, we note that sex, age and education are just as important in explaining the intensity, conditional on adoption of inorganic fertilizer, as other variables such market access, extension, food security and land pressure. Thus male and experienced farmers are more likely to apply higher quantities of inorganic fertilizer. However, in this case, the land pressure variable becomes negative, implying that as land increases relative to labour, farmers are unable to apply higher amounts of organic fertilizer. With limited opportunities to hire in labour, large farms are just as unproductive as smaller farms, thus not being able to afford inorganic fertilizer. As such, while per capita land holding size is important in explaining adoption, it does not significantly influence the intensity decision once the adoption decision has been made. Experience has shown that increased pressure on agricultural land drives away excess labour to off-farm activities, and the revenue generated from off-farm activities is seldom used to finance the purchase of inputs. The other issue we note from the intensity equation is that inorganic fertilizer intensity is likely to be higher on land with higher soil fertility index. This is because of high response rates that enable farmers to afford inorganic fertilizers.

Table 2: Maximum likelihood estimates for the joint Tobit and Hurdle models

Variable	Joint Tobit estimates		Double-Hurdle estimates	
	Coefficient (std. errors)	Marginal effects	Selection equation	Intensity equation
			Coeff. (Std. error)	Coeff. (std.error)
Age	0.24 (0.2)	0.15	1.55(2.57)	0.12(0.04)**
Sex	5.16(4.7)	6.86	0.12(0.08)	2.50(0.15)***
Education	12.12(2.5)***	12.20	29.5(9.4)**	5.15(0.42)***
Land holding size	6.43(9.83)	12.40	3.62(0.73)***	0.50(2.43)
% local maize area	-0.17(0.09)*	-0.20	-3.44(4.75)	-0.06(0.03)*
% hybrid maize area	0.009(0.1)	0.04	0.23(0.70)	0.02(0.017)
% tobacco area	0.12(0.14)	0.03	0.69(0.64)	0.01(0.06)
Livestock units	2.61(2.52)	2.44	2.81(14.68)	0.44(0.43)
Market access	5.61(5.76)	4.90	1.96(0.56)***	4.41(2.56)**
Credit access	0.94(1.1)	1.05	0.27(0.15)**	0.40(0.23)*
Extension access	6.81(3.90)*	0.02	7.47(16.36)	3.49(1.17)**
Food security index	0.43(0.08)***	0.39	10.20(8.71)***	0.12(0.02)***
Input cost	-2.08(0.44)***	-1.83	-1.63(0.37)***	-0.21(0.12)**
Land: labour ratio	0.06(0.11)	0.08	16.89(3.49)***	-0.03(0.02)*
Total nitrogen	49.06(29.6)*	0.04	8.11(18.33)	-0.15(7.20)
Soil organic matter	-17.76(5.8)**	-0.03	8.08(2.72)**	4.04(0.58)***
Mzuzu ADD	8.30(5.9)	10.86	5.58(3.09)*	2.02(1.86)
Lilongwe ADD	2.91(5.7)	3.14	0.44(2.93)	0.19(1.47)
Constant	-82.1(17.3)***	-78.5	-24.1(3.75)***	-13.84 (4.11)**
No. of obs.	161		376	161
Chi-square	185.9***			1761.2***
LL_function	-574.8			-916.1
Pseudo R^2	0.14			0.31
Sigma***				11.39
Lambda				0.80

Note: *** (P<0.000); ** (P<0.05); * (P<0.10)

6. Conclusions and Policy Implications

These results indicate the relative importance of each of the variables discussed in the adoption and intensity analysis and may specifically point to areas or strategies that may have to be considered in order to improve farmers' ability to adopt, and increase intensity of use of inorganic fertilizers. For example, the major hurdles in terms of probability of adoption and intensity of application are capacity to afford and access inputs as well as the perceived incentives. The results indicate an inverse relationship between the input output ratio (Input cost variable) and both the probability and intensity of fertilizer application. Controlling for other factors, market access is positively related to choice and intensity. The other capacity variable that is positively related to the first hurdle is the land:labour ratio. Food secure households are three times more likely to adopt and apply higher levels of inorganic fertilizers than food insecure households.

Our results indicate that although in general there is a positive correlation between probability of adoption and intensity of fertilizer application, we note some differences with regard to the factors that influence the two decisions. We note that while resource endowment in land, relative cost and access are important factors that allow farmers to be able to surmount the first hurdle, socio-economic variables such age and sex of the household head also influence the intensity of application.

These results have a number of implications in terms of sustaining smallholder agriculture, which is critical in arresting food insecurity and poverty. First, since the choice of the soil fertility management option is highly dependent on the capacity of the farmer to afford such investment, there is need for a more pro-poor focused approach to achieve sustainable soil fertility management among smallholder farmers. Agricultural policy can be made more pro-poor if it focuses on programmes that would promote the private incentives of sustainable soil fertility management options. For instance, increased budgetary support to agricultural research and development, extension, seasonal agricultural credit and promotion of access to viable soil fertility technologies in the rural areas would help reduce the opportunity costs that farmers perceive when making decisions on appropriate soil fertility management options. Secondly, given that factors that affect adoption are not necessarily the same as those that influence intensity, it is important to consider both stages in evaluating strategies aimed at promoting sustainable soil fertility management in the smallholder sub-sector.

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