Research Article

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Mineral fertilizer use in land-scarce conditions: Case of Rwanda

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Abstract: This study was undertaken to investigate the use of mineral fertilizer by smallholder farmers in order to understand the set of factors influencing the decisions of smallholder farmers to use fertilizers in land-scarce conditions. Using descriptive analysis and the Cragg's double-hurdle model, the study identified and analyzed factors that determine smallholder farmer adoption of mineral fertilizers and those that affect the intensity of household mineral fertilizer use. From factors that only influence the decision of smallholder farmers to use mineral fertilizers, distance to fertilizer market and livestock affects it negatively; while farmer association membership, landholding per capita, access to extension services and the size of household affect it positively. The variable "domestic assets" which is a proxy variable for smallholder farmers' wealth affects only the intensity of use of mineral fertilizers. Literacy of head of household, share of potatoes sold and extension services have an effect on the probability of adoption and intensity of mineral fertilizer use. Improving smallholder farmers' access to information (extension services and education) and increasing mineral fertilizer profitability through improving agricultural commodity markets are essential for raising both the adoption of mineral fertilizers and the extent of mineral fertilizer use among smallholder farmers in Rwanda.

Keywords: mineral fertilizer, technology adoption, intensity of adoption, double-hurdle model, Rwanda

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1 Introduction

Improving the management of soil fertility among smallholder farmers is part of important solutions of addressing food insecurity and rural poverty in the context of high population pressure and limited possibility of putting new land under cultivation. Paradoxically, the use of improved technical inputs such as mineral fertilizers and pesticides is in general low in sub-Saharan Africa (Adesina and Djato 1996; Nkamleu and Adesina 2000). On average, the rate of mineral fertilizer use is estimated at between 8 and 12 kg ha^{-1} in sub-Saharan Africa compared to over 83 kg ha^{-1} for all developing countries (Mwangi 1997); things are worse in Rwanda where the fertilizer use intensity was estimated at 5 kg/ha early this decade (Kelly et al. 2001a). However, blanket recommendations in fertilizer cannot address the soil heterogeneity in most rural settings and some farmers in developing countries overapply nitrogen, considering their degraded soil quality (Sheahan et al. 2013)

The government of Rwanda through its successive agricultural policies and strategic plans has been encouraging farmers to increase land and labor productivity through the use of improved technical inputs, thereby producing enough surpluses that can be sold to sustain the use of inputs and improve farm incomes. The Rwandan government has two major objectives with respect to fertilizer policy: (i) increase the number of users of fertilizers and (ii) increase the quantity of fertilizer applied by users.

Several empirical models have been specified to explain farmers' technology choice decisions. Studies on fertilizer demand have used various methods, each one with its strengths and weaknesses. Some of the most commonly used of these are probit (Negatu and Parikh 1999; Kaliba et al. 2000), logit (Sain and Martinez 1999; Chianu and Tsujii 2004; Chianu et al. 2007), tobit (Adesina and Zinnah 1993; Adesina and Baidu-Forson 1995; Nkonya et al. 1997) and Heckman two-step model (Heckman 1976; Heckman 1979; Demeke et al. 1998; Minot et al. 2000; Nkonya and Featherstone 2001). Another approach that is found in literature on agricultural input adoption is the

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Cragg's double-hurdle approach (Cragg 1971), which as the Heckman two-step model generates one set of coefficients predicting the probability that a smallholder farmer will use the input and another set of coefficients predicting the volume of input used, provided it uses some (Ricker-Gilbert et al. 2011; Akpan et al. 2012; Martey et al. 2014; Yu and Nin-Pratt 2014).

Negatu and Parikh (1999) in their research on randomly selected Ethiopian farmers for the adoption of improved crop variety found that the size of farm was part of significant variables that determine adoption. Kaliba et al. (2000) in their study examined variables affecting the use of improved maize seeds and the use of inorganic fertilizer in the intermediate and lowland zones of Tanzania and found that a variety of characteristics significantly and positively affected the use of inorganic fertilizers. Nkonya et al. (1997) analyzed the factors affecting the use of improved maize seed and fertilizers in northern Tanzania and found that farm size positively affect adoption and that farmers adopt improved seeds before adopting fertilizer. Freeman and Omiti (2003) using data from small farmers in semi-arid regions of Kenya found a positive and significant effect of household head's literacy on the adoption of mineral fertilizers. Olawale et al. (2009) with data from Northern Nigeria, and Minot et al. (2000) from Benin and Malawi observed a positive effect of the size of household on the use of mineral fertilizers. Mugwe et al. (2008) and Chianu and Tsujii (2004) found that the household head's age negatively influenced the uptake of integrated soil fertility management in Kenya and mineral fertilizer use in Nigeria.

Previous studies conducted in Rwanda to investigate the issues of land productivity including determinants of input use (Clay et al. 1995; Byiringiro and Reardon 1996; Kelly et al. 2001b; Clay et al. 2002) found that the use of improved inputs – organic matter (manure, mulch, etc.) – and purchased inputs (fertilizers and lime) increases with less slopes, owner-operated land, more stable prices, small farms, more nonfarm income, the presence of more livestock and extension. However, none of these studies had a specific focus on mineral fertilizer, especially for smallholder farmers.

This study intended to complement the mentioned previous studies by investigating the mineral fertilizer use by smallholder farmers operating in land-scarce conditions, hoping to provide more in-depth information that would guide the government in the process of improving policy design to meet the earlier mentioned fertilizer policy objectives. Fertilizer use decisions are indeed made by smallholder farmers and that is why it is really important to understand the set of factors influencing smallholder farmers' fertilizer use decisions. This study has used descriptive analysis and the double-hurdle model (DHM) to identify and analyze the factors that determine smallholder farmers' adoption of mineral fertilizers and those that affect their mineral fertilizer use intensity.

2 Methodology

2.1 Study area

This study covers three agroecological zones, namely, the Birunga zone, the Buberuka highlands zone and the Congo–Nile divide zone (Figure 1). All the three zones are part of the highlands of Rwanda but exhibit marked differences in soil types.

Birunga agricultural zone is made of the volcanic soils that go from an altitude of 2,500 to 1,600 m. With a rainfall that varies from 1,300 and 1,600 mm and fertile soils, it creates conditions that are favorable for agricultural production. The previous limitations that were due to limited soil depth have been addressed by growing crops on small ridges formed during soil preparation.

The Buberuka highlands are located in northern Rwanda and include high-altitude plateaus from 1,900 to 2,300 m above sea level. This region is characterized by a rainfall of about 1,200 mm annually and a two-month dry season. The Buberuka highlands even though characterized by acidic soils as the Congo–Nile divide region, they are more fertile and have more options for agricultural production.

Congo–Nile divide has newly reclaimed lands from Gishwati forest characterized by a small portion of volcanic soils and the rest being acidic soils as previously mentioned. It is characterized by a lower altitude of 1,900 m which corresponds to a level above the sea that does not accommodate most crops of the tropical lowlands and has tops of mountain chain that go beyond an altitude of 2,500 m. In general the annual rainfall varies between 1,300 and 1,500 mm and between 1,400 and 1,800 mm, respectively, in the Northern and the Southern parts of the zone. However, in the Nyungwe forest, the annual rainfall goes beyond 2,000 mm.

2.2 Analytical framework

In general smallholders use mineral fertilizers when the net benefit or perceived utility from applying these inputs

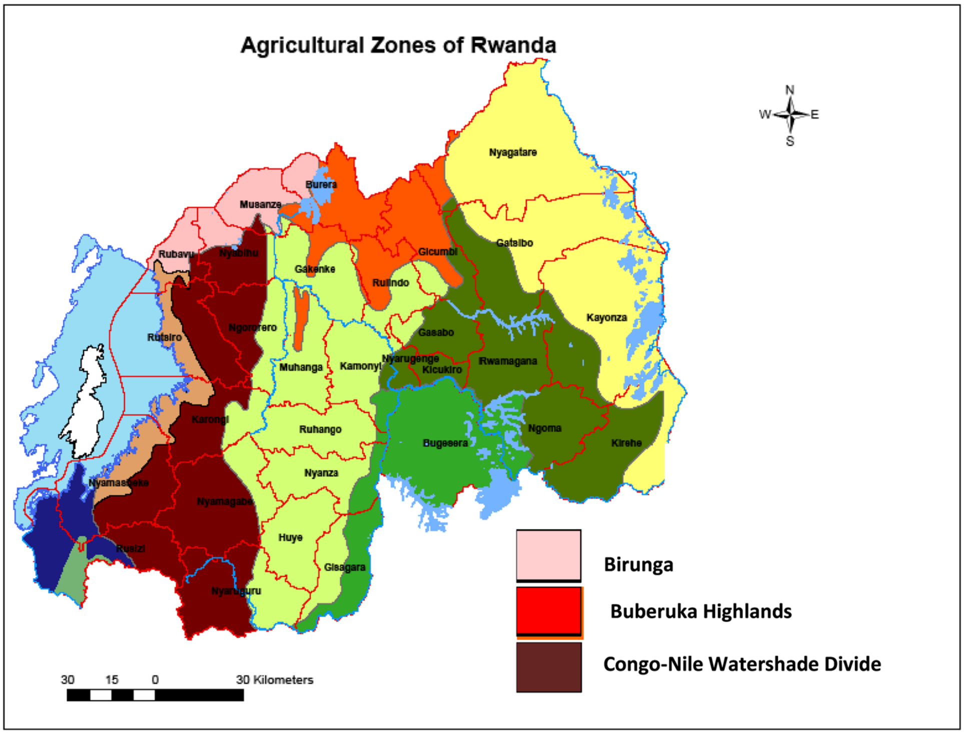

Figure 1: Map of Rwanda with the study areas.

is significantly higher than is the alternative of not using them. Farmers' utility from using technical inputs is not directly observed but the choices they make are reflected by their actions. Following Green (2000) and Pryanishnikov and Katarina (2003), the linear random utility model could be specified as:

$$U_n = \beta_n Z_m + u_n \text{ and } U_l = \beta_l Z_m + u_l \tag{1}$$

U_n and U_l are here perceived utilities of using mineral fertilizers and not using them, respectively, Z_m is the vector of explanatory variables that influence the perceived utility from using or not using mineral fertilizer, β_n and β_l are parameters to be estimated, and u_n and u_l are disturbance terms assumed to be independently and identically distributed (Green 2000). If a smallholder farmer decides to use mineral fertilizers (option n), it follows that the perceived utility or benefit from using these is greater than the utility from not using fertilizers (option k) depicted as:

$$U_{mn}(\beta_m Z_m + u_n) > U_{nl}(\beta_l Z_m + u_l), \quad l \neq n \tag{2}$$

The probability that a smallholder farmer will decide to use mineral fertilizers could then be defined as:

$$\begin{aligned} P(W=1|Z) &= P(U_{mn} > U_{nl}) \\ &= P(\beta'_n Z_m + u_n - \beta_l Z_m - u_l > 0|Z) \\ &= P(\beta'_n X_m - \beta_l Z_i + u_m - u_l > 0|Z) \\ &= P(\beta^* X_m + u^* > 0|Z) = F(\beta^* Z_m) \end{aligned} \tag{3}$$

with P being a probability function, U_{mn}, U_{ml} and Z_m are as defined earlier, $u^* = u_n - u_l$ is a random error term, $\beta^* = (\beta_n - \beta_l)$ is a vector of unknown parameters that can be interpreted as a net influence of the vector of independent variables influencing mineral fertilizer use, and $F(\beta^* Z_m)$ is a cumulative distribution function of ε^* evaluated at $\beta^* Z_m$. The exact distribution of F depends on the distribution of the random error term, u^*. Green (2000) considers that depending on the assumed distribution that the random disturbance term follows, several qualitative choice models can be estimated.

2.3 Estimation procedure

It is expected that some smallholder farmers do not use mineral fertilizers, which is an expression of its nonadoption. Gebremedhin and Swinton (2003) argued that the decision to adopt a technology and the decision on the extent of use of that technology are not necessarily made jointly. In fact, the decision on the intensity of use may be taken after the decision to adopt, and the factors affecting the first decision may be different from those affecting the second. Moffatt (2003) showed that both the straightforward binary and the censored data models may not be used in a case where factors affecting each decision are different because such models assume that the process that results in nonadoption of a technology is the same as the one that determines the extent of use of that technology. Previous studies (Ricker-Gilbert et al. 2011; Akpan et al. 2012; Martey et al. 2014; Yu and Nin-Pratt 2014) have revealed that in the case where the abovementioned two decisions are not jointly made, it is preferable to use the DHM, in which a truncated regression on the nonzero observations follows a probit regression on adoption which uses all observations. We opt then to use the double-hurdle approach by which probit regression model quantifies in the first level (first hurdle) the factors influencing smallholder farmers' decisions to adopt fertilizer technology followed (second hurdle) by the truncated regression model that determines the extent of fertilizer use intensity. The maximum-likelihood estimation for the DHM which is based on two equations is then used, one taking into account the access by farmers to fertilizer and the other one considering the level of application when access to fertilizer is granted.

The first decision variable (V) takes the value 1 for farmers who have adopted mineral fertilizers and takes the value 0 for otherwise. The expected utility of adopting mineral fertilizers (V_i^*) is a latent variable (that underlies an individual farmer's access to fertilizer) and is formulated as:

$$V_i^* = x_i\alpha + u_i \tag{4}$$

$$\begin{aligned} V_i &= 1 \text{ if } V_i^* > 0 \\ V_i &= 0 \text{ if } V_i^* \le 0 \end{aligned} \tag{5}$$

As mentioned earlier, not all mineral fertilizer adopters use the same quantity of fertilizer per unit of land. The quantity of fertilizer used is measured in general per hectare. The second decision variable (Y) which represents the intensity of use, that is, the level of application of fertilizer by farmers who have accessed it is then formulated as follows:

$$Y_i^{**} = w_i\beta + \varepsilon_i \tag{6}$$

$$Y_i^{**} = \max(Y_i^{**}, 0) \tag{7}$$

$$Y_i = V_i Y_i^* \tag{8}$$

In equations (4) and (6) "x" and "w" are vectors of explanatory variables, possibly containing common components, including intercepts, α and β are vectors of parameters to be estimated and disturbance terms u_i and ε_i are considered to be normally and independently distributed.

$$\begin{pmatrix} \varepsilon_i \\ u_i \end{pmatrix} \sim N(0,\ \Sigma), \Sigma = \begin{pmatrix} \sigma_{u_i}^2 & 0 \\ 0 & 1 \end{pmatrix}$$

Following the above DHM description, smallholder farmers can be grouped into three categories: (i) Category 1 represents the adopters and includes all farmers who have passed the positive demand threshold ($Y_i^* > 0$) and have access to fertilizer ($D_i^* > 0$), (ii) Group 2 represents farmers who are willing to use input ($Y_i^* > 0$) but fail to access it for different reasons ($D_i^* \le 0$) and (iii) group 3 comprises nonadopters who have decided not to use fertilizers ($Y_i^* < 0$) when accessible or not ($D_i^* > 0$ or $D_i^* \le 0$).

The DHM is thus made of a univariate probit model for the decision to adopt and a truncated regression model for the intensity of use, provided the assumption of independence between the disturbance terms ε_i and u_i holds. The estimates of parameters α and β in equations (4) and (5) were obtained using the stata command "craggit" following Burke (2009) with Stata version 11.

2.4 Variables and hypotheses

Empirical studies identify a wider range of important variables for a household that has decided to use a new technology. The effect of most of these factors is associated with market imperfections frequent in developing countries. Production and consumption decisions of smallholder farmers in these market conditions may not be separable, thereby the inclusion of household characteristics, asset endowments and other variables impacting the profitability of the proposed technology as explanatory variables in the adoption decision model as mandatory (Shiferaw and Holden 1998). The underlying characteristic of these variables is that they are assumed to affect the adoption of the technology. Two broad categories of variables were considered in this study: (i) household-level variables and (ii) access and geographical-level variables.

2.4.1 Household-level variables

2.4.1.1 Human resources

- *Household size*. The adoption of a new technology involves a need for additional labor, labor availability being frequently associated with successful adoption

(Doss and Morris 2001). Furthermore, in the context of imperfect labor and land markets, agricultural households with less land or a larger family-labor endowment per unit of land can be expected to use labor more intensively in agricultural production (Feder 1985; Shiferaw and Holden 1998). Household size is used as a simple measure of labor availability. A large family is usually associated with a higher labor endowment that would allow a household to complete agricultural tasks on time. However, household with large size may be forced to divert part of the labor force to off-farm activities to cope with the consumption pressure. Since the off-farm opportunities are scarce in Rwanda, it may be predicted that a household with a large family will be more likely to adopt mineral fertilizers.

- *Dependency ratio*. The dependency ratio is equal to the number of members of household aged below 15 or above 64 divided by the number of those aged 15–64. A high ratio means household members of working age face a greater burden in supporting those of nonworking age. The variable is then expected to be negatively associated with mineral fertilizer use.
- *Male-headed household*. This variable equals 1 if the household is male-headed, and 0 otherwise. It is assumed to be positively associated with the likelihood of mineral fertilizer adoption. In fact, Doss (1999) found that women farmers were less likely to be using improved agricultural inputs because they frequently lack access to productive inputs, cash income, credit, education, extension and technical information.
- *Literacy of household head*. It takes the value 1 if the household head is literate, and 0 otherwise. Literacy being associated with access to information, it is hypothesized that literate household heads are more likely to be mineral fertilizer users compared to illiterate household heads.
- *Age of household head*. The age of household head is taken as a proxy of years of experience in farming and is expected to be positively associated with mineral fertilizer use.

  Household assets: We consider in this category the size of the total household cropped area and asset ownership of the household (livestock and domestic assets).
- *Landholding size*. Landholding size is expressed in hectares. According to Hicks (1932, 1969) and Ruttan and Hayami (1998), biological and chemical technology corresponds to land-saving techniques. Since fertilizer is considered as a substitute, land households with less land are expected to intensify by using more mineral fertilizers.
- *Livestock*. Livestock was evaluated in monetary value (US dollars). It is assumed that households with more livestock are positively associated with the adoption of mineral fertilizers. In fact, if credit is constrained, which is the case in most of the developing countries, farmers who own more livestock or other physical assets may better able to finance the purchase of inputs.
- *Domestic assets*. Domestic assets include agricultural tools, means of transport and communication, furniture and household appliance and are expressed in monetary value. This variable is considered as a proxy of household wealth and is expected to impact positively both the probability and the intensity of adoption of mineral fertilizer.

  Financial liquidity: Access to credit and a better liquidity position of the farmer (e.g., growing a cash crop), by alleviating the liquidity constraint (cash shortage), allows farmers to have access to technical inputs such as mineral fertilizers, pesticides and improved seeds.
- *Access to credit*. This variable equals 1 if the head of the household has taken out any loan in the last 12 months before the survey. It is hypothesized to be positively associated with the probability and intensity of adoption of mineral fertilizer.
- *Share* (*percentage*) *of Irish potato sold*. It is hypothesized to have a positive impact on household's decision to adopt mineral fertilizers and on the amount of fertilizer used.

2.4.2 Access and geographical-level variables

Access: This category includes the distance to the place from where fertilizers can be purchased, access to the extension services and membership in various organizations.

- *Association membership*. It hypothesized that household membership in a service cooperative positively impacts mineral fertilizer adoption.
- *Extension services*. This variable equals 1 if any member of the household visited an agricultural extension agent/center or if an agricultural extension agent visited the household during the last 12 months. It is hypothesized to affect positively the probability of mineral fertilizer adoption.
- *Distance to fertilizer market*. The distance to fertilizer market expressed in walking time (minutes) is expected

to affect negatively both the adoption and the intensity of mineral fertilizer use.

- *Distance to paved road*. The distance to paved road expressed in walking time (minutes) is expected to negatively affect both the adoption and the intensity of mineral fertilizer use.

  Geographical-related variables: Three agroecological zones are included in the model to account for regional differences arising from location of fertilizer distributors, transportation infrastructure, climate, soil productivity and soil types: Buberuka highlands zone, Birunga zone and Congo–Nile divide zone.
- *Buberuka*: Dummy for the Buberuka highlands agroecological zone. It serves as the reference zone in econometric analysis.
- *Birunga*: Dummy for the Birunga agroecological zone
- *Congo–Nile divide*: Dummy for the Congo–Nile divide agroecological zone

Agroecological conditions do influence soil fertility management practices; these being labor-intensive activities. Barrett et al. (2002) found that, by increasing the marginal return and/or reducing the risks of inputs, a higher agricultural potential zone is expected to be associated with the more labor- and input-intensive practices. It is assumed that the probability and intensity of mineral fertilizer use would be higher in Birunga and Congo–Nile divide zones than in Buberuka zone.

2.5 Data collection

The data used in our study on mineral fertilizer use by smallholder farmers were collected through a household survey questionnaire. The survey covered three agroecological zones, namely, Buberuka highlands zone, Birunga zone and Congo–Nile divide zone. These zones are known to be the major fertilizer consuming regions on food crops in the country, especially Irish potato. In each zone, a 4-stage random sampling procedure was used to select rural households as follows.

1. First stage: from each zone four administrative sectors were randomly selected
2. Second stage: from a sampled sector, one cell (an administrative unit composed by at least three villages) was randomly selected.
3. Third stage: from a sampled cell, one village was randomly selected.
4. Forth stage: 30 households were randomly selected from each village.

Sampling frames were lists of sectors in each zone, lists of cells in each sector, lists of villages in each cell and lists of households in each village. The table of random numbers was used to select 4 sectors, 1 cell, 1 village and 30 households in each agroecological zone, each sector, each cell and each village, respectively. A village has between 150 and 200 households. The head of the village provided the list of his households and he was responsible to inform selected households on the day the survey had to be conducted. The appointment with selected households aimed at ensuring the presence of household head the day of the survey.

The draft of the survey questionnaire was field tested and the phrasing and order of some queries were revised. The survey was then conducted by four trained enumerators under our supervision, i.e., one village per working day. The survey questionnaire covered household socioeconomic characteristics, food production systems with emphasis on fertilizer use, accessibility of input and output markets and services, and risk factors. Survey data were cleaned before descriptive and regression analyses were performed. From the 360 households interviewed, 338 had all the data that were needed and were used in descriptive analysis. However, after a preliminary analysis, 16 of these were dropped out for showing outliers in some variables (land area and value of livestock) and only 322 cases were considered for the regression analysis.

3 Results and discussion

3.1 Descriptive analysis

3.1.1 Agroecological zone level

Results in Table 1 showed the proportion of households using different agricultural inputs in the three abovementioned agroecological zones. Pesticides were the most used technical inputs in these zones while improved seeds were the least used. Even though three agroecological zones are the major mineral fertilizer consuming zones in the country, about 40% of survey households did not use it, implying that a number of factors impeded a generalized use of mineral fertilizers.

The proportion of households using mineral fertilizers varies substantially by zone.

Birunga zone with fertile volcanic soils had the largest proportion of users (91%) while Buberuka zone had the

Table 1: Percentage of households using productivity enhancing technologies in the three major fertilizer consuming agroecological zones in Rwanda

Zone	Frequency of use of technology			
	Organic fertilizers	Mineral fertilizers	Pesticides	Improved seeds
Buberuka (n = 104)	97.1	35.6	80.8	68.3
Birunga (n = 117)	65.5	91.5	95.7	37.6
CN divide (n = 117)	52.1	49.6	89.7	3.4
Average of the three zones	70.6	59.8	89.0	35.2

Source: computed from household fertilizer survey data.

lowest (36%). Curiously, the latter zone had the highest proportion of households using organic fertilizers and improved seeds. A partial explanation for this was that Buberuka zone had soils that are relatively acidic with very low productivity without soil amendment using lime or organic fertilizers. Since the smallholder farmers could not afford the application of lime on their lands, they did their best to get some manure or other sources of organic matter. In fact, mineral fertilizers used in Buberuka on major crop production such as Irish potato, common beans, maize, wheat and vegetables are nitrogen-phosphorus-potassium (NPK), diamonium phosphorus (DAP) and urea. Better crop yield responses to these fertilizers on acidic soil require soil amendment as mentioned. Even though almost all farmers interviewed used organic manure to amend their acidic soil, the quantity used is in general very low compared to the recommended rate (at least 10 tons per hectare). Improved seeds used by households in this zone were mostly from a nearby ISAR (Rwanda agricultural research institute) station and consisted of seeds of wheat, common bean, sorghum and Irish potato.

Results on fertilizer use listed in Table 1 were disaggregated in Table 2 in categories of users (in terms of frequency of use). Households that were considered as mineral fertilizer users in Table 2 were those that fell in the three first categories, that is, households that had always, often or sometimes used mineral fertilizers.

On average 29% of sampled households had always used mineral fertilizers but with very high disparities between zones. In fact, more than half of sampled households in Birunga zone used mineral fertilizers each season and simultaneously in different plots while in Buberuka zone only roughly 5% of survey households could afford to do this. As a corollary, the latter zone had the highest proportion (55%) of households that had never used mineral fertilizers. The low proportion of farmers who use mineral fertilizers all the seasons and high proportion of those who never use it in Buberuka zone reflect the low accessibility of lime and mineral fertilizers by farmers in that zone. It is in fact widely believed that continued cultivation of acid soils degrades soils in humid tropics (von Uexkull 1980), which is the case in Rwanda and in Buberuka zone in particular.

Table 3 gives the average values of quantity of mineral fertilizers used per household in the three zones covered by the study. On average, a household from the three zones used 34 kg of mineral fertilizers per hectare per season, which was quite high compared to the national average (5 kg ha^{-1}) and the estimated average of sub-Saharan Africa (8–12 kg ha^{-1}) but less than half of the average of other developing countries (83 kg ha^{-1}).

Results in Table 3 revealed that Birunga zone was totally different from the other two zones in terms of intensity of mineral fertilizer use by smallholder farmers. The big difference was surely due to a combination of different factors. One of these was the more intensive land use, in particular with Irish potato. This zone, having the best agricultural soils in the country, had the highest population density in the country and one could expect the lowest farm size per household. In fact, the analysis of our survey data showed that on average a household owned 1.28 hectare in Buberuka zone, 0.78 hectare in Birunga zone and 0.83 hectare in Congo–Nile divide zone.

Table 2: Distribution of households using mineral fertilizers by categories of users

Zone	Frequency of using mineral fertilizers				
	Always	Often	Sometimes	Rarely	Never
Buberuka	4.8	6.7	22.1	11.5	54.8
Birunga	58.1	18.8	14.5	5.1	3.4
CN divide	21.4	11.1	17.1	10.3	40.2
Average of three zones	29.0	12.4	18.6	8.9	31.1

Source: computed from household fertilizer survey data.

Table 3: Mean values of quantities (kg per hectare) of mineral fertilizers by categories of users

Zone	Quantities of mineral fertilizers by category of users (kg ha^{-1})					
	Always	Often	Sometimes	Rarely	Never	Total
Buberuka	34.6	16.8	10.5	4.0	0.0	5.6
Birunga	84.7	64.2	46.3	8.9	0.0	69.4
CN divide	48.4	24.3	47.9	9.2	0.0	22.7
Average of three zones	72.4	45.3	33.1	6.8	0.0	33.6

Source: computed from household fertilizer survey data.

3.1.2 Household level

Mean values of variables hypothesized to affect fertilizer adoption were compared for farmers using and not using mineral fertilizers in Table 4. The technique used to measure the statistical significance of the differences between means of the two groups was the *t* test with stata 11. It has been hypothesized that the fertilizer adoption rate is higher for more profitable crops such as Irish potato and where complementary inputs are used. The proportion of households using improved seeds was low compared to those using organic fertilizers and pesticides and equally distributed among fertilizer users and nonusers (Table 4). Pesticides were the only complementary input that was more common to mineral fertilizer users. An interesting observation concerning these complementary practices was that contrary to what was expected, mineral fertilizer nonadopters used more organic fertilizer even though no statistically significant difference between the two groups was found. The implication of this result was that smallholder farmers will not benefit from the yield increasing effect that comes from the synergy in combining mineral and organic fertilizers. This missing link must be considered by all those involved in agricultural development and promotion in the study area.

Statistically significant difference was observed between mineral fertilizer users and nonusers with respect to age. In fact, mineral fertilizer users were on average 4 years younger than nonusers. The results showed that literacy had a positive influence on the uptake of mineral fertilizers. The rate of literacy was 17% higher among fertilizer users than among nonusers. The proportion of female head of household was higher for fertilizer nonusers but the difference between users and nonusers was not statistically significant. This result then rejected the argument that female-headed households lagged behind their male counterparts in terms of improved technology adoption.

Table 4: Mean difference between farmers using and those not using mineral fertilizers

Variables	Users	Non users	Mean difference
Organic fertilizers	0.67	0.75	+0.08
Improved seeds	0.37	0.33	−0.04
Pesticides	0.98	0.76	−0.22***
Share of potatoes sold	0.66	0.51	+0.15**
Age of household head	39	43	+4**
Proportion literate household heads	0.86	0.69	−0.17***
Proportion female household heads	0.16	0.20	0.04
Value of domestic assets (US$)	65.03	52.21	−12.82
Value of livestock (US$)	328.66	390.06	61.4
Land Owned (ha)	0.90	1.03	0.13
Proportion credit access	0.65	0.53	−0.12**
Proportion membership association	0.67	0.61	−0.06
Contact with extension agents	0.26	0.21	−0.05
Distance to paved road (walking time in minutes)	108	151	+43***
Distance to fertilizer source(walking time in minutes)	67	115	+48***

Mean differences marked with an asterisk are significantly different from zero at 95% level (**) and 99% (***).
Source: computed from household fertilizer survey data.

Household assets were represented by the variables value of domestic assets (value of household appliances and furniture), value of livestock and land owned (by households). It was hypothesized that households with more domestic assets and livestock were likely to adopt mineral fertilizers while households with less land would intensify more by using mineral fertilizers. No significant difference was observed between fertilizer users and nonusers for all three variables.

Financial liquidity of a household was proxied by the percentage of marketed cash crop, the access to credit and membership in association/cooperative. Results showed that the share of potatoes sold and credit access were important determinants of fertilizer adoption but were mixed for membership in farmer associations. In fact, the share of potatoes sold was 15% higher among users of mineral fertilizers than among nonusers, and the difference was statistically significant and the proportion of households that have access to credit was higher among fertilizer users than nonusers. It is important to mention that formal credit through banks being weak, all the sources of borrowing money were considered, that is, from relatives, friends, informal savings and credit groups, money lender, government and bank and microfinance institutions.

The distances to fertilizer market and to paved road did affect negatively the use of mineral fertilizer as expected. In fact, compared to mineral fertilizer users, nonusers appeared to be on average 43 and 48 min walking more far from the paved road and fertilizer market, respectively.

3.2 Regression analysis

While in the previous section mineral fertilizer use was analyzed using descriptive statistics, this section presents empirical results of the DHM that determines the probability of adoption as well as intensity of use of mineral fertilizer among smallholders. The dependent variable for the fertilizer access equation was binary, to indicate whether mineral fertilizers were used by a household (adoption of mineral fertilizers), whereas the dependent variable for the truncated regression was the amount of mineral fertilizers used by the household in kilogram per hectare (intensity of use of mineral fertilizers). Summary statistics of variables that were hypothesized to affect the adoption, mineral fertilizer use intensity or both variables are reported in Table 5.

Table 6 presents the results of the DHM for the 2 tiers, the probit and the truncated regression. The likelihood function of the model was statistically significant (Wald $\chi^2 = 98.17$ and p value = 0.0000), and the post estimation calculations showed that the probit portion of the model predicted correctly in 81.68% of the cases, suggesting a good explanatory power. These results were obtained using stata software version 11.

3.2.1 Determinants of decision to adopt mineral fertilizer

As shown in Table 6, of 16 variables included in the adoption equation, 12 were statistically significant (7 variables

Table 5: Summary statistics of variables hypothesized to affect fertilizer use

	n	Mean	Std. dev.	Min	Max
Buberuka AEZ (dummy)	322	0.313	0.464	0	1
Birunga AEZ (dummy)	322	0.357	0.479	0	1
Congo–Nile divide AEZ (dummy)	322	0.329	0.470	0	1
Distance to paved road (walking time in minutes)	322	126.754	86.875	5	540
Distance to fert. market (walking time in minutes)	322	79.748	66.439	2	360
Association membership (dummy)	322	0.649	0.478	0	1
Extension services (dummy)	322	0.242	0.429	0	1
Landholding per capita (hectare)	322	0.218	0.218	0.021	1.516
Value of domestic assets (US$)	322	56.976	74.752	0	617.41
Value of livestock (US$)	322	278.086	409.943	0	2407.41
Share potatoes sold (%)	322	60.51	21.75	0	100
Credit access (dummy)	322	0.602	0.490	0	1
Household size (number)	322	5.671	2.195	0	14
Literate head (dummy)	322	0.804	0.397	0	1
Age head (years)	322	40.304	13.247	20	78
Male-headed household (dummy)	322	0.826	0.380	0	1

Source: computed from household fertilizer survey data.

Table 6: Parameter estimates of double hurdle for mineral fertilizer use by smallholder farmers

	Double-hurdle model		
	Tier1 (probit)		Tier2 (truncated regression)
	Coefficient estimates	Marginal effects (d*y*/d*x*)	Coefficient estimates
Constant	−0.2731 (1.2137)		−416.7497** (165.6)
Birunga	2.0926*** (0.3477)	0.5662*** (0.0622)	360.1414*** (106.4)
Congo–Nile divide	0.9284*** (0.3101)	0.2927*** (0.0854)	283.2013*** (99.15)
Male-headed household	−0.3077 (0.2496)	−0.1025 (0.0780)	−14.3237 (32.90)
Age of household head	−0.1328** (0.0532)	−0.0468** (0.0189)	−2.1057* (1.159)
Age of head squared	0.0012** (0.0005)	0.0004** (0.0002)	
Literate household head	0.7003*** (0.2484)	0.2634*** (0.0954)	75.9081* (45.48)
Household size	0.2171*** (0.0599)	0.0765** (0.0211)	−8.8745 (6.713)
Domestic assets	0.0003 (0.0013)	0.0001 (0.0004)	0.3271** (0.1399)
Livestock	−0.0005** (0.0003)	−0.0002** (0.0001)	−0.0451(0.0336)
Association membership	0.4124** (0.1958)	0.14883** (0.0715)	17.0447(22.03)
Extension services	0.8677*** (0.2762)	0.2631*** (0.0682)	23.3686 (25.71)
Distance to paved road	−0.000539 (0.0016)	−0.0002 (0.0006)	−0.0187 (0.1851)
Distance to fertilizer market	−0.0048*** (0.0016)	−0.0017*** (0.0006)	0.1229 (0.1954)
Share of potato sold	2.1673*** (0.4731)	0.7643*** (0.1711)	203.8461** (80.03)
Dependency ratio	−0.0719 (0.1515)	−0.0254 (0.0534)	
Landholding per capita	1.4552*** (0.5535)	0.5132*** (0.1939)	−93.3903 (60.70)
Number of observations	322	322	322
Log likelihood	−1063.3765		
Wald $\chi^2(16)$	98.17		
Prob > χ^2	0.000		
Akaike criterion (AIC)	2192.753		
Percentagecorrectly predicted	81.68		

Notes: single, double and triple asterisks (*) denote significance at the 10%, 5% and 1% levels, respectively. Standard error is reported in parenthesis.
Source: computed from household fertilizer survey data.

at the 1% probability level and 5 variables at the 5% probability level).

All human capital characteristics but "male-headed households" significantly influenced the likelihood of using mineral fertilizers as hypothesized. Literate household heads and household size had positive impact as expected while the age of the household head as a proxy of experience in farming had unexpected negative impact. The result on household literacy confirmed our *a priori* expectations, and similar results were found by Freeman and Omiti (2003) with data from smallholder farmers in semi-arid areas of Kenya. A positive influence of household size on the adoption of mineral fertilizer was also observed by Olawale et al. (2009) with data from Northern Nigeria, and Minot et al. (2000) from Benin and Malawi. The result on the age of household head was consistent with the recent findings of Mugwe et al. (2008) and Chianu and Tsujii (2004) who also found that the age of the household head negatively influenced, respectively, the adoption of integrated soil fertility management in Kenya and mineral fertilizer in Nigeria. One of the reasons that could explain this situation was that older farmers have a tendency to stick to their usual production techniques while younger ones are associated with higher risk-taking behavior. Results failed to confirm the hypothesis that male-headed households were more likely to adopt mineral fertilizer than female-headed households and thus one can affirm that the factor "gender" did not impact the adoption of mineral fertilizers.

The two dummy variables representing two agroecological zones (Birunga and Congo–Nile divide) affected positively the adoption of mineral fertilizer as expected. The results indicated that, the chances of using mineral fertilizers by a smallholder farmer would be higher by 56.6% and 29.3%, respectively, in Birunga and Congo–Nile zones compared to its counterpart in Buberuka zone. These results confirmed what descriptive analyses revealed earlier and could be explained by the relatively higher agricultural potential in Birunga and Congo–Nile divide zones.

All the accessibility variables but distance to paved road had impact on mineral fertilizer adoption. As expected, the distance to fertilizer markets had negative impact and the access to extension services and being a member of an association had positive impact on household decision to use mineral fertilizers. In fact, the chances of using mineral fertilizers would be higher by 26.3% and 14.9% for households having access to extension services and those who are members of farmer associations, respectively.

3.2.2 Determinants of intensity of use of mineral fertilizer

Five of 12 variables that happened to be statistically significant in explaining the household decision to adopt mineral fertilizers were also important in explaining the intensity of use of mineral fertilizer by farmers (see Table 6). These were the two agroecological zones included in the model, the access to extension services, the share of potatoes sold and the literacy of the household head. The results on the access to extension services and the share of potatoes sold which constitutes a financial liquidity variable were consistent with the findings by Martey et al. (2014) who found that the income of household head and the distance to agricultural office significantly influenced the fertilizer use intensity. Results of this study then suggested that policy whose objective was to raise the level of mineral fertilizer use among smallholder farmers who had adopted it needed to focus on factors that improve the profitability of crops and those that improve smallholder accessibility to information.

One variable with no effect on the household decision to use mineral fertilizers appeared to be part of the determinants of the extent of mineral fertilizers used by adopters, namely, domestic assets which is a proxy for household wealth. Khor and Zeller (2016) using household panel data from the Hebei province of China found that the direction of wealth effect on fertilizer use does change across the different levels of farmers' wealth.

This result suggested then that all things being equal, wealthier smallholder farmers in Rwanda used more fertilizer.

The coefficient of the variable "landholding per capita" had a negative sign as expected but the variable had no significant effect on the intensity of mineral fertilizer. We failed then to confirm the hypothesis that households with less land would intensify by using more mineral fertilizers. Part of the explanation was that household farm land was in general small in Rwanda and households with very small landholdings had no means to buy mineral fertilizer.

4 Conclusion

This study examined the hypothesized determinants of mineral fertilizers demand in Rwanda. The results showed that the use of mineral fertilizers is influenced by variables related to financial liquidity, human resources, access to markets, household assets and extension services.

The regression analysis showed that the set of factors influencing the household decision to adopt mineral fertilizers is not necessarily the same as the those having impact on mineral fertilizer use intensity. In fact, only five of 12 factors that had impact on household decisions to use mineral fertilizers also effected the intensity of mineral fertilizer use. The most important of those factors were literacy of the head of household, share of potatoes sold and extension services. On the other hand, one factor with no effect on the probability of adoption had impact on the intensity of use, that is, domestic asset, the proxy variable of household wealth. Thus, policies aimed at improving smallholder farmers' livelihood are likely to increase the level of fertilizer use.

As far as the above findings are concerned, the strategies to mineral fertilizer use in Rwanda in general and in the study area in particular need to focus on factors that enhance both the probability of its adoption and the intensity of its use. Improving household access to information (extension services and education) and increased mineral fertilizer profitability through improvement in crop output and input markets are essential conditions for raising both the adoption of mineral fertilizers and the extent of mineral fertilizers use among smallholder farmers in Rwanda.

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