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Agricultural Technology Adoption:
A Panel Analysis of Smallholder Farmers' Fertilizer use in Kenya

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Abstract

Africa is the only region where agricultural productivity has continued to decline over the last decades and poverty levels have increased. This has necessitated the need to increase agricultural productivity. One way of increasing agricultural productivity is through introduction and use of improved agricultural technologies. This paper applied a double-hurdle model on a ten-year panel household survey data for 1,275 households to examine determinants of fertilizer adoption and use intensity in Kenya.

Results show that the proportion of households using fertilizer dramatically rose in the last decade while fertilizer application rates increased marginally. Fertilizer use in the drier agro ecological zones is still way below that in the higher agro ecologically potential zones, indicating higher risk involved in and lower profitability of using fertilizer in the drier areas. Econometric estimation results show that age, education, credit, presence of a cash crop, distance to fertilizer market and agro ecological potential are statistically significant in influencing the probability of adopting fertilizer. The strongest determinants of fertilizer use intensity are gender, dependency ratio, credit, presence of cash crop, distance to extension service and agro ecological potential.

The study suggests improving access to agricultural credit by especially low income farmers; concerted efforts to promote fertilizer use among farmers in the drier areas; and government investment in rural infrastructure, efficient port facilities and standards of commerce to reduce the cost of distributing fertilizer, as some of the ways to promote fertilizer use.

1. Introduction

Agriculture continues to be a fundamental instrument for sustainable development, poverty reduction and enhanced food security in developing countries. It is a vital development tool for achieving the Millennium Development Goals (MDG), one of which is to halve by 2015 the share of people suffering from extreme poverty and hunger (World Bank, 2008). In Africa, agriculture is a strong option for spurring growth, overcoming poverty, and enhancing food security. Agricultural productivity growth is also vital for stimulating growth in other sectors of the economy. However, agricultural productivity in Africa has continued to decline over the last decades and poverty levels have increased. Currently, agricultural productivity growth in sub-Sahara Africa (SSA) lags behind that of other regions in the world, and is well below that required to achieve food security and poverty goals. Increasing agricultural productivity in Africa is an urgent necessity and one of the fundamental ways of improving agricultural productivity is through introduction and use of improved agricultural technologies.

As noted by Duflo et al. (2006), the rapid population growth has made Africa to be no longer viewed as a land-abundant region where food crop supply could be increased by expansion of land used in agriculture. Large areas in Africa are increasingly becoming marginal for agriculture and arable land has become scarce in many African countries. This makes the need for intensification of land use through use of productivity enhancing technologies such as fertilizer critical for achieving food security. Yet, the rate of increase in fertilizer use has been substantially lower in Africa than in Asia and Latin America (Byerlee, 1997). Similar observations are also made by Ariga et al., (2006).

According to Howard et al., (1999), high external input technologies, lack of infrastructure, research, development, and even extension are major obstacles to increasing fertilizer application rates in sub-Saharan Africa. The fertilizer supply is limited and the cost is prohibitive for SSA farmers because fertilizer may cost as much as five times the global market price (Mosier et al., 2005). This problem has been aggravated by the recent spike in world fertilizer prices. For instance, after accounting for inland transport costs, the wholesale price of DAP fertilizer in Nakuru, Kenya, rose from 1,750 Ksh per 50kg bag in 2007 (US$538 per ton) to nearly 4,000 Ksh per 50kg bag (US$1,283 per ton) in 2008 (Ariga *et al*, 2008). Consequently, fertilizer application rates in SSA have remained the lowest in the world and continue to decline even though soils in SSA are considered as poor as those in Latin America and Asia (Kidane *et al*., 2006).

Despite the low application rates of fertilizer in SSA relative to other parts of the world, studies have shown that Kenya's fertilizer use relative to those of the countries in the region has increased dramatically since its fertilizer market was liberalized in the early 1990s. Kenya is the only country in Sub-Saharan Africa that has achieved at least 30% growth in fertilizer use per cropped hectare over the past decade and which already started from a relatively high base (25kgs per hectare or more by the early 1990s). Several studies have been conducted in Kenya on adoption of improved maize seed and fertilizer on maize production. However, few micro-studies on fertilizer adoption in general agriculture without focusing on a single crop have been conducted. In this study, therefore, we examine patterns in smallholder fertilizer use over time and estimate econometrically the determinants of fertilizer use in general agriculture. This is aimed at providing an empirical basis that would guide future fertilizer promotion policies and programs in Kenya and provide lessons for other SSA countries with regard to fertilizer use. By obtaining a clear understanding of farmer characteristics, institutional and geographic factors associated with fertilizer use in general agriculture, a platform is provided for policy makers to more accurately institute necessary programs that promote fertilizer use for agricultural productivity growth.

The remainder of the paper is organized as follows: a brief historical perspective of fertilizer use in Kenya is presented in section 2. Section 3 presents a review of selected agricultural technology adoption studies. Data and methods are discussed in section 4. Section 5 presents and discusses findings while section 6 concludes with conclusions and policy implications.

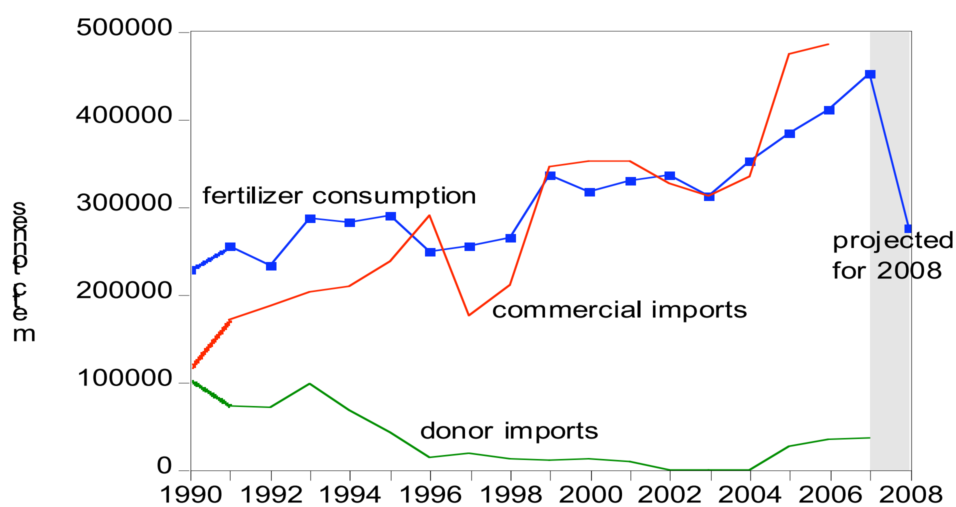
2. Historical perspective of fertilizer use in Kenya

Fertilizer market in Kenya was liberalized in the early 1990s, leading to phasing out of all fertilizer subsidy programs. Since then annual fertilizer consumption has progressively risen from a mean of 180,000 tons during the 1980s, to 250,000 tons during the early 1990s, to over 400,000 tons in the 2004/05 and 2005/06 seasons (Minde et al., 2008). In 2007, fertilizer consumption in Kenya stood at 451,219 metric tons. However, reports indicate that about

300,000 tons of fertilizer was consumed in 2008 and this drop was due to civil disruption and the escalating prices of fertilizer in the world markets. Evidence suggests that growth in fertilizer consumption in Kenya is occurring on smallholder farms - it is not driven by large-scale or estate-sector agriculture.

Growth in fertilizer consumption in Kenya is a phenomenon covering both food crops (mainly maize and domestic horticulture) as well as cash crops such as tea, sugarcane, and coffee. However, as Ariga et al. (2008) note, the recent increases in world fertilizer prices combined with the civil disruptions experienced in early 2008 are likely to break the steady upward trend in fertilizer use that Kenya has experienced over the past 15 years (Figure 1).

Figure 1: Trends in fertilizer consumption, commercial imports, and donor imports, 1990-2007, with projections for 2008



Source: Ariga et al., (2008)

The growth in fertilizer consumption in Kenya has been achieved without subsidies. Three main arguments being advanced for the expanded use of fertilizer by small farmers in Kenya are: a relatively stable fertilizer marketing policy since 1990; increasingly dense network of fertilizer retailers operating in rural areas, leading to enhanced farmers' access to fertilizer; and intense competition in fertilizer importing and wholesaling, creating pressure to cut costs and innovate in logistics. These arguments reveal the institutional factors that have contributed to expanded fertilizer use in Kenya. A micro-assessment of household and environmental factors associated with fertilizer use remains necessary to widen understanding of fertilizer adoption among especially smallholder farmers. This understanding can be a platform for designing informed strategies aimed at sustaining the momentum in fertilizer use in Kenya and promoting fertilizer use in other SSA countries.

3. A review of selected agricultural technology adoption studies in Kenya

Several adoption studies have been conducted in Kenya, most of them based on an initial desire to gather basic information about the use of modern crop varieties and inputs and to identify constraints to technology adoption and input use. A large number of these studies concentrate on cross-sectional analysis of the determinants of agricultural adoption at the farm level. The dynamics of the adoption process are not taken into consideration in cross-sectional analysis and the adoption process is represented as a snapshot in time. The coefficients may be biased since there may be a time-dependent element in the adoption decision. This section reviews some of these studies undertaken in the past.

A study by Jayne et al., (2006) determined the national-level, region-specific, and household-specific factors associated with smallholders' use of improved maize technologies (specifically fertilizer and hybrid seed) in Kenya and Zambia where over 25% of the farms use improved maize technology. Their study documented important factors that led to fertilizer and hybrid seed adoption on maize production. Among the factors identified included household characteristics such as education of head, distance to market, and regional differences. Though their study adopted a panel approach, the authors considered fertilizer adoption only on maize, excluding other crops such as coffee, tea and sugar cane whose production play a big role in household income in Kenya.

Ariga et al., (2008) used household panel survey data to examine trends in fertilizer use on maize by smallholder maize growers in Kenya. The study employed Probit and Tobit models to identify factors that affect the decisions by maize farmers to participate in fertilizer markets and conditional on participation, their level of purchases. The study found that the dominant factor influencing smallholders' decisions to use fertilizer on maize was location. The decision of households to purchase fertilizer for maize production was slightly related to farm size, and unrelated to household wealth. Proximity to fertilizer retailer was found to be an important influence on households' decision to purchase fertilizer for maize production in the relatively low-potential areas. Proximity to fertilizer seller, however, had very little influence on the quantity of fertilizer purchased. This study considered only fertilizer use on maize and excluded crops such as tea, coffee and sugar cane which, in Kenya, are important drivers of growth in fertilizer use.

In their study, Hugo De Groote et al. (2006) analyzed factors influencing adoption of maize technologies and fertilizer. Their study found that the proportion of farmers using improved varieties of maize had not changed but there was a positive tendency for the proportion of farmers using fertilizer on maize. They found that education, access to credit, access to extension and agro-ecological differences had significant influence on fertilizer adoption on maize.

A study by Ouma et al. (2002), using cross-sectional data, found agro-ecological differences, gender, manure use, hiring of labour and extension as statistically significant factors in explaining adoption of fertilizer and hybrid seed on maize production in Embu district. The CIMMYT studies in Kenya and other East African countries (Mwangi et al., 1998; and Doss, 2003) examined adoption decision processes for maize seed and fertilizer technologies and showed that farmer characteristics such as age, gender and wealth are key to adoption decisions.

In her study, Suri (2005) provided a succinct overview of the determinants of maize technology adoption in Kenya and showed that technology profitability, farmer learning as well as observed and unobserved differences among farmers and across farming systems were major determinants of adoption. Learning through social networks (Jackson and Watts, 2002) may also be an important determinant of technology adoption. Suri (2005) demonstrated that aggregate adoption rates may remain low or stagnant despite high average returns to new maize technologies, either because marginal returns to adoption are low, or because the farmers with comparative advantage in adoption have already done so.

Mwabu et al. (2006) in their study on adoption of improved maize varieties and impact on poverty in Laikipia and Suba districts found that the price of maize, education level, and distance to roads are the main determinants of hybrid maize adoption by farmers.

Karanja et al., (1998) applied a Tobit model on cross-sectional data to assess determinants of fertilizer adoption and use in Kenya. Their results indicated that fertilizer adoption and intensity of use was adversely affected by distance to fertilizer market and fertilizer price. Farmers closer to market tended to use more fertilizer. Farmers using hybrid maize seed used more fertilizer with the effect varying with agro-ecological zones. This indicates an existing complementarity between fertilizer and hybrid seed use. The study further noted that education, at post-secondary level, price of maize and extension positively influenced use of fertilizer on maize. Farmers with higher education tended to adopt and use more fertilizer on maize. This could be because they were able to use recommendations better or had a better ability to evaluate the difference fertilizer makes to productivity.

4.0 Data and Methods

4.1 Data and Sampling

The data for the study is obtained from a panel of households surveyed in 1996/97, 1999/00, 2003/04 and 2006/07 cropping years by Egerton University/Tegemeo Institute, with support from Michigan State University under Tegemeo Agricultural Monitoring and Policy Analysis Project (TAMPA). The sampling method for the panel of households was a mix of multistage and systematic. Twenty-four (24) districts were purposively chosen to represent the broad range of agro-ecological zones (AEZs) and agricultural production systems in Kenya. Next, all non-urban divisions in the selected districts were assigned to one or more AEZs based on agronomic information from secondary data. Third, proportional to population across AEZs, divisions were selected from each AEZ. Fourth, within each division, villages and households in that order were randomly selected. A total of 1,578 households were selected in the 24 districts within seven agriculturally-oriented provinces of the country. The sample excluded large farms with over 50 acres and two pastoral areas. Households in Turkana and Garissa districts were not interviewed in the 2004 and 2007 surveys. This analysis is based on 1,275 households which formed a balanced panel for the four cropping years (hereafter referred to as 1997, 2000, 2004 and 2007, respectively). The spread of the districts across the agro-ecological zones is presented in Annex 1.

Ariga et al (2008) observes that a major advantage of panel data is that it overcomes problems of sample comparability over time. While in many countries there exist various farm surveys that can be used to measure patterns and trends in technology adoption over time, the comparability of these surveys is often compromised by differences in sampled households, locations, month/season of interview, recall period, and the way in which data is collected. The balanced panel on which the findings reported in this study are based provides a unique opportunity to track historical patterns in and explore determinants of fertilizer use for a consistently defined nationwide sample of small-scale farmers.

4.2 Analytical Framework and Empirical Strategy

This paper seeks to build on existing work on agricultural technology adoption in sub-Saharan Africa by assessing fertilizer adoption behaviour of farmers in Kenya over time. It is well understood that technology generation and development is an iterative process and the supply of technologies needs to be driven by demand from the users. Adoption studies are, therefore, important for the following reasons: to assess impacts of agricultural research; to aid in priority setting for research; and to provide information for policy reform to reduce constraints to adoption.

This study reports historical patterns, based on the ten-year panel data, in smallholder fertilizer use to expose key trends. However, the historical patterns alone cannot provide information about the factors associated with fertilizer use. To provide a more accurate assessment of the household and environmental factors associated with household use of inorganic fertilizer, we undertake econometric analysis to explore determinants of fertilizer adoption and use intensity.

Limited dependent variables models are often used to evaluate farmers' decision-making process concerning adoption of agricultural technologies. Those models are based on the assumption that farmers are faced with a choice between two alternatives (adoption or no adoption) and the choice depends upon identifiable characteristics (Pindyck and Rubinfeld, 1997). In adopting new agricultural technologies, the decision maker (farmer) is also assumed to maximise expected utility (expected profit) from using a new technology subject to some constraints (Feder *et* al., 1985). In many cases (eg. Green and Ng'ong'ola, 1993; Kaliba et al., 2000) a Probit or Logit model is specified to explain whether or not farmers adopt a given technology without considering the intensity of use of the technology. The Probit or Logit models cannot handle the case of adoption choices that have a continuous value range. This is the typical case for fertilizer adoption decisions where some farmers apply positive levels of fertilizer while others have zero application (non-adopters). Intensity of use is a very important aspect of technology adoption because it is not only the choice to use but also how much to apply that is often more important. The Tobit model of Tobin (1958) can be used to handle such a situation. However, the Tobit model attributes the censoring to a standard corner solution thereby imposing the assumption that non-adoption is attributable to economic factors alone (Cragg, 1971). A generalization of the Tobit model overcomes this restrictive assumption by accounting for the possibility that non-adoption is due to non-economic factors as well.

Originally formulated by Cragg (1971), the *double-hurdle* model assumes that households make two sequential decisions with regard to adopting and intensity of use of a technology. Each hurdle is conditioned by the household's socio-economic characteristics. In the double-hurdle model, a different latent variable is used to model each decision process. The first hurdle is a sample selection equation estimated with a Probit model. The Probit model represents the probability of a limit observation, which is given by:

$$d_i = 1 \text{ if } d^*_i > 0 \text{ and } 0 \text{ if } d^*_i \leq 0$$

$$d^* = z'_i\alpha + \varepsilon_i \qquad (1)$$

where d^*_i is the latent discrete adoption choice variable, z is a vector of explanatory variables hypothesized to influence adoption choice and α is a vector of parameters. ε is the standard error term. All responses are included in the Probit model.

The second hurdle involves an outcome equation, which uses a truncated model to determine the extent of adoption (intensity of use) of the technology in question. This second hurdle uses observations only from those respondents who indicated a positive value of use of a technology. The truncated model, which closely resembles the Tobit model, is expressed as:

$$y_i = y^*_i \text{ if } y^*_i > 0 \; and \; d^*_i > 0$$

$$y_i = 0 \text{ otherwise}$$

$$y^* = x'_i\beta + u_i \qquad (2)$$

where y_i is the observed response on the intensity of adoption of the technology, x is a vector of explanatory variables hypothesized to influence intensity of technology use, _ is a vector of parameters and u is the standard error term.

The decision on whether or not to adopt a technology and how much of that technology to use can be *jointly* modelled if they are made *simultaneously* by the household; *independently* modelled if they are made *separately*; or *sequentially* modelled if one is made first and affects the other one as in the dominance model (Martínez-Espiñeira, 2006). If the independence model applies, the error terms are distributed as follows:

$$\varepsilon_i \sim N(0,1)$$

$$u_i \sim N(0,\delta^2)$$

If both decisions are made jointly (the dependent double - hurdle) the error term can be defined as:

$$(\varepsilon_i u_i) \sim BVN(0,Y)$$

where $$Y = \begin{bmatrix} 1 & \rho\delta \\ \rho\delta & \delta^2 \end{bmatrix}$$

The model is said to be a dependent model if there is a relationship between the decision to adopt and the intensity of adoption. This relationship can be expressed as follows:

$$\rho = \frac{\operatorname{cov}(\varepsilon_i u_i)}{\sqrt{\operatorname{var}(\varepsilon_i)\operatorname{var}(u_i)}}$$

If $\rho = 0$ and there is dominance (the zeros are only associated to non-adoption, not standard corner solutions) then the model decomposes into a Probit for adoption and a standard OLS for y.

Following Smith (2003) we assume that the error terms ε_i and u_i are independently and normally distributed. And, finally, the observed variable in a double-hurdle model is

$$y_i = d_i y^*_i.$$

The log-likelihood function for the double hurdle model is:

$$LogL = \sum_{0} \ln\left[1 - \emptyset(z'_i\alpha)\emptyset\left(\frac{x'_i\beta}{\delta}\right)\right] + \sum \ln\left[\emptyset(z'_i\alpha)\frac{1}{\delta}\emptyset\left(\frac{y_i - x'_i\beta}{\delta}\right)\right]$$

Empirical results by both Moffat (2003) and Martínez-Espiñeira (2006) reveal that the double-hurdle model gives superior results to those obtained from Tobit model. Thus in this study we estimate the decision to adopt fertilizer and the intensity of fertilizer use using a double-hurdle model.

4.3 Specification of the empirical model

It is important to first define what is meant by fertilizer adoption. For Probit estimation, a household is regarded as an adopter of fertilizer if it was found to be using any inorganic fertilizer. The dependent variable in this model is a binary choice variable which is 1 if a household used inorganic fertilizer and 0 if otherwise. For the second hurdle (truncated model), fertilizer adoption becomes continuous and the dependent variable is the amount of fertilizer (in kilograms) applied per acre of cultivated land by a household.

There is no firm economic theory that dictates the choice of which explanatory variables to include in the double-hurdle model to explain technology adoption behaviour of farmers. Nevertheless, adoption of agricultural technologies is influenced by a number of interrelated components within the decision environment in which farmers operate. For instance, Feder et al. (1985) identified lack of credit, limited access to information, aversion to risk, inadequate farm size, insufficient human capital, tenure arrangements, absence of adequate farm equipment, chaotic supply of complimentary inputs and inappropriate transportation infrastructure as key constraints to rapid adoption of innovations in less developed countries. However, not all factors are equally important in different areas and for farmers with different socio-economic situations.

In this section, we discuss the appropriateness of different variables considered in our model. The household characteristics deemed to influence fertilizer adoption in this study include household heads characteristics (age, gender and education), household size and dependency ratio. The conventional approach to adoption study considers age to be negatively related to adoption based on the assumption that with age farmers become more conservative and less amenable to change. On the other hand, it is also argued that with age farmers gain more experience and acquaintance with new technologies and hence are expected to have higher ability to use new technologies more efficiently. Education enhances the allocative ability of decision makers by enabling them to think critically and use information sources efficiently. However, since fertilizer is not a new technology, education is not expected to have strong effects on its adoption.

The effect of household size on fertilizer adoption can be ambiguous. It can hinder the adoption in areas where farmers are very poor and the financial resources are used for other family commitments with little left for purchase of farm inputs. On the other hand, it can also be an incentive for fertilizer adoption as more agricultural output is required to meet the family food consumption needs (Yonannes et al., 1989).

Institutional and infrastructural factors considered important in fertilizer adoption in this study include access to credit, farm size, presence of a cash crop, distance to fertilizer market, distance to extension service provider and distance to motorable road. Size of household landholding is included in the model to explore the effects of scale on fertilizer use. The size of landholding is expected to be positively correlated with fertilizer adoption, as farmers with bigger landholding size are assumed to have the ability to purchase improved technologies and the capacity to bear risk if the technology fails (Feder et al., 1985). However, the well-documented tendency for management intensity to decline with scale in tropical Africa (Feder et al., 1985) suggests that land size will be negatively correlated with the intensity of fertilizer use.

Lack of access to cash or credit does significantly limit the adoption of fertilizer but the choice of appropriate variable to measure access to credit remains problematic. On a discussion on the limitations, challenges and opportunities for improving technology adoption using micro-studies, Doss (2006) outlines the different measures often used but cautions the inherent problems of these methods, especially their endogeneity. Doss (2006) suggests that whether a farmer had ever received cash credit is a better measure of credit access than whether there is a source of credit available to the farmer. This study measures credit access by looking at whether a household received or did not receive any credit during a cropping year. The presence of a major cash crop[1] in the household is included in the model to capture the influence of commodity based inputs delivery systems in fertilizer adoption. In Kenya, commodities such as tea, coffee and sugar cane have inputs credit schemes for farmers.

Because inputs markets are widely distributed, farmers face travel costs when they buy inputs. Since the volumes of fertilizer purchases by smallholder farmers are not high and the location of fertilizer market can be inconvenient, the cost of travelling to purchase fertilizer is probably fixed over the quantities purchased. The distance to fertilizer market is thus expected to affect decision on whether or not to use fertilizer, but not the intensity of use.

Exposure to information reduces subjective uncertainty and, therefore, increases likelihood of adoption of new technologies (Langyintuo and Mekuria, 2005). Various approaches have been used to capture information including: determining whether or not the farmer was visited by an extension agent in a given time; whether or not the farmer attended demonstration tests for new technologies by extension agents; and the number of times the farmer has participated in on-farm tests. Due to absence of such data for this study, we use distance to extension service provider to capture the influence of information on adoption.

To explore the impact of infrastructure, which influences market access for both inputs and outputs, on fertilizer use, we include the distance to motorable road as a variable in the model.

To measure the influence of agro ecological factors on fertilizer adoption, we include dummies for agro ecological zones. The high potential maize zone is used as the base. The Coastal, Eastern and Western lowlands and Marginal rain shadow receive less rainfall and are prone to prolonged and frequent dry spells compared to the Central and Western highlands, Western transitional and High potential maize zone. Agro ecology variables pick up variation in rainfall, soil quality, and production potential. These variables may also pick up variation unrelated to agricultural potential, such as infrastructure and availability of markets for inputs and outputs.

A summary description of the explanatory variables used in the model is presented in Table 1.

1 Major cash crops are tea, coffee and sugar cane.

Table 2: Description of the variables specified in the model

Variable name	Variable description	Variable measurement
Age	Age of the households head	Number of years
Gender	Gender of household head	Dummy (1=Male, 0 otherwise)
Education1	Dummy for no formal education by household head	Dummy (1=No education, 0 otherwise)
Education2	Dummy for secondary education by household head	Dummy (1=Secondary education, 0 otherwise)
Education3	Dummy for post-secondary education by household head	Dummy (1=Post-secondary, 0 otherwise)
Hsize	Household size	Number of residents in the household
Dratio	Dependency ratio	Share of households residents over 64 and under 15years of age
Credit	Whether a household received credit during the cropping year	Dummy (1=Received, 0 otherwise)
Land	Size of land owned by a household	Acres
Crop	Whether household had grown major cash crop	Dummy (1=Had cash crop, 0 otherwise)
Fertkm	Distance from the household to nearest fertilizer seller	Kilometres
Extkm	Distance from the household to nearest extension service provider	Kilometres
Roadkm	Distance from the household to the nearest motorable road	Kilometres
AEZ1	Dummy for Coastal lowlands	Dummy (1=Coastal lowland, 0 otherwise)
AEZ2	Dummy for Easter lowlands	Dummy (1=Eastern lowland, 0 otherwise)
AEZ3	Dummy for Western lowlands	Dummy (1=Western lowland, 0 otherwise)
AEZ4	Dummy for Western transitional	Dummy (1=Western transitional, 0 otherwise)
AEZ5	Dummy for Western highlands	Dummy (1=Western highlands, 0 otherwise)
AEZ6	Dummy for Central highlands lowlands	Dummy (1= Central highlands, 0 otherwise)
AEZ7	Dummy for Marginal rain shadow	Dummy (1= Marginal rain shadow, 0 otherwise)

The above explanatory variables were used to estimate the Probit and truncated models of fertilizer adoption as specified below:

$$Adopt = \beta_1 Age + \beta_2 Gender + \beta_3 Education1 + \beta_4 Education2 + \beta_5 Education3 + \beta_6 Hsize + \beta_7 Dratio + \beta_8 Credit + \beta_9 Land + \beta_{10} Crop + \beta_{11} Fertkm + \beta_{12} Extkm + \beta_{13} Roadkm + \beta_{14} AEZ1 + \beta_{15} AEZ2 + \beta_{16} AEZ3 + \beta_{17} AEZ4 + \beta_{18} AEZ5 + \beta_{19} AEZ6 + \beta_{20} AEZ7$$

Adopt takes the value of 1 for adopters and 0 for non-adopters in the case of the Probit model and is the level of fertilizer used in kilograms per acre of cultivated land in the truncated model.

5.0 Results and discussion

Results of the patterns in smallholder farmers' fertilizer use over time are presented in this section. Econometric estimation results of the determinants of fertilizer adoption and intensity of use are also discussed.

5.1 Patterns in smallholder farmers' fertilizer use

Expanding fertilizer use is widely considered to be a pre-condition for broad-based farm productivity growth. Profitability of fertilizer use is, however, dependent on several factors, among them agro-ecological conditions (Marenya and Barrett, 2008). The differences in agro-ecological conditions facing Kenyan small-scale farmers have contributed to variations in fertilizer use among different regions. Table 2 shows trends in fertilizer use by households during the panel period.

Table 2: Percent of households using fertilizer by agro ecological zone

Agro ecological zone	1997	2000	2004	2007
Coastal Lowlands	2.7	6.8	8.0	12.3
Eastern Lowlands	35.2	48.3	56.6	56.6
Western Lowlands	5.9	11.8	15.0	30.5
Western Transitional	58.1	77.0	85.8	87.8
High Potential Maize Zone	86.1	90.5	90.5	93.6
Western Highlands	91.5	89.9	92.2	94.6
Central Highlands	99.2	99.6	97.1	97.9
Marginal Rain Shadow	27.0	35.1	32.4	54.1
Overall Sample	**63.9**	**69.9**	**71.9**	**76.3**

Generally, the proportion of sampled households using fertilizer rose from 64% in 1997 to 76% in 2007. However, these proportions vary considerably across agro ecological zones. The High Potential Maize Zone, Western Highlands and Central Highlands had the highest proportion (over 80%) of the households applying fertilizer. On the other hand, the proportion of households using fertilizer has remained relatively lower in the drier regions of Coastal Lowlands (7%), Western Lowlands (16%), Marginal Rain Shadow (37%) and Eastern Lowlands (49%). A notable increase in the proportion of households using fertilizer in Western Transitional was observed; from 58% in 1997 to 88% in 2007.

Trends in fertilizer use by cultivated land size are presented in Table 3. Landholding size is considered one of the indicators of wealth in Kenya. Two observations are made on the trends. First, across all the panel years the proportion of households adopting fertilizer increased with increasing cultivated land size. This may indicate that households with larger landholdings have greater ability to acquire and use fertilizer. Second, the proportion of households using fertilizer increased between 1997 and 2007 across all categories of cultivated land sizes.

Table 3: Percent of households using fertilizer by cultivated land size

Cultivated land size	1997	2000	2004	2007
Less than 1 acre	53.9	63.8	63.1	71.8
1-3 acres	63.4	66.4	73.6	73.6
Above 3 acres	70.0	75.1	75.0	81.5
Overall sample	**63.9**	**69.9**	**71.9**	**76.3**

A more detailed analysis of fertilizer use on selected crops across the panel period is presented in Table 4. The number of households producing maize has remained high and about the same over the panel period, pointing to the importance attached to maize by the smallholder farmers. The proportion of these households using fertilizer on maize consistently increased during the panel period from 57% in 1997 to 71% in 2007. On the contrary, the intensity of fertilizer application on maize has fluctuated between 55kg and 60kg per acre over the panel period. It is important to note that the application rates reported here are far below those recommended per acre for maize by the Kenya Agricultural Research Institute (KARI); 50 kg of DAP and 60 kg of CAN, resulting to a total of 110 kg.

The proportion of households applying fertilizer on coffee declined between 1997 and 2007 by 16%. Similarly, fertilizer application rate on coffee plummeted by 20% over the same period. A closer look reveals that the application rate consistently declined from 364 kg/acre in 2000 to 147 kg/acre in 2007, an average decline of 148% in a span of seven years. The gloomy picture in fertilizer use patterns on coffee can be attributed to two main factors: alleged mismanagement of coffee cooperatives, which are the main channels through which members receive their fertilizer; and the poor international coffee prices. Mismanagement in the cooperatives has made some farmers abandon coffee production (farmers in the coffee growing regions have in the recent past been reported to be uprooting the crop from their farms) while other farmers have opted to directly access fertilizers from private traders. This has made them disadvantaged in that they no longer access input credit facilities offered by the cooperatives as was the custom during the days when the cooperative movements were active and efficiently managed.

Table 4: Mean application rates of and percent of households applying fertilizer on different crops

Crop	1997	2000	2004	2007
Maize				
kgs/acre cultivated (users only)	56	55	60	59
% of households using fertilizer	57	63	67	71
No. of households producing	1261	1263	1264	1256
Coffee				
kgs/acre cultivated (users only)	183	364	256	147
% of households using fertilizer	44	51	45	37
No. of households producing	240	271	249	239
Tea				
kgs/acre cultivated (users only)	385	377	388	371
% of households using fertilizer	84	93	93	98
No. of households producing	167	175	189	192
Sugarcane				
kgs/acre cultivated (users only)	118	197	141	110
% of households using fertilizer	29	51	49	69
No. of households producing	157	152	154	145

With respect to tea, the fertilizer application rate has declined from 385 kg/acre in 1997 to 371 kg/acre in 2007. This decline is, however, marginal. The proportion of tea growing households using fertilizer on tea has, on the other hand, increased from 84% in 1997 to 98% in 2007. The fertilizer distribution system in the tea sector is the reason behind the impressive performance in fertilizer adoption on tea. The Kenya Tea Development Agency (KTDA) supplies fertilizer on credit to smallholder tea farmers and then deducts the cost plus interest from their deliveries of tea, which is sold by KTDA on behalf of the farmers.

Fertilizer adoption on sugarcane over the panel period has showed an impressive increase. Households using fertilizer has grown from 29% in 1997 to 69% in 2007. However, the application rate has fluctuated over the study period. Increased fertilizer adoption in smallholder sugarcane farming can be attributed to provision on credit of fertilizer and other inputs to smallholder cane farmers by the cooperatives to which the farmers belong. On the other hand, the dwindling fertilizer application rate can be attributed to inadequate supply of fertilizer by the cooperatives relative to farmers' demand, or it may be as a result of farmers' diversion of fertilizer acquired from the cooperatives from use on sugarcane to use on other crops. Ariga, et al., (2006) observed that some of the fertilizer acquired for intended use on the cash crops such as coffee and sugarcane under cooperative schemes is appropriate for use on maize and most horticultural crops as well, and there is likely to be some diversion of fertilizer targeted for use on sugarcane and coffee to food crops.

Fertilizer use on the different crops across agro ecological zones is presented in Annex 2. Both adoption and application rates are higher in the zones with higher agro ecological potential than in lower agro ecologically potential zones. This may indicate that fertilizer use on the crops is more profitable and less risky in higher agro ecologically potential zones.

5.2 Determinants of fertilizer use

Factors influencing the probability of adopting fertilizer

Table 5 presents results from the Probit model of fertilizer adoption. Age, education, credit, growing a cash crop, distance to fertilizer market and agro-ecological potential are statistically significant in influencing the probability of adopting fertilizer.

Table 5: Estimated results of Probit model of fertilizer adoption

Variable	Coefficient	Standard error	P-value	Marginal Effect
Constant	0.746**	0.153	0.000	
Age	0.007**	0.002	0.000	0.002
Gender	0.080	0.067	0.229	0.022
Education1	-0.258**	0.074	0.000	-0.076
Education2	0.468**	0.069	0.000	0.112
Education3	0.907**	0.131	0.000	0.165
Hsize	0.002	0.008	0.783	0.001
Dratio	-0.032	0.028	0.260	-0.009
Credit	0.487**	0.055	0.000	0.129
Land	-0.003	0.003	0.270	-0.001
Crop	0.600**	0.074	0.000	0.153
Fertkm	-0.025**	0.004	0.000	-0.007
Extkm	0.005	0.005	0.334	0.001
Roadkm	-0.010	0.015	0.509	-0.003
AEZ1	-2.456**	0.134	0.000	-0.770
AEZ2	-1.446**	0.077	0.000	-0.508
AEZ3	-2.413**	0.090	0.000	-0.772
AEZ4	-1.095**	0.099	0.000	-0.379
AEZ5	-0.302*	0.110	0.006	-0.090
AEZ6	0.262*	0.133	0.050	0.066
AEZ7	-1.666**	0.127	0.000	-0.593

Log likelihood -1597.39992; Chi-square 2894.23; **Significant at 1%; *Significant at 5%

The marginal effects of the Probit model show changes in the probability of adoption of fertilizer for additional unit increase in the independent variables. The probability of fertilizer adoption reduces by 0.2% for each additional year of farmer's age. Farmers with no formal education had 7.6% less probability of adopting fertilizer compared to those with primary education, while farmers with secondary and post-secondary education respectively had 11.2% and 16.5% higher probability of adopting fertilizer than their counterparts with primary education. Educated farmers can better process information more rapidly than otherwise (Schultz, 1975). It can also be presumed that educated farmers have a higher level of awareness of the benefits of fertilizer use in agricultural production.

Having received credit increased probability of fertilizer adoption by 12.9%. This suggests that relaxing liquidity binding constraints among smallholder farmers through access to credit will significantly increase their probability of adopting fertilizer.

Growing a cash crop is associated with 15.3% higher probability of fertilizer adoption. The major cash crops considered here have credit schemes that guarantee farmers' input (including fertilizer) acquisition on credit, which is repaid through deductions from the produce which farmers sell through the commodity cooperatives or factories. This indicates the important role of credit and guaranteed markets in promoting fertilizer adoption.

The probability of adopting fertilizer decreases by 0.7% for every kilometre increase in the distance to fertilizer seller. It is noteworthy that the distance to the nearest fertilizer seller declined from 8.1 km in 1997 to 3.4 km in 2007, which could be a result of improved input delivery systems after liberalization (Ariga et al., 2006).

Agro ecological potential significantly influences fertilizer adoption. Households in the drier and lower agro ecologically potential zones had between 50.8% and 77.2% lower probability of adopting fertilizer compared to those in the High potential maize zones, an indication that profitability of fertilizer use as dictated by ago ecological conditions has a significant impact on adoption. Compared to the Central highlands, an equally high potential region, probability of fertilizer adoption in the High potential maize zone was lower by 6.6%.

Factors determining the intensity of use of fertilizer

Determinants of fertilizer use intensity conditional on adoption are presented in Table 6. Having no education at all or secondary education compared to having primary education no longer plays significant role in fertilizer use intensity. The significant determinants of fertilizer use intensity are gender, post-secondary education, household size, dependency ratio, credit, growing of cash crop, distance to fertilizer seller, distance to extension and agro ecological potential. The marginal effects show that for an additional year of age, fertilizer use intensity declines by 0.12kg/acre. A household being male-headed is associated with 6.6 kg of additional fertilizer per acre. Compared to primary education, post-secondary education increases fertilizer application rate by 4.5kg/acre. A unit increase in the household size increases fertilizer application rate by 0.49kg/acre. This is plausible as households will strive to enhance their food security status by trying to increase yield levels. At the means, a unit increase in dependency is associated with a reduction of fertilizer use intensity by 2.5kg/acre.

Table 6: Estimated results of the truncated model of fertilizer use intensity

Variable	Coefficient	Standard error	P-value	Marginal Effect
Constant	-156.103**	33.286	0.000	
Age	-0.830*	0.338	0.014	-0.118
Gender	50.259**	13.469	0.000	6.573
Education1	24.185	13.126	0.065	3.600
Education2	-0.933	9.957	0.925	-0.132
Education3	30.312*	13.668	0.027	4.592
Hsize	3.468*	1.406	0.014	0.493
Dratio	-17.767**	5.230	0.001	-2.525
Credit	113.322**	11.835	0.000	16.256
Land	0.734	0.438	0.094	0.104
Crop	126.954**	12.921	0.000	18.632
Fertkm	3.287**	1.136	0.004	0.467
Extkm	-5.644**	1.199	0.000	-0.802
Roadkm	2.087	2.911	0.473	0.296
AEZ1	-1303.759**	317.783	0.000	-40.437
AEZ2	-778.298**	77.795	0.000	-44.419
AEZ3	-487.989**	71.171	0.000	-31.342
AEZ4	-192.454**	19.122	0.000	-20.356
AEZ5	-228.582**	21.978	0.000	-23.176
AEZ6	-3.540	11.368	0.755	-0.501
AEZ7	-287.585**	62.019	0.000	-23.628

Log likelihood --17698.624; Wald Chi-square 240.52; **Significant at 1%; *Significant at 5%

Conditional on a household using fertilizer, receiving credit increases fertilizer application rate by 16.2kg/acre, while growing a cash crop increases fertilizer application rate by 19kg/acre. A one kilometre increase in the distance to an extension service reduces fertilizer application rate by 0.8kg/acre. Paradoxically, unlike in the Probit model where distance to fertilizer seller negatively and significantly influenced fertilizer adoption, an increase in the distance to fertilizer seller positively and significantly influences fertilizer use intensity. This is a puzzling issue that may need further investigation.

As in the Probit analysis, fertilizer use intensity decreases as one moves from the High potential maize zone to the lower agriculturally potential zones. Fertilizer use intensity reduces albeit insignificantly in the Central highlands compared to the High potential maize zone.

6.0 Conclusions and policy implications

Fertilizer is considered one of the most important inputs for the achievement of increased agricultural productivity and food security in Kenya and, in deed, SSA. Although Kenya has registered high rates of fertilizer adoption, raising the intensity of use remains a key challenge. The patterns in households' fertilizer use showed dramatic rise in adoption in the last decade. Fertilizer application rates, however, showed marginal increase over the period. Fertilizer use in the drier agro ecological zones is still way below that in the higher agro ecologically potential zones. This may be associated with higher risk involved in and lower profitability of using fertilizer in the drier areas. The relatively higher fertilizer use in higher agro ecologically potential zones may also be influenced by the presence of major cash crops such as tea, sugarcane and coffee, which have organized input credit schemes which allow farmers to acquire inputs on credit and repay through deductions made on deliveries of the produce.

Econometric analysis has shown that age, education, credit, growing cash crop, distance to fertilizer market and agro ecological potential are statistically significant in influencing the probability of adopting fertilizer. On the other hand, the strongest determinants of fertilizer use intensity were gender, household size, dependency ratio, credit, growing cash crop, distance to extension services and agro ecological potential.

Increasing fertilizer use intensity in general and promoting fertilizer adoption in drier areas of Kenya require several interventions. First, there is need for relaxation of credit constraint through improved access to agricultural credit for especially low income farmers who depend on food crops and do not have access to credit opportunities offered under cash crops' input credit schemes. Another way of relaxing credit constraint would be to improve access to viable off-farm income generating activities. Existing literature suggests positive spill over effects of off-farm income on agriculture by substituting for credit when credit markets fail (Thirtle et al., 2003).

Secondly, concerted efforts to promote fertilizer use among farmers in the drier areas cannot be overemphasized. Extension efforts combined with fertilizer distribution innovations would ensure that farmers in these areas are sensitized on the benefits of using fertilizer for productivity growth. In addition, long term efforts are needed to establish and expand small-scale irrigation projects, which can help overcome the adverse effects of inadequate rainfall experienced in these areas.

Finally, the liberalization of the fertilizer sub-sector has led to increased national consumption of fertilizer and Kenya has been a success case where the private sector has thrived relatively well. One of the current factors impeding fertilizer use is the high world fertilizer prices in relation to the output price for commodities (Kibaara et al., 2008). The world prices per ton of DAP increased from US$ 260 in 2007 to US$ 800 in 2008. If such trends continue, gains in fertilizer adoption and intensity of use over the last decade may erode. Efforts to reduce the costs of fertilizer delivery would help to offset the effects of rising world prices. Government can invest in rural infrastructure, efficient port facilities and standards of commerce to reduce the costs of distributing fertilizer.

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Annex 1: Spread of sampled districts in agro-ecological zones

Agro-ecological zone	Districts	No. of households
Coastal Lowlands	Kilifi, Kwale	75
Eastern Lowlands	Machakos, Mwingi, Makueni, Kitui, Taita-Taveta	145
Western Lowlands	Kisumu, Siaya	153
Western Transitional	Bungoma (lower elevation), Kakamega (lower elevation)	148
Western Highlands	Vihiga, Kisii	129
Central Highlands	Nyeri, Muranga, Meru	242
High-Potential Maize Zone	Kakamega (upper elevation), Bungoma (upper elevation) Trans Nzoia, Uasin Gishu, Bomet, Nakuru, Narok	346
Marginal Rain Shadow	Laikipia	37
Overall sample		**1275**

Annex 2: Mean application rates of and percent of households applying fertilizer on different crops by region

Crop/Agro ecological zone	1997		2000		2004		2007	
	% of hhs	Mean kg/acre	% of hhs	Mean kg/acre	% of hhs	Mean kg/acre	% of hhs	Mean kg/acre
Maize								
Coastal Lowlands	3	11	6	5	7	3	12	7
Eastern Lowlands	28	10	34	18	49	15	56	16
Western Lowlands	2	24	5	14	7	10	12	12
Western Transitional	41	54	64	48	71	62	84	71
High Potential Maize Zone	84	65	89	67	89	74	92	75
Western Highlands	80	31	86	36	91	46	95	47
Central Highlands	93	68	92	64	93	64	91	58
Marginal Rain Shadow	8	12	14	15	11	43	16	43
Overall Sample	57	56	63	55	67	60	71	59
Coffee								
Eastern Lowlands	55	184	22	106	12	52	13	250
High Potential Maize Zone	22	70	-		22	37	9	400
Western Highlands	7	176	23	266	18	408	11	93
Central Highlands	66	186	74	389	69	243	58	149
Overall Sample	44	183	51	364	45	256	37	147
Tea								
High Potential Maize Zone	94	298	97	283	94	322	100	264
Western Highlands	68	209	79	403	84	345	94	373
Central Highlands	87	471	97	398	96	425	99	405
Overall Sample	84	385	93	377	93	388	98	371
Sugarcane								
Western Lowlands	8	67	7	54	7	85	37	119
Western Transitional	35	120	60	201	57	143	76	110
Overall Sample	29	118	51	197	49	141	69	110