Farmer Demand for Soil Fertility Management Practices in Kenya's Grain Basket

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Abstract

Use of soil amendments, including organic materials and mineral fertilizers, is highly recommended for the replenishment of soil nutrients, improved soil health and more efficient use of fertilizers in sub-Saharan Africa. Along with other constraints, underdeveloped markets are often cited as a reason for limited uptake of recommended practices. Recognizing the potential interrelationship among practices, we estimate seemingly-unrelated, multivariate probit models to identify the factors that determine use of inorganic fertilizer, other soil amendments, and practices to control erosion by smallholder farmers in Kenya. We then estimate demand for the most common soil nutrients (N and P). We find that, consistent with theory, farmers are price-responsive and remoteness depresses demand for mineral fertilizers. Knowledge and plot tenure have a strong influence on use of soil fertility management practices. Sex of household head affects use of soil fertility management practices only in maize production, and particularly in use of N and P. Decisions to use different categories of soil fertility management practices are correlated.

Key words: soil management, fertility, multivariate probit, demand, plot-level, Kenya

1. Introduction

Poor soils and nutrient depletion have been described as the 'fundamental biophysical root cause of declining per capita food production' in sub-Saharan Africa (Sanchez 1997). Land degradation cripples smallholder crop production in many communities, including those found in the densely-populated, grain-basket areas of Kenya. Founding research by Smaling et al. (1997) documented the magnitude of nutrient losses, but also characterized smallholder practices as 'abusive.' Soil related problems may also be inherent[1]; outside the deserts and drylands that comprise 60% of the continent, much of the land is old and weathered, requiring special attention to be of use in agriculture (http://eusoils.jrc.ec.europa.eu/library/maps/africa_atlas/).

Although experts debate the universality of the problem, as well as the adaptive capacity of smallholder farmers (see Place et al. 2006), there seems little doubt that when soils are degraded, raising productivity depends on restoring soil fertility through addition of both inorganic and organic matter (Chivenge et al. 2011; Vanlauwe et al. 2010; Zingore et al. 2007; Zingore 2011). Soil fertility experts have recommended integrating organic matter, such as manure from livestock or post-harvest crop waste, to raise soil carbon levels and make nutrients from mineral fertilizers more available to plants, enhancesoil structure, and improve the efficiency of fertilizer use. Interactions between inorganic fertilizers and available organic inputs (mixtures) results in greater nutrient efficiency (Giller et al. 1998; Vanlauwe et al. 2001). Addition of organic matter improves nutrient and water retention in soils and creates a better synchrony in nutrient supply and crop demand.

[1] For example, soils developed on non-calcareous parent materials (inherently acidic) or soils in humid regions become acidic naturally due to leaching under high rainfall conditions.

In some countries of Sub-Saharan Africa, extension messages now emphasize the use of more legumes, intercropping, organic manure, reduced tillage, herbicides and agroforestry, and there are some indications that farmers are adopting such practices (e.g., Holden and Lunduka 2010, Sauer and Tchale 2009). Successful cases of restorative options designed and promoted by coalitions of agricultural researchers, farmers, and non-governmental organizations have also been documented (Haggblade et al. 2010; Reij et al. 2009.

Recognition of the importance of the problem does not diminish the policy challenge for governments in sub-Saharan Africa. We see two key dimensions to the policy challenge. First, inorganic fertilizer continues to be viewed as a panacea for smallholder productivity, and is promoted via input subsidies and other campaigns. The social costs of such policies could be high, especially given the evidence that returns to use of inorganic fertilizer are low because it is often applied inefficiently. Fertilizer response varies, as does the marginal productivity of nitrogen, according to agro-ecological and soil conditions both among and within farms (Tittonell et al. 2005a,b; Vanlauwe et al. 2006; Zingore et al. 2007). Soils experts have shown that some soils do not respond to mineral fertilizer, as recently confirmed in Kenya by Chivenge et al. (2009) and Marenya and Barrett (2009). Farmers in the major maize-producing areas of Kenya may have surpassed the optimum level of inorganic fertilizer application, challenging the notion that higher rates of fertilizer use should be encouraged without considering the physical response of soils (Sheahan 2011). Soil acidity can generate inefficiencies due to soil acidity (Pearce and Sumner 1997; Evans and Kamprath 1970). Fixation of phosphorus also depresses returns to phosphatic fertilizers (Kanyanjua et al. 2002). These findings imply that considerable field research is needed to adapt an extensive menu of soil fertility management practices to locally-specific biophysical and socioeconomic conditions. In recognition of this fact, Vanlauwe et al. (2010) have defined integrated soil fertility management explicitly in terms of local adaptation.

The second dimension of the policy challenge is that adoption of the practices needed to restore soil properties and enhance response to inorganic fertilizer remains low. Economic incentives for adoption of soil fertility management practices are constrained by a host of factors, depending on the combination and timing. From an economics perspective, the most obvious impediment is the time lag between farmer investments and observable payoffs, and their public good nature when they involve land resource allocation. Some practices simply do not offer sufficient gains in land and labor productivity to make the investment worthwhile for farmers in the short term (Ruben et al. 2007; Pender 2008).

Studies in Eastern and Southern Africa have shown that adoption is limited by the amounts of land and labor required to produce, process and apply some techniques and practices, such as organic materials (Lunduka 2009, Marenya and Barrett 2007, Mugwe et al. 2009, Odendo et al. 2009). The choice of the practice, field, and timing are all important for successful application of principle. Extending and adopting location-specific menus of practices is knowledge-intensive, requiring substantial, innovative forms of investment in local research and training capacity (Sanginga and Woomer 2009; Giller et al. 2006). Human capital and social capital are thus crucial in diffusing such practices (Katungi 2006, Njuki et a. 2008, Mapila et al. 2012, Kassie et al. 2013.

Missing or underdeveloped markets for inorganic and organic fertilizer are often cited as a reason for low uptake, but too little is known about them to guide policy interventions and investment decisions. In this study, we characterize the market for management of soil fertility and land quality among smallholder farmers in the ‘grain basket’ areas of Kenya.

Our analysis contributes to understanding about smallholder demand for soil fertility management practices, including organic and inorganic fertilizer (N and P nutrients), and other soil amendments in Sub-Saharan Africa, in several ways. Recognizing that maintenance of soil quality/fertility entails the maintenance of the physical, chemical and biological properties of soil, including nutrient status as well as erosion control, we group soil fertility management practices into three bundles (categories): a) inorganic fertilizers b) other soil amendments; and c) erosion control. We derive reduced-form, input demand functions based on the underlying conceptual framework of the non-separable model of the agricultural household. To examine the binary choice among the three bundles of practices, we apply a seemingly unrelated, multivariate probit model to address jointness and interdependence among soil fertility management strategies. We then estimate demand for N and P nutrients with a censored variable regression. Data were collected by plot in 2008/9 from 1001 households in eight agro-ecological zones of western and central Kenya. In all models, we control for the clustered structure of the data.

The conceptual framework is presented next. Section 3 describes the data source, econometric approaches, and variables. Results are shown and interpreted in Section 4. Section 5 draws conclusions and discusses policy implications.

2. Conceptual framework

We view farming by smallholders in the grain basket areas of Kenya from the perspective of the non-separable model of the agricultural household. In this framework, the shadow prices faced by farmers reflect transaction costs that vary among households depending on their capital endowments and features of relevant markets (e.g., de Janvry and Sadoulet, 1991). We adapt the framework in order to focus on decisions regarding the adoption of soil fertility-enhancing inputs, following recent applications by Lunduka (2009) in Malawi and Marenya and Barrett (2007) in Kenya. Like Lunduka (2009), we conceptualize the decision in a static context where fertilizer markets are imperfect and markets for other soil amendments, such as manure, are incomplete or missing. Farm households maximize utility over a vector of consumption goods produced on the farm or purchased (**X**) and leisure time (h). The crop production technology is a function of labor input (L), the size of the landholding (A), and application of nutrients contained in mineral fertilizers ($\mathbf{z}_f$), conditional on land quality ($\dot{s}_i$), which is plot-specific. Land quality, a stock, is influenced by variable investments in soil amendments ($\mathbf{z}_a$) and erosion control ($\mathbf{z}_e$) in the current period, quality in the past period, and essential land characteristics. Utility is maximized conditional on household characteristics that shape preferences ($\mathbf{\Phi}_h$) and market characteristics ($\mathbf{\Phi}_{m,}$), subject to the crop production technology and an expenditure-income constraint ($<=Y$) that affects purchases of tradables, hired labor and mineral fertilizer, at observable prices **p**. *Y* includes any savings from the previous period, and cash earnings from outside the farm (O). Time allocated to farm production includes family and hired labor.

Maximizing utility subject to production technology and income constraints, and solving Kuhn-Tucker conditions leads to optimal input demand equations for mineral fertilizer, soil amendments and erosion control that can be expressed as a reduced form:

$$\mathbf{z^*} = \mathbf{z^*}\,(A, L, Y, \mathbf{p}, \mathbf{\Phi}_h, \mathbf{\Phi}_{m,}\ \dot{s}_i) \qquad (1)$$

Equation 1, which depicts demand for three classes of soil fertility inputs $\mathbf{z}^*=[\mathbf{z_f}, \mathbf{z_a}, \mathbf{z_e}]^*$ as a function of scale and plot-specific land quality, farm labor supply, prices, exogenous income, household and market characteristics, is the starting point for the econometric model.

The choice set, or combination of practices selected by the household in a growing season includes non-zero components of vector **z**. Following a random utility model, as did Marenya and Barrett (2007), a farmer decides to use a different combination of soil fertility practices if overall utility with the new set (U_1) is larger than the utility with the old set (U_0), or $(U_1 - U_0) > 0$. We can also define an unobservable demand $\tilde{\mathbf{z}}* = (U_1 - U_0)$, expressing it as a function of unobservable elements in a latent variable model:

$$\tilde{\mathbf{z}}_j* = \boldsymbol{\theta}_j \boldsymbol{\gamma} + \mathbf{u}_j \qquad (2)$$

Thus, we are able to introduce knowledge and learning into decision-making. In equation 2, $\boldsymbol{\theta}$ summarizes the explanatory factors shown in equation 1, conditional on farmer knowledge about soil fertility management and essential plot characteristics (*K*). Each single-valued, binary variable $(z_f, z_a, z_e)*$ then refers to a choice that is observed when household *j* decides whether to use mineral fertilizer, other soil amendments, or erosion control:

$$z_f, z_a, z_e = 1 \text{ if } \tilde{\mathbf{z}}_j* > 0, \boldsymbol{\theta}_j \boldsymbol{\gamma} \geq -u_j, \text{ or } 0 \text{ if } \tilde{\mathbf{z}}_j* < \boldsymbol{\theta}_j \boldsymbol{\gamma} < -u_j > 0 \qquad (3)$$

In equation (3), each of the decisions is represented in terms of parameters to be estimated γ and where u_j is the error term, assumed to be normally distributed. Genius et al. (2006) depict this as a threshold decision. Once the farmer has acquired information or knowledge above some threshold level ($\underline{K^0}$), a decision is made. Knowledge about technologies drives markets (Place et al. 2003).

Consistent with the random utility model, we assume that the individual components in the three bundles of soil fertility inputs (**z**) chosen by the household are mutually exclusive. On-farm (real life), farm households may be observed applying a combination of two or more mutually exclusive strategies. Farm households may choose more than one strategy for two reasons: one, because of the within-farm heterogeneity in terms of soil types, slope and fertility; and two, to exploit the complementarities between alternative strategies such as controlling for soil or nutrient loss, enriching the soil with nutrients or micro-organisms or even increasing the soils water holding capacity. Similarly, Marenya and Barrett (2007) grouped practices in terms of stover/trash lines for nutrient recycling, agroforestry for soil nutrient replenishment using woody species, use of livestock manure, and the use of inorganic chemical fertilizers. The estimation approach is described next.

3. Empirical approach

3.1. Data Source

Data were collected in 'grain basket' areas in Western (Western and Nyanza provinces) and Central Kenya, which are defined by the Alliance for a Green Revolution in Africa (AGRA) as those areas with high agricultural potential that has not been fully exploited. Within these predominantly smallholder production systems, districts were selected according to high inclusivity of staple crops. In the Central Highlands, these included Tigania West, Mukuruweini, Kirinyaga West and Muranga South. In Western and Nyanza regions of Western Kenya, four (Kakamega North, Teso North, Butula, and Bungoma) and three (Ugenya, Nyando, and Ndhiwa) districts were selected, respectively. The randomly selected sample comprises of 1001 households with a total of 5,967 easily identifiable farm plots. These can be easily identified as distinct units since farmers normally delineate their farm using live hedges, terraces, ditches and paths or permanent crops (Kamau et al. 2012). The number of plots per household ranged from four to eight, with plot sizes measuring between 0.36 to 0.92 acres. A structured questionnaire was used in collecting data. Cropping data refer to the 2008/2009 agricultural season while all other data (household, market) refer to the calendar year 2009. The location of study sites is shown in Figure 1.

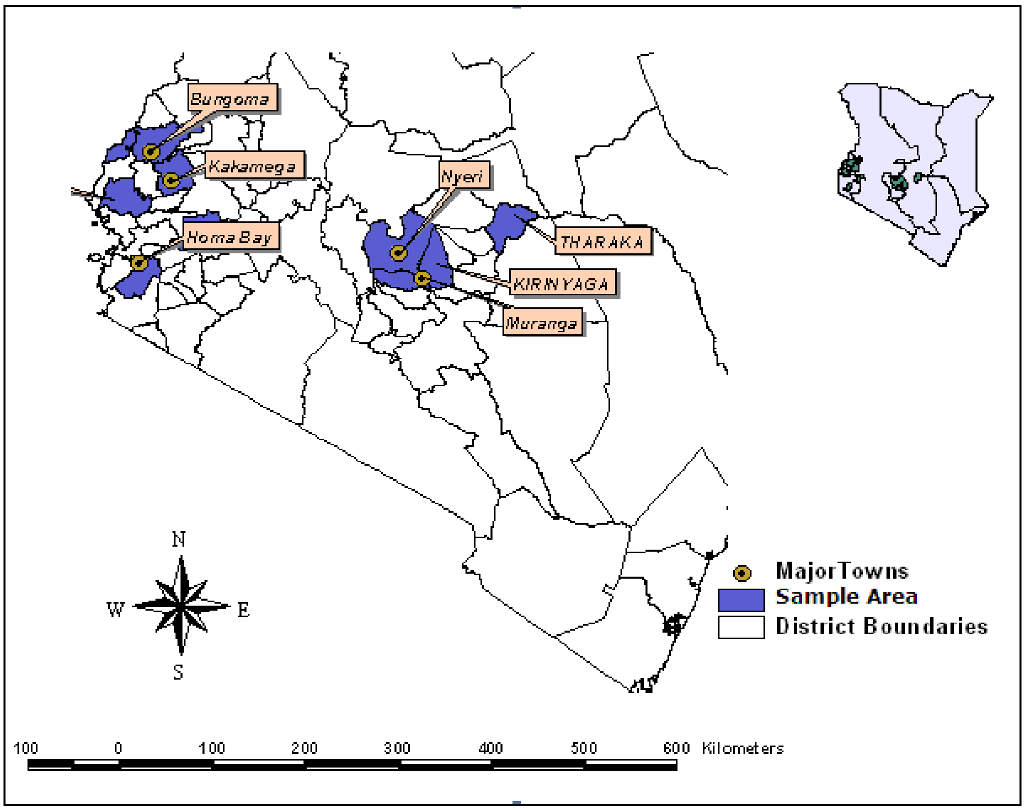

Figure 1: Location of Study Sites

3.2. Econometric approach

Statistical challenges of modeling adoption decisions involving packages or bundles of inputs have been addressed in a number of ways over the past few decades, particularly with regard to sustainable farming practices. In early research, despite the recognition that adoption of technology components is multivariate, econometric methods were limited to feasible approaches such as multinomial logit, in which adoption outcomes were redefined to create an order. For example, Caswell and Zilberman (1985) predicted the probability of adoption of either or both improved irrigation methods (drip and sprinkler) relative to the use of traditional furrow irrigation. Dorfman (1996) examined choices of bundles of irrigation techniques and integrated pest management practices among apple growers, applying Gibbs sampling in a Bayesian framework to treat the interrelationships among choices, and noting the difficulties of applying maximum-likelihood methods. Wu and Babcock (1998) recognized that failure to treat the interdependence of choices among soil fertility practices and techniques may under- or overestimate the influence of individual factors on choices. Recently, Genius et al. (2006) estimated a trivariate probit model to analyze organic farming decisions, using the simulation-based Geweke-Hajivassiliou-Keane (GHK) algorithm to apply maximum-likelihood methods. All of these studies were conducted in the US.

In Kenya, Omamo et al. (2002) used a two-stage approach to test whether organic and inorganic fertilizers were used as complements or substitutes, assuming a sequential adoption process. Several recent studies about adoption of soil fertility management practices in Eastern and Southern Africa have used a series of single probit or logit equations to model the range of practices independently (Odendo et al. 2009, Mugwe et al. 2009, Mapila et al. 2012). Recognizing that parameter estimates based on individual probit models may be biased by cross-practice correlations, Marenya and Barrett (2007) applied a multivariate probit model. Kassie et al. (2013) also analyzed the adoption of sustainable agricultural practices in Tanzania using a multivariate probit model, demonstrating the interdependence among choices. These authors emphasize that plot-level data are needed to control for within-farm heterogeneity and to accommodate, as much as is feasible in a cross-section of households, the specificity of soil management -related recommendations.

The data used in this study confirm that farmers in the grain basket areas of Kenya use one, several, or complex combinations of practices to address segregated and overlapping constraints in soil fertility. Research has also demonstrated that soil erosion lowers soil fertility through removal of organic matter and nutrients in eroded sediment (Young, 1989). The control of erosion is therefore necessary although not sufficient for maintaining soil fertility. Furthermore, the non-separable model of the agricultural household predicts that market failures, imperfections or missing markets for some components or practices may lead to variations in the way they are applied that depend on household endowments. Heterogeneous household endowments may result in substitution or complementary among practices.

Recognizing these features of the empirical context, and in concurrence with the recent studies mentioned earlier, we apply seemingly-unrelated multivariate probit[2] regression to estimate the probabilities that households use one, two, or three mutually exclusive soil fertility strategies (**z**), following equations 1-3. We estimate two MVP models. Given our geographical focus on the grain basket areas of Kenya, we estimated the first model for all the plots that were cultivated in both the main and minor seasons, while the second model as restricted to the plots that were planted with maize. We test for dependence among decisions, report average partial effects and

[2] M-equation multivariate probit model: The model has a structure similar to that of a seemingly-unrelated regression (SUR) model, except that the dependent variables are binary indicators. As in the SUR case (sureg), the equations need not include exactly the same set of explanatory variables.

also account for clustering among plots in computing robust standard errors of regression coefficients. We also report joint probabilities for successes and failure among the three strategies.

Building on the decision to use inorganic fertilizer in the multivariate probit model, we then use Tobit models to estimate reduced-form demand functions for nitrogen (N) and phosphorous (P), derived from total kgs of mineral fertilizer applied, by type[3]. The Tobit model is suitable for a corner solution response such as that of fertilizer use, where the variable is zero for a nontrivial fraction of a population but continuously distributed over positive values.

All models were estimated at the plot level, thus controlling for variability across plots in terms of slope, soil type, distance to the homestead and extent of degradation. This is consistent with our conceptual framework, Kassie et al. (2013), Kamau et al. (2012) and experimental research reported above. The factors affecting whether or not a household applied one or more of the soil fertility strategy are not expected to differ from those affecting the amount demanded for the elements, and thus the independent variables included in the Tobit models are those included in the MVP estimation.

3.3. Variable definitions

Definitions and descriptive statistics for variables are shown in Table 1, reflecting equation (1) and the knowledge threshold implied by equations (2-3).

Demand for three classes of soil fertility inputs $\mathbf{z}^*$ was measured using dummy variables with a value of one when investment was observed and zero otherwise (use of inorganic fertilizer $\mathbf{z_f}$; use of erosion control $\mathbf{z_e}$; use of soil amendments $\mathbf{z_a}$). The commonly used inorganic fertilizers

[3] Originally, we also attempted to estimate regressions for potassium demand, but the data were sparse given that very few farmers used fertilizers that contained this nutrient in more than zero or very small amounts,.

in the area of study are DAP, CAN, MAP, NPK, and urea. In the category of soil erosion control, we included investment in windbreaks, contour farming, grass strips, afforestation, agro-forestry and the construction of gabions, or cut off drains. Soil amendments included mulching; application of compost, green and farmyard manure, as well as growing of legumes.

The dependent variables in the demand equations for mineral nutrients were calculated by applying nitrogen (N) and phosphorus (P) percentages by fertilizer type to total kgs of fertilizer applied. Constructed per acre, these express intensity of use.

The independent variables are observed at the scale of plot, household, and market. Landholding size (A, equation 1) is measured in terms of plot size. Marenya and Barrett (2007) found that size has a positive effect on all practices especially fertiliser and manure. Differences among plots (size, tenure, soil fertility) affect their suitability for various investments (Tittonell 2005a,b; Abdulai et al., 2011). A dummy variable captures whether the plot is cultivated under fixed rent contracts. We represented intercropping, which is a common practice in the study areas, as the number of crops grown on the plot (the count, or 'richness' or crops). Having controlled for intercropping with legumes, this variable may also indicate the effect of other crop enterprises such as cash crops or vegetables on soil fertility management. The number of legume crops expresses the potential effect of leguminous crops (beans, cowpeas, French beans, groundnuts, bambara beans, pigeon peas, dolichos, soyabeans and green peas), which are promoted as sources of soil nutrients, particularly nitrogen through nitrogen fixation. A negative effect is expected on use of inorganic fertiliser since legumes are a substitute for some elements particularly N. Given that we do not have historical data on the land quality stock ($\dot{s}_i$), the number of legume crops provides some indication of other underlying factors that may affect nutrient availability.

Household characteristics ($\mathbf{\Phi}_h$) include human capital endowments, represented by the number of years the household has been farming. This factor is also related to the history of past investments in land quality ($\dot{s}_i$) and to knowledge gained through experience. We measure wealth by the value of livestock, which is also associated with the manure producing capacity (in quantity) of the household. Moreover livestock ownership is positively related to households wealth so wealthier households are more likely to use manure than poorer ones (Mekuria and Waddington 2002). However the effect of wealth on some of the investments/technologies is indeterminate because some investments such as organic sources of nutrient are known to be more affordable to poorer households than the inorganic sources (Soule and Shepherd 2000).

Male headship is expected to have a positive influence on all three investments in land. An extensive literature has documented that female-headed households are known to have less access to critical resources, especially cash and labour which are important in purchase of fertilisers, in labour intensive soil fertility management practices, and in construction and maintenance of erosion control measures. Women farmers are also known to have less access to information and technology. Marenya and Barrett (2007) found male household heads were more likely to adopt some ISFM practices (among them stover lines and agro-forestry), but found no difference between male and female heads in the likelihood to adopt organic fertilizers.

Cash-earnings from off the farm (O) are measured as the proportion of off-farm income in the household's annual income. Off-farm earnings relieve seasonal cash constraints on investments including the purchase of inorganic fertilisers and also for hiring labour to construct/maintain erosion control structures or apply organic inputs. Farm households with greater off-farm income often have more access to information on improved/new technologies, influencing the knowledge threshold for adoption. Marenya and Barrett (2007) found that off-farm income influenced use of soil fertility management practices in Western Kenya. On the other hand off-farm activities may divert labour thereby reducing investments in agriculture and also labour. The effect of increasing importance of off-farm income is therefore indeterminate a priori.

Labor input (L) is expressed in three variables calculated in terms of numbers of person-months residing in the household, by age category. We differentiate household labor supply according to age group, including young adults (15 - 23 years), mature adults (24 - 55 years) and seniors (>55 years). Labor constraints are hypothesized to impede use of many soil fertility management practices. Family labour is important for uptake of natural resource management technologies when cash constraints are binding, but also because of the moral hazard associated with hired labor. These variables may also reflect the role of life-cycle stage in adoption decisions. For example, younger farmers who are expected to cultivate the land for a longer time are better positioned to benefit from investments in soil-improving and conserving measures, if they are not credit constrained (Abdulai 2011). Moreover, Odendo et al. (2009) found a negative relationship of farming experience and adoption of manure, compost and chemical fertilizers. Odendo et al. (2009) explain that as household heads advance in years they are more risk averse and hence are less likely to adopt chemical fertilizers and other modern technologies.

Economic principles predict that an improvement in market infrastructure ($\mathbf{\Phi}_m$) encourages use of inputs through enhancing farm profitability. We include a factor score resulting from principal components analysis of variables measuring distances to distance to seed and fertilizer sellers, extension and vet service providers, tarmac road and telephone. The score represents the relative ease with which small holder farmers access ”soft” and “hard” market infrastructure. A negative sign on the regression coefficients suggests that lack of access to market services depresses the use of soil fertility management technologies and demand for fertilizers. The factor loading matrix is included in the Annex.

The vector **p** includes fertilizer prices. Not all farm households use chemical fertilizers while those who do may use more than one type. We computed prices for those who applied inorganic fertilizer as the kg-weighted sum of farm-gate prices across all types. For households that did not use inorganic fertilizer, we imputed a village-level mean price. In the choice model, we use predicted values for fertilizer price based on village effects to impute price. In the Tobit model, we replace the fertilizer price with the ratio of fertilizer-to-maize grain price. A higher ratio is expected to have a negative effect on the demand for inorganic fertilizers.

To represent *K*, we use an index computed from survey questions to proxy for knowledge of land and soil fertility management. Respondents were asked to indicate their awareness of each soil fertility management practice included in a pre-defined list, and then to rank knowledge of the practice on a scale of 1 to 3 (3=very well; 2=some knowledge; 1=no knowledge). The index is a 3-point Likert scale, in which the sum of the ranks over practices is standardized by the number of practices about which the household is aware.

Finally, we include a dummy variable for season. The major season runs from March to July whereas the minor season is from October to January.

4. Results

Average partial effects of explanatory factors on use of inorganic fertilizer, erosion control and other soil amendments are shown in Table 2, for all plots and maize plots only.

Renting land is positively and significantly related to use of inorganic fertilizers on all plots and on maize plots. When a farmer rents-in land, the focus is to maximize production, which may be directly enhanced by the use of chemical fertilizers. Benefits of chemical fertilizers are captured in the year the fertilizer is applied (Minot et al, 2000), although there may be some residual effects in subsequent years. The coefficient is smaller and less significant for plots planted with maize (0.232 compared with 0.472 for all plots), probably because households renting-in land mainly do so for planting other high value crops.

By contrast, there is a lower likelihood of having other soil amendments or soil erosion control measures on land which is rented-in, and particularly on maize plots. The large and negative coefficient shows a strong inclination for farmers not to invest in practices like increasing land quality (carbon content, water holding capacity etc.) and soil erosion control on land which does not belong to them (e.g. rented land), probably because such rented land is not accessible to them in the longer term. Overall, the magnitudes of the effects for renting-in land are relatively large compared to those of other explanatory variables, confirming the importance of land tenure.

As expected, and based on previous research (Minot et al. 2000; Marenya and Barrett 2007), the likelihood of using inorganic fertilizer increases with plot size and so does the likelihood of having soil erosion measures taken. The effect of plot size on fertilizer use is lower for plots planted with maize either because there is not enough variation in plot sizes or size may be a proxy for other factors (in the regression for all plots) which are unaccounted for in the model, such as growing of cash crops (Marenya and Barrett 2007). Marenya and Barrett (2007) also suggest that these technologies may not be scale-neutral (they depend on plot size).

As hypothesized, the likelihood that households will use soil fertility management practices appears to be influenced by other farm practices, such as a greater cropping intensity, which is associated positively with all three soil fertility practices on all plots and to a lesser extent (smaller magnitudes) on maize plots. The number of legume crops is also positively associated with use of soil amendments, but not on use of inorganic fertilizer—suggesting that legumes may be a substitute for inorganic fertilizers rather than a complement or supplement.

Results confirm that the effect of season is generally an important consideration in the uptake of soil fertility management practices. Households are more likely to use inorganic fertilizer on plots planted with maize during the major season, but less likely to use other soil amendments or engage in soil erosion control activities during this season. This finding is consistent with the notion that farmers will tend to maximize returns to fertilizer during the main rainy season when rains are heavier and more reliable. The lower uptake of labor intensive activities may be explained by a relatively higher labor constraint during the main season.

Male headship (as compared to female headship) is a significant factor only on maize plots, where the effect on use of inorganic fertilizer and soil erosion control is relatively large in magnitude and positive. These findings are consistent with those of Minot et al. (2000) and Marenya and Barrett (2007). Male headed household are more likely to apply erosion control practices probably because they may be less labor constrained and also because such activities are mainly accomplished by men.

As found in previous research, adult labor appears to constrain use of labor-intensive practices such as soil erosion control and other soil amendments (Lunduka 2009, Marenya and Barrett 2007, Mugwe et al. 2009, Odendo et al. 2009). However, disaggregating the family labour by age categories provides the additional insight that a larger number of young adults (15 – 23 years) reduces the likelihood that a household will use inorganic fertilizers, while increasing the supply of other adults (mature and seniors) does not influence its use. This variable may be a proxy for other factors, such as constraints on financial liquidity, which are greater in households with more young adults of tertiary school-going age. A higher number of seniors in the household had a positive effect (although weakly significant) on the likelihood that household had soil erosion control measures in place. Only an increase in mature adults (24 – 55 years) in the household showed a positive effect (weakly significant for maize plots) on the likelihood that a household uses soil amendments such as manure and compost, implying that family labor of this age group enhances the uptake of other soil amendments.

Capital variables (value of livestock, human capital) have no discernible effects in these models. The value of livestock is only a significant factor in the use of other soil amendments on all plots. This finding may be associated with capacity to produce manure on-farm, and is consistent with household behavior where markets are incomplete or missing (de Janvry et al. 1991; Lunduka 2009).

An increase in the share of off-farm earnings in total household income is positively associated with soil erosion control and use of inorganic fertilizers on maize or any other plot. The effect on erosion control is comparatively high. The result suggests that increasing off-farm income may be an important pathway to investments in integrated soil fertility management by smallholder farmers.

Knowledge of soil fertility management practices has a positively and significant influence on soil fertility management, increasing the likelihood of use in all three categories of practices (inorganic fertilizers, erosion control and other soil amendments). This effect was strongest and greatest in maize plots.

Findings underscore the strong price response of farmers to the fertilizer price when choosing soil fertility management practices. Households were less likely to use all categories of soil fertility management practices when the price of fertilizer increased. This effect was greater in maize plots with households being less likely to use inorganic fertilizers when the price of fertilizer increases relative to that of grain. The negative effect of an increasing price of inorganic fertilizer on the likelihood that soil amendments such as manure or compost will be used and on uptake of erosion control practices suggests some input complementarity. Lastly, poor access to market infrastructure diminishes the likelihood of use not only of inorganic fertilizers, particularly on maize plots, but also the use of soil amendments such as manure and compost.

Table 3 shows the diagnostic tests related to the independence of the three choices, for all plots and maize plots only. The significance and positive sign of ρ confirms a positive correlation between the unobserved factors affecting the use of inorganic fertilizer, other soil amendments and soil erosion control. Thus, the likelihood ratio test suggests that the multivariate probit model better represents the underlying data process than single probit equations.

The statistics in Table 4 indicate that soil erosion control practices are more likely to be established compared with either other soil amendments or use of inorganic fertilizers, and inorganic fertilizers are less likely to be used than other soil amendments, for all plots and also for maize plots. For any of the three practices, marginal probabilities are higher on maize fields than on all plots. Predicted joint probabilities of non-use average 12% on all plots and 19% on maize plots. The predicted joint probability of use for all three practices is 21% on all plots and only 12% on maize plots.

Demand models for nitrogen (N) and phosphorus (P) are shown in Table 5. Households applied higher rates of N and P on land which was rented-in and the effect is strong and highly significant. Consistent with the findings reported above, the two elements are more intensively used during the major rainy season. There was greater amount of N and P applied in plots planted with maize, which is in line with previous findings that inorganic fertilizers are more likely to be applied to maize than on other plots among smallholder farmers in this region. This effect was highly significant but also largest in magnitude amongst all factors considered. Farmers also applied N and P more intensively in larger plots, suggesting that land is a constraint to fertilizer use. The two elements were applied more intensively in plots with more crops grown but less intensively in plots planted with more legumes. This suggests that farmers are aware of the benefits of nitrogen fixing leguminous crops and that legumes are substitutes for inorganic fertilizer. The lower intensity of P applied may reduce nitrogen fixation since P is critical in nodulation in leguminous crops.

Again, households with greater knowledge about soil fertility management applied N and P more intensively. Male-headed households applied more N and P, a finding which is in line with previous studies. Family labour supply also affected demand for both N and P in similar ways to use of fertilizer in the multivariate probit model. Similarly, households with greater farming experience were found to apply both elements less intensively, a behavior associated with greater averseness to risk by older farmers.

The effect of markets on fertilizer demand is pronounced. Households in areas with unfavorable market conditions (higher fertilizer prices and less access to market infrastructure) applied N and P less intensively. Moreover, an increase in fertilizer price had a negative effect on demand, particularly for N. The effect on P has the expected negative sign but is not statistically significant.

5. Conclusions

Based on the conceptual framework of farmer decision-making with imperfect or missing markets and a knowledge threshold, we have examined the use of soil fertility management strategies as a multivariate probit model to allow for correlations between decisions. We then estimated the demand for N and P per acre with a Tobit model.

Strong effects were observed for plot size and for land tenure, signaling the importance of these variables and land use policy in encouraging greater adoption of integrated soil fertility management practices. Findings also confirm the price responsiveness of farmers, and the influence of market infrastructure (including various indicators of ‘hard’ and ‘soft’ infrastructure) on their use of not only inorganic fertilizer, but soil erosion control and other soil amendments. An increasing price of fertilizer, relative to that of grain, leads to a decline in demand for fertilizer, and particularly N.

The analysis suggests that off-farm earnings positively influences the use of soil fertility management practices, but reduces demand for inorganic fertilizer per acre. This finding raises questions for further research. Are households whose off-farm earnings constitute an increasing share of household income intensifying farm production or diversifying out of farming?

Multiple cropping and more cropping of legumes have various effects depending on the practice, reflecting farmer objectives to maximize returns form inorganic fertilizers and the role of nitrogen-fixing crops as substitutes. The higher demand for fertilizer per acre on plots planted with maize confirms that maize is indeed the most fertilized crop on smallholder farms in the grain basket of Kenya.

The crucial role of knowledge in uptake of integrated soil fertility management practices is evident. Farming experience, measured simply in terms of years farming, has no perceptible effect. The effect of numbers of household members, which we used to represent labor supply, depend on the practice and also the age group represented, likely because life-cycle factors are confounded with age groups. Female headship reduces uptake of soil fertility management measures on maize and also demand for fertilizer (both N and P).

The findings point to the important ways through which commonly used proxies for family labour influence soil fertility management, showing that different age groups within households have different effects. It is evident that labour is the limiting factor in soil fertility management during the main season.

6. Policy implications

Although the soils in smallholder farms in Kenya are highly degraded, there is less than half a chance that households will apply inorganic fertilizers or other soil amendments. The average intensity of fertilizer use is too low (4 kg/acre in all plots and 6 kg/acre in maize plots). From the study findings we suggest the following policy interventions to increase demand for various soil fertility management strategies in the study areas.

A better market environment and market-related incentives triggers the desired response of increasing uptake of practices to manage soil better and increase fertilizer use per acre. Our analysis suggests that policies aimed at improving the market infrastructure and services will improve soil fertility management, and not just fertilizer use.

Although the rental-land market seems to offer adequate incentives for intensive use of inorganic fertilizers, it currently lacks incentives that would promote the application of practices for which economic benefits accrue over time, such as soil erosion control and use of soil amendments. Policies aimed at improving the land rental market are necessary in this regard. For example increasing tenant security in the long term would enable tenants to realize benefits of good or sustainable soil fertility management.

Other than markets and infrastructure, efforts should be directed towards educating farmers about soil fertility management strategies, and the potential for complementarity and substitutability among practices. Targeted support is needed for households headed by women and for young families. Innovations to reduce the laborintensivity of soil fertility management practices should be encouraged. Further research is needed to explore the relationship between off-farm earnings and investments in soil fertility management.

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Table 1: Variable definitions and summary statistics

Variable	Definition	All plots		Maize plots	
		Mean	Std. Error	Mean	Std. Error
Inorganic	Whether inorganic fertilizer was used? 1=yes; 0=no	0.31	0.01	0.49	0.01
Erosion	Whether erosion control structures in plot? 1=yes; 0= no	0.59	0.01	0.68	0.01
Amendments	Whether there were other soil amendments?1=yes; 0=no	0.40	0.01	0.54	0.01
Rent land	Whether land is rented-in 1=lease; 0= no	0.10	0.00	0.14	0.01
Season	Season (1=major; 0=minor)	0.65	0.01	0.58	0.01
Plot size	Size of plot (acres)	0.55	0.01	0.82	0.01
Ncrops	Number of crops planted in plot	2.09	0.02	3.09	0.04
Nlegumes	Number of legumes planted in plot	0.56	0.01	0.95	0.01
Maize	Whether plot was planted with maize=1; else 0	0.42	0.01	1.00	0.00
	Phosphorus (P) use intensity (kg per acre)	4.51	0.25	6.09	0.50
	Nitrogen (N) use intensity (kg per acre)	4.85	0.18	6.04	0.28
Off-farm income	Proportion of household income from off-farm activities	0.35	0.01	0.35	0.01
Female headship	Sex of household head (1=male;0 female)	0.76	0.01	0.76	0.01
Labour 1	Number (person months) residing in household (15 to 23 years)	12.42	0.45	12.41	0.45
Labour 2	Number (person months) residing in household (24 to 55 years)	17.28	0.35	17.30	0.35
Labour 3	Number (person months) residing in household (over 55 years)	6.69	0.27	6.69	0.28
	Number of years household has been farming	23.72	0.49	23.71	0.49
Infrastructure	Market infrastructural development (factor score)	-0.03	0.00	-0.02	0.00
Livestock value	Value of livestock owned by household (KES)	32887	1264	33061	1272
Fertilizer price	Fertilizer price - predicted (KES per kg)	60.89	0.45	60.87	0.45
Priceratio	Fertilizer to maize grain price ratio	-	-	2.68	0.11
Knowledge	Household knowledge on ISFM	2.54	0.01	2.54	0.01

N=6048 plots of which 2513 were maize plots; N=1000 households of which 992 planted maize.
Source: Authors

Table 2: Multivariate probit regressions explaining investments in soil fertility management

	All Plots			Maize Plots Only		
	Inorganic Fertilizer	Soil Erosion Control	Other Soil Amendments	Inorganic Fertilizer	Soil Erosion Control	Other Soil Amendments
Rent land	0.4721**	-0.3783**	-0.4423**	0.2321*	-0.6444**	-0.8127**
	(0.080)	(0.088)	(0.115)	(0.103)	(0.110)	(0.120)
Off-farm income	0.1602*	0.3284**	0.1675+	0.2860*	0.2348+	0.0702
	(0.081)	(0.119)	(0.093)	(0.113)	(0.140)	(0.108)
Season	-0.0048	-0.3578**	-0.3044**	0.1629**	-0.2842**	-0.2101**
	(0.038)	(0.028)	(0.026)	(0.055)	(0.044)	(0.046)
Plot size	0.4197**	0.1566**	0.0505	0.1337**	-0.0081	-0.0552
	(0.043)	(0.043)	(0.036)	(0.047)	(0.047)	(0.049)
Ncrops	0.1177**	0.1403**	0.1404**	0.0621**	0.1198**	0.0955**
	(0.012)	(0.014)	(0.013)	(0.016)	(0.019)	(0.017)
Nlegumes	0.0395	0.0144	0.2054**	-0.0279	-0.0236	0.1752**
	(0.039)	(0.037)	(0.035)	(0.057)	(0.059)	(0.055)
Female headship	0.1013	0.1042	-0.1324	0.3425**	0.2397*	0.0310
	(0.083)	(0.088)	(0.083)	(0.105)	(0.108)	(0.106)
Labor 1	-0.0053**	0.0024	-0.0014	-0.0050+	0.0037	0.0020
	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)
Labor 2	0.0031	0.0021	0.0073*	0.0020	0.0034	0.0072+
	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)
Labor 3	-0.0053	0.0089+	0.0022	-0.0084	0.0127+	-0.0021
	(0.005)	(0.005)	(0.005)	(0.006)	(0.007)	(0.006)
Experience	-0.0023	0.0011	-0.0002	-0.0021	0.0007	0.0024
	(0.003)	(0.003)	(0.002)	(0.004)	(0.004)	(0.003)
Livestock value	-0.0000	-0.0000	0.0000**	0.0000	0.0000	0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Markets	-0.1643**	0.0179	-0.1005**	-0.2237**	-0.0237	-0.0749+
	(0.034)	(0.041)	(0.032)	(0.044)	(0.049)	(0.039)
Fertilizer price	-0.0373**	-0.0119*	-0.0273**	-0.2305**	-0.0418	-0.1585*
	(0.004)	(0.005)	(0.005)	(0.070)	(0.075)	(0.073)
Knowledge	0.1836*	0.3444**	0.1526+	0.5931**	0.4040**	0.3630**
	(0.078)	(0.091)	(0.078)	(0.105)	(0.103)	(0.102)
Constant	0.7808*	-0.2955	0.7145+	-1.5595**	-0.9436*	-0.8625*
	(0.393)	(0.448)	(0.405)	(0.369)	(0.380)	(0.360)
Observations	5,801	5,801	5,801	2,413	2,413	2,413

Robust standard errors in parentheses.** p<0.01, * p<0.05, + p<0.1

Table 3: Diagnostic tests for multivariate probit models

	All Plots	Maize Plots Only
Inorganic fertilizer and erosion control (atrho21)	0.0863**	0.0513
	(0.029)	(0.045)
Inorganic fertilizer and other soil amendments (atrho31)	0.1820**	0.0259
	(0.028)	(0.041)
Erosion control and other soil amendments (atrho32)	0.0699*	0.1368**
	(0.032)	(0.045)
Chi-square for LR test of rho (ρ) = 0	90.69***	19.58***

Source: Authors

Table 4: Predictions from the multivariate probit model (simulated maximum likelihood)

	Mean (All Plots)	Mean (Maize Plots)
Marginal predicted probability of inorganic fertilizer use	0.32	0.47
Marginal predicted probability of erosion control	0.60	0.66
Marginal predicted probability of soil amendment	0.40	0.51
Predicted joint probability of failure in every outcome	0.12	0.19
Predicted joint probability of success in every outcome	0.21	0.12

Note: The mvprobit program in STATA fits multivariate probit models using the simulated maximum likelihood using the Geweke–Hajivassiliou–Keane or the so-called GHK simulator (Cappellari, L. and S. P. Jenkins, 2003).
Source: Authors

Table 4: Tobit regressions explaining intensity (kg per acre) of fertilizer (inorganic) use

	Nitrogen (N)	Phosphorous (P)
Rent land	8.750***	12.21***
	(1.609)	(2.644)
Off-farm income	-1.370	-5.056*
	(1.519)	(2.649)
Season	4.711***	5.258***
	(1.176)	(1.940)
Maize	17.59***	28.78***
	(1.349)	(2.235)
Plot size	6.024***	6.059***
	(0.757)	(1.245)
Ncrops	1.352***	1.688***
	(0.324)	(0.531)
Nlegumes	-6.065***	-7.513***
	(1.016)	(1.682)
Livestock value	2.21e-05*	3.28e-05*
	(1.18e-05)	(1.94e-05)
Experience	-0.138***	-0.160**
	(0.0462)	(0.0768)
Female headship	4.986***	5.267**
	(1.448)	(2.398)
Labor 1	-0.0599*	-0.174***
	(0.0350)	(0.0589)
Labor 2	0.109**	0.197**
	(0.0555)	(0.0914)
Labor 3	-0.0321	-0.144
	(0.0814)	(0.136)
Markets	-4.422***	-4.600***
	(0.594)	(0.955)
Fertilizer to maize price ratio	-4.147***	-1.135
	(0.945)	(1.530)
Knowledge	8.701***	12.39***
	(1.420)	(2.344)
Constant	-46.37***	-87.81***
	(5.101)	(8.520)
Observations	5,801	5,801

Robust standard errors in parentheses. ** p<0.01, * p<0.05, + p<0.1

Source: Authors

Annex.

Factor Analysis

```
Factor analysis/correlation                        Number of obs    =     6048
    Method: principal factors                      Retained factors =        9
    Rotation: (unrotated)                          Number of params =      108
```

Factor	Eigenvalue	Difference	Proportion	Cumulative
Factor1	3.19302	1.88280	0.6191	0.6191
Factor2	1.31022	0.65794	0.2540	0.8732
Factor3	0.65228	0.12666	0.1265	0.9996
Factor4	0.52562	0.20853	0.1019	1.1015
Factor5	0.31709	0.10948	0.0615	1.1630
Factor6	0.20761	0.07463	0.0403	1.2033
Factor7	0.13298	0.08788	0.0258	1.2291
Factor8	0.04510	0.01941	0.0087	1.2378
Factor9	0.02569	0.08305	0.0050	1.2428
Factor10	-0.05736	0.04028	-0.0111	1.2317
Factor11	-0.09765	0.04752	-0.0189	1.2127
Factor12	-0.14517	0.03896	-0.0281	1.1846
Factor13	-0.18413	0.02619	-0.0357	1.1489
Factor14	-0.21032	0.04468	-0.0408	1.1081
Factor15	-0.25501	0.04753	-0.0494	1.0587
Factor16	-0.30254	.	-0.0587	1.0000

LR test: independent vs. saturated: chi2(120) = 2.8e+04 Prob>chi2 = 0.0000

Factor loadings (pattern matrix) and unique variances

Variable	Factor1	Factor2	Factor3	Factor4	Factor5	Factor6	Factor7	Factor8	Factor9
fertkm	0.8002	-0.4631	0.1895	-0.1129	0.0054	-0.0719	0.0160	-0.0214	-0.0098
seedkm	0.7928	-0.4662	0.2079	-0.1239	-0.0062	-0.0646	0.0005	-0.0282	0.0139
road	0.2679	0.0724	-0.0410	0.0640	0.0002	-0.0085	0.1891	0.0434	-0.0973
tarmac	0.4933	-0.2127	0.0056	0.2819	-0.0734	0.1096	0.0272	0.0987	0.0431
delect	0.3716	0.2682	0.1563	0.1880	-0.1411	0.0646	0.0712	-0.0575	-0.0507
dwater	-0.0634	0.1008	0.0944	0.3456	0.1044	-0.1986	0.1160	0.0192	0.0384
dpry	0.1671	0.3221	0.0511	-0.3597	0.0980	-0.1146	0.0705	0.0865	0.0003
dsecy	0.3945	0.4905	0.1432	-0.2254	-0.0933	-0.0193	0.0120	0.0371	0.0408
distdry	0.2044	0.1262	0.0563	-0.0965	0.3164	0.2077	-0.0252	-0.0100	-0.0317
distwet	0.0591	0.0772	0.1849	0.0420	0.1653	0.2140	0.1404	-0.0202	0.0669
distshop	0.3320	0.4364	0.2160	0.1018	0.0141	-0.0648	-0.0485	-0.0845	-0.0099
dmarket	0.3601	0.2413	0.0370	0.1963	0.2288	-0.1304	-0.1420	0.0087	0.0054
dhealth	0.3627	0.3424	-0.0016	0.0006	-0.2802	0.0823	-0.0424	0.0058	0.0238
dtelephone	0.5992	0.0413	-0.1245	0.1183	0.0298	0.0874	-0.1471	0.0755	-0.0336
dextension	0.4951	0.0968	-0.4745	0.0202	0.0485	-0.0643	0.0678	-0.0136	0.0143
dvet	0.5123	0.0511	-0.4347	-0.0681	0.0284	0.0197	0.0413	-0.0777	0.0295

Percentage of Households Aware of and Practicing Various Soil Fertility Management Technologies

	Western		Nyanza		Central		Overall	
Use of farm yard manure	93.5	69.3	91.3	61.1	99.7	92.5	95.1	75.3
Use of inorganic fertilisers	98.0	71.8	96.0	46.8	98.3	87.1	97.6	70.8
Terracing	89.8	58.6	75.8	42.1	91.7	57.2	86.9	53.9
Crop rotation	87.5	75.8	84.5	52.8	64.7	24.7	78.8	52.2
Grass trips	77.1	47.6	57.1	20.6	95.1	79.9	78.3	52.0
Wind breaks	62.8	38.9	63.1	26.2	65.5	42.0	63.8	36.8
Contour farming	56.4	38.9	70.2	38.9	51.4	27.3	58.1	34.9
Cut-off drains/soil bounding	67.1	42.6	65.9	48.0	45.4	12.1	59.2	33.4
Composting	84.0	46.4	56.7	25.4	53.4	13.5	66.5	29.7
Mulching/cover crop	68.1	38.7	71.4	21.4	66.4	19.0	68.3	27.5
Fallow	70.8	31.7	92.5	50.0	47.4	5.5	68.1	27.2
Afforestation	58.6	27.9	64.7	21.0	61.5	21.0	61.1	23.8
Agro forestry (other trees)	33.7	12.2	25.8	4.8	65.5	50.3	42.8	23.6
Growing legume crops	24.9	17.5	39.3	29.8	20.1	10.3	26.9	18.1
Slash and burn	67.3	20.7	77.8	26.6	39.7	4.3	60.3	16.5
Water pans/planting basins	11.5	7.0	35.3	17.9	16.1	6.3	19.1	9.5
Use of green manure	33.7	12.2	20.2	6.0	25.9	6.6	27.6	8.7
Minimum tillage	17.7	6.0	43.7	11.5	23.6	4.3	26.3	6.8
Agro forestry (legume trees	27.2	11.5	29.8	3.6	10.1	2.0	21.9	6.2
Gabions/storm bands	33.9	3.2	39.7	5.2	45.1	3.2	39.3	3.7
Use of lime	9.2	1.2	6.7	0.0	8.6	0.9	8.4	0.8
Use of inoculums	1.7	0.2	1.2	0.0	0.6	0.0	1.2	0.1