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Factors affecting the use of fertilizers and manure by smallholders: the case of Vihiga, western Kenya

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Abstract Sub-Saharan Africa faces huge food supply challenges due to increasing human population, limited opportunities to increase arable land, and declining yields associated with continuously declining soil fertility. To cater for their food requirements, smallholders use only modest levels of inorganic fertilizers and rely to a large extent on manure, which is generally of low quality. To explore factors influencing fertilizer and manure use at the farm level, 253 farm households in Vihiga district of western Kenya were sampled. A pair of Tobit models was used to relate amounts of manure and fertilizer used to household variables. The results indicate that the use of both manure and fertilizer reciprocally influence each other and are strongly influenced by household factors, and also imply that manure and fertilizer uses are endogenous. Policy changes are required to (1) reduce the burden on farming alone in rural areas; (2) promote the use of higher-cost, higher-value inputs such as fertilizers; (3) improve access to input and output markets; and (4) encourage farmer education so as to promote sustainable soil fertility management. Improved understanding of the biophysical and socioeconomic environment of smallholder systems can help target sustainable soil fertility interventions more appropriately.

Keywords Soil fertility management · Smallholders · Policy · Kenya · Tobit models

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Introduction

The human population in sub-Saharan Africa (SSA) will reach 1.2 billion by the year 2025 from its current level of about 611 million (Thornton et al. 2002). This will have profound implications for agriculture in all regions of the continent. Demand for cereals in SSA will treble to 150 million tonnes by 2020 (Badiane and Delgado 1995), but demand is likely to outstrip supply even under the most favourable projected response scenarios. Most tropical soils not only have low production potential due to inherent nutrient deficiency, low organic matter, aluminium and iron toxicity, and moisture stress, but are also vulnerable to chemical and physical degradation and soil erosion (Place et al. 2003). In most mixed smallholder systems, low input levels and poor land management worsen the situation further. This is caused by shortage of land and capital resources, which constrain adoption of economically sustainable land management practices (Shepherd and Soule 1998). System sustainability in terms of nutrient depletion[1] is thus likely to become an increasingly serious issue, unless there is better integration of mixed crop-ruminant livestock systems in the short run and ultimately increased fertilizer use. In mixed systems, livestock can maintain some level of sustainability of heavily cropped land by providing incentives for increased nutrient inputs via imported feeds and fodder and through nutrient cycling with reasonably efficient management of manure (Shepherd and Soule 1998).

Many parts of sub-Saharan Africa are characterized by soil nutrient depletion (Heisey and Mwangi 1996; De Jager et al. 1998). Sanchez et al. (1997) showed annual losses of 4.4 million tons of nitrogen (N), 0.5 million tons of phosphorous (P) and 3 million tons of potassium (K) in 37 countries in sub-Saharan Africa. These losses greatly outweigh the annual additions from fertilizer applications, at rates of 0.8 million tons of N, 0.26 million tons of P and 0.2 million tons of K. Countries with the highest levels of nutrient depletion are in eastern and southern Africa, those with moderate depletion levels are in coastal western Africa, while those with the lowest depletion levels are in the Sahel belt, which extends from Senegal to Sudan, and central Africa. This pattern mirrors human population pressure and its toll on natural resources. The steady fall in soil nutrients appears to be linked to poor soil fertility management driven by continuous cropping under ever-increasing population pressure. But it has been argued (Omamo et al. 2002; Heisey and Mwangi 1996) that increasing population pressure need not lead to soil nutrient depletion; this is demonstrated in Asia with much higher population densities, where average grain yields are three times those of Africa and growing, while those in Africa have stagnated. Although the potential returns to fertilizer[2] use have been demonstrated for a long time in many places, farmers still use inadequate levels of inorganic fertilizers (Heisey and Mwangi 1996). Fertilizer use in sub-Saharan Africa has not changed much from the 1960s to the 1990s (MSU 1998): an increase from 5 kg per hectare to 8 kg per hectare. In comparison, fertilizer use in the 1990s rose from 10 kg per hectare to 110 kg in India and 240 kg in China.

The main constraints to fertilizer use can be grouped into those related to external factors and those related to household conditions and circumstances—internal factors (MSU 1998). External factors include those related to rainfall (e.g., greater than 700 mm per year); access to irrigation that would allow crop production; infrastructure that minimizes transfer costs; credit, because the costs associated with purchase, storage and transportation of (bulky) fertilizer are high; and a critical mass of commercial farming in the area, which increases economies of scale in the fertilizer trade. Internal factors include availability of cash and access to credit, access to input and output markets and to complementary inputs which have ''thin'' markets (such as manure), and the appropriate knowledge base. Pockets of high fertilizer use have been reported in areas with good market access such as Mutoko, Zimbabwe and central Kenya; moderate use in western Kenya and Shurugwi, Zimbabwe; and very low use in central and western Uganda, which incur higher transport costs (Palm et al. 1997; MSU 1999a).

[1] This is the most devastating form of soil degradation in sub-Saharan Africa but may also be closely associated with soil erosion.

[2] ''Fertilizer'' in this paper represents inorganic fertilizer.

Background

Well-established nutrient management practices undertaken by smallholders include use of manure and intercropping legumes while composting and agroforestry are relatively new and limited (Place et al. 2003). Manure use is widespread in areas where cattle is a component of the mixed cropping systems and more so in those areas that have intensive livestock systems. Thorne et al. (2002) report substantial manure use in the relatively intensive systems of central and western Kenya, Tanga and Kilimanjaro in Tanzania, Gokwe, Chiota and Chiduku in Zimbabwe, and limited use of both fertilizers and manure in the relatively extensive systems of Ntonda and Chisepo in Malawi.

Manure releases nutrients to the soil slowly and helps soils to build organic matter with long-term benefits (Place et al. 2003; Palm et al. 1997). High soil organic matter contents tend to reduce infestation of *Striga hermonthica*, a parasitic weed which causes major losses to maize yields. In areas that are susceptible to drought, adequate organic matter helps to retain soil moisture. Manure and compost suffer from the fact that they require much labour to carry and spread on the fields. Manure generally has only 1.5% to 2% N, but often may be only 0.5% in these smallholder systems, and only limited amounts (less than 0.5 tons per ha per year) are often applied (Shepherd et al. 1995). At these low N concentrations, manure will decrease N availability to crops, rather than increasing the supply. Recommended application rates by the Ministry of Agriculture in Vihiga for all crops of are 10 tons per ha (Salasya 2005). Compost making, which can help to reduce carbon to nitrogen ratios and increase N availability, is rarely practiced as readily available sources of material are limited. The system of grazing does not allow for the collection of good-quality manure, and farmers generally leave manure to dry, leading to further loss of nutrients. While there are slightly more nutrients in urine, farmers rarely use it because collection and subsequent delivery to the field is cumbersome and labour intensive. Only 56% of farmers in Vihiga use manure and the average quantity used is quite low at 211 kg per ha (Table 1). In parts of Ethiopia, manure is burned as fuel (Thorne et al., 2002). As in other parts of sub-Saharan Africa, crop residues are not retained in the field as they are used as cattle fodder or burned as fuel.

In Vihiga, extension workers recommend the use of organic manure and/or triple super phosphate (TSP), calcium phosphate (CaP) or rock phosphate, but not di-ammonium phosphate (DAP), which is soil acidifying. However, DAP makes up about one half of all the fertilizer used among the 12 types available (MOA 1994, 2000). There is no good agronomic reason why DAP should be superior to other phosphorus sources, since in East African soils there is a pronounced flush of nitrogen mineralization at the start of the rains, and the small amounts of N supplied in DAP are likely to be leached out of the root zone by the time that high crop demand for N occurs. Farmers' preference for DAP could be due to historic reasons: DAP has been more readily available country-wide than TSP or calcium phosphate. For example, while total fertilizer use increased gradually from 879 tons in 1994 to 2,356 tons in 2000, there was a decline in the use of TSP and rock phosphate, largely because of their unavailability. Recommended application rates by the ministry of agriculture in Vihiga for all crops of are 130 kg per ha (Salasya 2005). Although 70% of the farmers in Vihiga use fertilizers, the amount used is quite low. It was on average 10.7 kg of fertilizer per ha (Table 1), which is much lower than the already-low Kenyan average of 46 kg per ha, of which 20–28% goes to food crops (Mugunieri et al. 1997). Ehui and Pender (2005) contend that this is due to limited production of cash crops and low use of hybrid maize in western Kenya.

Other soil fertility enhancement practices promoted in western Kenya are intercropping with leguminous plants and improved fallow rotations. While intercropping of maize and bean or groundnuts is common, farmers are reluctant to give up crop production in a field even for one season of improved fallow even if total production over a two seasons would be significantly increased due to land scarcity (Ehui and Pender 2005).

Table 1 Descriptive statistics for key variables

	Number of observations 253[a]
Farmer characteristics	
Average age of household head in years	51.1 (13.5)
Average education level of household head in years spent in school	8.1 (4.2)
Percentage of male managed households	41
Percentage of households owning means of transport	47
Average annual total income in US $	224.3 (524.1)
Average annual farm income in US $	78.1 (221.1)
Average annual non-farm income in US $	146.2 (367.1)
Farm characteristics	
Average farm size in ha	0.86 (0.98)
Average food crops area in ha	0.48 (0.66)
Average cash crops area in ha	0.11 (0.15)
Average number of casuals engaged	6.1 (2.2)
Percentage of households using fertilizer	70
Average fertilizer use in kg per ha	10.7 (15.3)
Minimum (maximum) fertilizer use in kg per ha	0 (127)[b]
Percentage of households using more than 100 kg of fertilizer per ha	1
Percentage of households using less than the sample average fertilizer use per ha	67
Percentage of households using manure	56
Average manure use in kg per ha	211.6 (408.46)
Minimum (maximum) manure use in kg per ha	0 (3,237.6)[b]
Percentage of households using more than 1,000 kg of manure per ha	6
Percentage of households using less than the sample average manure use per ha	75
Average tropical livestock units (TLU[5]) per ha	0.4 (0.5)
Average household size in number of persons	15.0 (5.6)
Average household members aged 15–61 years	9.3 (5.3)
Average distance to nearest market in km	2.0 (1.5)

[a] numbers in parenthesis are standard deviation unless otherwise indicated

[b] number in parenthesis is maximum use in kg per ha

In this paper, we identify the factors that constrain fertilizer and manure use by smallholders in Vihiga District in western Kenya, as part of a project on systems prototyping and impact assessment in East Africa, named PROSAM (Booltink et al. 1999). PROSAM seeks to contribute to improved sustainability of mixed farming systems in the high-potential areas. It incorporates households' objectives into a coherent decision-making framework that can evaluate the feasibility of alternative practices, and identify promising options for farmer experimentation. The framework combines simulation modelling and participatory approaches that allow farmers to analyse and define appropriate agronomic practices that suit their own conditions. The objective of this study was to identify household-level factors that affect use of fertilizer and manure (intensity of manure and fertilizer use in kg per ha) with a view to improving our understanding of why the intensity of use of manure and fertilizers has been low despite prolonged demonstrations of their potential benefits and improved availability of fertilizers after market liberalization. Basing the analyses on use (applying or not applying) rather than on intensity of use could mask the fact that usage below recommended threshold levels will generally limit returns from the use of inputs to suboptimal levels. We draw policy conclusions that would be applicable to areas with similar characteristics to Vihiga, and highlight the importance of understanding the basic rationale of small-scale mixed farming in such systems. This work contributes to our understanding of smallholder fertility management decisions so that R&D efforts to raise incomes and/or increase sustainability can be more effective in the future.

Methodology

Vihiga district lies between 1,300 and 1,500 m above sea level and is predominantly in the upper midland (UM1) agroecological zone (Jaetzold and Schmidt 1983), with well-drained Nitosols that support the growing of various cash and food crops. The fertility of these soils is low from continuous cropping with annuals and leaching over several decades. The area receives adequate bimodal rainfall that ranges from 1,800 to 2,000 mm per year. The average household has 15 persons living on 0.9 ha of land (a population density of 886 persons per square km), creating a very high dependency on agriculture (Central Bureau of Statistics 2001). Maize is the main food crop while tea is the main cash crop, and the predominant livestock is local Zebu. Farming is mainly low-external-input subsistence production. Vihiga falls in the maize mixed system of the FAO farming systems classification[3] (Hall et al. 2001). This system extends across the plateau and highland between 800 and 1,500 m above sea level. It is common in Kenya, Tanzania, Malawi, Zambia, Zimbabwe, South Africa, Swaziland and Lesotho, and accounts for 10% of the cultivated area and sustains an agricultural population of some 80 million. In this region, most maize grain is used for human consumption with only 5% being used to feed livestock. Green stover (thinnings, leaf stripping, plant tops or entire green plants) and dry stover from the mature plant after grain harvest are commonly used as ruminant feeds.

Data for this study were collected in a large characterization survey covering western Kenya (Waithaka et al. 2002). Using structured questionnaires, data were collected on farmer and household characteristics, crop and livestock production, income and soil fertility management practices. Data from some 253 households in Vihiga district were extracted from this sample and used in subsequent stages of the analysis. Selected household characteristics are presented in Table 1. Soil samples for analysis of soil fertility were collected in sample farms that were monitored over a period of time by the PROSAM team.

Technology adoption

Assuming that farmers make adoption decisions based upon the objective of utility maximization, a farmer will adopt a technology when the utility of a new technology (U_n) exceeds the utility of a traditional technology (U_t). The utility derivable from a new technology is postulated to be a function of the vector of observed farm characteristics (e.g., farm size, distance to the market) and farmer characteristics (e.g., farm size, age of farmer), perceived technology characteristics (X_i) and a disturbance term having a zero mean. Perceived technology characteristics themselves are a function of objective/or subjective characteristics of a technology, farm and farmer-specific characteristics.

Farmers then weigh the consequences of adoption of a new technology against its economic, social, and technical feasibility and choose the technology (T) that promises higher utility than the traditional technology (Adesina and Zinnah 1993; Rahm and Huffman 1984). Suppose an individual household's preference or utility of adopting a new technology, for a given vector of economic, social and physical factors (X), is denoted by $U_n(X)$ and the preference of adopting the traditional technology $U_t(X)$; then the preference for adopting the new and old technologies can be defined as a linear relationship:

$$U_n(X) = XB_n + E_n \quad (1)$$

$$U_t(X) = XB_t + E_t \quad (2)$$

where B_n, B_t and E_n, E_t are response coefficients and random disturbances associated with the

[3] This classification, based on available natural resource base, dominant pattern of farm activities and household livelihoods, defines eight distinct systems. Thorne et al. (2003) break down this system by scale of production and intensity of livestock production.

adoption of new and traditional technologies, respectively. If the index of adoption is denoted by Y, it will take a value of one if the farmer is willing to adopt the new technology and zero otherwise. The probability that a given farmer will adopt the new technology can be expressed as a function of X as follows:

$$\begin{aligned} P(Y=1) &= P(U_n > U_t) \\ &= P(XB_n + E_n > XB_t + E_t) \\ &= P[X(B_n - B_t) > E_t - E_n] \\ &= P(XB > E) \\ &= F(XB) \end{aligned} \quad (3)$$

where P is the probability function, $B = (B_n - B_t)$ a vector of unknown parameters that can be interpreted as the net influence of the vector of independent variables on adoption of the new technology, $E = (E_n - E_t)$ a random disturbance term and $F(XB)$ is cumulative distribution function F evaluated at XB (Rahm and Huffman 1984).

Empirical model

Models that are used to study adoption behaviour range from simple relationships between two variables to complex multivariate analyses. Simple and complex multivariate regression models have been used to analyze factors influencing a certain outcome, as in Omamo et al. (2002) and MSU (1999b). However, analyses that seek to identify factors influencing the use or adoption of a technology typically use logit, probit and/tobit models (such as Makokha et al. 2001). Logit and probit models and their modified forms have been used extensively to study adoption behaviour of farmers but they are restricted to functional forms with limited dependent variables that are continuous between zero and one.

A Tobit model in this study is appropriate because not all farmers use fertilizer and/or manure. Tobit models are desirable in that they measure not only the probability of adoption but the intensity of use of a technology once adopted - thus the variable Y_i becomes a continuous function of the explanatory variables. Other studies that have used a similar approach include Freeman and Omiti 2003; Adesina and Baidu-Forson 1995; Adesina and Zinnah 1993. The model was specified as follows:

$$Y_i^* = B^1 X_1 + e_i \quad (4)$$

$$Y_i = Y_i^* \quad \text{if} \quad Y_i^* > c \quad (5)$$

$$Y_i = 0 \quad \text{if} \quad Y_i^* \leq c \quad (6)$$

Where Y_i^* is a latent variable indexing adoption, Y is an observable variable measuring both the adoption and intensity of use of fertilizer, c is an unobservable threshold, B is a vector of unknown parameters, X is a vector of explanatory variables, and e_i are residuals that are independently distributed with zero mean and constant variance. Several farmers did not use any fertilizer and manure and so c was censored at the lower tail. If Y_i^* was greater than zero c then the observation was on Y_i^*, and otherwise zero. We did not carry out estimations of probability of use in this study because the initial intensities of fertilizer and manure use were very low and skewed towards zero (Table 1). The observed data on the amount of fertilizer and manure used by farmers contain a cluster of zeros and very low application rates. In the case of fertilizer even the maximum level of use at 127 kg per ha is just about the optimal requirement for all crops in Vihiga (130 kg per ha) (Salasya 2005). However, only three farmers (1% of the sample) were using more than 100 kg per ha while 67% were using rates below the sample average of 10.7 kg per ha. The case for manure is even worse given that 10 tons per ha are required in Vihiga to achieve reasonable nutrient requirements given the low concentrations of N (1.5 to 2%) and P (0.5%) in the manures (Salasya 2005). Only 15 farmers (6% of the sample) were applying more than one ton per ha and 73% were using rates much lower than the sample average of 211 kg per ha. Because the distribution of quantity of fertilizer and manure use is censored, in the lower tail, we used a Tobit model. In such cases, Ordinary Least Squares (OLS) is not suitable as the OLS estimators will be biased (Greene 2000). Understanding the intensity of use can add to knowledge about the reciprocity of fertilizer and manure use which would not otherwise be forthcoming with other models. This understanding can help us to propose more meaningful strategies for soil fertility management in small-scale mixed farming systems.

The choice of independent variables is driven by the hypothesis that fertilizer and manure use are influenced by a combination of farm and farmer characteristics. Farm characteristics measure levels of resource management and access to markets. These are size of the farm, area of the farm under cash crops, number of casuals engaged on the farm, size of household dependent on the farm and distance to the market. Households with large farms are expected to grow both cash and food crops and practice land management practices such crop rotation and fallowing (Crowley et al. 1996). Farm size is expected to be positively related to intensity of fertilizer and manure use. Area of farm under cash crops is expected to relate positively with fertilizer use and negatively with manure use (Omamo et al. 2002). Cash crops with interlinked markets such as tea provide farmers with fertilizers while they guarantee an outlet for the final produce. In such systems manure use is limited by the fact that farmers would expect the fertilizers to boost yields adequately without recourse to manures. Further, since such crops take a large proportion of the farms, farmers will prefer to use the little amounts of manure available to crops not benefiting from fertilizer use. Availability of casual labour will allow farmers to open more land or improve management practices such as land preparation, weeding and application of fertilizers or manure (Crowley et al. 1996). Thus availability of casual labour is expected to be positively related to fertilizer and manure use. It is also be expected that short distances to the market will reduce the relative costs and availability of inputs and improve access to output markets hence generate better incomes. Thus distance to the market is expected to be negatively related to fertilizer use and positively related to manure use, since farmers located far away from supply sources are likely to incur higher transportation and search costs. This is so because manure markets do not exist as such and thus distance to markets has a bearing only on fertilizer costs. However, since manure and fertilizer also have complementary effects, we would expect that increasing distance would raise fertilizer costs, which would tend to make farmers turn to manure. Households with many members dependent on the farm are expected to use less fertilizer, but rely more on manure. This is based on the assumption that such households will be more concerned with meeting food security needs before pursuing income related objectives (Omamo et al. 2002).

Farmer characteristics used in the analysis relate to levels of resource endowment and experience and include education level of the household head, gender of the farm manager, size of the household, ownership of means of transport and income of the household. Older farmers are expected to command more resources and hence have wider investment options including use of fertilizers. However, it will be expected that older household heads will have relatively large farms while younger household heads will own smaller parcels of land. Older household heads will be expected to be less educated and so may not be able to relate well to complex fertilizer management, but will be more comfortable with using manures. Thus education level of the household head may be taken as a proxy for being exposed to (or able to access) technical information on fertilizer use, and thus may be positively associated with fertilizer use (Omamo et al. 2002; Omamo and Mose 2001). Male-headed households are associated with being in command of productive resources. Even where women play key roles in farming decisions, they may not lack access to inputs, cash incomes, credit and technical information. It is expected that female-headed households will be negatively associated with fertilizer and manure use, because women may not command the resources that would allow them access to fertilizers or manure. Households that have some means of transport are expected to be able to access input and output markets and should relate positively with fertilizer and manure use (Jayne et al. 2003). Households with higher incomes (often from off-farm income) have been shown to obtain larger harvests because they are able to access farm inputs (Crowley et al. 1996). A positive relationship is expected between income and fertilizer use, but a negative relationship is expected between income and manure use. This is because with higher incomes, farmers would be expected to afford fertilizers and because of the reciprocal nature of manure and fertilizer use, manure use would be expected to decrease. Salasya 2005, shows that in Vihiga and Kiambu districts in Kenya, manure is mainly used on maize production and with higher incomes households shift from maize to cash crops of higher value and rely on the markets for their maize requirements.

Results and discussions

Mean values and standard deviations of key variables used in the Tobit model are presented in Table 1. There was generally low correlation between most variables (Table 2) implying reasonable independence between the factors identified above. However, and as expected, there was a significant correlation between household size and number of household members aged between 15 and 61 years. Unexpectedly, there was high correlation between casual labour and household size, which implies that as household size increases, the use of casual labour also increases. This can only hold if the household members are not available to offer their labour, e.g., if they are in school or work elsewhere.

The Tobit models results offer some insight into the relationship between manure and fertilizer use (Table 3). The amount of manure used on-farm increases significantly with increased fertilizer use, higher education of the household head, and availability of family labour. However, it declines with increasing incomes. There is an unexpected significant decrease in manure use with increasing casual labour. This could be as a result of the fact that only small quantities of manure are collected from tethered cattle and family labour is adequate for this task. This is because farmers leave the manure to dry and in the process much is lost through trampling and dispersal by the cattle as they walk around. Farm size, proportion of land under crops, gender of farm manager, distance to the market, and availability of means of transport, do not significantly influence the amount of manure used. These outcomes are expected because manure is neither sold nor bought in Vihiga. Increasing the proportion of land under cash crops appears to reduce the amount of manure used, supporting the observation that manure is applied mainly for food crop production using household labour.

The results show that the amount of fertilizer used on a farm increases significantly with increasing farm size, larger proportion of land devoted to cash crops, increasing incomes, ownership of some means of transport, higher education levels of household head, and use of manure. The amount of fertilizer used declines with increasing distance to the nearest market centre. Gender of farm manager, number of casual labourers engaged, and family labour, do not influence significantly the amount of fertilizer used on a farm.

The significance of increased education level of the household head on increased amount of fertilizer used presumably arises from a better understanding of the usefulness of fertilizers, and it may also imply better crop management. Because there are many types of fertilizers, appreciation of the appropriate types for specific crops, soil types and their specific requirements, application regimes, rates and timing increases with exposure through education. In other situations, as here gender is not an issue, males may use more fertilizer simply because they command most of the household resources, including use of cash income. In Malawi, for example, an average female-headed household uses 34 kg per ha of fertilizer, significantly less than the 51 kg per ha used by male headed households, and similar statistics were obtained in Cameroon (Palm et al. 1997). In this study, only 41% of the households were male-headed (Table 1).

Food production may continue to decline if most of the incentives to increased fertilizer use are in the cash crop sector. With the withdrawal of farm subsidies across the region, input prices have risen while food prices have dropped. In Vihiga, the fertilizer to maize price ratio increased from 1.1 in the pre-liberalization era to 2.1 in 2002. With the decline in maize prices over time and continuing unrestricted movement of maize from surplus to deficit areas, the shift to

Table 2 Correlation coefficients of key variables (n = 253)

	Means of transport	Fertilizer use	Manure use	Household size	Household head education	Gender of farm manager	Proportion of cash crops	Farm size	Income category	Casual labour	Distance to nearest market
Fertilizer use	0.234										
Manure use	0.029	–0.112									
Household size	–0.016	0.037	0.030								
Household head education	0.308	0.178	0.190	0.144							
Gender of farm manager	0.073	0.015	0.015	–0.033	0.144						
Proportion of cash crops	–0.034	0.224	–0.077	–0.049	–0.123	–0.013					
Farm size	0.201	–0.043	–0.206	–0.058	0.109	0.117	–				
Income category	0.357	0.197	–0.046	0.010	0.368	0.001	–0.048	0.280			
Casual labour	0.048	0.076	0.012	0.674	0.196	–0.023	–0.060	–0.010	0.098		
Distance to nearest market	–0.086	–0.050	0.013	0.053	0.028	–0.047	0.178	0.018	–0.087	0.049	
Household members 15–61 years	0.110	0.037	0.030	0.597	0.156	–0.035	–0.063	0.057	0.076	0.605	–0.004

Table 3 Results of Tobit models on factors influencing use of manure and fertilizer in Vihiga (*n* = 253)

Variable	Amount of manure used as dependent variable	Amount of fertilizer used as dependent variable
Manure use (kg applied)		0.009* (0.004)
Fertilizer use (kg applied)	3.503* (1.761)	
Ownership of means of transport (1 = yes 0 = none)	326.794 (269.772)	39.851*** (11.720)
Household head education (years spent in school)	53.029* (32.063)	3.709** (1.417)
Gender of farm manager (1 = male 0 = female)	135.261 (248.249)	16.761 (10.920)
Proportion of cash crops (%cash crops area in acres to total cropped area)	–147.265 (819.691)	127.696*** (35.867)
Farm size (acres)	30.580 (52.367)	10.480*** (2.212)
Income category (1 = <US$ 65; 2 = US$ 65 – US$ 260; 3 = >US$ 260 per year)	–690.802** (258.193)	42.350*** (10.380)
Casual labour (number engaged)	–122.183* (67.673)	3.345 (3.030)
Distance to nearest market (km)	–54.640 (62.370)	–11.248*** (2.670)
Household members (15–61 years)	57.528* (28.300)	0.625 (1.242)
Constant	326.000 (555.866)	–114.300*** (24.733)
Log likelihood	–1,330.160	–1,072.751
Number of observations	253	253

* Significant at 10% level, ** Significant at 5% level and *** Significant at 1% level

cash crops may reflect the change in comparative advantage of cash crop production over food production. This may be desirable because resources (land, labour and capital) will be shifted to activities where they receive the highest benefits. However, in the short and medium runs, unless concurrent changes occur in improving access to inputs and opening up of output markets, improvements in infrastructure to reduce costs, and generation of rural incomes, maize production will still be the most important economic activity in Vihiga and other areas in the mixed maize system. However, maize yields are low and national averages are about 1.5 tons per ha in eastern and southern African countries (Thorne et al. 2003). From PROSAM surveys, most smallholder households in Vihiga have maize deficits for six to ten months each year. Annual production levels average 287 kg per ha. At this level of production and fertilizer use, the net returns to maize cultivation are negative. To break even, maize production would have to increase to 660 kg per ha or, alternatively, maize prices would have to double. These yields are well below the research potential of 4.5 tons per ha for hybrid H622 and 4 tons per ha for hybrid H512 within the area.

Higher incomes mean that a household will be able to satisfy its basic requirements and have a surplus for productive activities such as buying fertilizer. Such incomes may also allow a household to engage casual labour, thereby releasing household labour to pursue other endeavours such as keener management of the farm or seeking higher returns from off-farm employment. Large households may spend all income on food and other essential expenditures, leaving little for investment on farms including the purchase of fertilizers. Such households may also be tempted to grow food crops in place of cash crops to satisfy household food requirements. Average total income is US$ 0.73[4] per household per day, indicating that most households are mired in poverty. The main sources of this income are wages and remittances, with an average of US$ 146 per year, while food and cash crops and other farm produce gave on average income of US$ 78 per year. The high contribution of non-farm income to total income (59%) compares with the 65% quoted in Crowley et al. (1996) for the same region.

Longer distances to urban centres where major markets are located increase both the final costs of fertilizers and the time required to access them. The implications of these results are that infrastructure still plays a major role in determining

[4] 1 US$ is equivalent to Kenya Shillings 72 (September 2006)

the availability of crucial inputs. While this is not a household factor per se, it still has considerable influence on decisions made by the household.

Frequent use of manure highlights the crucial role that livestock play in smallholder farming systems that are in the process of intensifying, by allowing the use of manure for food and fodder crops, leaving the use of high-value, high-cost fertilizer to enterprises with higher returns. The average number of tropical livestock units (TLU) per ha of 0.4 is lower than numbers reported for other parts of the country (Staal et al. 2000; Waithaka et al. 2002), and the system of tethering livestock does not allow for the collection of good quality manure. This is why farmers in Vihiga use only 211 kg of manure per ha (Table 1).

The results imply that manure use is more important to the production of food crops (than of cash crops), and this is critical to low-income households. Endogeneity of manure and fertilizer use is supported in this analysis because both influence each other positively and significantly. This suggests that yield improvements observed from use of manure and/or fertilizer encourage further use of fertilizer and/or manure to boost yields of food and cash crops. It can be argued further that in a smallholder setting, manure use is critical to food production, because it can maintain or increase yields at low cost in subsistence systems. In the semi-commercial setting where cash crops such as tea are grown, manure use boosts food production on small plots, thereby allowing larger portions of the land to be used for cash crops of higher value.

Although manure may never replace fertilizers in the short- and medium-terms, and as long as fertilizer-to-maize price ratios remain high, efforts to improve manure management at the farm level promise high pay-offs with respect to household food security and overall income earnings. This calls for more education and creation of awareness, as well as research on ways of producing higher-quality manures using locally available resources (Lekasi et al. 2003). While use of cattle concentrate feeds would be a way of improving the levels of phosphorous in manures, this is only possible in areas where there is intensive milk production driven by availability of good markets, such as in peri-urban areas. In this study, only 13% of the farmers used concentrate feeds. At the same time, increasing the availability of fertilizers, and improving access to input and output markets that will increase returns at the farm level, are options that need to be addressed at the policy level.

Conclusions

The results of this analysis show that the use of both manure and fertilizer in subsistence and semi-commercial systems in western Kenya are strongly influenced by household factors, suggesting several policy implications. First, policy changes are needed that provide incentives and opportunities for off-farm employment in the rural areas. This will reduce the burden on farms and also boost farm incomes in the form of remittances. Results of the analysis suggest that income gained by such employment could further promote the use of high-cost, high-value inputs such as fertilizers.

Second, in areas with shrinking farm sizes due to high population pressure, intensification and diversification out of maize into high-value crops and livestock along with increasing off-farm income are important strategies. Technology options for smaller farms could include increasing the quality of manure, composting plant materials and crop waste, reducing use of dung and crop residues for fuel, and application of fertilizers. For larger farms, possibilities of increasing land under fallow enrichment are needed to maximize returns to land. To the extent that markets allow, encouraging smallholders to shift out of maize to high-value crops and intensive livestock production may be called for.

Third, the results of the analysis clearly imply that policies aimed at improving access to farm input and output markets would encourage sustainable use of fertilizers. Such policies could include investment in improved rural infrastructure and improved marketing mechanisms.

Fourth, education is crucial; soil fertility management is complex and seems to require formal learning or at least guidance from extension providers. The results here show that fertilizer use increases once the benefits have been seen on farmers' own plots, so it is possible that appropriate soil fertility management practices can be extended relatively easily. Participatory learning and research on appropriate soil fertility management practices for smallholders should encourage sharing of knowledge and experiences. These approaches must target women particularly, because they may not control sufficient resources to make meaningful changes to the farming system where they are held responsible for day-to-day management.

These results can provide useful insights to regions with similar characteristics to Vihiga within the maize mixed system covering most of eastern and southern Africa. In this system which is characterized by high population density and declining land holdings, farmers are struggling to find the balance between production of food and cash crops as well as livestock intensification.

A key requirement to overcoming the socio-economic as well as the biophysical constraints to improved soil fertility management at the farm level is an understanding of the basic rationale of small-scale mixed farming in systems such as those in Vihiga. The broader aim of the prototyping and impact assessment work (Waithaka et al. 2006) of which the study is a part, is to incorporate households' objectives into a coherent decision-making framework that can give insights into which practices are feasible and which can then be experimented with by farmers in their own conditions. With an adequate understanding of smallholders' attitudes and objectives, this work can greatly facilitate the targeting of technology and policy-related interventions that are suited to the biophysical and the socioeconomic environment within which smallholders operate. Such information is crucial if targeting is to be effective in the future, to help smallholders modify their systems within a rapidly-changing agricultural sector to expand their livelihood options and combat poverty.

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References

Adesina AA, Baidu-Forson J (1995) Farmers' perceptions and adoption of new agricultural technology: evidence from analysis in Burkina Faso and Guinea, West Africa. Agric Econ 13:1–9

Adesina AA, Zinnah MM (1993) Technology characteristics, farmers' perspectives and adoption decisions: a Tobit model application in Sierra Leone. Agric Econ 9:297–311

Badiane O, Delgado CL (1995) A 2020 vision for food, agriculture and the environment in sub-Saharan Africa. Food, agric. and the Environ. Discussion Paper 4. International Food Policy Research Institute (IFPRI), Washington DC, USA

Booltink HWG, Thornton PK, Waithaka MM, Shepherd KD, Jones JW (1999) System prototyping and impact assessment for sustainable alternatives in mixed farming systems in high-potential areas of Eastern Africa. A proposal to the Ecoregional Fund to Support Methodological Initiatives. Wageningen University, The Netherlands. http://www.cgiar.org/ilri/prosam

Central Bureau of Statistics (2001) 1999 Population and housing census. Counting our people for development. Vol. I Population distribution by administrative areas and urban centers and Vol. II Socio-economic profile of the population. Central Bureau of Statistics, Ministry of Finance and Planning, Nairobi, Kenya

Crowley EL, Soule MJ, Carter SE (1996) Off-farm income and farming in western Kenya. Report to USAID/Kenya, Nairobi

De Jager A, Kariuki I, Matiri FM, Odendo M, Wanyama JM (1998) Linking economic performance and nutrient balances in different farming systems in Kenya: a synthesis towards an integrated analysis of economic and ecological sustainability. Agric Ecosyst Environ 71:81–92

Ehui S, Pender J (2005) Resource degradation, low agricultural productivity, and poverty ijn sub-Saharan Africa: pathways out of the spiral. In: Colman D, Vink N (eds) Reshaping agriculture's contributions to society. Proceedings of the 25th International Conference of Agricultural Economists 16–22 August, 2003 Durban, South Africa. Blackwell Publishing, pp 225–242

Freeman AH, Omiti JM (2003) Fertilizer use in semi-arid areas of Kenya: analysis of smallholder farmers' adoption behaviour under liberalized markets. Nutr Cycl Agroecosys 66:23–31

Greene WH (2000) Econometric analysis. 4th edn. Prentice-Hall, Inc., Upper Saddle River, New Jersey

Hall M, Dixon J, Gulliver A, Gibbon D (eds) (2001) Farming systems and poverty. Improving farmers' livelihoods in a changing world. FAO and World Bank, Rome and Washington D.C

Heisey PW, Mwangi W (1996) Fertilizer use and maize production in Sub-Saharan Africa. CIMMYT Economics Working Paper 96-01. CIMMYT, Mexico, DP

Jaetzold R, Schmidt H (1983) Farm management handbook of Kenya, vol 1. Nairobi
Janhke HE (1982) Livestock production and livestock development in tropical Africa. Weltforum Verlag, Munich
Jayne TS, Govereh J, Wanzala M, Demeke M (2003) Fertilizer market development: a comparative analysis of Ethiopia, Kenya, and Zambia. Food Policy 28:293–316
Lekasi JK, Tanner JC, Kimani SK, Harris PJC (2003) Cattle manure quality in Maragua district, central Kenya: effect of management practices and development of simple methods of assessment. Agric Ecosyst Environ 94:289–298
Makokha S, Kimani S, Mwangi W, Verkuijl H, Musembi F (2001) Determinants of fertilizer and manure use in maize production in Kiambu district, Kenya. International Maize and Wheat Improvement center (CIMMYT) and Kenya Agricultural Research Institute (KARI), Mexico DF
Ministry of Agriculture 1994–2000. Annual report. Nairobi, Kenya
MSU, (1999a) Successes and challenges of food market reform: experiences from Kenya, Zambia and Zimbabwe. In: International Development Working Paper No. 72 Department of Agricultural Economics, Michigan State University (MSU), East Lansing, MI
MSU (1999b) Effects of agricultural commercialization on food crop input use and productivity in Kenya. In: International Development Working Paper No. 71 Department of Agricultural Economics, Michigan State University (MSU), East Lansing, MI
MSU (1998) Incentives for fertilizer use in sub-Saharan Africa: a review of empirical evidence on fertilizer response and profitability. In International Development Working Paper No. 70 Department of Agricultural Economics, Michigan State University (MSU), East Lansing, MI
Mugunieri GL, Nyangito HO, Mose LO (1997) Agronomic and socio-economic factors determining maize yield response to fertilizers in western Kenya. In: Adipala E, Tenywa JS, Ogenga-Latigo MW (eds) African crop science conference proceedings. Pretoria, 13–17 January 1991 pp 1465–71
Omamo SW, Williams JC, Obare GA, Ndiwa NN (2002) Soil fertility management on small farms in Africa: evidence from Nakuru district, Kenya. Food Policy 27:159–170
Omamo SW, Mose LO (2001) Fertilizer trade under market liberalization: preliminary evidence from Kenya. Food Policy 26:1–10
Palm CA, Myers RJK, Nandwa SM (1997) Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In: Buresh RJ, Sanchez PA, Calhoun F (eds) Replenishing soil fertility in Africa. Soil Science Society of America, Madison, Wisconsin
Place F, Barrett CB, Freeman HA, Ramisch JJ, Vanlauwe B (2003) Prospects for integrated soil fertility management using organic and inorganic inputs: evidence from smallholder African agricultural systems. Food Policy 28:365–378
Rahm MR, Huffman WE (1984) The adoption of reduced tillage: the role of human capital and other variables. American Journal of Agricultural Economics 66:405–413
Salasya BDS (2005) Crop production and soil nutrient management: an economic analysis of households in western and central Kenya. PhD Thesis, Development Economics Group, Wageningen University, The Netherlands
Sanchez PA, Shepherd KD, Soule MJ, Place FM, Buresh RJ Izac A-MN, Mokwunye AU, Kwesiga FR Ndiritu CG, Woomer PL (1997) Soil Fertility Replenishment in Africa: An Investment in Natural Resource Capital. In: Buresh RJ, Sanchez PA, Calhoun F (eds) Replenishing Soil Fertility in Africa. Soil Science Society of America, Madison, Wisconsin
Shepherd KD, Soule MJ (1998) Soil fertility management in west Kenya: dynamic simulation of productivity, profitability and sustainability at different resource endowment levels. Agric Ecosyst Environ 71: 131–145
Shepherd KD, Ohlsson E, Okalebo JR, Ndufa JK, David S (1995) A static model of nutrient flow on mixed farms in the highlands of western Kenya to explore the possible impact of improved management. In: JM Powell, Fernandez-Rivera S, Williams TO, Renard C (eds) Livestock and sustainable nutrient cycling in mixed farming systems in sub-Saharan Africa. Proceedings of an international conference, 22–26 November 1993, held at the International Livestock Centre for Africa, Addis Ababa, Ethiopia. ILCA, Addis Ababa, pp 523–538
Staal SJ, Owango M, Muriuki H, Kenyanjui M, Lukuyu B, Njoroge L, Njubi D, Baltenweck I, Musembi F, Bwana O, Muriuki K, Gichungu G, Omore A, Thorpe W (2000) Dairy systems characterisation of the greater Nairobi milk shed. MoARD/KARI/ILRI Collaborative Research Report, Smallholder Dairy (R&D) Project, Nairobi, Kenya
Thorne PJ, Thornton PK, Kruska RL, Reynolds L, Waddington SR, Rutherford AS, Odero AN (2003) Maize as food, feed and fertilizer in intensifying crop-livestock systems in East and southern Africa: an ex ante impact assessment of technology interventions to improve smallholder welfare. ILRI Impact Assessment Series 11. ILRI (International Livestock Research Institute), Nairobi, Kenya. 123 pp

Thornton PK, Kruska RL, Henninger N, Kristjanson PM, Reid RS, Atieno F, Odero A, Ndegwa T (2002) Mapping poverty and livestock in the developing world. ILRI (International Livestock Research Institute), Nairobi, Kenya, 124 pp

Waithaka MM, Thornton PK, Shepherd KD, Herrero M (2006) Bio-economic evaluation of farmers' perceptions of viable farms in western Kenya. Agricultural Systems 90:243–271

Waithaka MM, Nyangaga JN, Wokabi A, Muriuki K, Staal SJ, Njoroge L, Njubi D (2002) Characterization of dairy systems in the western Kenya region. Smallholder Dairy (Research & Development) Project Report, Ministry of Agriculture and Rural Development, Kenya Agricultural Research Institute and the International Livestock Research Institute. Nairobi, Kenya