Farmers’ perceptions of soil fertility and fertilizer yield response in Kenya

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Abstract

To develop soil fertility techniques that respond to farmers' actual concerns, researchers and agricultural development practitioners in developing countries need to identify how farmers in those regions form perceptions on soil quality and crop response to inputs. Using survey and farm soils data collected in 2002 and 2005 from smallholder farmers in western Kenya, we study whether farmers' subjective perceptions of soil fertility and impacts of fertilizer vary statistically with objective estimates generated by laboratory and statistical procedures. Our results show that farmers' perceptions of soil fertility on their plots are largely determined by observed crop yields. By contrast, farmers' perceptions on the impacts of fertilizer on yields vary rather closely with estimated returns to fertilizer application. This suggests that farmers' perceptions of soil fertility and the impacts of fertilizer are driven by observed yields. Implications for fertilizer use (the focus of current soil fertility management policies) and long term and integrated soil fertility management are drawn.

Introduction

Scientists, policy makers, and extension workers concerned with land management strategies in agricultural areas can benefit from understanding the local knowledge and perceptions of agricultural resource managers. It is of particular interest to know whether farmers' perceptions of resource conditions and the returns to proposed responses to resource deficiencies diverge from those suggested by scientific measurements and, if so, by how much and why. Within sub-Saharan Africa (SSA), this is an important issue given the degradation of farmlands and very low levels of fertilizer use. For example, at application rates of 9 kg per hectare of fertilizer-derived nutrients, compared to 73 in Latin America and 100–135 in Asia, fertilizer use in SSA lags far behind the rest of the world (IFDC 2006). Yet, recent studies repeatedly show that fertilizer can be remunerative across a broad range of agro-ecological and socio-economic conditions, especially when fertilizer use is accompanied by organic inputs.

Why then are many farmers in SSA not using soil nutrient amendments at all or at least not anywhere near recommended levels (IFDC, 2006)? Several prospective explanations exist. First, traders' liquidity constraints and thin fertilizer markets and poor infrastructure often make fertilizer trade unprofitable, leading to limited supplies available on rural African markets. Second, farmers' liquidity constraints and perhaps low expected returns to fertilizer use on some plots may discourage farmers from buying and applying fertilizer when it is available. Third, farmers might not perceive soil fertility status nor the returns to fertilizer use the way agricultural scientists do, leading to what outsiders interpret as underapplication that may be appropriate to farmers' perceptions. This chapter focuses on this latter possibility, which remains seriously under-investigated in the existing literature. For a variety of reasons — e.g., low levels of education, poor access to and quality of agricultural extension services, etc. – farmers may misperceive soil conditions and yield responses from fertilizer inputs.[1] In particular, if farmers underestimate one or both, they may fail to replenish

[1] Throughout the paper we will assume that scientific measures are accurate and thus that any divergence between farmers' perceptions and scientific measures reflect farmer "misperception". This is certainly a contestable claim, but one that is inherently untestable. It may be that there is some

soil nutrients because they erroneously view such investments as unnecessary, unprofitable, or both.

In this paper we ask whether farmers' subjective perceptions of soil fertility state and of maize yield response to fertilizer application vary systematically with objective estimates generated by laboratory and statistical procedures. First, we study how farmers' perceptions of soil fertility relate to laboratory measurements of soil fertility - as represented by soil carbon content (SCC)-from the same plots. This comparison captures how accurately farmers perceive a crucial proxy for soil fertility. Second, we then test how farmers' perceptions of the medium-term effects of fertilizer on crop yields relate to econometrically estimated expected returns to fertilizer, current soil fertility and socio-economic attributes. This allows us to test how well farmers perceive dynamic response processes related to soil quality and the effect of soil fertility amendments.

The information thus generated is important in exploring whether apparent errors in farmers' subjective perceptions may explain at least part of the weak demand for fertilizers among smallholder farmers in the western Kenya sites we study, and perhaps in similar environments elsewhere in the developing world. For example, a farmer may observe high crop yields due to favourable weather, improved seed, or

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conflation of concepts, with farmers referring to broader characteristics than those scientists measure. And there is certainly room for measurement error in and bias in laboratory testing and statistical estimation. While we are open to alternative ways of viewing discordant scientific and farmer perceptions, we think the most likely explanation is indeed farmer misperception; but the fundamental points of this paper are invariant to the way in which one interprets differences between scientific measures of a state or response and farmers' perceptions of the same state or response.

other factors and as a result overestimate the quality of the soils they are cultivating. Thinking their soils are fine, they do not bother to apply fertilizer. Or they might understand that the application of chemical fertilizers is agronomically desirable, but perceive that it is unprofitable – perhaps because of past experience on other plots or neighbors' experience cultivating other plots with somewhat different biophysical conditions – even though for their specific plot conditions fertilizer use offers positive expected economic returns.

These questions have important policy implications. If farmers err in overestimating their soil's health or in misjudging fertilizer use as unprofitable, then extension efforts may be necessary to correct these errors. And researchers may need to identify more clearly what are the indicators farmers use to track soil quality and crop response to fertilizer so as to develop measures that both scientists and farmers might use to improve congruence in perceptions so that applied research might better respond to farmers' concerns. This is critical given at the core of agricultural development policies in sub-Saharan Africa is the need for market-driven increased use of fertilizers driven by smallholder farmers (IFDC 2006). Current and future research and development efforts, extension programming, and policies to promote fertilizer distribution and use may fail to reach their full potential impact unless such misperceptions are rectified.

The rest of the paper proceeds as follows. Section 2 presents a review of the relevant recent literature and the overarching conceptual framework on farmer perceptions and how these relate to agricultural resource management. In section 3 we propose an empirical model for relating farmers' perceptions on soil fertility and fertilizer impact to certain observable factors at plot and household level. Section 4 describes the data sources generated by household surveys and laboratory tests of soil samples from those same households' plots. Section 5 discusses the empirical results. The paper concludes, in section 6, by summarizing the main findings and their implications for agricultural policy and rural development.

Literature overview and conceptual framework

Humans constantly construct mental models of reality, based on beliefs, experiences and biases about the world. Models allow individuals to understand and function in a complex world. Yet these models necessarily oversimplify the complex reality they represent and are therefore incomplete (Johnson-Laird, 1983). People construct mental models to try to understand various phenomena in order to allow themselves to function in situations where they lack complete comprehension of the relevant system(s). Mental models for the purpose of decision-making include an individual's perception of a situation and system responses to any intervention, among others (Morecroft, 1983).

The usefulness of farmers' own knowledge and perceptions in sustainable rural development has been highlighted by many researchers (Altieri, 1992; Lamers and Feil, 1995; Toledo, 1997). The guiding framework for much of the work in this area is that traditional agriculture draws on the accumulated experience of generations of local farmers. In this view, the structural and functional characteristics of traditional agro-ecosystems emerge naturally as part of an indigenous knowledge base that can guide the design of sustainable farming systems (Altieri, 1995; Gliessman, 1998).

The study of farmers' indigenous knowledge has taken place primarily within ethnopedology, the study of how local peoples classify their soils based on their collective experience. Several studies have documented farmers' knowledge of different soil types, management skills, and farmers' ability to help scientists classify soils (Tabor, 1992; Pawluk et al., 1992; Hecht, 1990). Other researchers have focused on the social, economic, and/or cultural rationale behind farmer knowledge and practices (Bellon and Taylor, 1993). Another group of authors has promoted using farmers' indicators as the basis for environmental management and monitoring in recognition of the fact that farmers' perceptions can offer accurate indications of environmental conditons (Ericsen and Ardon, 2003; Gray and Morant, 2003; Payton et al., 2003). In one study, Gray and Morant (2003) report that a majority of farmers indicated that they believed that their fertilizer was less effective now than it had been in the past, which confirms that with time farmers begin to perceive changes in returns to fertilizers. Other studies have analyzed the structure and nature of local soil knowledge as it differs from that of scientists (Sandor and Furbee, 1996; Zimmerer, 1994; Sillitoe, 1998).

Despite the importance of farmers' perception of resource conditions and expected economic outcomes, most ethnopedological reports focus on soil classification. The need to broaden the research agenda beyond looking merely at the validity of farmers' knowledge in soil classification has been argued for by Niemeijer and Mazzucato (2003). WinklerPrins (1999) similarly calls for studies that compare local and scientific soil knowledge for the purposes of better management of soil resources. Similar calls for the widening of the research coverage to include multiple issues in agriculture and environment have also been made by Sherwood and Uphoff (2000). A few studies have tried to tackle such issues, including Lamers et al. (1998), who documented the economic value of farmer application of crop residues in millet production in the West African Sahel, Hecht (1990), who reported on indigenous populations' complex management of ash and organic matter in the Brazilian Amazon, and Maskey and Bhattarai (1984), who researched the use of indigenous plant materials as fertilizers among hill farmers in Nepal. The importance and need for an in-depth understanding of local knowledge and practices is understood and stressed throughout the agricultural sciences literature and differences between local and scientific knowledge systems have been highlighted with some regularity.

Yet the extant literature on farmer perception vis-à-vis scientific measurements is almost entirely sociological, relying mainly on descriptive summaries from field surveys and on qualitative information generated by participatory processes. To the best of our knowledge, there are no published econometric studies relating farmer perceptions to scientific measurements of resource characteristics. Furthermore, the vast majority of the literature that does compare farmer perceptions of soil status to scientists' measures makes strictly static comparisons and does not explore farmers' expectations of the effects of changing soil fertility status via fertilizer amendments. Our contributions to the literature are threefold. First, our empirical analysis, based on discrete choice econometric methods, offers a novel quantitative addition to the literature on ethnopedology and to the broader agricultural sciences. In particular, by using multivariate regression techniques we are able to demonstrate important specious correlations between farmers' stated perceptions and objective scientific measures of soil state and crop response to fertilizer application. Second, we take the study of farmers' perceptions beyond observable biophysical phenomena to the realm of more abstract economic factors that shape economic expectations and resource use behaviors. This more direct connection to farmer behavior is an important and overdue step. Third, we study not only the correspondence between farmers' static perceptions of the current state of their soils and laboratory measurement of the same, we also investigate farmers' perceptions of dynamic response of crop yields to fertilizer application. This is an important first step in the direction of linking farmer perceptions to the dynamics of the system they try to manage.

Empirical model: hypotheses and estimators

We sketch a simple empirical model to study how farmers' perceptions relate to laboratory and statistical measurements of the same variables concerning soil status and how fertilizer application to soils might change crop yields. First, we explore whether farmers' perceptions of soil fertility are strongly correlated with soil testing results. Is there a strongly positive and statistically significant relation between the perceptions and laboratory measures? If so, does this relation hold once one controls for other covariates – e.g., crop yield, farmer and plot characteristics – that might be correlated with both measures of soil fertility status? Taking S_i^p to represent farmer i's perception of the fertility of his soil, we first regress S_i^p on an alternative measure of the quality of the same soil, in this case as determined by laboratory tests, S^L. Then we add plot-specific and household characteristics, $\boldsymbol{Z}$, ultimately estimating the equation:

$$S_i^{\,p} = \beta_{i0} + \beta_L S_i^L + \beta_Z Z_i + \varepsilon_i \qquad (1)$$

The key hypotheses to be tested in this equation are as follows.

H1: Perceived soil fertility is positively related to laboratory measures of soil fertility. ($H1_0 : \beta_L = 0$ versus $H1_A : \beta_L > 0$)

This provides a weak test as to whether farmer perceptions of soil quality are correlated with laboratory measurements of the same variable. Of course, in the absence of other controls, rejecting this hypothesis does not rule out the possibility that laboratory measures of soil fertility are only correlated with farmer perceptions via one or more omitted variable(s) that are correlated with both measures, such as observed crop yield on the plot. If, for example, crop yields respond to soil nutrients as measured in laboratory tests and farmers then form beliefs about soil fertility based on observed crop yields, then the two soil quality measures will be correlated, but perhaps only through their common covariate, crop yield.[2]

[2] Such a result would also signal a statistical endogeneity concern related to the use of farmers soil quality perceptions as an independent variables in crop production or yield or farm income functions.

This possibility raises a second hypothesis that poses a stronger test of the relationship between scientific measures of soil quality and farmers' perceptions of the same variable.

H2: Farmers' perceptions of soil fertility are associated only with soil quality as reflected in laboratory measurements. ($H2_0: \beta_L, \beta_Z = 0$ versus $H2_A: \beta_L > 0; \beta_Z = 0$).

If $H2_0$ is rejected in favor of $H2_A$, then farmers' perceptions and measurements are substitutes for one another (up to some algebraic transformation). In the context of the probabilistic model developed below, rejection of $H2_0$ in favor of $H2_A$ means that the probability that a farmer views his soil as fertile accurately matches up with scientific assessments with no systematic deviations. This would imply that explanations of low rates of fertilizer use could not be attributed to farmer misperception of the state of the soils they cultivate. By contrast, failure to reject the null would signal that farmer perceptions of soil quality are unrelated to any of the covariates, essentially a random variable that conveys little information.

If one cannot reject $H2_0$ in favor of $H2_A$, then it would be helpful to identify any pattern(s) to the deviation of perceptions data from laboratory measures. Such deviations could provide a basis for targeting extension visits, fertilizer commercialization strategies, or other public or private sector interventions. The question then becomes whether plot- or household-specific variables affect farmers'

This is not a concern in the present paper but prospectively raises questions about a large literature that employs soil fertility perceptions data as if it were an objective, exogenous measure of soil quality.

perceptions independent of laboratory soil fertility measures. This yields our third hypothesis test:

H3: Farmer soil quality perceptions are systematically related to variables other than measured soil fertility. ($H3_0 : \boldsymbol{\beta}_z = 0$ versus $H3_A : \boldsymbol{\beta}_Z \neq 0$)

This tests whether there exist farmer or plot characteristics associated with systematic deviations of perceptions from laboratory measures, independent of crop yield. For example, farmer education level or age or gender or the size of the plot might affect farmer perceptions and also provide targeting criteria for those who wish to intervene to attempt to rectify misperceptions that might affect soil fertility management practices. Rejection of the null $H3_0 : \boldsymbol{\beta}_z = 0$ implies the existence of structural information gaps that are perhaps remediable.

We equally wish to learn whether farmers perceive fertilizer application – one of the principal soil fertility management techniques in the region (Marenya and Barrett 2007) – to affect crop yields similarly to the best available estimates of those effects. If farmers' perceptions of crop yield effects closely track scientifically predicted effects, there would seem to be little room for extension or other advisory services to teach farmers more about the benefits of fertilizer use. But if the two measures of the crop yield effects of fertilizer use are weakly correlated or independent, or if there exist deviations between the two measures that are systematically related to targetable farm or farmer characteristics then, again, misperceptions are potentially remediable.

Let $\hat{r}$ represent scientists' estimated marginal physical product of nitrogen fertilizer application on a farmer's plots. We explain the estimation of $\hat{r}$ below. Taking Y_i is the crop yield on *i*'s farm and Δ is the intertemporal change operator, then let

$$\Delta Y_i^p = \lambda_0 + \lambda_r \hat{r}_i + \lambda_L S_i^L + \lambda_z \boldsymbol{Z_i} + \varepsilon_{iY} \tag{2}$$

represent farmers' perceived (represented by the p superscript) change in crop yield as a function of the laboratory measure of soil quality, S^L, the household and farm characteristics, Z, and the estimated impact of fertilizer on yields, $\hat{r}$, more precisely in our empirical application, the marginal physical product of N fertilizer on maize yields. This specification yields our next testable hypothesis:

H4: Farmers' perceptions of crop yield response to fertilizer application exactly and exclusively track scientific estimates of response. ($H4_0: \beta_L, \beta_r, \beta_Z = 0$ versus $H4_A: \beta_r > 0; \beta_L, \beta_Z = 0$)

This is akin to the strong hypothesis test in H2. Once again, we seek to determine whether farmers' perceptions are essentially perfect substitutes for scientists' perceptions of the same phenomenon (in this case, crop yield response rather than soil fertility state), or if there exist important farmer misperceptions that can perhaps be targeted so as to improve soils management, agricultural productivity, or both. If farmers' perceived impacts of fertilizer statistically significantly (positively) track estimated marginal returns (yield response) and only that variable – i.e., if we reject the null in favor of the strong-form alternate hypothesis – then farmers' fertilizer demand patterns should reasonably accurately reflect optimal agronomic use patterns within the community unless inter-household variation in market access, cash liquidity or other economic factors impede the translation of household perception of marginal returns into actual demand . If we cannot reject the null in favor of that particular alternate hypothesis, then there exist farmer misperceptions[3] that, again, might be remediable through targeted interventions.

Such interventions are targetable if there exist systematic relationships between farmers' expectations of fertilizer response and farm or farmer characteristics, controlling for the scientifically estimated returns to fertilizer on that specific farm. This raises the final hypothesis we test:

H5: Farmers' perceptions of crop yield response to fertilizer are systematically related to variables other than estimated crop yield response. ($H5_0 : \lambda_z = 0$ versus $H5_A : \lambda_z \neq 0$)

Just as with H3 with respect to soil fertility status, H5 provides a straightforward test of whether there exist targetable farm and farmer characteristics systematically associated with farmer errors in estimating fertilizer yield response. Even if farmers' subjective perceptions are consistent with the relevant scientific estimate of the same phenomenon, there may still exist systematic deviations due, for example, to demographic and other farm-specific factors.

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[3] It is important to note that in the crop yield response regressions, the lack of perfect correspondence between the farmer perception variable and the scientific estimate of the same variable could be due to statistical estimation error. Such error could arise for many reasons. In what follows we have used the best available data and estimation techniques, which generate statistical estimates very similar to experimental agronomic ones. So although it is certainly possible that any lack of correspondence purely reflects estimation errors by scientists, rather than by farmers, we think this somewhat unlikely. More likely, we are all a bit off the mark.

The starting point of our econometric model are equations (1) and (2), with the two dependent variables, one describing farmers' perception of soil quality, the other reflecting farmers' perceptions of the impact of fertilizer on yields, on an ordered scale. In order to test the above hypotheses and given that perceptions are recorded as ordinal categorical variables, we use the ordered probit model. The advantage of the ordered probit over related, common models such as multinomial logit and probit, is that these latter models neglect the data's ordinality, require estimation of more parameters (in the case of three or more alternatives, thus reducing the degrees of freedom available for estimation), and require undesirable assumptions such as the independence of irrelevant alternatives in the case of a multinomial logit (Ben-Akiva and Lerman 1985) or lack of a closed-form likelihood in the case of a multinomial probit (Greene 2000).

The following econometric specification of equation (1) was used:

$$S_i^p = \beta_{i0} + \beta_L S_i^L + \beta_Z Z_i + \varepsilon_i \tag{3}$$

In the context of discreet choice model, let S_{ij}^* be individual i's latent and ordered measure of perceived soil fertility on plot j and ε_{ij} is a normally distributed error term. The observed and coded discrete perception of soil fertility, s_{ij} , is determined from the model as follows:

$$S_{ij} = \begin{cases} 0 \text{ if } -\infty \le S_{ij} \le c_1 & \text{(not fertile)} \\ 1 \text{ if } c_1 < S_{ij} \le c_2 & \text{(somewhat fertile)} \\ 2 \text{ if } c_2 < S_{ij} \le \infty & \text{(very fertile)} \end{cases} \tag{4}$$

where $\{c_1, c_2\}$ represent the threshold levels to be estimated along with the parameter vector β. The interpretation of this model's primary parameter set, β, is as follows: positive and statistically significant estimates indicate higher perceived soil fertility is associated with increases in the value of those variables, while negative and significant marginal effects estimates suggest the opposite.

Similarly, we specify an ordered probit model for equation (2), in this case with four unknown cutoff points to be estimated related to five ordered, discrete farmer responses (crop yield would be a lot worse, a little worse, unchanged, a little better or a lot better in response to a certain fertilizer application rate). The complication in estimating (2) is that we need to first generate an estimate of the marginal physical product of fertilizer, $\hat{r}$, to use as an explanatory variable in the ordered probit. We do this by estimating a crop production function and then generating plot-specific estimates of $\hat{r}$ which then serve as regressors in the second-stage ordered probit estimation. This procedure is explained in more detail below.

This probabilistic approach to estimating farmers' perceptions of the returns to fertilizer and soil quality enables us to directly test each of the five hypotheses specified above. In each case, we estimate a sequence of models so as first to isolate the apparent relationship between farmer perceptions and the relevant scientific measure of the same variable, then to test the robustness of that relationship to the inclusion of other covariates.

Data description

The data used in this chapter were collected from a region in western Kenya within Nandi and Vihiga Districts, an area approximately 300 km west of the capital city, Nairobi. Agro-ecologically, the region is classified by the Kenya Agricultural Research Institute as a moist transitional agro-ecozone characterized by medium to low soil fertility levels. The climate in the area is conducive for crop agriculture with plentiful and reliable rains (1200-1800 mm/year) spread across two cropping seasons, with a long rainy season that runs from February to June and a short rainy season from September to November (Lynam and Hassan, 1998). The cropping system is dominated by maize, many times with bean intercrops, grown on small plots averaging 0.5 to 1.0 ha. (Place et al. 2002). The rural populations in this region are among the poorest in the country, with 49.9 and 58.1 percent of the population in Nandi and Vihiga Districts, respectively, living below the national rural poverty line of Kshs 1239 /month (US$0.57/day) per person (Kenya 2000a, 2000b). The average fertilizer application rate of 5.41kg N/ha in the sample (equivalent of 28kg diammomium phosphate fertilizer) is well below the 41kg N (equivalent of 225kg diammomium phosphate fertilizer) minimum recommended by extension systems in this area.

We use two complementary data sets to enable us to analyze the relationships of interest. To study the relationship between laboratory measurements of soil fertility and farmers' perceptions of the fertility of the same plots, we use data collected in 2002 on both farmers' perceptions of soil fertility and laboratory measures of the same soils' fertility. Those data do not include farmers' perceived impacts of fertilizer on crop yields.

The 2002 data were collected from 123 smallholder households surveyed by a USAID BASIS CRSP[4] research project, involving Cornell University, the Kenya Agricultural Research Institute, the World Agroforestry Center (ICRAF), and the University of Nairobi. A stratified proportional random sample was drawn with the stratification based on the smallest administrative unit: the sub-area. Six sub-areas within Madzuu Location in Vihiga District were randomly selected and from these sub-areas households were randomly picked in proportion to the population in each sub-area. A total of 123 households completed surveys relating to the soil management practices they employ for soil improvement and conservation, as well as the perceived soil fertility of plots where they plant maize, beans and maize/bean intercrop. For each plot of the above enterprises that the farmer tends, farmers were asked to classify their soil as infertile, somewhat fertile or very fertile. These therefore generated plot level data matching farmers' soil fertility perceptions with the relevant repressor in each data cell.

[4] The USAID-funded Broadening Access and Strengthening Input Supply Systems: Collaborative Research Support Group (BASIS CRSP) project on Rural Markets, Natural Capital and Dynamic Poverty Traps in East Africa. For more details on the procedures used to collect these data. See Marenya and Barrett (2007), which uses the same data.

The second data set, collected in 2005, includes observations of different farmers in the same general region. These data include perceived impacts of fertilizer (used at the rates recommended by the local extension agents) on maize yields after four years of use, as well as laboratory measurement of soil fertility on those same plots. The 2005 data do not include farmers' perceptions of current soil fertility.

The 2005 data came from seven different sites in seven different villages (Bonjoge, Kamulembe Kapsengere, Kechire, Koibem, Serem and Sikisk) in the Vihiga and South Nandi Districts in western Kenya. The basic sampling design for the second data set was based on a soil chronosequence in order to establish the effect of time on soil processes given that long-term experiments are infeasible (Stevens and Walker 1970). We randomly sampled 260 households across villages stratified on the basis of how long cultivation had taken place there since the area was originally converted from forest, providing de facto sample stratification based on plot age. The sites were converted from forest to agriculture in roughly 1900, 1930, 1950, 1970, 1985, 1995, and 2000. To establish that these sites actually were converted at the times specified, we investigated local records from district and agricultural offices and spoke with elderly community members. Specific locales within the study area had been cultivated for varying lengths of time, providing more continuous variation in plot ages within the strata.

Household- and plot-level data were then collected in June-July 2005 using a structured questionnaire to elicit recall information regarding farm production and other pertinent data for the immediately previous long rains season. All the maize and maize-bean plots cultivated by each sample household were included in the survey. The adult household member responsible for managing each plot was interviewed to provide information that included crop outputs, variable inputs (family labor and hired labor used, disaggregated for each major activity, fertilizer, manure and other inputs use), the age of the plot (i.e., the year in which it was converted from forest) and details on the plot manager (gender, age, educational attainment).

Data on farmers' perception of the expected impact of fertilizer on maize yield over a four-year period were collected through a thought experiment. The question was asked such that each respondent had to visualize a one acre plot whose soil fertility was typical of all their own maize plots and to imagine the impact of applying 75kg of DAP fertilizer (the extension recommended rate) for four years continuously on that one acre. The responses were ordered on a scale of 1-5 with 1 representing a strong deterioration in yield and 5 indicating a robust positive improvement. There was an important difference in the perceptions response between the 2002 and the 2005 data in that in the latter case the perceptions data on effects of fertilizer were not reference to how the respondent perceived response on each plot but on how they perceived the response on average on all maize plots. Therefore the 2005 observations are at the respondent/household level.

For both the 2002 and 2005 data, soil samples were collected from each of the 198 and 445 maize and maize-bean plots, respectively, at 10 cm depth (i.e., the plough layer) at

5 different positions within each plot. These soil cores were mixed together to create a composite soil sample for each plot. The samples were analyzed by ICRAF's soil laboratories for carbon and nitrogen content in each plot. We chose to use soil organic carbon stocks because soil organic carbon content (SCC) has become increasingly recognized as the single best summary statistic for soil organic matter stocks and soil fertility status (Tiessen et al. 1994; Bationo and Mokwunye 2005; Palm et al. 2001; Manlay, Feller and Swift 2007). SCC was measured as the percentage of compounds in the total dry weight of each sample. Given the large number of plots involved, and therefore the high financial and time costs of conventional soil chemistry analysis of all the samples, we employed the much cheaper and quicker near-infrared reflectance spectroscopy (NIRS) method, following protocols developed by Shepherd and Walsh (2002) and Cozzolino and Moron (2003) and as described in detail for these data in Marenya and Barrett (2008). We thereby generate plot-specific SCC estimates. Note that while soil sampling was plot specific, the observations on farmers' perceptions of impact of fertilizer yields and soil quality on a one acre plot are specific only to the household. We therefore matched the perceptions data with laboratory data by averaging the plot level carbon content for all plots in each household (using simple unweighted average).

The variables used in the regression models are discussed in Tables 2.2 and 3.1. There is obviously no scientific measure of crop response to fertilizer application in observational data. So, as indicated in the previous section, we must generate first stage estimates of $\hat{r}$ to use in estimating equation (2) using an ordered probit model.

In order to get as precise estimates as possible of the marginal physical product of N fertilizer application, $\hat{r}$, we estimated an exact second-order local approximation of the unknown true maize production function by using a generalized quadratic specification (Chambers 1988):

$$y_i = \alpha_0 + \sum_{i=1}^{m} \alpha_i x_i + \sum_{i=1}^{m} \sum_{j=1}^{m} \alpha_{ij} x_i x_j + e_i \qquad (5)$$

Here y is output (kilograms of maize), x_i is the vector of independent variables -- plot size, labor, nitrogen fertilizer applied, plot age, soil carbon stocks, age and years of education completed for the household head, plus dummy variables for maize-bean intercrop, use of draft power in land preparation and gender of the household head – the β vector comprises the parameter estimates of interest and e is an iid N(0, σ^2) error term.[5] In order to fit an exact second-order approximation at the sample mean, all data were first normalized arithmetically by subtracting the sample mean of each variable from each observation. Table 2.3 in chapter 2 reports for complete production function estimates. The resulting marginal product estimates for each plot were also matched to the perceptions and laboratory data by averaging the plot-level marginal

[5] Of course, some of the explanatory variables – including N fertilizer application, the regressor of greatest interest – could be endogenous given that farmers could well be aware of phenomena or factors unobserved by us that affect yields and then adjust application rates accordingly. Unfortunately, there are no good instruments available with which to address prospective endogeneity concerns in the production function estimation. The alternative, dual formulation of estimating cost or profit functions is likewise infeasible in this setting because of insufficient variation in price data within a single season for a geographically compact zone. Thus the production function estimates reported here represent the best one can do with these data. See appendix for production function estimates.

physical product estimates for all plots cultivated by each household (using simple unweighted average).

The key descriptive statistic of variables used in soil fertility perception regressions are displayed in table 1. Most of the sample plots (51%) are viewed as infertile and 28% are perceived as very fertile. This appears to be consistent with the average plot-level carbon content of 1.68%. Only a minority of the plots receives any fertilizer (16%) or manure (23%). Most of the of the household heads are males (61%) and the average age of a household head is about 52 years suggesting a middle aged population of smallholder farmers and limited participation of youth in smallholder farming. The scarcity of land can be seen from the average plot size of 0.45 ha, perhaps emphasizing the crucial need for increased production to occur at the intensive margin. Variables used in studying the perception on fertilizer impact on yields are found in Table 2.2. As was highlighted in Chapter 2, the key features of the data is the low use of fertilizers with 12% of the plots not receiving any fertilizer applications at all and only 3% receiving the recommended amounts of fertilizer (225kg of diammonium phosphate fertilizer at planting time followed by a similar amount of calcium ammonium nitrate). The average yield was 1015kg/ha[6] against a potential of 4-7 tons/ha. Farm sizes are equally small judging from the size of maize plots (0.57ha). Both show land scarcity and low input use. The mean annual per capita household income (excluding own consumption) is Kshs 16352.00 ($268) for the 2005 data and Kshs 11132 ($183) which translates to less than $1/day.

[6] This refers to dried and bagged maize which is typically 14% moisture.

The general picture of land scarcity, low yields, little input use and low incomes are true for both data sets. Table 2 indicate that the majority of respondents (79%) regarded the application of the recommended rate of fertilizer as improving both crop yields and soil fertility. Yet 15-17% of respondents expected four-year use of the recommended rates of fertilizer to lead to no improvement on maize yield and soil fertility. In the actual regressions, we drop the observations corresponding to the response category 'Do not know'. This left a total of 245 households to be used in the ordered probit regressions. These perceptions about the impact of fertilizer are broadly consistent with the returns to fertilizer that we estimated econometrically based on the generalized quadratic maize production function (see Appendix for detailed results). Figure 4.1's kernel density plot[7] of the estimated marginal physical product of N fertilizer shows that on

FIGURE 1 ABOUT HERE

a majority of plots an extra kilogram of N fertilizer generates an estimated marginal product of more than 10kg of maize. Hence the majority response that maize yields are

[7] A kernel density plot can be considered a refinement of a histogram or frequency plot by using nonparametric smoothing functions.

“a lot better” if one applies recommended levels of fertilizer (Table 2). Figure 4.1 indicates that for a small number of plots, about ten percent, as it happens, there is no statistically significant expected marginal yield gain to fertilizer application, again rather like the farmers’ qualitative, ordered responses.

TABLE 1 ABOUT HERE

TABLE 2 ABOUT HERE

Empirical findings

The results presented in Table 3 report a sequence of ordered probit models of equation (2), relating farmer soil perceptions to laboratory measurement of SCC. These models differ in specification based on the covariates included on the righthand side of the regression equation. Model 1 offers the barest bones specification, simply a univariate regression of farmer soil fertility perception on lab measures of SCC. We find that without controlling for any other covariates, there exists a very strong, statistically significant, positive relation between farmers' perception of soil fertility and percent soil carbon content. Indeed, the two change one-for-one. While few farmers in this region benefit from any formal soil testing, they appear to have reasonably accurate appraisals of soil fertility, based on a range of local indicators of soil health (Payton et al., 2003).

TALE 3 ABOUT HERE

The fact that farmers' perceptions of soil quality are based on other indicators and not directly caused by measurable soil fertility is confirmed by model 2, which simply adds the plot –specific maize yield as another regressor along with plot SCC. Once we control for yield, soil perceptions are no longer statistically significantly correlated with plot-level SCC. Farmers appear to form perceptions of soil fertility based on crop yields and variation in soil quality that is not manifest in yields has no discernible effect on farmers' assessment of their soils. Of course, since yields are a complex function of an array of management practices (e.g., seed type, timing of farming operations, labor effort, etc.) and agroecological conditions (e.g., rainfall, pest incidence, wildlife damage, etc.), this suggests that farmers routinely err in their soil fertility assessments when non-soil factors affect yields, as they almost surely do.

In model 3, we add a number of farmer demographic factors and plot- or household-specific variables. Crop yield continues to be the variable that best explains farmer soil fertility perceptions, although even in this model, the pseudo-r^2 is only 0.13. Most farmer soil quality perceptions are not readily explainable using measured soil carbon content, crop yields or basic characteristics of the farmer, household or plot. None of the apparent deviations of farmer soil quality perceptions from laboratory soil fertility measures appear readily targetable. But the fact that farmers' view of soil fertility tracks yields closely is an important factor that may influence farmers' input use behavior as reliance on yield alone may be a poor indicator of when and how to intervene in replenishing soil nutrients.

The results in Table 3 yield clear results for the first three hypotheses specified earlier. We can only reject the null for H1 when no other covariates are included along with laboratory SCC measures. The correlation between farmers perceptions and scientific measures of soil fertility appear to be specious. We can reject H2, but not in favor of the strong form alternate hypothesis. Rather, the covariate that appears almost uniquely associated with farmer soil fertility perceptions is crop yield. Thus we overwhelmingly reject the null hypothesis in H3 in favor of the alternate hypothesis that farmer soil quality perceptions track crop yields, diverging from scientific measures of soil quality as yields move above or below the average due to other management or biophysical factors. Farmer misperception of soil quality appears widespread and strongly associated with yields, but unfortunately does not appear readily targetable based on easily-observed farmer or plot characteristics (e.g., gender, age, size of plot, etc.).

Now we turn to the ordered probit estimates of equation (2) so as to more carefully establish the relationship between farmers' perceptions of crop yield response to fertilizer application to amend soil nutrients and the best available statistical estimates of those same responses. Table 3.4 reports the estimation results for several different models similar to the steps used in table 3. Similar to results in table 3 we find that without controlling for any other covariates, there is a statistically significant relationship between farmers' perceived impact of fertilizer and its estimated marginal product. This suggests a match-up between farmers' perceptions of returns to fertilizer and those objectively estimated.

This relationship between perceived impact of fertilizer and its marginal product persists even in model 2 where we control for SCC. This contrasts with results of table 3 where the effect of SCC disappeared once we controlled for yields. This may not be surprising because unlike actual yields, econometric estimates marginal product is necessarily done with a degree of statistical error. We estimated an intermediate model including excluding plot age to test how radically the estimates change due to the expected correlation between soil carbon and plot age. The results remain largely similar between the model 3 and 4 with exception of the non-significance of soil carbon in model 4, perhaps arising from imprecise estimation occasioned by the apparent collinearity. In model 4 the effect of SCC is eliminated. The effect of marginal product of fertilizer persists in model 1-3 showing that similar to results in the soil fertility regression, it is yields and their derivatives (marginal product of fertilizer or yield response) that affect farmers' perceptions on the usefulness of fertilizer (as proxied by their perceptions on its impact).

The negative and significant coefficient estimate of plot age for perceived impact of fertilizer on yield seems to support the conclusion that owners of older plots have dimmer expectations on the impact of fertilizer than those operating younger and inherently more fertile plots. Greater contact with extension agents was significantly associated with the perception that use of fertilizer would be yield increasing. Given that this effect exists when controlling for the estimated returns to fertilizer use on the respondent's plots, this suggests that extension agents exercise influence over farmers' perceptions quite apart from the real returns to N application, as in Moser and Barrett (2006). Those with more area under maize appear to be more optimistic about effect of fertilizer on yields. Since we have controlled for income, the effect of plot size may proxy greater management or other resource endowment factors associated with ownership of larger maize plots.

Judging from the significance of some household and plot specific variables, the results imply that while the two measures generally track each other, there remain some systematic patterns of deviations between statistical estimates and farmers' perceptions of returns to fertilizer. This is consistent with results by Enyong, Debra and Bationo (1999), Desbiez et al. (2004), Gruver and Weil (2007) and Moges and Holden (2007) who invariably show that farmer' perceptions on soil fertility match up with laboratory measurements. This is similar to our results which show accurate perceptions on fertilizers' impact accompanied by low levels of fertilizer use. We therefore have to reject H4 and H5 because marginal product of fertilizer is

FIGURE 2 ABOUT HERE

persistently and significantly related to perceived returns. This is also true of a number of the other covariates once we specify a full model such as in table 4.

The relationship between marginal product of nitrogen and SCC can be seen from Fig.3.2 which is a local polynomial fit of plot-level nitrogen application rates on plot carbon content (with 95% confidence bands). Fig. 3.2 shows that returns to fertilizer rise with SCC and farmers perceived impact of fertilizer seem to track this, overall average application rates of 5kg of N/ha are still below the 40kg of N/ha recommended by government extension systems in this area. TABLE 4 ABOUT HERE

Summary and Conclusions

Farmers' behavior necessarily follows from their perceptions of the state of their resource base and the likely response of crops to different interventions, including soil nutrient supplementation through fertilizer application. If scientists and policymakers are concerned about insufficient fertilizer application by smallholder farmers in sub-Saharan Africa, it becomes important to ascertain whether farmer misperception of soil conditions, yield response to fertilizer, or both, might play a role addressable through targeted extension and other interventions. We explore this surprisingly under-studied issue using novel data collected from household surveys and soil samples collected among farmers in western Kenya.

Our ordered Probit regression results show that farmers' perceptions of soil fertility on their plots are strongly associated with observed yields. Crop yields are widely accepted as important indicator of soil fertility. Therefore farmers' reliance on yields as the main indicator of soil fertility is consistent with current soil science paradigms which use yield as one the best proxies for soil fertility (Holden 2007). The consistency of farmers' soil fertility perceptions and yields are not without errors as seen by the fact that part of the variation in farmers' subjective, categorical assessments of soil quality can be explained by the set of farm, household and plot covariates such as plot size, measures of income and livestock ownership and extension exposure signifying the importance of agricultural extension but also of factors which are not easily targetable by extension.

On famers' perception of returns to fertilizer we find that without controlling for any other covariates, there is a statistically significant relationship between farmers' perceived impact of fertilizer and its estimated marginal product. This relationship between perceived impact of fertilizer and its marginal product persists even when we controlled for other plot and household level factors. Judging from the significance of some household and plot specific variables in explaining the relationship between estimated returns and farmers' perceptions of these returns, the results imply that while the two measures generally track each other, there remain some systematic patterns of deviations between statistical estimates and farmers' perceptions of returns to fertilizer.

We therefore conclude that farmers' perceptions of the current state of their soils and the expected returns to increased fertilizer use track laboratory and statistical estimates albeit with some systematic deviations. However, the role of errors of perceptions in discouraging fertilizer use appear small at best. The most significant implication is that the use of yields as a key indicator of soil fertility may introduce delays in perceiving these changes. Because farmers use yields as the key soil fertility indicator, they may be unable to perceive small but important soil fertility changes over time. This is especially true if yield changes lag behind that of soil fertility (especially considering factors such as soil organic matter), in which case they may delay in initiating soil fertility remedies. Such delays can lead to significant deterioration in soil quality, making it more costly to regenerate. By the time they perceive a permanent yield decline, with underlying soil fertility deterioration; they correctly begin to perceive the use of fertilizer as unprofitable. By relying on a slow indicator of soil fertility (yields), farmers may miss the best time for intervention (e.g. increased organic matter incorporation and fertilizer application) assuming of course that household liquidity and market supply constraints are not binding.

APPENDIX (Table 5) ABOUT HERE

APPENDIX (Table 6) ABOUT HERE

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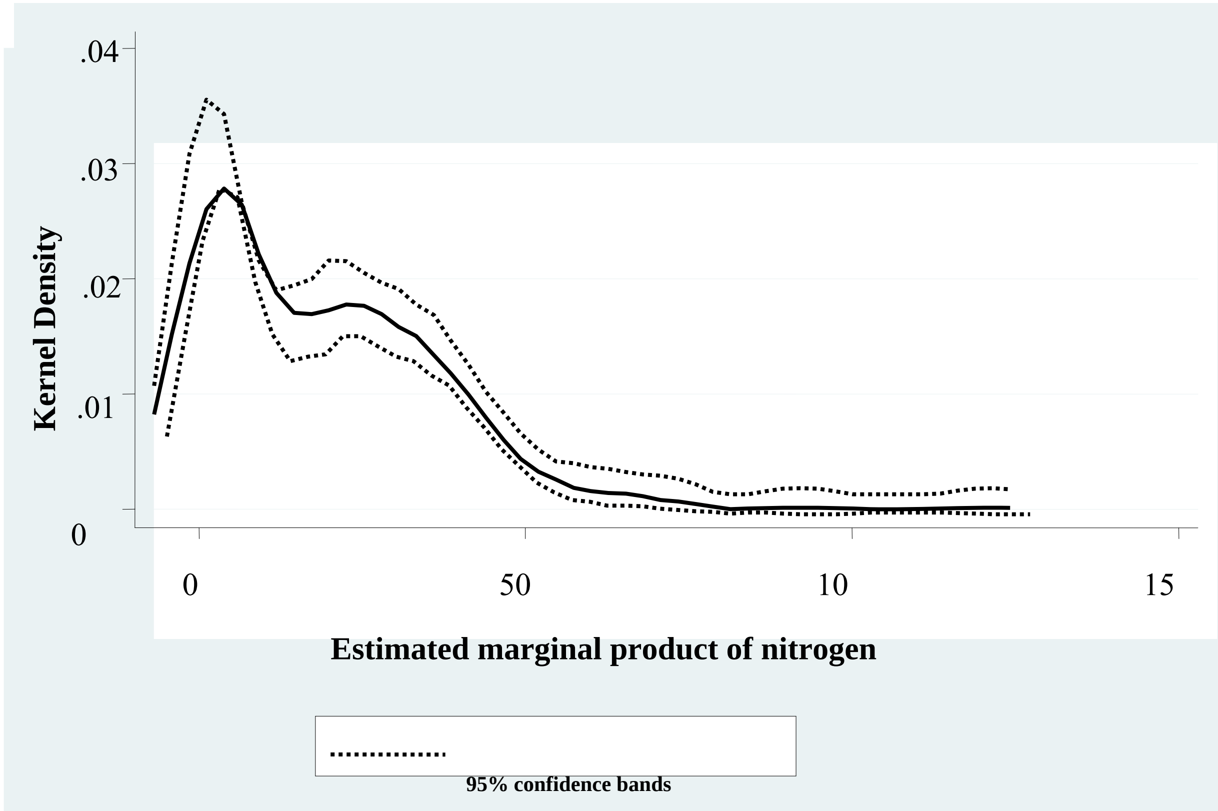

Figure 1: Kernel density of estimated marginal physical product of nitrogen

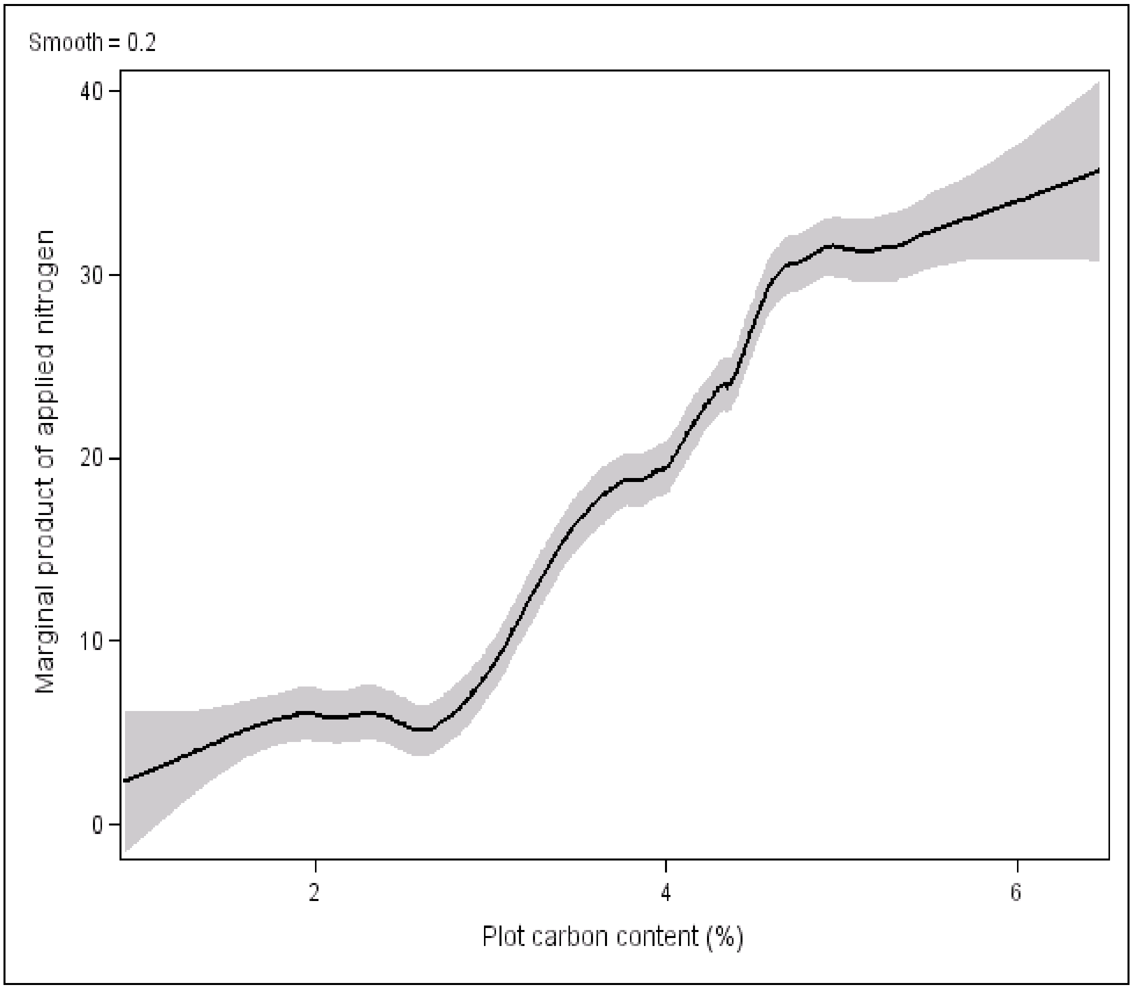

Figure 2: Estimated marginal value product of nitrogen fertilizer (Kshs/Kg N), by plot soil carbon content

Table 1: Description of Variables Used in the Regression Analysis for Perception of Soil Fertility Status (Madzuu 2002 data)

Variable	**Definition**	**Mean**	**Standard Deviation**
Soil fertility perception	Ordered dependent variable. Variable = 1 if soil was perceived as infertile, 2 if response was somewhat fertile and 3 if response was very fertile	NA	NA
Soil carbon content	Plot carbon content (%)	1.68	0.77
Fertizer application	If any amount of inorganic fertilizers were applied on plot (yes=1)	0.16	NA
Manure application	If any amount of manure was applied on plot (yes=1)	0.23	NA
Age of household head	In years	51.90	15.00
Gender of household head	Gender of household head (male=1, female=0)	0.61	NA
Education level (household head)	If household head had formal education (yes=1)	0.8	NA
Crop income	Income per month from agricultural sources in Kenya shillings	3407.00	1501.00
Non-crop income	Income per month from non-agricultural sources in Kenya shillings	2025.00	1325.00
Value of livestock owned	Average sale value of livestock owned at the time of the survey in Kenya shillings	9675.00	10200.00
Plot size	Plot size in hectares	0.45	0.20

Plots perceived to have:	**Number of plots**	**Percent of total plots**
Very fertile soil	56	28
Fertile soil	42	21
Infertile soil	100	51
Total number of plots	198	100

Table 2: Frequency of Responses on Perceived Impact of Fertilizer on Crop Yield

Response	Percent
Do not know	6.2
A lot worse	1.9
A little worse	2.3
No significant change	10.4
A little better	16.9
A lot better	62.3
Total	100.0

Table 3: Factors Affecting Farmers' Soil fertility Perceptions: Ordered Probit Marginal Effects

Variable	Model 1		Model 2			Model 3
	Coefficient Estimate	Standard Error	Coefficient Estimate	Standard Error	Coefficient Estimate	Standard Error
Constant	0.612	0.323	0.085	0.3825	0.3655	0.4845
Soil carbon content	0.9265	0.1955	1.224	3.2215	0.153	0.34
Plot-level yield (kg/ha)			1.3855	0.3485	1.224	0.578
Age of household head					-0.0085	0.0051
Gender of household head					-0.0425	0.1615
Formal education					0.0935	0.17
Plot size					-0.051	0.255
Number of adults in household					-0.0085	0.0595
Crop income					0.00595	0.00255
Non-crop income					0.0034	0.00595
Value of livestock owned					-0.0017	0.0034
Model statistics						
Cutoff 1	-0.72	0.38	0.11	0.45	-0.3655	0.4845
Cutoff 2	2.41	0.41	1.66	0.4	1.2155	0.493
Number of observations	198		198			198
Log likelihood	-189.94		-182.98			-172.83
LR χ^2 (Prob> χ^2)	28.76(0.00)		39.68(0.00)			45.56(0.00)
Pseudo R^2	0.06		0.1			0.13

Note: ***, ** and * indicate statistical significance at the 1%, 5% and 10% levels, respectively(using z-values)

Table 4: Factors Affecting Perceived Impact of Fertilizer on Maize yields: Ordered Probit Marginal effects

Variable	Model 1		Model 2		Model 3		Model 4	
	Marginal Effect	Standard Error	Marginal Effect	Standard Error	Marginal Effect	Standard Error	Marginal Effect	Standard Error
Constant	1.90	1.66	1.59	1.11	2.62	2.45	1.89	1.69
Estimated marginal product of N	0.52	0.13***	0.38**	0.17	0.32*	0.14	0.47*	0.23
Plot carbon content			0.03*	0.012	-0.27*	0.12	0.13	0.20
Frequency of extension contact					0.15**	0.07	0.16*	0.09
Age of household head					0.20	0.08	-0.04	0.51
Gender of household head					0.11	0.11	-0.07	0.29
Formal education of household head					0.01	0.01	0.01	0.04
Credit access					-0.25	0.42	0.16	0.17
Plot size					0.17**	0.06	0.12**	0.05
Annual partial income per capita					0.45**	0.28	0.33**	0.16
Value of livestock owned per household					0.04**	0.02	0.07**	0.03
Plot age							-0.007**	0.002
Cutoff 1	-1.13	0.30	-1.03	0.60	5.82	3.41	5.82	3.41
Cutoff 2	-0.77	0.29	-0.72	0.60	6.15	3.42	6.15	3.42
Cutoff 3	-0.62	0.29	-0.59	0.60	6.30	3.42	6.29	3.42
Cutoff 4	1.58	0.31	1.26	0.61	8.24	3.44	8.24	3.44
Number of observations	245		245		245		245	
Log likelihood	-118.94		-161.73		-173.65		-163.65	
LR χ^2 (Prob> χ^2)	53.76(0.00)		61.68(0.00)		67.56(0.00)		77.56(0.00)	
Pseudo R^2	0.04		0.09		0.15		0.15	

Note: ***, ** and * indicate statistical significance at the 1%, 5% and 10% levels, respectively (using z-values)

Appendix Table 5: Ordered Probit regression of soil fertility perception as a function of soil carbon content and socioeconomic variables in Madzuu

Variable	**Model 1**		**Model 2**		**Model 3**	
	Coefficient Estimate	Standard Error	Coefficient Estimate	Standard Error	Coefficient Estimate	Standard Error
Constant	0.72	0.38	0.10	0.45	0.43	0.57
Soil carbon content	1.09	0.23***	1.44	3.79	0.18	0.40
Plot-level Yiled (kg/ha)			1.63***	0.41	1.44**	0.68
Age of household head					-0.01	0.006
Gender of household head					-0.05	0.19
Formal education					0.11	0.20
Plot size					-0.06	0.30
Number of adults in household					-0.01	0.07
Crop income					0.00004*	0.00003
Non-crop income					0.000005	0.000004
Value of livestock owned					-0.000002	0.000004
Manure application					0.40*	0.19
Model statistics						
Cutoff 1	- 0.72	0.38	0.11	0.45	-0.43	0.57
Cutoff 2	2.41	0.41	1.66	0.40	1.43	0.58
Number of observations	198		198			198
Log likelihood	-179.94		-172.98			-162.83
LR Chi square (Prob>chi square)	23.76(0.00)		37.68(0.00)			50.56(0.00)
Pseudo R-square	0.06		0.10			0.13

Appendix Table 6: Ordered Probit regressions of perceived impact of fertilizer on maize yields

Variable	Model 1		Model 2		Model 3		Model 4	
	Coefficient Estimate	Standard Error	Coefficient Estimate	Standard Error	Coefficient Estimate	Standard Error	Coefficient Estimate	Standard Error
Constant	2.85	2.49	3.30	2.31	3.93	3.68	2.84	2.54
Estimated marginal product of N	0.78***	0.195	0.14**	0.06	0.48*	0.21	0.71*	0.35
Plot carbon content			0.06***	0.02	-0.41*	0.18	0.20	0.30
Frequency of extension contact					0.23**	0.11	0.24*	0.14
Age of household head					0.30	0.12	-0.06	0.77
Gender of household head					0.17	0.17	-0.11	0.44
Formal education of household head					0.02	0.02	0.02	0.06
Credit access					-0.38	0.63	0.24	0.26
Plot size					0.26**	0.09	0.18**	0.08
Annual partial income per capita					0.68**	0.42	0.50**	0.24
Value of livestock owned per household					0.06**	0.03	0.11**	0.05
Plot age							-0.01**	0.00
Cutoff 1	-1.33	0.35	-1.42	0.83	-0.3	0.21	8.05	4.72
Cutoff 2	-0.91	0.34	-0.99	0.83	1.11	0.36	8.51	4.73
Cutoff 3	-0.73	0.34	-0.81	0.83	0.3	0.12	8.71	4.73
Cutoff 4	1.86	0.37	1.75	0.84	0.165	0.165	11.4	4.76

Number of observations	245	245	245	245
Log likelihood	-108.94	-151.73	-144.12	-143.65
LR Chi square (Prob>chi square)	43.76(0.00)	41.68(0.00)	47.96(0.00)	57.56(0.00)
Pseudo R-square	0.04	0.09	0.11	0.15

*Note: ***, ** and * indicate statistical significance at the 1%, 5% and 10% levels, respectively (using z-values)*