School of Business,
Economics and Law
UNIVERSITY OF GOTHENBURG

WORKING PAPERS IN ECONOMICS

No 334

Organic Farming Technologies and Agricultural Productivity: The case of Semi-Arid Ethiopia

Menale Kassie, Precious Zikhali, John Pender, and Gunnar Köhlin

December 2008

ISSN 1403-2473 (print)
ISSN 1403-2465 (online)

SCHOOL OF BUSINESS, ECONOMICS AND LAW, UNIVERSITY OF GOTHENBURG

Department of Economics
Visiting adress Vasagatan 1,
Postal adress P.O.Box 640, SE 405 30 Göteborg, Sweden
Phone + 46 (0)31 786 0000

Organic Farming Technologies and Agricultural Productivity: The case of Semi-Arid Ethiopia

Menale Kassie[1], Precious Zikhali[2], John Pender[3], Gunnar Köhlin[4]

4 December 2008

Abstract

Organic farming practices, in as far as they rely on local or farm renewable resources, present desirable options for enhancing agricultural productivity for resource-constrained farmers in developing countries. In this paper we use plot-level data from semi-arid area of Ethiopia to investigate the impact of organic farming practices on crop productivity, with a particular focus on conservation tillage. Specifically we seek to investigate whether conservation tillage results in more or less productivity gains than chemical fertilizer. Our results reveal a clear superiority of organic farming practices over chemical fertilizers in enhancing crop productivity. Thus our results underscore the importance of encouraging resource-constrained farmers in developing countries to adopt organic farming practices, especially since they enable farmers to reduce production costs, provide environmental benefits, and as our results confirm, enhance crop productivity.

Keywords: Conservation tillage, Chemical fertilizer, Crop productivity, Matched observations, Ethiopia
JEL Classification: C21**;** Q12; Q15; Q16; Q24

---

[1] Department of Economics, University of Gothenburg, Box 640, SE405 30, Gothenburg, Sweden. Email: Menale.Kassie@economics.gu.se

[2] Department of Economics, University of Gothenburg, Box 640, SE405 30, Gothenburg, Sweden. Email: Precious.Zikhali@economics.gu.se

[3] International Food Policy Research Institute, (IFPRI). Email: J.Pender@cgiar.org

[4] Department of Economics, University of Gothenburg, Box 640, SE405 30, Gothenburg, Sweden. Email: Gunnar.Kohlin@economics.gu.se

1. Introduction

Agriculture accounts for about 30% of Africa's gross domestic product (GDP) and 75% of total employment (World Bank, 2007). However, nearly half of the area of Africa, which is home to more than 14% of the low-income countries in the world, is either arid or semi-arid, and over 90 percent of agricultural production is rain-fed (Fisher *et al.*, 2004; WDI, 2005). This implies that erratic rainfall patterns present serious challenges to food production in these areas (Fisher *et al.*, 2004), and this will be further worsened by climate change which is expected to increase rainfall variability in many African countries that are already at least partly semi-arid and arid.

These challenges are also of concern in Ethiopia where the agriculture sector, though it remains the most important sector for poverty reduction, has been undermined by lack of adequate nutrient supply, the depletion of soil organic matter and soil erosion (Grepperud, 1996). In an effort to overcome these challenges, the government and non-governmental organizations have consistently promoted inorganic fertilizer as a yield augmenting technology. Despite this, inorganic fertilizer adoption rates remain very low (Byerlee et al., 2007) and in some cases there has been evidence suggesting dis-adoption of fertilizer (EEA/EEPRI, 2006), possibly due to escalating prices and production and consumption risks (Kassie et al., 2008b; Dercon and Christiaensen, 2007).

The key to tackling these challenges lie not only in the adoption of farming technologies that enhance water retention capacities of soils in these areas, but also in the adoption of farming technologies that rely mainly on local or farm renewable resources, thereby reducing production costs and risks. Sustainable agricultural production practices are a good example of such technologies. Sustainable agricultural production systems are agricultural systems that; conserve resources such as land and water, are environmentally non-degrading, technically appropriate, and economically and socially acceptable (FAO, 2008). In practice, sustainable agriculture uses less external off-farm inputs (e.g. purchased fertilizers) and more of locally available natural resources (Lee, 2005). Conservation agriculture is an example of a sustainable agricultural practice that seeks to achieve sustainable agriculture through minimal soil disturbance (i.e. zero- or minimum-tillage farming), permanent soil cover and crop rotations. The potential benefits from conservation or reduced tillage lie in not only conserving but also in enhancing the natural resources (e.g. increasing soil organic matter) without sacrificing yield levels; making it possible for fields to act as a sink for carbon-dioxide; increasing the soils' water retention capacities and reducing soil erosion; and reducing the production costs through reducing time and labor requirements as well as costs associated with mechanized farming e.g. costs of fossil fuels (FAO, 2008). It is due to its ability to address such a broad set of farming constraints that makes conservation tillage a widely adopted component of sustainable farming (Lee, 2005).

Moreover, the water retention characteristics of conservation tillage (Twarog, 2006) make it especially appealing in water-deficient farming areas such as our study area. In addition to reducing natural risks, conservation tillage enables poor farmers to avoid the financial risk of taking chemical fertilizer on credit, and also overcomes the prevailing problem of late delivery of chemical fertilizer. Consequently since 1998 Ethiopia included conservation tillage as part of extension packages to reverse extensive land degradation (Sasakawa Africa Association, 2008).

While encouraging adoption of reduced tillage is important, an equally if not even more important aspect is whether or not it enhances productivity. How does it compare to external inputs such as chemical fertilizers, in terms of its impact on crop productivity? These are important questions that farmers presumably consider when deciding to adopt a given technology. Whether reduced tillage increases yields might be influenced by agro-ecology. For example research has shown that in Ethiopia, the economic returns to soil and water conservation investments as well as their impacts on productivity are greater in lower rainfall areas than in more humid areas (Sutcliffe, 1993; Benin, 2006; Kassie and Holden, 2006; Kassie et al., 2008a).

In this paper we examine the productivity gains associated with adoption of sustainable agricultural production practices, with a particular focus on the adoption of reduced tillage (hereafter conservation tillage). We go a step further to investigate how these productivity gains compare with the productivity gains associated with adoption of chemical fertilizer. To achieve this and at the same time ensure robustness we pursue an estimation strategy that employs both semi-parametric and parametric econometric methods, permitting us to (1) explore how household and plot characteristics influence decisions to adopt either conservation tillage or chemical fertiliser, (2) assess and compare the impact of these technologies on crop productivity, and (3) explore determinants of crop production in general. The semi-parametric method we use is the Propensity Score Matching Method (PSM) while the parametric methods are pooled OLS and random effects estimators which allow us to treat each plot observation within a given household as a variable unit thereby controlling for unobserved effects. The parametric analysis is based on observations that found matches in the PSM; this is to ensure a comparable sample. Our results reveal a clear superiority of organic farming practices over chemical fertilizers in enhancing crop productivity. Our results also demonstrate the significance of both plot and household characteristics on crop productivity and technology adoption decisions.

The rest of the paper is organized as follows. The next section presents the econometric framework and estimation strategy we pursue followed by a description of the dataset in section three. The empirical results are presented in section four. Finally, section five concludes the paper and draws some policy implications of the study.

2. Econometric framework and estimation strategy

We use semi-parametric and parametric techniques to overcome the econometric problems mentioned below and ensure robustness. The semi-parametric method we use is the propensity score matching while the parametric analysis uses a switching regression framework. The parametric analysis is based on matched observations from the propensity score matching (PSM) process.

2.1. Semi-parametric analysis

The propensity score matching method (PSM) is used here to address the ‘selection on observables’ problem, that is, it might be the case that adoption of conservation tillage and/or chemical fertilizer is non-random. This is especially the case here since we have observational rather than experimental data. Farmers are not randomly assigned to the two groups (adopters and non-adopters) but make the adoption choices themselves, or they might be systematically selected by development agencies based on their propensity to participate in the adoption of technologies. Furthermore, farmers or development agencies are likely to select plots non-randomly based on their quality attributes (often unobservable). If this is the case, there is a risk that the non-random selection process may lead to differences between adopters and non-adopters that can be mistaken for effects of adoption. Failure to account for this potential selection bias could lead to inconsistent estimates of the impact of technology adoption.

The rationale behind the PSM is that one group of people participates in a programme or treatment (adopting a given technology in this case) while another group does not, and the objective is to assess the effectiveness of the treatment by comparing the average outcomes. A matching process based on observed characteristics is used to compare adopters and non-adopters. Comparisons are therefore between plots with and without technology adoption but with characteristics that are similar and relevant to the technology choice. This reduces the potential for bias from comparing non-comparable observations, although there still may be selection bias caused by differences in unobservables. The PSM method is a semi-parametric method used to estimate the average treatment effect of a binary treatment on a continuous scalar outcome (Rosenbaum and Rubin, 1983). We take adoption as the treatment variable, while crop productivity is the outcome of interest. Adopters constitute the treatment group, while non-adopters form the control group.

In order to estimate the average treatment effect of technology adoption on crop productivity among adopters, we would ideally want to estimate the following:

$$ATT = E[y_{hp1} \mid d_{hp} = 1] - E[y_{hp0} \mid d_{hp} = 1] \quad , \tag{1}$$

where ATT is the average effect of the treatment on the treated households or plots, $d_{hp} = 1$ when the technology has been adopted by household h on plot p and $d_{hp} = 0$ when no adoption has taken place. $y_{hp0} \mid d_{hp} = 1$ is the level of crop productivity that would have been observed had the plot *not* been subjected to the technology under analysis, while $y_{hp1} \mid d_{hp} = 1$ is the level of productivity actually observed among adopters. The challenge is that $y_{hp0} \mid d_{hp} = 1$ cannot be observed i.e. we do not observe the outcome of plots with conservation tillage or chemical fertilizer had they not had these technologies. This creates a need for the creation of a counterfactual of what can be observed by matching treatment and control groups.

Matching on every covariate is difficult to implement when the set of covariates is large. To overcome the curse of dimensionality, propensity scores ($p(x_{hp})$) – the conditional probabilities that plot p receives conservation tillage or chemical fertilizer treatment conditional on x_{hp} – are used to reduce this dimensionality problem. Here x_{hp} is the set of household and plot covariates that influence the decision to adopt a particular technology. The model matches treated units to control units with similar values of x_{hp}. The equation to be estimated is thus:

$$ATT = E[y_{hp1} \mid d_{hp} = 1, p(x_{hp})] - E[y_{hp0} \mid d_{hp} = 0, p(x_{hp})] \; . \tag{2}$$

The PSM relies on the key assumption that conditional on x_{hp}, the outcomes must be independent of the targeting dummy d_{hp} (the conditional independence assumption, or CIA).

Rosenbaum and Rubin (1983) show that if matching on covariates is valid, so is matching on the propensity score. This allows matching on a single index rather than on the multidimensional x_{hp} vector.

We perform the matching process in two-steps. In the first step, we use a probit model to estimate the propensity scores and in the second stage, we use nearest neighbor matching based on propensity scores estimates to calculate the ATT. The nearest-neighbour matching matches each treated unit to the *n* control units that have the closest propensity scores. Compared to other weighted matching methods such as kernel matching, the nearest neighbor matching method allows us to identify the specific matched observations that entered the calculation of the ATT which we then use for parametric regressions.

2.2. Parametric analysis

Besides non-randomness of selection into technology adoption, the other econometric issue is that using a pooled sample of adopters and non-adopters (dummy regression model where a binary indicator is used to assess the effect of conservation tillage or chemical fertilizer on productivity) may be inappropriate. This is because pooled model estimation assumes that the set of covariates has the same impact on adopters as non-adopters (i.e. common slope coefficients for both groups). This implies that conservation tillage and chemical fertilizer adoption have only an intercept shift effect, which is always the same irrespective of the values taken by other covariates that determine yield. However, for our sample a Chow test of equality of coefficients for adopters and non-adopters of conservation tillage and chemical fertilizer rejected equality of the non-intercept coefficients at 1% significance level.[5] This supports the idea of using a regression approach that differentiates coefficients for adopters and non-adopters.

To deal with this problem we employ a switching regression framework which is such that the parametric regression equation to be estimated using multiple plots per household is:

$$\begin{cases} y_{hp1} = x_{hp}\beta_1 + u_h + e_{hp1} \text{ if } d_{\text{hp}} = 1 \\ y_{hp0} = x_{hp}\beta_0 + u_h + e_{hp0} \text{ if } d_{\text{hp}} = 0 \end{cases}, \tag{3}$$

---

[5] χ^2(35) = 100.81 (p-level = 0.000), χ^2 (35) = 161.20 (p = 0.000), and χ^2 (35) = 64.49 (p = 0.000) for models comparing only reduced tillage versus chemical fertilizer adoption plots, reduced tillage versus all other plots, and chemical fertilizer versus all other plots, respectively. Although not reported, similar results were found without the Mundlak approach.

where y_{hp} is value of crop production per hectare (hereafter gross crop revenue)[6]obtained by household h on plot p, depending on its technology adoption status (d_{hp}); u_h captures unobserved household characteristics that affect crop production, such as farm management ability, average land fertility; e_{hp} is a random variable that summarizes the effects of plot-specific unobserved components on productivity, such as unobserved variation in plot quality and plot-specific production shocks (e.g. microclimate such as variation in rainfall, frost, floods, weeds, pests and diseases infestations); x_{hp} includes both plot-specific and household-specific observed explanatory variables and β is a vector of parameters to be estimated.

To obtain consistent estimates of the effects of conservation tillage and chemical fertilizer we need to control for unobserved heterogeneity (u_h) that may be correlated with observed explanatory variables. One way to address this issue is to exploit the panel nature of our data (repeated cross sectional plot observations per household), and use household specific fixed effects. The main shortcoming of fixed effects in our case is that we have many households with only a single plot. At least two observations per household are needed to apply fixed effects. These households therefore do not play a role in a fixed effects analysis. Random effects and pooled OLS models are consistent only under the assumption that unobserved heterogeneity is uncorrelated with the explanatory variables. As an alternative, we use the modified random effects model framework proposed by Mundlak (1978), whereby we include on the right hand-side of each equation the mean value of plot-varying explanatory variables[7]. Mundlak's approach relies on the assumption that unobserved effects are linearly correlated with explanatory variables such that:

$$u_h = \bar{x}\gamma + \eta_h,\ \eta_h \sim \mathrm{iid}(0, \sigma_\eta^2), \qquad (4)$$

where $\bar{x}$ is the mean of plot-varying explanatory variables within each household (cluster mean), γ is the corresponding vector coefficients and η is a random error unrelated to the $\bar{x}'s$. We include average plot characteristics, such as average plot fertility, soil depth, slope and conventional inputs, as we believe they have an impact on production and technology adoption decisions.

---

[6] To compute the value of production, we used average crop prices based upon the community and household level surveys.

[7] We did not use Mundlak's approach for the model that compares only reduced tillage versus chemical fertilizer impact on crop production value per hectare because the control group (plots with chemical fertilizer) has insufficient observations.

The selection process in the parametric switching regression model can be addressed using the inverse Mills ratio derived from the probit criterion equation, which addresses the problem of selection on unobservables. However, the criterion models turned out to be insignificant (i.e. the overall model significance test statistics (Wald χ^2) is insignificant). This is perhaps not surprising since we use matched samples obtained from nearest neighbor propensity score matching. As a result we did not use the inverse Mills ratio derived from such insignificant model instead we assumed that addressing selection on observables using propensity score matching, we may also reduce problems with selection on unobservables. Kassie et al. (2008a), in estimating the impact stone bunds on productivity, found that the problem of selection on unobservables can be addressed by addressing selection on observables using propensity score matching. However, if selection and endogeneity bias are due to plot invariant unobserved factors such as household heterogeneity, the selection process and endogeneity bias can be addressed using the panel nature of our data and Mundlak's approach (Wooldridge, 2002). In addition, our rich plot and household characteristics dataset (see Table 1A in the appendix) can assist reducing both household and plot unobserved effects. In terms of plot characteristics, the dataset includes plot slope, position on slope, plot size, soil fertility, soil depth, soil color, soil textures, plot distance from homestead, and input use by plot. Including observed plot characteristics and inputs could also address selection due to idiosyncratic errors, such as plot heterogeneity, —as is likely—observable plot characteristics were positively correlated with unobservable ones (Fafchamps 1993; Levinsohn and Petrin 2003; Assunção and Braido 2004). Including input use also help control for plot heterogeneity because farmers typically responded to shocks (positive or negative) by changing input use (Ibid).

Controlling for the above econometric problems and incorporating equation (4) into (3), the expected yield difference between adoption and non-adoption of conservation tillage or chemical fertilizer becomes:

$$E(y_{hp1} \mid x_{hp}, u_h, d_{hp} = 1) - E(y_{hp0} \mid x_{hp}, u_h, d_{hp} = 1) = x_{hp}(\beta_1 - \beta_0) + \bar{x}(\gamma_1 - \gamma_0). \quad (5)$$

The second term on the left-hand side of (5) is the expected value of y if a plot had not received conservation tillage or chemical fertilizer treatment. This is the counterfactual outcome, which will be approximated by non-conservation tillage and non-fertilized plot observations after taking into account the selection process. This is our parameter of interest in the parametric regression analysis. Equation 5 will also be estimated without including the second term of the right hand side equation (i.e. without the Mundlak approach) for comparison purposes and to generate a greater degree of confidence in the robustness of the econometric results. It is important to note that the parametric analysis is based on observations that fall within common support from the propensity score matching process i.e. matched observations.

3. The data and descriptive statistics

The data used in this study are from a farm survey conducted in 1999 and 2000 in the Tigray region of Ethiopia. The dataset includes 500 farm households, 100 villages, 50 *kebeles* and 1067 plots located above 1500 meters[8]. To compare the productivity impact of conservation tillage with that of chemical fertilizer we dropped plot observations with neither technology (586 observations). Similarly, plots that received a combination of fertilizer and conservation tillage inputs are also dropped from the analysis (27 observations) in order to investigate their pure impact on productivity.

Table 1A in appendix 1 presents the descriptive statistics for the sub-samples of plots after matching. The sub-samples in the analysis include: plots that have adopted conservation tillage (column 1 of Table 1A) and the rest of plot observations (non-conservation tillage adopters) (column 3 of Table 1A); plots that have adopted chemical fertilizer (column 4 of Table 1A) and the rest of plot observations (non-chemical fertilizer adopters) (column 5 of Table 1A); and only those have adopted only conservation tillage (column 1 of Table 1A) and chemical fertilized (column 2 of Table 1A).

About 13% and 34% of the sample plots had conservation tillage and chemical fertilizer, respectively. Fertilizer use averages about 40 kilograms per hectare. The mean plot altitude, which is associated closely with temperature and rainfall, ranged 2146-2207 meters above sea level. Similarly, the mean population density ranged 124 to 153 persons per square kilometer.

In addition to these variables, plot characteristics, household endowments and indicators of access to infrastructure are included in the empirical model. The choice of these variables is guided by economic theory and previous empirical research. Given missing and/or imperfect markets in Ethiopia, households' initial resource endowments and characteristics are expected to play a role in investment and production decisions and thus included in the analysis (Holden *et al.*, 2001; Pender and Kerr, 1998).

---

[8] For more details on study areas, sampling techniques and criterions used to select sample areas please see Pender and Gebremedhin (2006).

4. The empirical results

In this section we present and discuss the empirical results, starting with results from semi-parametric analysis followed by results from parametric estimations.

4.1. Results from semi-parametric analysis

As the foregoing discussion on the econometric strategy shows, the use of the PSM method allows us an opportunity to explore how the plot and households' characteristics influence the households' decisions to adopt either conservation tillage or chemical fertiliser as well as how the adoption subsequently impacts crop productivity. In addition we use the PSM to compare conservation tillage with chemical fertiliser adoption decisions; what determines the decision to adopt conservation tillage instead of chemical fertiliser and how do the productivity impacts of the two technologies compare?

Table 1 below presents probit results of the decisions to adopt (1) conservation tillage (column 1), (2) chemical fertiliser (column 2) as well as (3) conservation tillage instead of chemical fertilizers (column 3). At this stage our main interest is to analyse factors affecting adoption of sustainable farming practices (conservation tillage) over chemical fertlizers. Accordingly the ensuing discussion of the results focuses on factors that influence the household's decision to adopt conservation tillage instead of chemical fertilizers i.e. the discussion is based on results reported in column (3).

Table 1: Conservation tillage and chemical fertilizer adoption decisions

	(1)		(2)		(3)	
	Conservation tillage		Chemical fertilizer		Conservation tillage vs. Chemical fertilizer	
Variable	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Socioeconomic characteristics						
Gender	-0.31	0.19	0.06	0.16	-0.22	0.25
Age	0.04	0.21	0.12	0.15	-0.24	0.26
Family size	-0.11***	0.03	0.01	0.02	-0.14***	0.05
Education low	-0.09	0.24	0.40**	0.16	-0.39	0.29
Education high	-0.19	0.28	0.01	0.17	-0.33	0.34
Extension contact	0.29*	0.16	0.12	0.11	0.33*	0.20
Oxen	-0.25***	0.07	0.08	0.05	-0.40***	0.12
Livestock	0.02***	0.00	-0.00	0.00	0.03***	0.01
Farm size	0.35***	0.10	-0.10	0.08	0.51***	0.13
Population density	-0.00	0.00	0.00***	0.00	-0.002	0.001
Altitude	0.00	0.00	-0.00***	0.00	0.000	0.00
Market distance	0.03	0.03	-0.11***	0.02	0.11***	0.04
Plot characteristics						
Plot distance	0.20	0.16	-0.58***	0.16	0.65***	0.23
Rented	0.06	0.19	-0.45***	0.14	0.31	0.27
Soil and water conservation	-0.22	0.23	0.02	0.15	-0.05	0.27
Stone covered	0.27*	0.14	-0.08	0.11	0.32*	0.18
Deep soils	-0.07	0.17	-0.03	0.12	0.14	0.21
Moderately deep soils	0.16	0.17	0.04	0.12	0.23	0.21
Brown soils	0.60**	0.27	0.14	0.18	0.49	0.31
Gray soils	0.54**	0.27	-0.16	0.18	0.62**	0.31
Red soils	0.44*	0.26	0.13	0.17	0.42	0.29
Loam soils	0.10	0.24	0.15	0.17	-0.12	0.27
Clay soils	-0.23	0.25	0.27	0.17	-0.50*	0.28
Sandy soils	-0.58*	0.34	0.35*	0.20	-1.07**	0.44
Moderate erosion	0.03	0.14	0.06	0.10	-0.07	0.18
Severe erosion	0.01	0.25	-0.24	0.20	0.15	0.35
Moderate slope	-0.07	0.17	-0.00	0.13	-0.16	0.24
Steep slope	-0.33	0.26	0.04	0.20	-0.39	0.34
Middle slope	-0.45**	0.22	0.11	0.18	-0.19	0.29
Bottom slope	-0.34	0.22	0.22	0.18	-0.35	0.28
No slope	-0.23	0.21	0.38**	0.17	-0.31	0.28
Constant	-1.49	1.01	-0.38	0.76	-0.35	1.37
Pseudo R-squared	0.20		0.10		0.30	
Model chi-square	142.23***		133.54***		121.87***	
Log likelihood	-286.21		-590.09		-178.66	
Number of observations	1039		1039		453	

*Note: * significant at 10%; ** significant at 5%; *** significant at 1%*

The results suggest that both socioeconomic and plot characteristics are significant in conditioning the households’ decisions to adopt any technology. In addition there is heterogeneity with regards to factors influencing the choice to adopt conservation tillage or chemical fertilizer.

It has been argued that one of the advantages of adopting conservation tillage is that it helps households save on labor or relaxes labor shortage (Lee, 2005). Our results support this contention; specifically we find that the probability of adopting conservation tillage instead of chemical fertilizers decreases with family size. Family size is a crude proxy of household's assured labor in this analysis. This underscores the importance of labor availability in technology adoption, consistent with findings by Caviglia and Kahn (2001) and Shiferaw and Holden (1998). The results could also be implying that compared to adoption of conservation tillage, adoption of chemical fertilizer is labor intensive as farmers might have to travel long distance to obtain this input.

Access to agricultural extension services, indicated by whether or not the household has contact with an extension worker, impacts the decision to practice conservation tillage over using chemical fertilizers positively. This is intuitive given that access to information on new technologies is crucial in creating awareness and attitudes towards technology adoption (Place and Dewees, 1999). Contact with extension services allows farmers to have access to information on new innovations and advisory inputs on establishment and management of technologies. In most cases, extension workers establish demonstration plots where farmers have the possibility of learning and experimenting with new farm technologies. Consequently, access to extension is thus often used as an indicator of access to information (Adesina et al., 2000; Honlonkou, 2004). These results might be indicating that the decision to include conservation tillage as part of extension packages has been successful in encouraging conservation tillage adoption.

The fact that we find evidence that livestock ownership and farm size increase the likelihood of adopting conservation tillage over chemical fertilizer suggests that poverty significantly limits technology adoption. Wealth intuitively affects adoption decisions since wealthier farmers have greater access to resources and may be better able to take risks. It must be acknowledged, however, that the wealth measures we use might be confounded with other factors related to adoption. For instance farm size, though measuring farmers' wealth, could also suggest for economies of scale in production using conservation tillage. All the same, these results suggest that policies that alleviate poverty among farmers will impact the adoption of sustainable agricultural practices positively. The negative impact of oxen ownership, on the other hand, on the decision to adopt conservation tillage over chemical fertilizer might be capturing the fact that in the local setting crop residues are used as feed for oxen and intuitively this disadvantages the adoption of conservation tillage, which has crop residues as its component. Alternatively this result implies that conservation tillage can relax household's oxen constraints.

The further away the household is from the input markets, the more likely they are to adopt conservation tillage over adopting chemical fertilizers. Distance from input markets increases the transaction costs associated with the use of external inputs such as inorganic fertilizers, and this intuitively stimulates the adoption of practices that rely on locally or farm-derived renewable farm resources. This applies to the significance of the distance from the homestead to the plot in negatively affecting the use of chemical fertilizers as compared to conservation tillage. The distance captures the transaction costs households incur in carrying purchased fertilizers from their residences to the plots as well as in carrying crop residues from their plots to residences to use them as livestock feed.

With regards to the impact of plot characteristics on adoption decisions; households are less likely to adopt conservation tillage over chemical fertilizers on clay and sandy soils while the likelihood of adoption is higher on gray soils as well as on plots that are covered, to a certain extent, in stone. These results imply that for sustainable agricultural practices to be successful they must address site-specific characteristics as these condition the need for adoption as well as the type of the technology adopted.

The estimated propensity scores are used to generate samples of matched observations using the nearest neighbour matching method. We start by matching plots that have adopted conservation tillage to control plots, which is basically the rest of the observations (hereafter Model 1). The results are then used to calculate the impact of the conservation tillage on crop productivity. Second, we match plots that have been fertilised to control plots, which is basically the rest of the observations and use the results to calculate the impact of the chemical fertilizers on crop productivity (hereafter Model 2). Lastly we match plots that have adopted conservation tillage to plots that have been fertilised; here fertilized plots constitute the control group (hereafter Model 3). This allows us to compare the productivity impacts of the two technologies. The PSM results are presented in Table 2 below. ATT is the average treatment effect on the treated. The results are reported for gross crop revenue per hectare.

Table 2: Productivity impacts estimated by PSM

	Model 1	Model 2	Model 3
ATT	744.55***	448.74***	768.24**
Std. Error	364.32	169.12	392.27
Number of observations			
Treated	113	340	113
Control	80	211	57

*Note: ** significant at 5%; *** significant at 1%.*

The results indicate that, based on both household and plot characteristics, both conservation tillage and chemical fertilizers enhance productivity. However, interestingly, comparing the impact of conservation tillage with that of chemical fertilizer suggests that conservation tillage leads to significantly higher productivity gains than chemical fertilizers. The results are comparable to when net crop revenue are used i.e. when the monetary cost of fertilizer has been deducted, although the impact of chemical fertilizer turned out to be statistically insignificant (results are not reported but available upon request).

4.2. Results from parametric analysis

All regression models except for the control group (chemical fertilizer adoption) in model 3 are estimated using random effects methods with and without Mundlak's approach[9]. The dependent variable in all cases is the gross crop revenue per hectare in logarithmic form. Our parameter of interest as indicated in equation (5) is to estimate the ATT (mean gross crop revenue per hectare difference) of conservation tillage and chemical fertilizer adoption. In the interest of space we focus the discussion of the results on the ATT. The detailed results are presented in Tables 2A, 2B, and 2C in the appendix 2. Table 2A reports the factors that determine agricultural productivity of plots that are subjected to conservation tillage as well as factors determining the productivity of plots that are not subjected to conservation tillage (Model 1). Table 2B presents the factors that determine agricultural productivity of plots that are fertilized together with factors that determine the productivity of non-fertilized plots (Model 2). Finally, column (1) of Table 2C shows the factors that determine agricultural productivity of plots that are subjected to conservation tillage while column (2) reports factors affecting the productivity of chemical fertilized plots (Model 3).

---

[9] The control group (fertilizer adoption) has no sufficient observations to run random effects but pooled OLS. However, the same conclusion is reached when both treatment (conservation tillage plots) and control groups are run using pooled OLS. Similarly, the Mundlak approach is not applied in model 3 because of few observations.

In brief the results underscore the significance of plot and household characteristics as well as conventional agricultural inputs (seeds, labour and oxen)[10] in influencing crop productivity. More importantly the results suggest that the effectiveness of these factors in influencing crop productivity varies depending on the technology that has been adopted on a given plot. Thus understanding how these factors interact with specific technology is crucial for policy makers as this will enable them to formulate more effective and appropriate polices.

The switching regression estimates from Tables 2A, 2B, and 2C, are used to investigate the predicted gross crop revenue gap between conservation tillage and chemical fertilized plots as well as the revenue gap between plots that have these technologies and those that do not.

Consistent with results from semi-parametric analysis, parametric results indicate that while both conservation tillage and chemical fertilizer enhance productivity, conservation tillage leads to significantly higher productivity gains than chemical fertilizers (Table 3). Again these results are robust to both gross and net crop revenue per hectare but Model 2 where impact of fertilizer is negative and significant.[11]

Table 3: Productivity impacts from parametric regression analysis

Model types	Predicted mean gross crop revenue per hectare from			Predicted mean gross crop revenue difference (standard errors)
	Conservation tillage	Withoutconservation tillage /chemical fertilizer	Chemical fertilizer	
Model 1				
With Mundlak	2028.360	1419.472		608.892(258.159)**
Without Mundlak	1952.656	1416.285		536.371(235.633)**
Model 2				
With Mundlak		1320.182	1696.55	376.369(105.214)***
Without Mundlak		1283.297	1667.345	384.048(97.0942)***
Model 3				
Without Mundlak	1952.656		1339.506	536.371(235.633)**

*Note: ** significant at 5%; *** significant at 1%.*

---

[10] Traditionally, farm households retain their own seeds from previous harvests for planting. Seed use is therefore a pre-determined variable. Improved seeds were used only on 3% of all sample plots. We assume labor and oxen use are fixed in the short term since households usually depend on family resources.

[11] These results (not reported) are also robust after controlling for crop types.

In sum, the empirical results show that adoption of organic technologies such as conservation tillage could create a win-win situation for resource-constrained farmers in developing countries i.e. they can result in reduction in production costs, environmental benefits and at the same, as the results demonstrate, they can lead to increased yields. Thus promotion of organic farming techniques could go a long way in ensuring increased yields in Sub-Saharan Africa.

5. Conclusions and policy implications

Inadequate nutrient supply, depletion of soil organic matter and soil erosion continue to present serious challenges to crop production in semi-arid Ethiopia. This is further compounded by increased population pressure which is not accompanied by technological and/or efficiency progress. Efforts by the government to promote the adoption of chemical fertilizers have been frustrated by escalating fertilizer prices and production and consumption risks associated with fertilizer adoption. This means that sustainable agricultural production practices such as conservation tillage; in as far as they rely on local or farm renewable resources, present good options for resource-constrained farmer to improve productivity of their plots.

In this paper we use plot-level data from semi-arid Ethiopia to examine the productivity gains associated with adoption of sustainable agricultural production practices, with a particular focus on the adoption of conservation tillage. In addition we compare the productivity impacts of conservation tillage with the productivity impacts of chemical fertilizers. In so doing we employ both semi-parametric and parametric econometric methods which permit us to (1) explore how household and plot characteristics influence decisions to adopt either conservation tillage or chemical fertiliser, (2) assess the impact of these technologies on crop productivity, and (3) explore determinants of crop production in general. Our results, though indicating that both conservation tillage and chemical fertilizer enhance productivity, reveal a clear superiority of conservation tillage over chemical fertilizers in enhancing crop productivity.

The results thus suggest that the promotion of organic farming techniques could go a long way in ensuring increased yields in sub-Saharan Africa. There is a need for governments and non-governmental organizations in developing countries to shift their focus from chemical fertilizer to considering organic farming technologies as yield augmenting technologies. Organic farming technologies not only increase yields but could also provide multiple benefits whereby farmers are also able to reduce production costs, provide environmental benefits, and can reduce crop failure risk due to moisture stress and financial risks associated with taking chemical fertilizer on credit.

References

Adesina, A.A., D. Mbila, G.B. Nkamleu, and D. Endamana. 2000. Econometric Analysis of the Determinants of Adoption of Alley Farming by Farmers in the Forest Zone of Southwest Cameroon. *Agriculture, Ecoystems and Environment* 80: 255–65.

Assunção, J.J., and B.H.L. Braido. 2004. "Testing among Competing Explanations for the Inverse Productivity Puzzle." Unpublished paper. http://www.econ.puc-rio.br/PDF/seminario/2004/inverse.pdf. Accessed October, 2008.

Benin, S., 2006. Policies and programs affecting land management practices, input use and productivity in the highlands of Amhara region, Ethiopia, in Pender, J., Place, F. and Ehui, S., Eds., Strategies for Sustainable Land Management in the East African Highlands. International Food Policy Research Institute, Washington, D.C.

Byerlee, D., D. J. Spielman, D. Alemu, and M. Gautam. 2007. Policies to Promote Cereal Intensification in Ethiopia: A Review of Evidence and Experience. International Food Policy Research Institute Discussion paper 00707, pp. 37. Washington DC.

Caviglia, J.L., and J.R. Kahn. 2001. Diffusion of Sustainable Agriculture in the Brazilian Rain Forest: A Discrete Choice Analysis. *Economic Development and Cultural Change* 49: 311–33.

Dercon, S., and L. Christiaensen. 2007. Consumption risk, technology adoption and poverty traps: evidence from Ethiopia, World Bank Policy Research Working paper 4527.

Edwards, S., A. Asmelash, H. Araya, and T.B. Gebre-Egziabher. 2007. Impact of compost use on crop production in Tigary, Ethiopia. Natural Resources Management and Environment Department, FAO of UN, Rome, Italy.

EEA/EEPRI (Ethiopian Economic Association/Ethiopian Economic Policy Research Institute). 2006. Evaluation of the Ethiopian agricultural extension with particular emphasis on the participatory demonstration and training extension system *(PADETES).* Addis Ababa: EEA/EEPRI.

Fafchamps, M. 1993. "Sequential Labour Decisions under Uncertainty: An Estimable Household Model of West Africa Farmers," *Econometrica* 61: 1173–97.

FAO 2008. Conservation Agriculture webpage: http://www.fao.org/ag/ca/ Accessed 2008.

Fischer T., Turner, N., Angus, J., McIntyre, L., Robertson, M., Borrell, A., Lloyd, D., 2004. New directions for a diverse planet: Proceedings for the 4th International Crop Science Congress, Brisbane, Australia, 26 September – 1 October 2004.

Grepperud, S. (1996) Population pressure and land degradation: The case of Ethiopia. *Journal of Environmental Economics and Management* 30: 18-33.

Holden, S. T., Shiferaw, B., Pender, J., 2001. Market imperfections and profitability of land use in the Ethiopian Highlands: a comparison of selection models with heteroskedasticity. J. Agric. econ. 52(2), 53-70.

Honlonkou, A.N. 2004. Modelling Adoption of Natural Resources Management Technologies: The Case of Fallow Systems. *Environment and Development Economics* 9: 289–314.

Kassie, M., J. Pender, M. Yesuf, G. Kohlin, R. Bulffstone, and E. Mulugeta. 2008a. Estimating Returns to Soil Conservation Adoption in the Northern Ethiopian Highlands. *Agricultural Economics* 38: 213–232.

Kassie, M., Yesuf, M. and Köhlin, K. 2008b. The Role of Production Risk in Sustainable Land-Management Technology Adoption in the Ethiopian Highlands", EfD Discussion Paper 08-15, Resources for the Future, Washington DC, March 2008.

Kassie, M., Holden, T. S., 2006. Parametric and Non-parametric estimation of soil conservation adoption impact on yield. Contributed paper prepared for presentation at the international Association of Agricultural Economists Conference, Gold Coast, Australia, August 12-18, 2006.

Lee, D.R. 2005. Agricultural sustainability and technology adoption: issues and policies for developing countries. *American Journal of Agricultural Economics* 87(5): 1325-1334.

Levinsohn, J., A. Petrin. 2003. “Estimating Production Functions Using Inputs to Control for Unobservable,” *Review of Economic Studies* 70: 317–41.

Mundlak, Y., 1978. On the pooling of time series and cross section data. Econometrica 64(1), 69-85.

Pender, J., Gebremedhin, B., 2006. Land Management, Crop Production and Household Income in the Highlands of Tigray, Northern Ethiopia: An Econometric Analysis. In: Pender, J., Place, F., Ehui, S., Eds., Strategies for Sustainable Land Management in the East African Highlands. International Food Policy Research Institute, Washington, D.C..

Pender, J., Kerr, J. M., 1998. Determinants of farmer’s indigenous soil and water conservation investments in semi-arid India. Agric. Econ. 19, 113-125.

Place, F., and P. Dewees. 1999. Policies and Incentives for the Adoption of Improved Fallows. *Agroforestry Systems* 47: 323–43.

Rosenbaum, P.R., Rubin, D. B., 1983. The central role of the propensity score in observational studies for causal effects. Biometrika 70(1), 41-55.

Sasakawa Africa Association (2008). Country Profile. http://www.saa-tokyo.org/english/country/ethiopia.shtml. accessed on October 2008.

Shiferaw, B., and S.T. Holden. 1998. Resource Degradation and Adoption of Land Conservation Technologies in the Ethiopian Highlands: A Case Study in AnditTid, North Shewa.” *Agricultural Economics* 18: 233–47.

Sutcliffe J. P., 1993. Economic assessment of land degradation in the Ethiopian Highlands. A Case Study. National Conservation Strategy Secretariat, Ministry of Planning and Economic Development, Transitional Government of Ethiopia, Addis Ababa, Ethiopia

Twarog. 2006. Organic Agriculture: A Trade and Sustainable Development Opportunity for Developing Countries. In UNCTAD. 2006. Trade and Environment Review 2006. UN, New York and Geneva. At http://www.unctad.org/en/docs/ditcted200512_en.pdf.

WDI. 2005. World development indicators database.

Wooldridge, J. M., 2002. Econometric Analysis of Cross Section and Panel data. The MIT Press.

World Bank. 2007. World development report 2008: Agriculture for development. World Bank, Washington, DC.

Appendices

Appendix 1

Table 1A: Descriptive statistics (means)

Variable	Description	Column 1	Column 2	Column 3	Column 4	Column 5
Production						
Gross crop revenue	Gross crop value production (ETB/ha)	2094.19	1365.87	1421.37	1925.61	1598.72
Net crop revenue*	Net crop production value (ETB/ha)	2094.19	1129.97	1283.56	1641.15	1598.72
Inputs						
Seed	Seed use on the plot, kg/ha	182.00	117.07	93.75	171.39	145.21
Labor	Labor use on the plot, days/ha	42.27	75.36	58.30	85.59	73.34
Oxen use	Oxen use on the plot, days/ha	14.39	30.04	28.19	34.18	28.61
Socioeconomic characteristics						
Gender	Sex of household head (1=male;0=female)	0.82	0.79	0.84	0.92	0.90
Age	Household head age	48.34	49.07	48.11	49.30	49.52
Family size	Number of household members	5.48	5.93	5.77	6.24	6.01
Illiterate	Head illiterate (1= yes;0=otherwise)	0.90	0.84	0.88	0.82	0.88
Education low	Head had up to grade one and two (1=yes;0=otherwise)	0.06	0.05	0.07	0.10	0.08
Education high	Head has above grade 3 (1=yes;0=otherwise)	0.04	0.11	0.06	0.07	0.05
Extension contact	Extension contact	0.18	0.25	0.19	0.22	0.24
Oxen	Number of oxen owned by household	1.19	1.25	1.27	1.49	1.47
Livestock	Livestock number other than oxen, in tropical livestock units	15.11	11.90	15.40	10.22	10.54
Farm size	Total land holdings, hectares	1.85	1.18	1.31	1.02	0.97
Population density	Village population density , person/km2	124.39	153.75	132.27	152.99	151.95

Altitude	Village altitude, in meters	2145.51	2150.07	2086.13	2168.34	176.14
Market distance	Residence distance to markets, walking hrs	3.54	3.02	3.96	2.26	2.50
Plot characteristics						
Plot distance	Distance from the residence to plot, walking hrs	0.37	0.30	0.34	0.22	0.246
Rented	Plot rented in (1= yes;0=otherwise)	0.11	0.12	0.08	0.09	0.11
Soil and water conservation	Soil and water conservation structures on the plot (1= yes; 0= otherwise)	0.06	0.05	0.03	0.09	0.09
Stone covered	Plot covered in stone (1=yes;0=otherwise)	0.38	0.32	0.32	0.19	0.16
Deep soils	Deep soil depth (1=yes;0=otherwise)	0.34	0.37	0.36	0.39	0.43
Moderately deep soils	Moderately deep soils (1=yes;0=otherwise)	0.49	0.51	0.49	0.38	0.33
Shallow soils	Shallow soil depth (1=yes;0=otherwise)	0.18	0.12	0.16	0.23	0.24
Black soils	Black soils (1=yes; 0=otherwise)	0.10	0.19	0.12	0.20	0.20
Brown soils	Brown soils (1=yes; 0=otherwise)	0.21	0.23	0.20	0.41	0.14
Gray soils	Gray soils (1=yes; 0=otherwise)	0.35	0.20	0.29	0.20	0.24
Red soils	Red soils (1=yes; 0=otherwise)	0.34	0.46	0.39	0.46	0.42
Loam soil	Loam soil plots (1=yes;0=otherwise)	0.60	0.34	0.51	0.34	0.33
Clay soil	Clay soil plots (1=yes;0=otherwise)	0.23	0.35	0.27	0.35	0.32
Sandy soil	Sandy soil plots (1=yes;0=otherwise)	0.04	0.07	0.06	0.13	0.16
Silt soil	Silt soil plots (1=yes;0=otherwise)	0.12	0.21	0.17	0.19	0.19
No erosion	Plots with no erosion problem (1=yes;0=otherwise)	0.63	0.60	0.66	0.67	0.66
Moderate erosion	Moderately eroded plots (1=yes;0=otherwise)	0.27	0.28	0.24	0.29	0.30
Severe erosion	Severely eroded plots (1= yes;0=otherwise)	0.10	0.12	0.10	0.04	0.04
Flat slope	Plot is of flat slope (1=yes; 0= steep slope)	0.57	0.51	0.57	0.69	0.65

Moderate slope	Plot is of moderate slope (1=yes; 0= steep slope)	0.34	0.37	0.33	0.25	0.28
Steep slope	Plot is of steep slope (1=yes; 0= steep slope)	0.10	0.12	0.10	0.07	0.07
Top slope	Top slope position (1=yes;0=otherwise)	0.18	0.18	0.16	0.08	0.09
Middle slope	Middle slope position (1=yes;0=otherwise)	0.20	0.23	0.23	0.18	0.24
Bottom slope	Bottom slope position (1=yes;0=otherwise)	0.24	0.16	0.20	0.21	0.23
No slope	Not on slope position (1=yes;0=otherwise)	0.39	0.44	0.41	0.54	0.44
Total observations		113	57	90	340	211

*Fertilizer cost deducted from value of crop production

Column 1 = Refers to mean of variables from matched sample with conservation tillage (CT).
Column 2 = Refers to mean of variables from matched sample with chemical fertilizer (where only CT & Chemical fertilizer considered as treatment & control group, respectively)
Column 3 = Refers to mean of variables from matched sample without conservation tillage (where CT & rest of plot observations considered as treatment & control group, respectively)
Column 4 = Refers to mean of variables from matched sample with chemical fertilizer (where chemical fertilizer & rest of plot observations considered as treatment & control group, respectively)
Column 5 = Refers to mean of variables from matched sample without chemical fertilizer (where chemical fertilizer & rest of plot observations considered as treatment & control group, respectively)

Appendix 2

Table 2A: Productivity analysis using switching regression: conservation tillage adopters vs. non-adopters (Model 1)

	Using Mundlak’s approach				Without Mundlak’s approach			
	Conservation tillage adopters		Conservation tillage non-adopters		Conservation tillage adopters		Conservation tillage non-adopters	
Variable	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Socioeconomic characteristics								
Gender	-0.081	0.39	0.47	1.48	-0.27	0.34	0.33	1.15
Age	-0.10	0.41	-0.24	1.51	-0.42	0.49	-0.80	1.29
Family size	0.10	0.08	0.14	0.26	0.00	0.08	0.16	0.21
Education low	0.04	0.33	-0.21	1.97	-0.10	0.43	-0.241	1.54
Education high	-1.60***	0.46	-0.99	1.92	-0.35	0.55	-1.09	1.57
Population density	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Altitude	0.000	0.00	0.00	0.00	0.00	0.00	-0.00**	0.00
Extension contact	-0.40	0.32	-0.24	1.22	-0.00	0.35	0.26	1.01
Farm size	-0.0	0.04	-0.10	0.65	-0.03	0.08	0.30	0.41
Oxen	-0.26	0.19	0.10	0.67	-0.11	0.19	-0.45	0.51
Livestock	0.02*	0.01	-0.01	0.04	0.02*	0.01	0.012	0.03
Market distance	0.03	0.06	-0.16	0.23	-0.00	0.05	-0.05	0.16
Inputs								
Ln(Seed)	0.61***	0.16	1.34***	0.16	0.34***	0.11	1.21***	0.13
Ln(Labour)	0.08	0.09	-0.38***	0.13	0.06	0.09	-0.27**	0.11
Ln(Oxen days)	-0.137	0.16	1.63***	0.30	0.05	0.16	1.31***	0.24
Plot characteristics								
Plot distance from residence	0.339*	0.19	2.11*	1.23	0.09	0.16	1.65*	0.90
Rented in plots	-0.640	0.40	-0.35	0.33	-0.66*	0.36	-0.30	0.28
Soil and water conservation	0.611	0.43	0.931	1.95	0.39	0.34	1.13	1.09
Stone covered plot	0.04	0.25	-1.52	1.49	0.02	0.16	-1.03	0.77
Deep soil plots	0.54**	0.23	-0.38	1.20	0.38	0.27	0.60	0.65
Medium soil plots	-0.01	0.25	-1.95	1.23	0.06	0.31	-0.75	0.66
Brown soil plots	-0.17	0.32	0.01	1.63	-0.23	0.30	-0.49	0.94
Gray soil plots	-0.42	0.34	0.32	1.79	-0.30	0.27	-1.02	1.05
Red soil plots	-0.97***	0.37	0.90	2.03	-0.62**	0.26	-0.37	1.06
Loam soil plots	0.50*	0.27	-0.33	1.24	0.186	0.28	0.545	0.68
Clay soil plots	-0.06	0.31	1.28	1.74	-0.316	0.29	1.95**	0.88
Sandy soil plots	0.64*	0.37	-0.53	3.88	0.212	0.34	0.856	2.27
Moderately eroded plots	0.14	0.18	0.07	1.34	-0.05	0.18	-0.44	0.71
Severely eroded plots	-0.50**	0.22	-0.94	2.40	-0.42*	0.22	0.79	1.36
Gently slope plot	0.16	0.24	-0.17	1.71	-0.09	0.27	-1.48**	0.71
Steep slope plot	0.54	0.34	-0.79	2.08	0.15	0.39	-1.67	1.20
Middle slope position	1.01***	0.3	-0.91	2.14	0.54**	0.25	1.01	1.19
Bottom slope position	0.67***	0.21	-1.85	1.91	0.46*	0.27	-0.08	1.01
Not on slope position	1.67***	0.24	-1.05	2.5	0.84***	0.32	-0.95	1.05
Constant	5.42**	2.15	8.99	8.07	6.69***	2.01	7.50	5.47
R-squared	0.71		0.48		0.41		0.29	
Model chi-square	1070.28		414.03		269.90		521.13	
Number of observations	113		90		113		90	

*Note: * significant at 10%; ** significant at 5%; *** significant at 1%*

Table 2B: Productivity analysis using switching regression: fertilizer adopters vs. non-adopters (Model 2)

	Using Mundlak's approach				Without Mundlak's approach			
	Fertilizer adopters		Non-Fertilizer adopters		Fertilizer adopters		Non-Fertilizer adopters	
Variable	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Socioeconomic characteristics								
Gender	0.43**	0.20	0.69***	0.23	0.32*	0.19	0.59***	0.23
Age	-0.23	0.17	-0.19	0.21	-0.27	0.16	-0.32	0.21
Family size	0.02	0.03	-0.05	0.03	0.03	0.03	-0.06	0.04
Education low	-0.08	0.16	-0.03	0.29	-0.13	0.16	0.05	0.28
Education high	-0.25	0.21	-0.25	0.27	-0.27	0.20	-0.12	0.31
Population density	0.00	0.00	-0.00	0.00	-0.00	0.00	-0.00	0.00
Altitude	-0.00***	0.00	-0.00***	0.00	-0.00**	0.00	-0.00**	0.00
Extension contact	0.03	0.12	0.29*	0.16	-0.03	0.12	0.17	0.15
Farm size	-0.15	0.10	-0.12	0.15	-0.11	0.10	-0.08	0.15
Oxen	-0.02	0.09	-0.02	0.08	-0.06	0.08	-0.02	0.08
Livestock	0.00	0.01	0.01	0.01	0.01	0.01	0.01*	0.01
Market distance	-0.06**	0.03	0.00	0.05	-0.06**	0.03	-0.03	0.04
Inputs								
Ln(Seed)	0.31***	0.06	0.29***	0.10	0.34***	0.05	0.23***	0.06
Ln(Labor)	0.37***	0.09	0.02	0.12	0.28***	0.07	0.04	0.08
Ln(Oxen days)	-0.04	0.11	0.07	0.24	0.05	0.09	0.20	0.15
Plot characteristics								
Plot distance	-0.24	0.18	-0.24	0.26	-0.26	0.16	-0.17	0.25
Rented in plots	0.09	0.14	-0.27	0.19	0.18	0.12	-0.10	0.17
Soil and water conservation	-0.01	0.17	0.28	0.27	0.10	0.14	0.11	0.17
Stone covered plot	-0.01	0.12	-0.04	0.21	-0.03	0.10	-0.16	0.17
Deep soil plots	-0.22**	0.10	-0.05	0.19	-0.26***	0.08	-0.17	0.15
Medium soil plots	-.53***	0.11	0.21	-0.09	-0.50***	0.10	-0.13	0.18
Brown soil plots	-0.08	0.18	-0.36	0.38	0.08	0.15	0.10	0.28
Gray soil plots	-0.15	0.15	-0.26	0.40	-0.05	0.13	0.15	0.29
Red soil plots	-0.11	0.16	-0.14	0.40	0.01	0.13	0.13	0.28
Loam soil	0.07	0.16	0.66*	0.34	-0.01	0.15	0.14	0.27
Clay soil	0.06	0.15	0.28	0.39	0.05	0.14	0.09	0.28
Sandy soil	0.23	0.23	0.22	0.37	0.08	0.17	0.05	0.25
Moderately eroded	0.12	0.10	0.05	0.21	0.09	0.08	-0.00	0.14
Severely eroded plots	-0.29*	0.17	0.41	0.46	-0.33**	0.13	0.07	0.36
Gently slope plot	-0.03	0.15	-0.21	0.21	-0.02	0.11	-0.31**	0.14
Steep slope plot	0.07	0.19	-0.38	0.39	0.13	0.19	-0.76**	0.34
Middle slope position	0.16	0.22	0.08	0.31	0.08	0.19	-0.03	0.20
Bottom slope position	0.30*	0.18	0.10	0.34	0.23	0.17	-0.22	0.25
Not on slope position	0.21	0.21	0.12	0.38	0.07	0.18	-0.20	0.24
Constant	7.23***	0.96	7.77***	1.33	7.03***	0.79	7.96***	1.10
R-squared	0.47		0.41		0.40		0.31	
Model chi-square	410.95***		196.57***		289.90***		99.34***	
Number of observations	340		211		340		211	

*Note: * significant at 10%; ** significant at 5%; *** significant at 1%*

Table 2C: Productivity analysis using switching regression: conservation tillage vs. chemical fertilizer adopters (Model 3)

	(1) Conservation tillage		(2) Chemical Fertilizer	
Variable	Coeff.	Std. Error	Coeff.	Std. Error
Socioeconomic characteristics				
Gender	-0.27	0.34	-0.03	0.43
Age	-0.42	0.49	-0.14	0.43
Family size	0.00	0.08	0.07	0.08
Education low	-0.09	0.43	-0.11	0.42
Education high	-0.35	0.55	-0.73	0.45
Population density	0.00	0.00	0.00	0.00
Altitude	0.00	0.00	-0.00	0.00
Extension contact	-0.00	0.35	-0.13	0.33
Farm size	-0.03	0.08	-0.07	0.34
Oxen	-0.11	0.19	0.03	0.17
Livestock	0.02*	0.01	0.01	0.01
Market distance	-0.00	0.05	-0.07	0.08
Inputs				
Ln(Seed)	0.34***	0.11	0.25*	0.12
Ln(Labour)	0.06	0.09	0.31*	0.18
Ln(Oxen days)	0.05	0.16	0.32	0.31
Plot characteristics				
Plot distance from residence	0.08	0.16	-0.08	0.48
Rented in plots	-0.66*	0.36	0.14	0.42
Soil and water conservation plots	0.39	0.34	-0.09	0.54
Stone covered plot	0.02	0.16	-0.42	0.41
Deep soil plots	0.38	0.27	-0.55	0.46
Medium soil plots	0.05	0.31	-0.66	0.46
Brown soil plots	-0.23	0.30	0.71	0.57
Gray soil plots	-0.30	0.27	0.18	0.53
Red soil plots	-0.62**	0.26	0.46	0.55
Loam soil plots	0.19	0.28	-0.02	0.64
Clay soil plots	-0.32	0.29	-0.34	0.54
Sandy soil plots	0.21	0.34	-0.42	0.71
Moderately eroded plots	-0.05	0.18	0.41	0.34
Severely eroded plots	-0.42*	0.22	-0.02	0.50
Gently slope plot	-0.09	0.27	-0.19	0.37
Steep slope plot	0.15	0.39	-0.59	0.56
Middle slope position	0.54**	0.25	0.03	0.59
Bottom slope position	0.46*	0.27	-0.51	0.60
Not on slope position	0.84***	0.32	-0.74	0.54
Constant	6.69***	2.01	6.43**	3.00

R-squared	0.41	0.78
Model chi-square	269.90***	2.32**
Number of observations	113	57

*Note: * significant at 10%; ** significant at 5%; *** significant at 1%*