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Menale Kassie, Precious Zikhali, Kebede Manjur and Sue Edwards

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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

Adoption of Organic Farming Technologies: Evidence from Semi-Arid Regions of Ethiopia

Menale Kassie[1], Precious Zikhali[2], Kebede Manjur[3] and Sue Edwards[4]

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Abstract

In the wake of resource constraints faced by farmers in developing countries in using external farm inputs, sustainable agricultural production practices that rely on local or farm renewable resources present desirable options for enhancing agricultural productivity. In this paper we use plot-level data from the semi-arid region of Ethiopia, Tigray, to investigate the factors influencing farmers' decisions to adopt sustainable agricultural production practices, with a particular focus on conservation tillage and compost. While there is heterogeneity with regards to factors influencing the choice to use either practice, results from a multinomial logit analysis underscore the importance of both plot and household characteristics on adoption decisions. In particular we find that poverty, and access to information, among other factors, impact the choice of farming practices significantly. We also find evidence that the impact of gender on technology adoption is technology specific while the significance of plot characteristics indicate the decision to adopt specific technologies is location-specific. Furthermore the use of stochastic dominance analysis supports the contention that sustainable farming practices enhance productivity -they even prove to be superior to the use of chemical fertilizers- justifying the need to investigate factors that influence adoption of these practices and use this knowledge to formulate policies that encourage adoption.

Keywords: Sustainable agriculture, Adoption, Productivity, Compost, Conservation tillage, Ethiopia.

JEL Classification: Q12; 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] Tigray Agricultural Research Institute, Alamata Agricultural Research Center P.O. Box 56, Alamat. E-mail: kmanjur2006@yahoo.com

[4] Institute for Sustainable Development, PO Box 171-1110, Addis Ababa, Ethiopia. E-mail: sustaindeveth@ethionet.et

1. Introduction

Sustainable agriculture can be broadly defined as an agricultural system involving a combination of sustainable production practices in conjunction with the discontinuation or the reduced use of production practices that are potentially harmful to the environment (D'Souza et al., 1993). More specifically, the Food and Agricultural Organization (FAO) argues that sustainable agriculture consists of five major attributes: it conserves resources (e.g. land, water, etc), is 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 employs locally available natural resources as well as purchased inputs more efficiently (Lee, 2005).

Conservation agriculture (CA) and the use of organic fertilizers (e.g. compost) are two examples of sustainable agriculture practices. CA seeks to achieve sustainable agriculture through minimal soil disturbance (i.e. zero- or minimum-tillage farming, stubble tillage), permanent soil cover and crop rotations. The potential benefits from CA lie in not only conserving but also in enhancing the natural resources (e.g. increase 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 CA a widely adopted component of sustainable farming (Lee, 2005). The use of organic fertilizers such as compost, on the other hand, is part of an organic farming system which emphasizes maximum reliance on locally or farm-derived renewable resources. Compost is an organic fertilizer and mulch which has the advantage that it is cheap (if not free); improves soil structure, texture, and aeration; increases the soil's water retention abilities; and stimulates healthy root development (Twarog, 2006). Thus, both conservation tillage and compost are appealing options for enhancing productivity to resource-poor farmers especially in developing countries.

The agriculture sector in Ethiopia is the most important sector for sustaining growth and reducing poverty. However, lack of adequate nutrient supply, the depletion of soil organic matter and soil erosion are a major concern for sustained agricultural production (Grepperud, 1996; Kassie et al., 2008a). The key to a sustained increase in agricultural production is improvement in productivity, which can be achieved through technological and efficiency changes. Inorganic fertilizer remains the main yield augmenting technology being aggressively promoted by the government and institutions. Despite this, inorganic fertilizer adoption rates remain very low. Until recently, only 37 percent of farmers were using inorganic fertilizer, and application rates remained at or below 16 kg/ha of nutrients (Byerlee et al., 2007). In addition to low application rates, there are significant evidences suggesting dis-adoption of fertilizer (EEA/EEPRI, 2006). Escalating prices and production and consumption risks have been cited as one of the factors limiting the use of inorganic fertilizers in Ethiopia (Kassie et al., 2008b; Dercon and Christiaensen, 2007).

Thus given the aforementioned challenges to inorganic fertilizer adoption, a key policy intervention for sustainable agriculture is to encourage adoption of agricultural technologies that rely to a greater extent on local or farm renewable resources. Organic farming practices such as compost and conservation tillage are among such technologies. The water retention characteristics of these technologies (Twarog, 2006) make them especially appealing in water-deficient farming areas, as is the case for our study area, Tigray region of Ethiopia. In addition to reducing natural risks, it enables poor farmers to avoid the financial risk of taking chemical fertilizer on credit, and given that compost and conservation tillage are available when needed they overcome the prevailing problem of late delivery of chemical fertilizer. Since 1998 Ethiopia included conservation tillage and compost as part of extension packages to reverse extensive land degradation (Edwards et al., 2007; Sasakawa Africa Association, 2008). There exist ample evidences to show that compost and conservation tillage can result in higher and/or comparable yields compared to when chemical fertilizer is used (Edwards et al. 2007**;** Hemmat and Taki, 2001; SG2000, 2004; Mesfine et al., 2005; UNCTD and UNEP, 2008). This implies that these organic farming techniques create a win-win situation whereby farmers are able to reduce production costs, provide environmental benefits and at the same increase yields.

While numerous studies have been conducted in Ethiopia to examine the determinants and the resulting economic impact of chemical fertilizer, improved seeds, and physical conservation structures (e.g. Croppenstedt et al., 2003; Dercon and Christiaensen, 2007; Hagos, 2003; Kassie *et al*., 2008a, 2008b; Negatu and Parikh,1999; Shiferaw and Holden, 1998), no study, to best of our knowledge, has investigated the determinants of adoption of compost and conservation tillage by farmers in Ethiopia. The objective of this paper is to do this by investigating how socioeconomic and biophysical characteristics determine adoption of compost and/or stubble tillage (hereafter conservation tillage)[5] in the semi-arid region of Tigray, Ethiopia. By identifying significant characteristics associated with adoption of sustainable agricultural production practices such as compost and conservation tillage, we are able to better inform policies that seek to promote adoption of such practices. In addition we use a dataset that has data on crop production and organic technology adoption (compost) to perform a stochastic dominance analysis with the aim of examining whether adoption of these technologies has any productivity impacts. This is to show the importance of organic farming practices in enhancing productivity and thus justify the need to further investigate the factors that condition their adoption. Our results reveal a clear superiority of the use of compost compared to chemical fertilizers when it comes to crop yields. With regards to determinants of adoption decisions; we find that while there is heterogeneity with regards to factors affecting the choice to use compost or conservation tillage, both plot and household characteristics influence adoption decisions. Interestingly we find evidence that the impact of gender on technology adoption is technology specific while the significance of plot characteristics indicate the decision to adopt a given technology is location-specific.

The rest of the paper is structured as follows: section 2 presents the analytical and econometric framework that forms the basis of the empirical approach used in the paper. The data used in the analysis is discussed in section 3 while a discussion of the empirical results is done in section 4. Section 5 concludes the paper with policy recommendations.

2. The analytical and econometric framework

We start the analysis by using a non-parametric technique, the stochastic dominance analysis (SDA), to assess how the use of organic farming technology impacts crop productivity. Due to data limitations we are only able to examine how the use of compost impacts crop production. Stochastic dominance analysis is used to compare and rank distributions of alternative risky outcomes according to their level and dispersion (riskiness) of returns (Mas-Colell et al., 1995). The comparison and ranking is based on

[5] It is a type of conservation tillage where farmers entirely retain the stubble on soil's surface and mix the stubble with the soil surface with rough tillage right after harvest to avoid grazing by livestock as well as to facilitate decomposition of organic materials before the next copping season starts.

cumulative density functions (CDF). Unlike other non-parametric (e.g. matching method) and parametric (e.g. linear regression models) methods, the entire density of yields is examined in SDA instead of focusing only on mean yield. The reason for this analysis is to motivate the use of organic farming technologies by establishing support for the fact that they enhance productivity. Thus assuming that the main goal of farmers is to realise increased productivity of their plots, the next interesting research question is then to investigate the factors that limit or encourage adoption of organic farming technologies and formulate policies accordingly.

In investigating this, we posit that both plot and households' socioeconomic characteristics are important in influencing the decision to adopt technologies. Plot characteristics condition the decision to adopt a specific technology over another through their impact on the increment of plot profit or the productivity impact derived from participation. Farmers' socioeconomic characteristics and preferences, on the other hand, might result in different adoption decisions even when plots have similar characteristics. Accordingly the maximization of farmers' utility forms the basis of our econometric model and estimation strategy. This framework posits that if adoption of several farming practices is possible, it is expected that to decide on adoption of one or several practices, a farmer compares the indirect utility values associated with each practice or a combination of practices.

Consequently, to study the *i*th farmer's choice we postulate random utility models, each one being associated with the *j*th choice of farming practice, such that:

$$V_{ij} = \mathbf{X}\boldsymbol{\beta}'_{j} + \varepsilon_{ij}, \qquad (1)$$

where V_{ij} is the indirect utility level which the *i*th farmer associates with the *j*th farming practice, $\mathbf{X}_i$ is a vector describing the farmer's socioeconomic characteristics as well as plot characteristics. The vector of parameters to be estimated is denoted by $\boldsymbol{\beta}$ while ε is the stochastic error term. Given the two organic farming practices we focus on i.e. conservation tillage and compost, we have four feasible choices available to the farmer. These are classified such that *j*=0 if neither of the two practices is adopted, *j*=1 if compost is adopted, *j*=2 if conservation tillage is adopted and *j*=3 if adoption of both compost and conservation tillage takes place.

Given a dummy variable, d_{ij} capturing the choice of the *i*th farmer regarding the *j*th farming practice, the farmer's decision rule then becomes

$$\begin{cases} d_{ij} = 1 \\ d_{im} = 0 \ \forall m \neq j \end{cases} \Leftrightarrow \quad \left(V_{ij} > V_{im} \quad \forall m \neq j\right). \tag{2}$$

To make the econometric model operational we assume that the disturbances of the different combinations are independent and identically distributed with the Gumbel cumulative distribution function which implies that the probability of choosing the *j*th combination becomes (Greene, 1997):

$$P_{ij} = \Pr(d_{ij} = 1) = \frac{\exp(\mathbf{X}\boldsymbol{\beta}'_j)}{\sum_{m=0}^{j} \exp(\mathbf{X}\boldsymbol{\beta}'_m)}, \tag{3}$$

which is the multinomial logit model, characterised by the independence of irrelevant alternatives, which implies that from equation (3) we can arrive at the following:

$$\frac{P_{ij}}{P_{im}} = \exp(\mathbf{X}'(\boldsymbol{\beta}_i - \boldsymbol{\beta}_m)) \quad \forall m \neq j, \tag{4}$$

a condition which holds whatever the subset of eligible combinations which include *j* and *m*. Given that the model is based on the difference of expected utility levels in each pair of combinations, we draw on the assumption that $\boldsymbol{\beta}_0 = 0$ to solve the problem of the indeterminacy which could complicate the estimation of the model (Greene, 1997). The maximum likelihood procedure is used to solve the model.

3. The data and descriptive statistics

This study benefits from two datasets. The first data is a cross-sectional dataset collected in 2006 in Ofla districts of Tigray region to analyze the determinants of adoption of compost and conservation tillage. It includes a random sample of 130 households, 5 villages, and 348 plots. In addition to information on adoption of compost and/or conservation tillage, the dataset had data on household and plot characteristics, and indicators of access to infrastructure which, based on economic theory and previous empirical research, are included in the analysis. The descriptive statistics of variables used in the regression analysis are presented in Table 1.

Table 1: Descriptive statistics (means) of variables used in the analysis

Variable	Description	Non-adopters	Compost	Conservation tillage	Both
Socioeconomic characteristics					
Male	Sex of household head (1= male; 0= female)	0.83	0.67	1.00	0.98
Age	Age of household head	44.17	41.00	38.36	38.98
Dependents	Number of economically inactive household members	2.71	2.50	2.61	2.54
Household labour	Number of economically active household members	2.23	2.28	2.51	2.46
Illiterate	Household head has no education (1= yes; 0= otherwise)	0.60	0.28	0.38	0.42
Religious education	Household head has religious education (1=yes; 0= otherwise)	0.11	0.11	0.05	0.07
Formal education	Household head has formal education (1= yes; 0= otherwise)	0.29	0.61	0.58	0.51
Farmer organizations	Membership in farmers' organization (1= yes; 0= otherwise)	0.08	0.22	0.25	0.22
Extension	Household extension contact (1= yes; 0= otherwise)	0.56	0.83	0.82	0.83
Livestock	Household livestock holding, in Tropical Livestock Units	2.92	4.09	3.69	3.42
Farm size	Total farm size, in hectares	0.83	0.92	1.39	1.09
Market distance	Distance from residence to the district market, in hours	2.01	2.30	2.48	2.07
Plot characteristics					
Ownership	Whether the household owns the plot (1=yes; 0= otherwise)	0.71	0.83	0.67	0.83
Distance	Distance from residence to the plot, in minutes	0.62	0.69	0.64	0.61
Flat to moderate slope	Plot is of flat to medium slope (1=yes; 0= steep slope)	0.35	0.17	0.30	0.17
Fertile soil	Plot is of fertile soil (1= yes; 0= infertile)	0.33	0.50	0.36	0.32
Black soil	Predominantly black soil (1=yes; 0= otherwise)	0.57	0.50	0.72	0.61
Deep soil	Deep soil depth (1= yes; 0= otherwise)	0.39	0.50	0.30	0.44
Moderately deep soil	Moderately deep soils (1= yes; 0= otherwise)	0.24	0.11	0.31	0.15
Shallow soils	Shallow soil depth (1= yes; 0= otherwise)	0.37	0.39	0.39	0.42
Degradation	Plot perceived as being degraded (1=yes; 0= otherwise)	0.36	0.28	0.38	0.37
Number of observations		202	18	87	41

Source: Authors' own calculation.

Around 5, 24 and 12 percent of the plots used compost, conservation tillage and a combination of both, respectively. Regarding household's perceptions of compost and reduced tillage; about 40 and 74 percent of compost and reduced tillage adopters perceived positive impacts of these technologies on soil fertility; about 20 and 42 percent of compost and tillage adopters, respectively, believe that these technologies reduce soil erosion; and 32 and 69 per cent of compost and reduced tillage adopters, respectively, believe these technologies are labor intensive. The data also reveals that adopters of compost have more livestock compared to tillage adopters. On the other hand, tillage adopters have more farm size compared to compost adopters which is expected to enable them to produce more straw for livestock feed and use stubble mulch tillage to increase soil fertility.

The fact that the first dataset does not include production data, limits our use of this dataset to analyze how adoption of these technologies impacts crop production. To achieve this objective we employed a second dataset to conduct a stochastic dominance analysis. It is cross-section time series on-farm production data collected between 2000 and 2006. The primary objective of collecting this data by the Institute for Sustainable Development (ISD), which is engaged in the promotion of organic agriculture in Ethiopia, was to investigate the impact of compost on crop production and soil fertility. The dataset covers eight districts and nineteen villages of Tigray region, which includes Ofla district. Of the nineteen villages, seventeen are located in drought prone areas of the Southern, Eastern and Central zone of Tigray region. The soils are poor and rainfall is erratic in these areas. The institute only collected agronomic data, grain and straw yields, for eleven crops from 974 plots. The FAO crop sampling method was used to collect yield data from those plots which had received compost, chemical fertilizer, and no inputs (control plots). Three one-meter square plots were harvested from each field to reflect the range of conditions of the crop. All the crop management practices including the amount of compost and fertilizer application was decided by the farmers themselves. The responsibility of the ISD is to provide information and training on compost making and application and recording grain and straw yields data during harvest in collaboration with farmers. The average amount of compost application ranges 5-15 tons per hectare depending on availability of materials (Edwards et al., 2007) and that of fertilizer is 0-275 kg per hectare (the average being is 40 kg per ha) (Kassie et al., 2008a). The average per hectare cost of applying compost is about ETB 370 whereas commercial fertilizer (DAP and Urea) is about ETB 594 (Edwards of ISD director, personal communication).

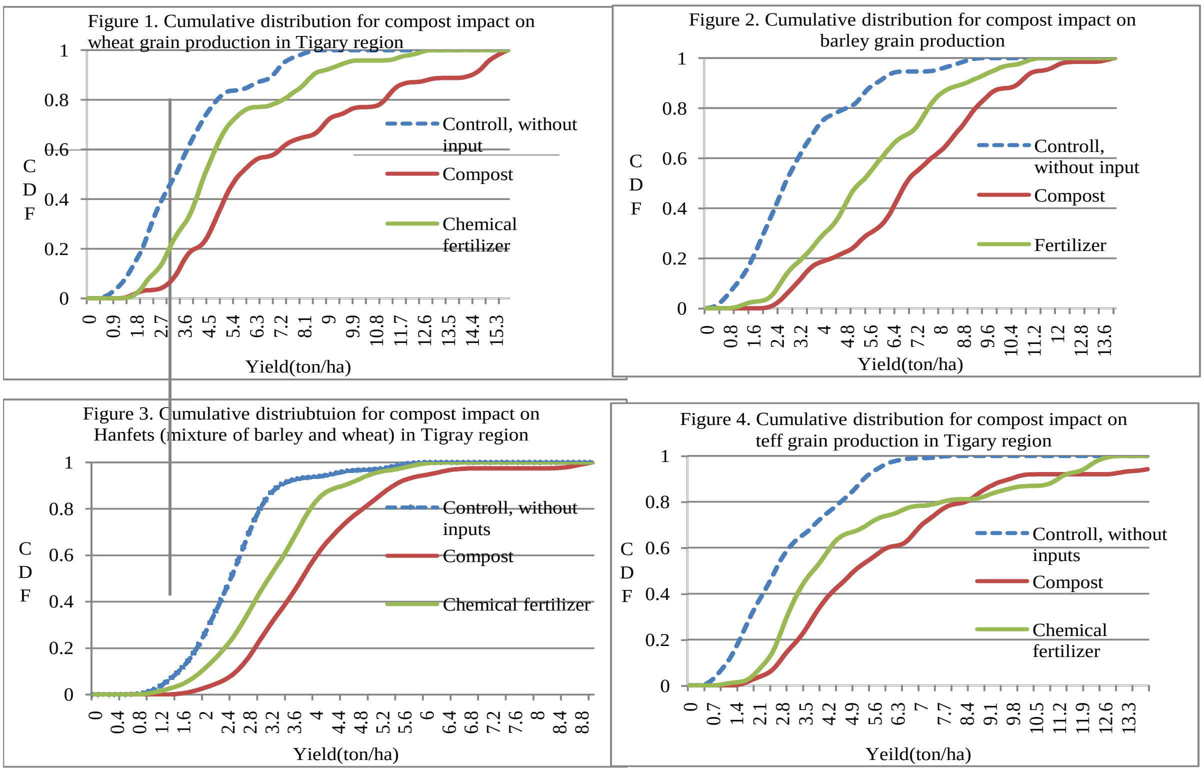
4. Estimation results

In this section we present the stochastic dominance analysis and multinomial logit adoption model results. The stochastic dominance analysis is used to investigate the impact of compost on crop productivity while the multinomial logit model is used to investigate factors that determine the decision to adopt compost, conservation tillage and/or a combination of both.

4.1. Stochastic dominance analysis

For the purposes of this analysis we focused on four major crops (wheat, barley, *teff*[6] and hanfets (mixture of barley and wheat) and compared yield distributions obtained from compost, chemical fertilizer, and control (without any input) plots. The outcome variable is physical grain yields (ton/ha) of the respective crops. Figures 1-4 show cumulative density functions for yields obtained from compost, chemical fertilizer, and control plots.

Figures 1-4: Stochastic dominance analysis of the impact of compost on crop productivity



As illustrated in the figures, for all crops the yield cumulative distribution with compost is entirely to the right of the chemical fertilizer and control yield distributions,

[6] Teff is a small grain crop endemic to Ethiopia.

indicating that yield with compost unambiguously holds first-order stochastic dominance over chemical fertilizer and control plots.

The non-parametric Kolmogorov-Smirnov statistics test for first-order stochastic dominance (or the test for the vertical distance between the two cumulative density functions (CDFs)) also confirmed this result (see Table 2 below). Interestingly, compared to control plots and plots that use chemical fertilizer, plots with compost give higher yield levels. Furthermore, except for hanfets crop, yield distribution of plots with chemical fertilizer dominated yield distributions of control plots i.e. plots without any input (see Table 2).

Table 2: Kolmogorov-Smirnov statistics test for first-order stochastic dominance

Crop	Treatments		
	Compost + control	Compost + fertilizer	Fertilizer + control
Barley	0.355 (0.000)***	0.192 (0.008)***	0.241 (0.000)***
Wheat	0.484 (0.000)***	0.384 (0.000)***	0.270 (0.000)***
Teff	0.591 (0.000)***	0.195 (0.003)***	0.396 (0.000)***
Hansfet	0.363 (0.000)***	0.330 (0.000)***	0.132 (0.407)

*Note: *** significant at 1%*

The foregoing analysis reveals an interesting finding; adoption of sustainable or organic farming practices such as the use of compost is not inferior, in terms of its impact on yields, to the use of chemical fertilizers. In fact, as the results show, use of compost can lead to significantly higher yields. This means that adoption of organic technologies presents multiple benefits; reduction in production costs, environmental benefits and at the same increased yields. Thus given these potential benefits what then constrains farmers from adopting such technologies and if they decide to adopt, what determines their choice of organic technology? We attempt to answer these questions by estimating a multinomial logit model as outlined in the discussion of the econometric strategy we pursue. We discuss the results in the following section.

4.2. Multinomial logit model results

Table 3 below gives the multinomial logit estimation results for the impact of both plot and socioeconomic characteristics of the household on the decision to adopt a given farming practice. The base outcome is adopting neither of the practices i.e. j=0. This implies that the ensuing discussion of the results focuses on the impact of the explanatory variables on a specific choice relative to no adoption. The model was tested for the validity of the independence of the irrelevant alternatives (IIA) assumptions using the Hausman test for IIA. The test failed to reject the null hypothesis of independence of the adoption of organic farming technologies, suggesting that the multinomial logit specification is appropriate to model adoption of organic technologies.

Table 3: Multinomial Logit estimates

	Compost		Conservation tillage		Both	
Variable	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Socioeconomic characteristics						
Male	-1.99**	0.79	19.60***	0.92	2.21**	1.11
Age	-0.01	0.03	-0.06***	0.02	-0.06***	0.02
Dependents	-0.23	0.18	-0.20**	0.10	-0.17	0.12
Household labour	-0.14	0.42	0.40**	0.20	0.36	0.24
Religious education	0.39	1.06	-0.53	0.67	-0.31	0.76
Formal education	1.41*	0.73	0.14	0.39	0.25	0.47
Farmer organizations	0.90	0.77	1.46***	0.47	1.24**	0.58
Extension	1.95**	0.85	1.00**	0.40	1.09**	0.51
Livestock	0.20**	0.10	0.05	0.05	0.06	0.07
Farm size	0.31	0.42	0.54***	0.20	0.39	0.25
Market distance	0.16	0.16	0.06	0.09	-0.07	0.12
Plot characteristics						
Ownership	1.38*	0.78	0.41	0.34	1.29**	0.50
Distance	0.64	0.44	0.51*	0.26	0.43	0.33
Flat to moderate slope	-1.26	0.78	-0.74**	0.37	-1.35***	0.52
Fertile soil	0.56	0.62	0.20	0.36	-0.16	0.45
Black soil	-0.57	0.61	0.65*	0.36	0.25	0.42
Moderately deep soil	-0.68	0.86	0.38	0.41	-0.74	0.57
Shallow soils	0.52	0.71	0.50	0.43	0.40	0.50
Degradation	-0.32	0.64	0.14	0.34	0.02	0.42
Number of observations			348			
Pseudo R2			0.23			
LR chi2(54)			168.60***			
Log likelihood			-287.18			

*Note: Base outcome= no adoption, * 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 sustainable agricultural production practices. While there is heterogeneity with regards to factors influencing the choice to adopt compost and/or conservation tillage, our results suggest that significant determinants of adoption can be broadly classified into; socio characteristics of household head, labor intensity, access to information, wealth, and plot characteristics which includes whether or not the household owns the plot.

There is a heterogeneous impact of the gender of the head of the household on adoption decisions regarding the two practices. Specifically we find that households with a male head are less likely to adopt the use of compost while they are more likely to either adopt conservation tillage or to combine it with the use of compost. While some researchers have found that male-headed households are more likely to adopt sustainable agricultural technologies (Adesina et al., 2000); our results underscore the need to avoid generalizing the impact of gender on farm technology adoption, emphasizing that the impact of gender on technology adoption is technology specific. In this study area it seems male-headed households have a comparative advantage in conservation tillage while female-headed households enjoy an advantage in the use of compost. Still on the characteristics of the household head, we find a negative and significant impact of age on the likelihood of adopting conservation tillage as well as combining it with compost. This could be suggesting that younger farmers are better able to try new innovations and in addition they might have lower risk aversion and longer planning horizons to justify investments in technologies whose benefits are realized over time. The result suggests the need to develop gender and age specific technologies instead of blanket recommendations of technologies regardless of farmers' type for encouraging adoption of sustainable agricultural practices.

Labor concerns seem to be more of concern in the decision to adopt conservation tillage. Specifically the probability to adopt conservation tillage, relative to no adoption, increases with the number of household members that actively provide farm labor. This is in line with the descriptive statistics results where about 69 per cent of conservation tillage adopters reported that conservation tillage adoption is labor intensive. This is not surprising because stubble tillage is done during the peak period of one of the agricultural activities, crop harvesting. This underscores the importance of labor availability in technology adoption, consistent with findings by Caviglia and Kahn (2001) and Shiferaw and Holden (1998). In such circumstances it is important to consider strengthening and structuring the existing local labor sharing mechanism. On the other hand, this probability declines with the number of dependents in the household, capturing the intuitive expectation that the time spent caring for dependents shifts labor away from adoption activities.

Access to information on new technologies is crucial in creating awareness and attitudes towards technology adoption (Place and Dewees, 1999). In line with this we find that access to agricultural extension services, indicated by whether or not the household has contact with an extension worker, impacts adoption of all technology choices positively. 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). Also as an indicator of information that shapes management skills or simply human capital, having formal education as opposed to no education at all increases the probability to adopt the use of compost relative to not adopting any practice at all. This could be suggesting that using compost is relatively knowledge intensive and thus management skills are crucial in its adoption. It has been argued that farmer associations and unions constitute one of the important sources of information available to farmers (Caviglia and Kahn, 2001). Our results confirm this; we find that household's membership of at least one farmers' organization significantly increases the likelihood of practicing conservation tillage as well as the likelihood of choosing to combine both the use of compost and conservation tillage. These results underscore the role of public policy in encouraging the adoption of sustainable agricultural practices.

The fact that we find evidence that livestock ownership limits the adoption of compost while the household's total landholdings limit the adoption of conservation tillage as well as combining the two practices, 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 example the use of livestock ownership as an indicator of wealth may be compromised by the fact that oxen provide draft power as well as manure, which, being organic matter could be a component of compost.

Furthermore as the data shows, adopters of compost have more livestock compared to tillage adopters and thus the result here could be implying that the opportunity cost of crop residue is small for tillage adopters than compost adopters. The size of total landholdings, on the other hand, though measuring farmers' wealth, could also suggest for economies of scale in production using conservation tillage as well as the social status of the household which could also influence its ability to obtain credit (though in the case of Ethiopia, credit markets are highly imperfect). All the same these results suggest that policies that alleviate poverty and increase crop productivity among farmers will impact the adoption of sustainable agricultural practices positively.

Given the fact that the benefits from investing in both compost and conservation tillage accrue over time, this inter-temporal aspect implies that secure land access or tenure will impact adoption decisions positively. In this analysis we use plot ownership as a proxy for assured land access. Our results reveal that this particularly impacts positively the decision to use compost and the decision to combine the two practices. Ownership of the plot increases the assurance of future access to the returns of investments. In the same vein the positive impact of distance from the homestead to the plot on the decision to adopt either conservation tillage or the use of compost could be reflecting the fact that further away plots present tenure security challenges since they are more difficult to monitor; consequently farmers might invest more in them as a way of securing tenure.

Sustainable agricultural systems are intuitively site-specific (Lee, 2005). This is further confirmed by the finding that plot characteristics influence the decision to adopt conservation tillage as well as to combine it with the use of compost. In particular we find that the likelihood of households choosing to practice conservation declines with the perceived slope of the plots. This could be reflecting the fact that plots with steeper slopes are more prone to experiencing soil erosion thereby necessitating the adoption of farming techniques such as conservation tillage since these are meant to mitigate soil erosion and subsequent nutrient losses. The plot slope impacts the decision to combine both the use of compost and conservation tillage in a similar way. We also find that conservation tillage is more likely to be practiced on plots with predominantly black soils, indicating the role of soil type and quality in influencing adoption decisions. Interestingly plot-specific characteristics seem not to impact the decision to only adopt the use of compost. 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 technology adopted.

5. Conclusions and policy implications

The viability of the agricultural production systems in Ethiopia is, as in many semi-arid areas in developing countries, highly constrained by inadequate nutrient supply, depletion of soil organic matter and soil erosion. This problem is further compounded by an increasing population which is not accompanied by technological and/or efficiency progress. Efforts by the government to promote the adoption of chemical fertilizers have not been successful owing largely to escalating fertilizer prices and production and consumption risks associated with fertilizer adoption. Given these constraints it can be argued that sustainable agricultural production practices create a win-win situation whereby farmers are able to reduce production costs (by relying on local or renewable farm resources), provide environmental benefits and at the same time increase yields. In this paper we use plot-level data from the semi-arid region of Tigray, Ethiopia to investigate the factors influencing farmers' decisions to adopt sustainable agricultural production practices, with a particular focus on the adoption of compost and conservation tillage. By identifying significant characteristics associated with adoption of these practices, we are able to better inform policies that seek to promote adoption of sustainable agricultural production practices. Furthermore the use of stochastic dominance analysis supports the contention that these sustainable farming practices enhance productivity, further justifying the need to investigate factors that influence adoption of these practices.

While there is heterogeneity with regards to factors influencing the choice to adopt compost and/or conservation tillage, our results underscore the importance of both plot and household characteristics on adoption decisions. Our findings imply that public policy can play a role in affecting adoption of sustainable agricultural production practices. In particular we find that poverty limits adoption which implies that polices aimed at alleviating poverty will impact adoption decisions positively. In addition the significant and positive impact of access to information indicates that public policies aimed at improving access to information as well as the quality of these sources will help promote adoption of organic farming practices.

Furthermore we find evidence that such public polices should acknowledge the fact that there could not only be gendered differences in adoption of different technologies but age of the household head, by affecting aversion to risk and/or life cycle dynamics, will have a differential impact on adoption depending on the type of technologies. In the same light availability of household labor conditions the choice of technology adopted, given that the labor requirements differ from technology to technology. Thus public policy should factor in the impact of these socioeconomic characteristics.

We find evidence for the significance of land rights in influencing adoption and this impact varies from technology to technology. This indicates that assurance of access to future returns to adoption is vital in adoption decisions and thus policies should strive to create security of tenure among farmers.

In addition the significance of plot characteristics indicates the decision to adopt specific technologies is site-specific, and as such public policy should be informed by analyses of how different sustainable agricultural practices are conditioned by plot characteristics. Thus the next interesting research question would be to analyze how plot characteristics affect the productivity implications of different practices.

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.

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.

Croppenstedt, A., M. Demeke, and M.M. Meschi. 2003. Technology Adoption in the Presence of Constraints: the Case of Fertilizer Demand in Ethiopia. *Review of Development Economics,* 7(1): 58–70.

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

D'Souza G., D. Cyphers, and T. Phipps. 1993. Factors affecting the adoption of sustainable agricultural practices, *Agricultural Resource Economics Review* (October): 159-165.

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.

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.

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

Hagos, F. 2003. Poverty, institution, Peasant behavior and conservation investments in Northern Ethiopia. Department of Economics and Social Sciences Agricultural University of Norway. PhD. Dissertation no.2003: 2 .174p.

Greene W. H. 1997. *Econometric analysis.* Third edition. Prentice-Hall International, Inc

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

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

Hemmat, A., and Taki, O. 2001. Grain yield of irrigated winter wheat as affected by stubble-tillage management and seeding rates in Central Iran. *Soil and Tillage research* 63: 57-64.

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.

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

Mas-Colell, A., Whinston, M. D., Green, J. R., 1995. Microeconomic Theory. Oxford University Press, New York.

Mesfine, T., Abebe, G. and Al-Tawaha, A.R.M. 2005. Effect of reduced tillage and crop residue ground cover on yield and water use efficiency of Sorghum (*Sorghum bicolor* (L.) Moench) under semi-arid conditions of Ethiopia. *World Journal of Agricultural Sciences* 1(2): 152-160.

Negatu, W., and Parikh, A., 1999. The impact of perception and other factors on the adoption of agricultural technology in the Moret and Jiru Woreda (district) of Ethiopia. *Agricultural Economics* 21(2), 205-216.

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

SG2000 (Sasakawa Global 2000). 2004. Proceedings of the workshop on conservation tillage, April 6, 2004. Melkassa Agricultural Research Center, East Shewa, Ethiopia. Organized and sponsored by SG 2000 Ethiopia, Addis Ababa.

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.

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.

UNCTD/ UNEP(United Nations Conference on Trade and Development/ United Nations Environment Programme). 2008**.** Organic Agriculture and Food Security in Africa. *UNEP-UNCTAD Capacity-building Task Force on Trade, Environment and Development.* United Nations, New York and Geneva.