ADOPTION OF ORGANIC FARMING TECHNOLOGIES: EVIDENCE FROM A SEMI-ARID REGION IN ETHIOPIA

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CONTENTS

TABLES

FIGURES

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EDITORIAL NOTES

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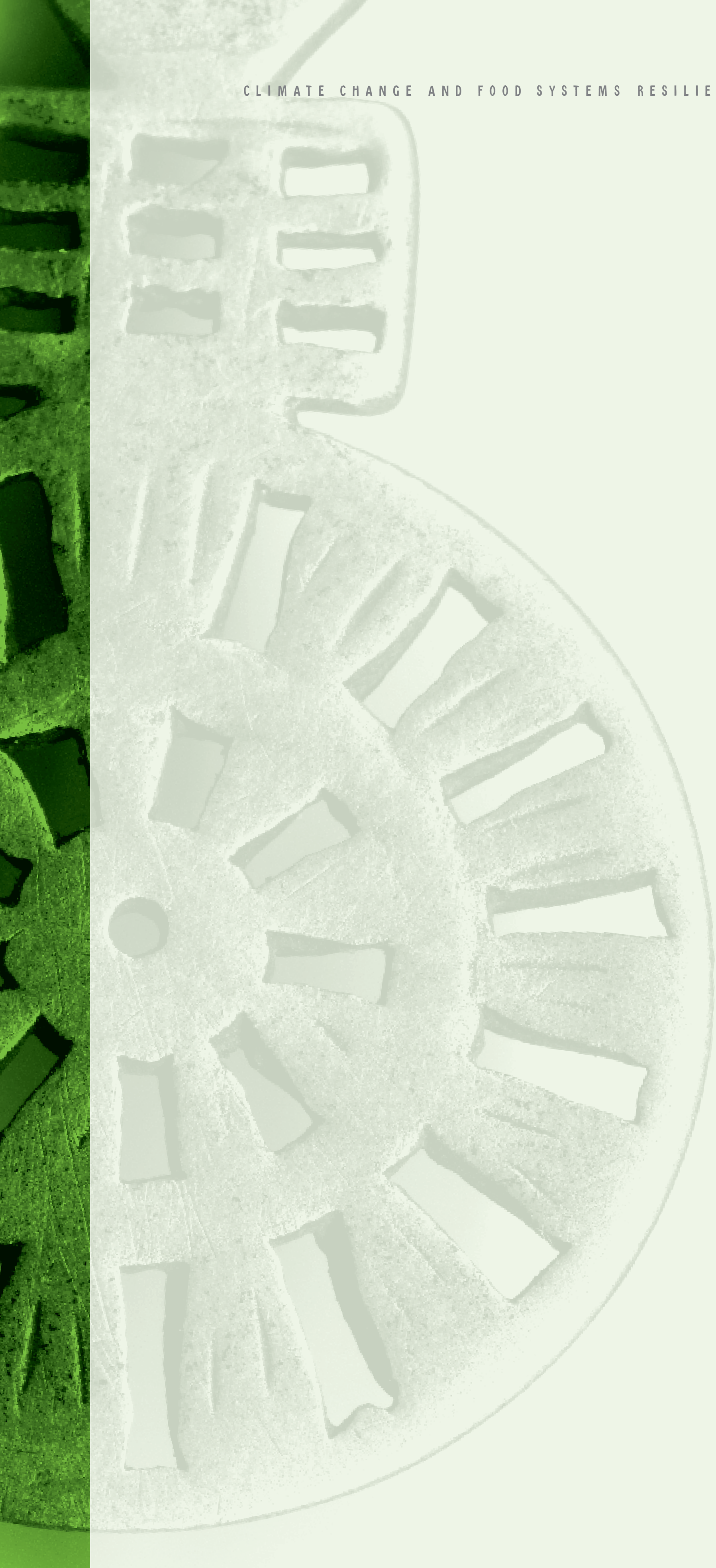

INTRODUCTION

Sustainable agriculture, which can lead to formally recognized organic farming, 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 Agriculture Organization of the United Nations (FAO) argues that sustainable agriculture consists of five major attributes: it conserves resources, it is environmentally non-degrading, technically appropriate, economically and socially acceptable (FAO, 2008). In practice, sustainable agriculture uses fewer external off-farm inputs such as purchased fertilizers and employs locally available natural resources, as well as purchased inputs, more efficiently (Lee, 2005).

Stubble tillage and compost are two examples of sustainable agriculture practices appropriate for organic farming.

Stubble tillage is a type of conservation farming in which farmers leave all or most of the stubble from the previous crop in place and turn it into the soil by ploughing soon after harvest to avoid grazing by livestock so that the organic material can decompose before the next cropping season. Conservation farming seeks to achieve sustainable agriculture through minimal soil disturbance with a permanent soil cover and crop rotation. The potential benefits from conservation farming lie not only in conserving but also in enhancing the natural resources, such as increasing soil organic matter, without sacrificing yield levels. This makes it possible for fields to act as a sink for carbon dioxide (i.e. for carbon sequestration), increase soil water-holding capacity, and reduce soil erosion. It also cuts direct production costs for the farmer and reduces the emission of greenhouse gases associated with mechanized farming (FAO, 2008). That conservation farming can address such a broad set of farming constraints makes it a widely adopted component of sustainable agriculture (Lee, 2005). However, conservation farming that is based on zero tillage is usually associated with the use of synthetic herbicides, which is not appropriate for or acceptable in organic farming.

The use of compost is part of an organic agriculture system that emphasizes maximum reliance on renewable farm and other local resources. Compost is an organic fertilizer that has the advantage that it improves soil structure and aeration, increases the soil's water-holding capacity and stimulates healthy root development (Twarog, 2006). Thus, both stubble tillage and compost may be appealing options for enhancing productivity with resource-poor farmers, especially in developing countries.

The agriculture sector in Ethiopia is the most important sector for sustaining growth and reducing poverty. It accounts for 50 percent of gross domestic product (GDP), 88 percent of export value and is a source of employment for more than 85 percent of the country's population of more than 70 million (Deressa, 2007). However, lack of adequate nutrient supply, the depletion of soil organic matter and soil erosion are major obstacles to improving agricultural production (Grepperud, 1996; Kassie *et al*., 2008a). The key to a sustained increase in agricultural production is to improve the productive capacity of farmers, which can be achieved for example through improved farming management practices and more effective use of existing and new technologies. Inorganic fertilizer remains the main yield-augmenting technology being aggressively promoted by the government and other institutions. Despite this promotion, inorganic fertilizer adoption rates remain very low. Until recently, only 37 percent of farmers used inorganic fertilizer, and application rates remained at or below 16 kg/hectare of nutrients (Byerlee *et al*., 2007), which is far below the recommended rate of 110 kg/hectare of nutrients.[1] In addition to low application rates, there is evidence suggesting a pull back from using fertilizer (EEA/EEPRI, 2006). Escalating prices and production and consumption risks (that is, variability of agricultural production due to rainfall variability which causes consumption variability in the absence of consumption smoothing mechanisms) have been cited as among the factors limiting the use of inorganic fertilizers in Ethiopia (Dercon and Christiaensen, 2007; Kassie, *et al*., 2008b).

1 The recommended rates are 100 kg per hectare of diammonium phosphate (DAP) and 50 kg per hectare of urea.

Thus, given the aforementioned challenges to inorganic fertilizer adoption, a key policy intervention for sustainable agriculture is to encourage adoption of farming technologies that rely, to a greater extent, on renewable farm and other local resources. Organic farming practices, such as the use of compost and stubble tillage, are among such technologies. The water retention characteristics of these technologies (Twarog, 2006) make them especially appealing in water-deficient farming areas, such as the Tigray Region in northern Ethiopia. In addition to reducing natural risks, organic farming practices enable poor farmers to minimize the financial risk of buying chemical fertilizer on credit and - given that compost and stubble tillage are available when needed - alleviate the prevailing problem of late delivery of chemical fertilizer (Hailu and Edwards, 2006).

Since 1998, Ethiopia has included stubble tillage and use of compost as part of its extension package to reverse extensive land degradation (Edwards *et al.*, 2007; Sasakawa Africa Association, 2008). There exists ample evidence to show that use of compost and stubble tillage can result in higher and/or comparable yields compared to chemical fertilizer (Edwards *et al.*, 2007; Hailu and Edwards, 2006; Hemmat and Taki, 2001; Kassie *et al.*, 2008b; Mesfine *et al.*, 2005; Sasakawa-Global 2000, 2004; UNCTAD and UNEP, 2008). This implies that these two organic farming technologies can create a win-win situation, where farmers are able to reduce direct production costs, improve environmental benefits, and, at the same time, increase their crop yields.

Although numerous studies have been carried out in Ethiopia on the adoption and subsequent economic impacts of chemical fertilizer, improved seed and physical soil and water conservation structures, some of which have been published (e.g. Croppenstedt *et al.*, 2003; Dercon and Christiaensen, 2007; Hagos, 2003; Kassie *et al.*, 2008a; Shiferaw and Holden, 1998), no study, to the best of our knowledge, has investigated the determinants of the adoption of compost use and conservation farming in the form of stubble tillage by farmers in Ethiopia (Neill and Lee, 2001). The objective of this study was to look at how socio-economic and biophysical characteristics determine adoption of compost and chemical fertilizer use, and stubble tillage in the semi-arid region of southern Tigray, Ethiopia. By identifying significant characteristics associated with the adoption of these sustainable agriculture practices, information to support formulation of policies and strategies that promote the adoption of these practices can be put forward. In addition, a dataset containing information on the use of compost and chemical fertilizer in relation to grain yields was used to perform a stochastic dominance analysis with the aim of examining whether adoption of these technologies had any impacts on productivity. By showing the importance of organic practices in enhancing productivity, we can validate the need to further investigate the factors that condition their adoption by farmers.

The results reveal a clear superiority with the use of compost, compared to chemical fertilizers, when it comes to crops yields. Regarding the determinants of adoption decisions, it was found that, while there is heterogeneity in the factors affecting the choice to use compost and/or stubble tillage, both plot and household characteristics influenced adoption decisions. Interestingly, we also found evidence that the impact of gender on technology adoption is technology-specific, while the significance of plot characteristics indicated that the decision to adopt a given technology is location-specific.

THE ANALYTICAL AND ECONOMETRIC FRAMEWORK

The analysis began by using a non-parametric technique, the stochastic dominance analysis, to assess how the use of compost and chemical fertilizer 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 cumulative density functions using the entire density of yield data, rather than averages, in the yield data set.

It was posited that both plot and household socio-economic characteristics influence the decision to adopt technologies. Plot characteristics condition the decision to adopt one specific technology over another by their impact on the increment of plot profit or the productivity impact derived from participation. Farmers' socio-economic characteristics and preferences, on the other hand, might result in different adoption decisions, even when plots have similar characteristics. Accordingly, the maximizing of a technology's utility for a farmer forms the basis of our econometric model and estimation strategy. The framework assumes that if adoption of several farming practices is possible, it is expected that, in deciding to adopt one or more practices, a farmer compares the indirect utility values associated with each practice or a combination of practices.

Consequently, to study the ith farmer's choice, random utility models were postulated, each being associated with the jth choice of farming practice, such that:

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

where V_{ij} is the indirect utility level which the ith farmer associates with the jth farming practice, and $\mathbf{X}_i$ is a vector describing the farmer's socio-economic 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, use of compost and stubble tillage, this provided four feasible choices available to the farmer. These were classified such that $j = 0$ if neither of the two practices is adopted, $j = 1$ if compost is adopted, $j = 2$ if stubble tillage is adopted, and $j = 3$ if both compost and stubble tillage are adopted.

Given a dummy variable, d_{ij}, to capture the choice of the ith farmer regarding the jth farming practice, the farmer's decision rule then becomes:

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

To make the econometric model operational, it was assumed 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):

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

This is the multinomial logit model, characterized by the independence of irrelevant alternatives, which implies that from equation (3) the following expression can be derived:

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

a condition which holds for whatever subsets of eligible combinations include *j* and *m*. Given that the model is based on the difference of expected utility levels in each pair of combinations, it was assumed 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 was used to solve the model.

THE DATA AND DESCRIPTIVE STATISTICS

This study benefited from two datasets. The first was a cross-sectional dataset collected in 2006 in the Ofla Woreda (district) of South Tigray Region that was used to analyse the determinants of adoption of compost, stubble tillage and chemical fertilizer. It included a random sample of 130 households across five villages from which observations from 355 plots were collected. Due to missing values for some of the explanatory variables the number of observations used in the final sample is for 348 plots. In addition to information on adoption of compost, stubble tillage and chemical fertilizer, the dataset contained household and plot characteristics, plus indicators of access to infrastructure which, based on economic theory and previous empirical research, were included in the analysis. The descriptive statistics of the variables used in the regression analysis are presented in Table 1.

TABLE 1

Descriptive statistics of variables from Ofla Woreda used in the analysis

VARIABLES	DESCRIPTION	MEAN	STD. DEVIATION
Dependent variables			
Stubble tillage	Plots received stubble tillage (1 = yes; 0 = otherwise)	0.368	0.483
Compost	Plots received compost (1 = yes; 0 = otherwise)	0.170	0.376
Chemical fertilizer	Plots received chemical fertilizer (1 = yes; 0 = otherwise)	0.236	0.425
Wheat grain yield with compost	Wheat grain yield in tonne per hectare	7.480	4.020
Wheat grain yield with chemical fertilizer	Wheat grain yield in tonne per hectare	5.080	2.470
Wheat grain yield without compost and chemical fertilizer (control yield)	Wheat grain yield in tonne per hectare	3.680	1.870
Barley grain yield with compost	Barley grain yield in tonne per hectare	7.047	2.725
Barley grain yield with chemical fertilizer	Barley grain yield in tonne per hectare	5.583	2.380
Barley grain yield without compost and chemical fertilizer (control yield)	Barley grain yield in tonne per hectare	3.217	1.960
Teff* grain yield with compost	Teff grain yield in tonne per hectare	6.790	5.000
Teff grain yield with chemical fertilizer	Teff grain yield in tonne per hectare	5.228	2.665
Teff grain yield without compost and chemical fertilizer (control yield)	Teff grain yield in tonne per hectare	3.450	2.780

VARIABLES	DESCRIPTION	MEAN	STD. DEVIATION
Explanatory variables			
Socio-economic characteristics			
Male	Sex of household head (1 = male; 0 = female)	0.822	0.379
Age	Age of household head	41.084	12.902
Dependents	Number of economically inactive household members	2.504	1.642
Household labour	Number of economically active household members	2.275	0.869
Illiterate (cf.)	Household head has no education (1 = yes; 0 = otherwise)	0.529	0.489
Religious education	Household head has religious education (1 = yes; 0 = otherwise)	0.114	0.319
Formal education	Household head has formal education (1 = yes; 0 = otherwise)	0.357	0.468
Farmers' organizations	Membership in farmers' organization (1 = yes; 0 = otherwise)	0.134	0.334
Extension	Household extension contact (1 = yes; 0 = otherwise)	0.636	0.469
Livestock	Household livestock holding, in Tropical Livestock Units (one TLU is equivalent to an animal that weighs 250 kg)	2.774	2.522
Farm size	Total farm size, in hectares	0.777	0.666
Market distance	Distance from residence to the district market, in hours	2.054	1.971
Plot characteristics			
Ownership**	Whether the householder owns the plot (1 = yes; 0 = otherwise)	0.718	0.450
Distance	Distance from residence to the plot, in minutes	0.626	0.629
Flat to moderate slope	Farmer's perception: plot is of flat to moderate slope (1 = yes; 0 = steep slope)	0.305	0.461
Fertile soil	Farmer's perception: plot is of fertile soil (1 = yes; 0 = infertile)	0.342	0.475
Black soil	Predominantly black soil (1 = yes; 0 = otherwise)	0.388	0.488
Deep soil (cf.)	Farmer's perception: plots with deep soil depth (1 = yes; 0 = otherwise)	0.379	0.486
Moderately deep soil	Farmer's perception: plots with moderately deep soils (1 = yes; 0 = otherwise)	0.241	0.429
Shallow soils	Farmer's perception: plots with shallow soil depth (1 = yes; 0 = otherwise)	0.379	0.486
Degradation	Plot perceived as being degraded (1=yes; 0=otherwise)	0.359	0.480
Number of plot observations			348

* Teff (*Eragrostis tef*) is a cereal crop with very small grains that is the main ingredient of a fermented pancake-like bread called injera.

** There is no private land ownership in Ethiopia, hence "ownership" indicates that the household head has a written legal leasehold to the land.

Source: Author's own calculations

Around 17, 36.8, and 23.6 percent of the plots used compost, stubble tillage, and chemical fertilizer, respectively. Regarding the householders' perceptions of the impacts of using compost and stubble tillage, about 40 and 74 percent of the adopters, respectively, perceived positive impacts of these technologies on soil fertility; about 20 and 42 percent, respectively, believed that these technologies reduced soil erosion; and 32 and 69 percent, respectively, believed that these technologies were labour intensive. The data also revealed that those farmers who adopted use of compost had more livestock compared to those who adopted stubble tillage. Conversely, farmers that adopted stubble tillage had larger farms (average 1.30 ha) compared to those who adopted using compost (average 1.03 ha). It was assumed that those farmers with larger farms who adopted stubble tillage could expect to produce more straw for livestock feed and could afford to plough in their stubble to increase soil fertility.

The fact that the first dataset did not include production data precluded our use of this dataset to analyse how adoption of these technologies impacted crop production. To achieve this objective, we employed a second dataset to conduct a stochastic dominance analysis. It was a cross-section time series of farm-level production data collected between 2000 and 2006 by the Institute for Sustainable Development (ISD)[2]. The dataset does not have any information on plot and household characteristics. ISD's primary objective for collecting these data was to investigate the impact of compost on crop production and soil fertility. The dataset covered eight districts and 19 villages in the Tigray Region, including the Ofla district from where the data used in the econometric analysis was collected. Of the 19 villages, 17 are located in drought-prone areas of the southern, eastern and central zones of Tigray. ISD collected agronomic data (grain and straw yields) for 11 crops from 974 plots. The FAO crop-sampling method was used to collect yield data from the plots which had received compost, chemical fertilizer and no inputs (control plots).

2 ISD promotes ecological agriculture in Ethiopia. It also has the responsibility of providing information and training on making compost and its application, and recording grain and straw yield data during harvest in collaboration with the local agricultural extension workers and farmers.

Three one-metre-square plots were harvested from each field to reflect the range of conditions of the crop. All of the crop management practices, including the amount of compost and fertilizer application, were decided by the farmers themselves as ISD did not set the level of inputs to be used by the farmers. The average-per-hectare cost of applying compost in 2007 was about ETB[3] 307 whereas commercial fertilizer (DAP and urea) is about ETB 497 (Hailu, 2010). The major cost component of compost is a labour cost, which accounts for 55% of the total cost (Michaele, 2005. Unpublished).

ESTIMATION RESULTS

In this section, the results obtained from stochastic dominance analysis and the multinomial logit adoption model are discussed.

Stochastic dominance analysis

For the purposes of this analysis, the three crops (wheat, barley, and teff) most widely grown by the farmers were used in order to compare yield distributions obtained from plots using compost, chemical fertilizer, and no inputs (control). The outcome variable is the physical grain yield (tonne/hectare) of the respective crops. Figures 1–3 show cumulative density functions for yields obtained from compost, chemical fertilizer and control plots.

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, indicating that yield with compost unambiguously holds first-order stochastic dominance over chemical fertilizer and control plots. That is, compared to control plots and plots that used chemical fertilizer, plots with compost gave significantly higher yield levels. Yield distribution of plots with chemical fertilizer

3 ETB = Ethiopian birr. 1 USD = 9.50 ETB as at December 2008.

FIGURES 1-3

Stochastic dominance analysis of the impact of compost on crop productivity in Tigray Region, Ethiopia, 2000-2006 inclusive

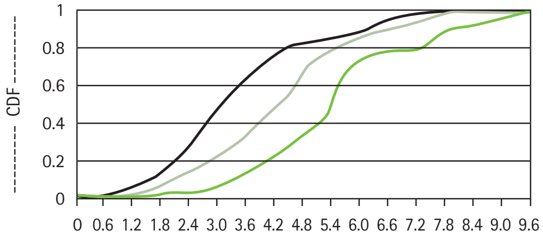

FIGURE 1

CDF for compost impact on wheat grain production in Tigray region

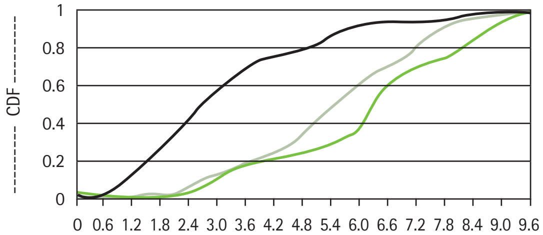

FIGURE 2

CDF for compost impact on barley grain production in Tigray region

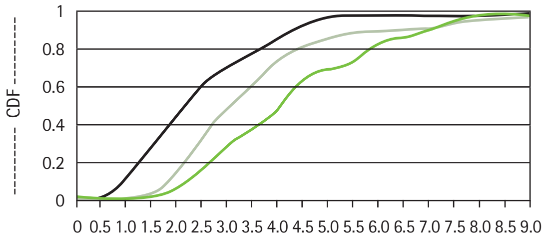

FIGURE 3

CDF for compost impact on teff grain production in Tigray region

yield (ton/ha)

- control
- fertilizer
- compost

Notes:
CDF = cumulative density function
Yield is in metric tonnes as given on the X axis

dominated yield distributions of control plots, i.e. plots with no input. However, crop production can also be influenced by plot and household characteristics apart from adoption of farming practices, for example, the gender of the household head (see later discussion).

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) also confirmed this result (see Table 2 below).

TABLE 2

Kolmogorov-Smirnov statistics test for first-order stochastic dominance

CROP	TREATMENTS		
	Compost versus control	Compost versus chemical fertilizer	Chemical fertilizer versus 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)***

Note: *** significant at 1%

The foregoing analyses revealed an interesting finding: adoption of sustainable 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 showed, use of compost can lead to significantly higher yields. While the use of profitability could be argued to be better than the use of yields (it could be the case that production plans with the best yields are not necessarily the most profitable), assuming the cost functions are correct, these results indicate that the use of compost could be more profitable than the use of chemical fertilizer. Other benefits from the use of compost could have been identified if these had been associated with measurements of environmental services and their long-term impacts on plot productivity. For example, unlike fields that receive chemical fertilizer in the current year, fields that received compost may not need a fertility enhancing input in the following year. Given these benefits, what constrains farmers from adopting such technologies? And, if they decide to adopt, what determines their choice of technology? The multinomial logit model was used to answer these questions. The results are discussed in the following section.

Multinomial logit model results

Table 3 below gives the multinomial logit-estimation results for the impact of both plot and socio-economic 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 following 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 the independence of the adoption of organic farming technologies, suggesting that the multinomial logit specification is appropriate for a model for adoption of organic technologies.

TABLE 3

Multinomial logit estimates

	COMPOST		STUBBLE TILLAGE		BOTH	
Variable	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error
Socio-economic characteristics						
Male household head	-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
Farmers' 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 or 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 soil	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					

Notes: Base outcome = no adoption; * significant at 10%; ** significant at 5%; *** significant at 1%

The results suggest that both socio-economic and plot characteristics are significant in conditioning the householders' decisions to adopt sustainable agricultural production practices. While there is heterogeneity with regard to factors influencing the choice to adopt compost and/or conservation tillage, these results suggest that significant determinants of adoption can be broadly classified into social characteristics of household head, labour availability, access to information, wealth and plot characteristics, which include whether or not the householder "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, households with a male head are less likely to adopt the use of compost, while they are more likely to either adopt stubble tillage or 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 underscored the need to avoid generalizing the impact of gender on unspecified farm technology adoption, emphasizing that the impact of gender on technology adoption is technology-specific. In this area, it seems male-headed households had a comparative advantage in using stubble tillage, while female-headed households enjoyed an advantage in the use of compost. This is probably linked to the cultural constraint that prevents women from handling plough oxen and constraints on labour availability at harvest time when stubble tillage should be done. Still with the characteristics of the household head, there was a negative and significant impact of age on the likelihood of adopting stubble tillage, as well as combining it with compost. This could suggest that younger farmers are more likely to try innovations and, in addition, they might also have a lower risk aversion and longer planning horizon to justify investments in technologies whose benefits are realized over time. The results also suggest the need to develop gender- and age-specific technologies instead of blanket recommendations of technologies, regardless of the characteristics of the farmers, to encourage adoption of sustainable agricultural practices.

Labour issues seem to be of more concern in the decision to adopt stubble tillage. Specifically, the probability of adopting stubble tillage, relative to no adoption, increased with the number of household members who actively provided farm labour. This is in line with the results of the descriptive statistics, where about 69 percent of those farmers that adopted stubble tillage reported that it was labour intensive. This is not surprising because stubble is tilled during crop harvesting, which is one of the peak periods for agricultural labour. This underscores the importance of labour availability to technology adoption, consistent with findings by Caviglia and Kahn (2001) and Shiferaw and Holden (1998). In such circumstances, it is important to consider strengthening the existing local labour-sharing mechanisms. On the other hand, this probability declined with the number of dependents in the household, capturing the intuitive expectation that the time spent caring for dependents shifts labour away from adoption activities.

Access to information on new technologies is crucial to creating awareness and attitudes towards technology adoption (Place and Dewees, 1999). In line with this, access to agricultural extension services, indicated by whether or not the household head had contact with an extension agent, impacted the adoption of all technology choices positively. Contact with extension services gives farmers access to information on innovations, advice on inputs and their use, and management of technologies. In most cases, extension workers establish demonstration plots where farmers get hands-on learning and can experiment with new farm technologies.

Another indicator of information that shapes management skills is the amount of formal education (as opposed to no education at all), which increases the probability of using compost relative to not adopting any sustainable agriculture practice at all. This suggests that using compost is relatively knowledge-intensive and, thus, that management skills are crucial in its adoption. It has been argued that farmers' associations and unions constitute important sources of information for farmers (Caviglia and Kahn, 2001). These results confirm this: a householder's membership in at least one farmers' organization significantly increased the likelihood that the farmer would practice stubble tillage, as well as the likelihood that the farmer would use both compost and stubble tillage. These results underscore the role of public policy supporting farmers' organizations in encouraging the adoption of sustainable agricultural practices.

In addition, livestock ownership, i.e. fewer animals, limited the adoption of compost, while a householder's size of landholdings limited the adoption of stubble tillage (as well as combining the two practices). This 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 used might be confounded with other factors related to adoption. For example, using livestock ownership as an indicator of wealth may be compromised by the fact that oxen provide draft power as well as manure (which, as organic matter, is a component of compost). Furthermore, as the data show, farmers who use compost have more livestock compared to those who adopt stubble tillage. This result could imply that the opportunity cost of crop residues is smaller for stubble tillage adopters than compost adopters. The size of total landholdings, on the other hand, although measuring farmers' wealth, could also suggest economies of scale in production using stubble tillage, as well as indicating the social status of the household head – both of which could influence the farmers' ability to obtain credit. All the same, these results suggest that policies to alleviate poverty and increase crop productivity among farmers will impact the adoption of sustainable agricultural practices positively.

The results revealed that plot ownership has a positive impact on adoption decisions consistent with Arellanes (1994) for adoption of minimum tillage in Honduras and Neill and Lee (2001) for adoption of cover crops in Honduras. This is in line with the theory of Marshall's disincentive hypothesis where input use on rented land, particularly on sharecropped land, is found to be lower than on owned land because of the disincentive effect of output sharing (Kassie and Holden, 2007). Given the fact that the benefits from investing in both compost and stubble tillage accrue over time, this inter-temporal aspect implies that secure land access or tenure will impact adoption decisions positively. Distance of plots from residence positively and significantly influences adoption of stubble tillage. This could be reflecting the fact that, for example, crop residues in plots that are farther away from the homestead are less accessible to be used as livestock feed. This would then mean that farmers might prefer to use crop residues in these plots for stubble tillage instead. Alternatively, plots close to the homestead could be relatively fertile compared to distant plots because homestead plots may benefit from household refuse and other soil fertility enhancing materials (e.g. ash).

Sustainable agricultural systems are intuitively site-specific (Lee, 2005). This is further confirmed by the finding that plot characteristics influence the decision to adopt stubble tillage, as well as to combine it with the use of compost. In particular, the likelihood of householders choosing to practice stubble tillage declined with the perceived increase in the slope of the plots. This could reflect the fact that plots with steeper slopes are more prone to soil erosion, which necessitates adoption of farming techniques, such as stubble tillage, since they are meant to mitigate soil erosion and subsequent nutrient losses. The plot slope impacted the decision to combine the use of compost and conservation tillage in a similar way. It also found 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 did not seem to impact the decision to adopt only the use of compost. These results imply that, for sustainable agricultural practices to be successful, they must address site-specific characteristics since these condition the need for adoption as well as the type of technology adopted.

CONCLUSION

In this paper, plot-level data from the semi-arid region of Tigray, Ethiopia, have been used to investigate the factors influencing farmers' decisions to adopt sustainable agriculture practices, with a particular focus on the adoption of stubble tillage and compost. In addition, stochastic dominance analysis is used to examine and compare the productivity gains of sustainable farming practices and chemical fertilizers.

While there is heterogeneity with regard to factors that influence the choice of any of the two practices, these results underscore the importance of both plot and household characteristics in adoption decisions. The findings imply that public policy can affect the adoption of sustainable agriculture. Specifically, the significant and positive impact of access to information, and the quality of that information, indicates that public policies aimed at improving access to information will help promote adoption of organic farming practices.

Moreover, it is shown that such public policies should take into consideration the influence of gender differences, particularly as these are linked to culture and differential labour demands between sexes, in adoption of different technologies. There is also evidence that the age of the household head (whether affecting aversion to risk and/or life-cycle dynamics) will have a differential impact on adoption, depending on the type of technologies. Availability of household labour also conditions the choice of technology adopted, given that the labour requirements differ from technology to technology as well as the timing of the application of the technology. Thus, public policy should factor in the impact of these socio-economic characteristics.

Security of access to land has a significant influence on a farmer's decision whether or not to adopt a technology, and its impact varies from technology to technology. Policies should strive to ensure that the drive to give farmers secure tenure rights are not undermined by other decisions on land use that could undermine the security of these tenure rights.

The viability of the agricultural production systems in Ethiopia, as in many areas in developing countries, is highly constrained by degraded soils and increasing lack of reliability in rainfall resulting from climate change. These problems are further compounded by an increasing population that is not accompanied by improvements in local technologies and land management practices. Even though efforts by the government are resulting in a larger proportion of the farmers making use of chemical fertilizers, the sustainability of this approach to increasing crop productivity and food security is at risk because of escalating prices for fertilizer and transport to bring the crops to market. Given these constraints, it can be argued that sustainable agricultural practices that emphasize the management capacity and self-reliance of farmers to improve their productivity can create a win-win situation for both the local communities and the country as a whole. Farmers are able to reduce production costs by relying on renewable local resources that, at the same time, improve environmental services and increase yields.

REFERENCES

Adesina, A.A., D. Mbila, G.B. Nkamleu & D. Endamana. 2000. Econometric analysis of the determinants of adoption of alley farming by farmers in the forest zone of Southwest Cameroon. *Agriculture, Ecosystems and Environment* 80: 255–65.

Byerlee, D., D.J. Spielman, D. Alemu & M. Gautam. 2007. *Policies to promote cereal intensification in Ethiopia: A review of evidence and experience*. International Food Policy Research Institute Discussion Paper 00707. IFPRI, Washington DC.

Caviglia, J.L. & 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 & 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. & L. Christiaensen. 2007. *Consumption risk, technology adoption, and poverty traps: Evidence from Ethiopia*. World Bank Policy Research Working Paper 4527. World Bank, Washington DC.

Deressa, T.T. 2007. *Measuring the economic impact of climate change on Ethiopian agriculture: Ricardian appproach*. World Bank Policy Research Working Paper 4342. World Bank, Washington DC.

D'Souza G., D. Cyphers & T. Phipps. 1993. Factors affecting the adoption of sustainable agricultural practices. *Agricultural Resource Economics Review* 22(2): 159–65.

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

Edwards, S., Arefayne Asmelash, Hailu Araya & Tewolde Berhan Gebre Egziabher. 2007. *Impact of compost use on crop production in Tigray, Ethiopia*. FAO, Rome Avaliable at http://www.fao.org/documents/pub_dett.asp?lang=en&pub_id=237605 (verified 24 March 2010).

FAO. 2008. Conservation agriculture. Available at http://www.fao.org/ag/ca/ (accessed 16 December 2008; verified 24 March 2010).

Greene, W.H. 1997. *Econometric analysis*. 3rd edition. Prentice Hall.

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

Hagos, F. 2003. *Poverty, institution, peasant behavior, and conservation investments in Northern Ethiopia*. Department of Economics and Social Sciences, Agricultural University of Norway, Aas. (PhD dissertation, no. 2003:2)

Hailu Araya (2010). *The impact of compost in soil fertility and yield: A case of Tigray Region, Ethiopia*. Hohenheim University, Germany. (PhD dissertation)

Hailu Araya & S. Edwards, 2006. *The Tigray experience: A success story in sustainable agriculture*. Environment and Development Series No. 4. Third World Network, Penang.

Hemmat, A. & O. Taki. 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. Köhlin, R. Bluffstone & E. Mulugeta. 2008a. Estimating returns to soil conservation adoption in the northern Ethiopian highlands. *Agricultural Economics* 38: 213–32.

Kassie, M., M. Yesuf & G. Köhlin. 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.

Kassie, M. & S.T. Holden. 2007. Sharecropping efficiency in Ethiopia: Threats of eviction and kinship. *Agricultural Economics* 37: 179-188.

Lee, D.R. 2005. Agricultural sustainability and technology adoption: Issues and policies for developing countries. *American Journal of Agricultural Economics* 87(5): 1325–34.

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

Mesfine, T., G. Abebe & A.R.M. Al-Tawaha. 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): 152–60.

Michaele Kahsay. 2005. Assessment on the economics of organic farming in Tahtay-Maichew Woreda in 'Tabia' Akab-Seat, May-Siye, May-Berazio and Kewanit. Unpublished report from 10th Cycle Practical Attachment Program of Mekelle University, Faculty of Dryland Agriculture and Natural Resource, Department of Natural Resource Economics and Management (NREM).

Neill, S.P. & D.R. Lee. 2001. Explaining the adoption and disadoption of sustainable agriculture: The case of cover crops in northern Honduras. *Economic Development and Cultural Change* 49(4): 793-820.

Place, F. & P. Dewees. 1999. Policies and incentives for the adoption of improved fallows. *Agroforestry Systems* 47: 323-43.

Sasakawa-Global 2000. 2004. *Proceedings of the Workshop on Conservation Tillage*. Melkassa Agricultural Research Center, East Shewa, Ethiopia, April 6, 2004.

Sasakawa Africa Association. 2008. Country profile: Ethiopia. Available at http://www.saa-tokyo.org/english/country/ethiopia.shtml (accessed October 2008; verified 23 March 2010).

Shiferaw, B. & S.T. Holden. 1998. Resource degradation and adoption of land conservation technologies in the Ethiopian highlands: A case study in Andit Tid, North Shewa. *Agricultural Economics* 18: 233–47.

Twarog, S. 2006. Organic agriculture: A trade and sustainable development opportunity for developing countries. *In*: *UNCTAD Trade and Environment Review 2006*. United Nations, New York and Geneva.

UNCTAD & UNEP. 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.