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Title of the Paper

Interdependence in Farmer Technology Adoption Decisions in Smallholder Systems: Joint Estimation of Investments in Sustainable Agricultural Practices in Rural Tanzania" (Reference Number '16789')

Authors Author Affiliation and Contact Information

Menale Kassie[a1], Moti Jaleta[b] , Bekele Shiferaw[a], Frank Mmbando[c], Mulugetta Mekuria[d]

[a]International Maize and Wheat Improvement Center (CIMMYT), Po.Box 1041, 00621 Village market, Nairobi, Kenya

[b]International Maize and Wheat Improvement Center (CIMMYT), Po.Box, 5689, Addis Ababa, Ethiopia
[c]Selian Agricultural Research Institute(SARI), Po. Box 6024, Arusha, Tanzania

[d]International Maize and Wheat Improvement Center (CIMMYT), Po.Box, MP 163 Mount Pleasant, Harare, Zimbabwe

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[1] Corresponding Author:
Menale Kassie: m.kassie@cgiar.org. Tel: 254(20) 722 4628; Fax: 254(20) 7224600

Interdependence in Farmer Technology Adoption Decisions in Smallholder Systems: Joint Estimation of Investments in Sustainable Agricultural Practices in Rural Tanzania

Menale Kassie[a1], Moti Jaleta[b], Bekele Shiferaw[a], Frank Mmbando[c], Mulugetta Mekuria[d]

[a]International Maize and Wheat Improvement Center (CIMMYT), Po.Box 1041, 00621 Village market, Nairobi, Kenya

[b]International Maize and Wheat Improvement Center (CIMMYT), Po.Box, 5689, Addis Ababa, Ethiopia

[c]Selian Agricultural Research Institute(SARI), Po. Box 6024, Arusha, Tanzania

[d]International Maize and Wheat Improvement Center (CIMMYT), Po.Box, MP 163 Mount Pleasant, Harare, Zimbabwe

Abstract

Soil fertility depletion is considered one of the main biophysical limiting factors for increasing per capita food production for smallholder farmers in Sub-Saharan Africa. The adoption and diffusion of sustainable agricultural practices (SAPs), as a way to tackle this challenge, has become an important issue in the development policy agenda in the region. This paper examines the adoption decisions for SAPs, using recent primary data of multiple plot-level observations collected in 4 districts and 60 villages of rural Tanzania. The paper employs a multivariate probit technique to model simultaneous interdependent adoption decisions by farm households. The analysis reveals that rainfall, insects and disease shocks, government effectiveness in provision of extension services, tenure status of plot, social capital, plot location and size, and household assets, all influence farmer investment in SAPs. Policies that target SAPs and are aimed at

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[1] Corresponding author: Menale Kassie: m.kassie@cgiar.org. Tel: 254(20) 722 4628; Fax: 254(20) 7224600.

organizing farmers into associations, improving land tenure security, and enhancing skills of civil servants can increase uptake of SAPs in smallholder systems.

Key words: Sustainable agricultural practices, multiple adoption, multivariate probit, Tanzania

1. Introduction

The economies of most countries in sub-Saharan Africa, including Tanzania, heavily depend on agriculture that is dominated by smallholder farmers that are partially integrated into markets. The fate of the agricultural sector directly affects economic development, food security, poverty alleviation, and social welfare. However, the performance of agriculture in this region has not lived up to expectations, characterized by decades of stagnation and volatility in production and marketed volume. While the sector employs about 65 percent of labor force, it contributes only about 25-30 percent of the total gross domestic product (Pretty et al. 2011).

Several biophysical and socioeconomic factors have been identified as key constraints limiting productivity growth in agriculture in sub-Saharan Africa (Pender et al. 2006; Ajayi 2007; Misiko and Ramisch 2007). Soil fertility depletion is considered as the main biophysical limiting factor for increasing per capita food production for most smallholder farmers in the region. The average annual nutrient balance for the region for the period 1983–2000 was estimated to be minus 22–26 kg of nitrogen (N), 6–7 kg of phosphorus (P), and 18–23 kg of potassium (K) per hectare (Smaling et al. 1997). On the other hand, the average intensity of fertilizer use in sub-Saharan Africa is only 8 kg/ ha of cultivated land, much lower than in other developing countries (Morris et al. 2007). In our study of over 1500 plots merely 4 percent of the plots received chemical fertilizers, despite the fact that 52 percent of the plots were planted with improved maize varieties.

When no external inputs are used, plots require long fallow periods to replenish nutrients taken up by crops and washed away by erosion. However, as the population increases and the availability of new land to exploit decreases, allowing plots to lie fallow has become more and more difficult, and continuous cropping has become commonplace in Africa. This has resulted in a vicious cycle of poor agricultural productivity, low investment capacity, continued soil degradation, and further pressure on available lands to generate necessary food supplies (Pender et al. 2006; Misiko and Ramisch 2007).

The adoption and diffusion of specific sustainable agricultural practices (SAPs) have become an important issue in the development policy agenda for sub-Saharan Africa (Scoones and Toulmin 1999; Aiayi 2007), especially as a way to tackle these impediments. The Food and Agricultural Organization (FAO) argues that sustainable agriculture consists of five major attributes: (1) conserves resources, (2) environmentally non-degrading, (3) technically appropriate, (4) economically, and (5) socially acceptable (FAO 2008). Accordingly these practices broadly defined may include conservation tillage, legume intercropping, legume crop rotations, improved crop varieties, use of animal manure, complementary use of organic fertilizers, and soil and stone bunds for soil and water conservation (de Souza Filho et al. 1999; Lee 2005; Kassie et al. 2009; Wollni et al. 2010).

The potential benefits of SAPs lie not only in conserving but also in enhancing the natural resources (increasing soil fertility and soil organic matter) without sacrificing yield levels. This makes it possible for fields to act as a sink for carbon dioxide, to increase the capacity of the soil to hold water, and reduce soil erosion (Allmaras et al. 2000). Furthermore, by retaining fertile and functioning soils, SAPs can also have positive impacts on food security and biodiversity (Wollni et al. 2010). Crop rotation and diversification via intercropping enable farmers to grow products that can be harvested at different times and that have different climate or environmental stress-response characteristics. These varied outputs and degrees of resilience are a hedge against the risk of drought, extreme or unseasonal temperature, and rainfall variations that affect productivity of stallholder systems.

Notwithstanding their benefits, the adoption rate of SAPs is still low in rural areas of developing countries (Somda et al. 2002; Tenge et al. 2004; Jansen et al. 2006; Kassie et al. 2009; Wollni et al. 2010), despite a number of national and international initiatives to encourage farmers to invest in them. This is true for Tanzania, where, despite accelerated erosion and considerable efforts to promote various soil and water conservation technologies, the adoption of many recommended measures is minimal and soil degradation continues to be a major constraint to productivity growth and sustainable intensification (Mbaga-Semgalawe and Folmer 2000; Tenge et al. 2004). Moreover, relatively little empirical work has been done to examine the factors that impede or facilitate the adoption and diffusion of SAPs, especially conservation tillage, legume intercropping, and legume crop rotations (Arellanes and Lee 2003).

The objective of this paper is to fill this gap. We use a rich primary data set, generated by Selian Agricultural Research Institute (SARI) of Tanzania in collaboration with the International Maize and Wheat Improvement Center (CIMMYT), to identify the key factors influencing simultaneous adoption of several agricultural technologies and practices, and their impact on household welfare in the maize-legume cropping system zones. We use multiple plot observations to jointly analyze the factors that facilitate or impede the probability of adopting multiple SAPs in smallholder system in Tanzania. We particularly investigate interdependent adoption of legume intercropping (LI), legume crop rotations (LCR), animal manure, conservation tillage (CT- that entails zero/minimum tillage), soil and water conservation practices (SWC), chemical fertilizer (CF), and introduction of improved seeds (improved crop varieties). Understanding the determinants of household choices of SAPs can provide insights into identifying target variables and areas that enhance the use of these practices.

The contributions of the paper are threefold: First, although there is a well-developed literature on the impact of a host of explanatory variables on technology adoption, the analysis provides new evidence on policy relevant variables such as on the impact of governance indicators (e.g., government effectiveness in the provision of extension services and political connections), kinship, rainfall shocks, and farmers' expectations on social safety nets (social insurance) during crop failure. Second, we provide a more comprehensive and rigorous analysis of the interdependent adoption of SAPs in Tanzania. Past studies (Mbaga-Semgalawe and Folmer 2000; Isham 2002; Tenge et al. 2004) assessed the specific technology adoption decision (fertilizer or soil and water conservation structures), which fails to account for complementarities and/or substitutabilities among different practices. Earlier studies also did not take into account important variables, such as plot characteristics, shocks, governance indicators and institutional factors.

2. Conceptual Framework and Econometric Estimation Strategy

Farmers are more likely to adopt a mix of technologies to deal with a multitude of agricultural production constraints than adopting a single technology. A shortcoming of most of the previous studies on adoption of SAPs is that they do not consider the possible inter-relationships between the various practices (Yu et al. 2008). These studies mask the reality faced by decision-makers who are often faced with technology alternatives that may be adopted simultaneously and/or sequentially as complements, substitutes, or supplements. Such adoption analysis is possible when other technology adoption decisions are made exogenously. But, when other decisions are made in conjunction with the SAP adoption decision considered, this approach may under- or over-estimate the influences of various factors on the adoption decisions (Wu et al. 1998).

This suggests that the number of technologies adopted may not be independent, but path dependent (Cowen and Gunby 1996). The choice of technologies adopted more recently by farmers may be partly dependent on earlier technology choices. Some recent empirical studies of technology adoption decisions assume that farmers consider a set (or bundle) of possible technologies and choose the particular technology bundle that maximizes expected utility (Moyo and Veeman 2004; Marenya and Barrett 2007; Nhemachena and Hassan 2007; Yu et al. 2008; Kassie et al. 2009). Thus, the adoption decision is inherently multivariate and attempting univariate modeling excludes useful economic information contained in interdependent and simultaneous adoption decisions.

In this paper, we adopt multivariate probit (MVP) econometric technique, which simultaneously models the influence of the set of explanatory variables on each of the different practices, while allowing the unobserved and/or unmeasured factors (error terms) to be freely correlated (Belderbos et al. 2004; Lin et al. 2005). One source of correlation may be complementarities (positive correlation) and substitutabilities (negative correlation) between different practices (Belderbos et al. 2004).

In contrast to MVP models, univariate probit models ignore the potential correlation among the unobserved disturbances in the adoption equations, as well as the relationships between the adoptions of different farming practices. As mentioned above, farmers may consider some combination of practices as complementary and others as competing. Failure to capture unobserved factors and inter-relationships among adoption decisions regarding different practices will lead to bias and inefficient estimates.

The multivariate probit econometric model is characterized by a set of binary dependent variables (Y_{hpj}), such that:

$$Y^{*}_{hpj} = X^{'}_{hpj}\beta_{j} + u_{hpj}, \qquad j = 1,\dots,m \quad \text{and} \tag{1}$$

$$Y_{hpj} = \begin{cases} 1 \text{ if } Y^{*}_{hpj} > 0 \\ 0 \text{ otherwise} \end{cases}, \tag{2}$$

where $j = 1, \dots m$ denotes the technology choices available (SAPs in our case).

In equation (1), the assumption is that a rational h^{th} farmer has a latent variable, Y^{*}_{hpj}, which captures the unobserved preferences or demand associated with the *j*th choice of SAP. This latent variable is assumed to be a linear combination of observed characteristics (X_{hpj}), both household and plot characteristics that affect the adoption of j^{th} SAP, as well as unobserved characteristics captured by the stochastic error term u_{hpj}. The vector of parameters to be estimated is denoted by β_{j}. Given the latent nature of Y^{*}_{hpj}, the estimations are based on observable binary discrete variables Y_{hpj}, which indicate whether or not a farmer undertook a particular SAP on plot p.

If adoption of a particular practice is independent of whether or not a farmer adopts another practice (i.e., if the error terms, u_{hpj} are iid with a standard normal distribution), then equations (1) and (2) specify univariate probit models, where information on farmers' adoption of one farming practice does not alter the prediction of the probability that they will adopt another practice. However, if adoption of several farming practices is possible, a more realistic specification is to assume that the error terms in equation (1) jointly follow a multivariate normal (MVN) distribution, with zero conditional mean and variance normalized to unity, where $u_{hpj} \sim MVN(0, \Sigma)$ and the covariance matrix Σ is given by:

$$\Sigma = \begin{bmatrix} 1 & \rho_{12} & \rho_{13} & \cdots & \rho_{1m} \\ \rho_{12} & 1 & \rho_{23} & \cdots & \rho_{2m} \\ \rho_{13} & \rho_{23} & 1 & \cdots & \rho_{3m} \\ \vdots & \vdots & \vdots & 1 & \vdots \\ \rho_{1m} & \rho_{2m} & \rho_{3m} & \cdots & 1 \end{bmatrix}. \tag{3}$$

Of particular interest are the off-diagonal elements in the covariance matrix, ρ_{jm}, which represent the unobserved correlation between the stochastic component of the *j*th and *m*th type of SAPs. This assumption means that equation (2) gives a MVP model that jointly represents decisions to adopt a particular farming practice. This specification with non-zero off-diagonal elements allows for correlation across the error terms of several latent equations, which represent unobserved characteristics that affect choice of alternative SAPs.

3. Data and Description of Variables

We use detailed primary household and plot survey data from 681 farm households and 1,539 plots (defined on the basis of land use), in 60 villages in 4 districts of Tanzania. The survey was conducted in November and December 2010.

In the first stage in the sampling procedure, four districts from two regions/zones selected based on their maize-legume production potential: Karatu and Mbulu, from the northern zone; and Mvomero and Kilosa, from the eastern zone. Each of the two zones was assigned equal number of sample households. The households within a zone were distributed within the two respective districts according to district household size (proportionate sampling). The remainder of the sampling process was fully proportionate random sampling: 5–13 wards were selected in each district, 1–4 villages in each ward, and 2–30 farm households in each village.

The survey covered detailed household, plot, and village information. For each plot, the respondent recounted the type of SAPs practiced, such as intercropping, conservation tillage, soil and water conservation practices, animal manure, crop rotations, chemical fertilizer, and improved seeds during the sample year. Information on plot soil fertility, soil depth, slope, size in acres, and distance of the plot from the household dwelling, in minutes of walking, are collected. Other information collected at the plot level was tenure status of plots, crop production estimates, and inputs associated with each type of agricultural activity types.

Key socioeconomic elements collected about the household include age, gender, education level, family size, asset ownerships, membership in farmers' organizations, consumption expenditures, distance a household resides from input and output markets and extension offices, whether households believe they can rely on government support during crop failure when crop production fails (1= yes, and zero otherwise), number of relatives that households in the sample can rely on for critical support in times of need, number of traders the respondent knows in their vicinity, production constraints (such as crop pests, diseases, and input availability), and how much land a households owns.

Information was also collected on governance indicators, such as government effectiveness[2] and political connections (Kaufmann et al. 2007). Empirical evidence supports the positive role of government effectiveness and political connections on economic growth and a firm's investment performance (Dixit 2004). Recent literature in new institutional economics suggests that formal institutions provided for by the state are not the only ones that matter for economic development (Ibid). Informal institutions, such as political connections—which are a

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[2] Government effectiveness measures the quality of civil services and quality and quantity of public infrastructure, as well as organizational structure of public offices (Kaufmann et al. 2007).

more fundamental aspect of networking—play a significantly positive role in the performance of firms or individuals by facilitating investment and credit. In our case, connection with local administrators and agricultural officials may lead to better access to inputs and credit supplied by the public institutions.

We measured government effectiveness using respondents' perception of the competence of extension workers. Farmers were asked to score their confidence (on a scale of 1 to 7, where 7 signifies high confidence) in the ability of extension workers to accomplish their jobs. This variable is converted into a dummy variable, where 1 indicates confidence in the qualification of extension workers (slightly agree to strongly agree) and zero shows lack of confidence (strongly disagree to indifferent). For the political connection variable, we set a dummy variable equal to 1 if the respondent has relatives or friends in a leadership position in and outside the village, and zero otherwise. In addition, distance to extension office which can serve as a proxy to extension visit and contact is collected and included in the regression model.

The household survey also includes individual rainfall shock variables derived from respondents' subjective rainfall satisfaction, in terms of timelines, amount, and distribution. The individual rainfall index was constructed to measure the farm-specific experience related to rainfall in the preceding three seasons, based on such questions as to whether rainfall came and stopped on time, whether there was enough rain at the beginning and during the growing season, and whether it rained at harvest time.[3] Responses to each of the questions (yes or no) were coded as favourable or unfavourable rainfall outcomes and averaged over the number of questions asked (five questions), so that the best outcome would be equal to 1 and the worst to zero.[4]

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[3] We followed Quisumbing (2003) to construct this index.

[4] Actual rainfall data is, of course, preferable, but getting reliable village-level data in most developing countries, including Tanzania, is difficult.

3.1. Explanation of Variables and Hypotheses

Following the adoption literature (e.g., Bandiera and Rasul 2006; Marenya and Barrett 2007; Pender and Gebremedhin 2007; Bluffstone and Köhlin 2011), the explanatory variables included in our regression analysis and their hypothesized effect on adoption of SAPs are discussed below.

Shocks. We considered individual farmer's perception of the timeliness, adequacy and distribution of rainfall (Rainfalindex) and prevalence of pests and diseases (Pestdisease). Agricultural production in sub-Saharan Africa is characterized by wide variability in the timing and levels of rainfall, and the increase in temperatures. In addition, crops are subject to various pests and diseases. Adoption of certain farm management strategies, such as CT, SWC, LI, LCR, and manure, can reduce exposure to such shocks by conserving soil moisture; increasing soil organic matter; reducing soil loss from erosion and flooding; reducing weeds, pest infestations, and diseases; and diversifying crop products. Thus, favourable rainfall outcome (a rainfall stratification index close to 1) is hypothesized to positively impact decisions to adopt improved seed types and fertilizer use.

On the other hand, unfavorable rainfall outcome (a rainfall stratification index close to zero) encourages farmers to adopt CT, SWC, LI, and animal manure. High rainfall can stimulate weed growth and increase water logging (Jansen et al. 2009; Kassie et al. 2010), which may negatively influence the likelihood of adoption of CT and SWC. In the presence of pests and diseases, farmers tend to adopt practices that involve smaller cash outlays and low-risk technologies and practices (such as LI and LCR) that reduce such shocks. The expected sign on the pest-disease coefficient is positive for LI, LCR, CT, SWC, and animal manure adoption and negative for CF and improved seeds.

Social capital. This represents a combination of variables, such as membership in farmers' groups or associations, number of relatives in and outside the village that a household can rely on for critical support (Kinship), and number of traders (Trader) that a respondent knows in and outside the village. Recent literature has focused on the effect of social networks and personal relationships on technology adoption (Barrett 2005a; Bandiera and Rasul 2006; Matuschke and Qaim 2009; Isham 2007; Nyangena 2011). With scarce or inadequate information sources and imperfect markets and transactions costs, social networks facilitate the exchange of information, enable farmers to access inputs on schedule, and overcome credit constraints. Social networks also reduce transaction costs and increase farmers' bargaining power, helping farmers earn higher returns when marketing their products. This, in turn, can affect technology adoption (Pender and Gebremedhin 2007; Wollni et al. 2010; Lee 2005).

Farmers who do not have contacts with extension agents may still find out about new technologies from their networks, as they share information and learn from each other. Membership in farmers' groups or associations (Group) is therefore hypothesized to be positively associated with adoption of SAPs. The number of traders that a farmer knows (Trader) is included because it proxies the degree of market integration and incentive for sustainable intensification. It may also capture interlinked contracts that are common in the presence of imperfect markets. They are important means of accessing credit, inputs, and spreading information about technologies, and offer stable market outlet services to farmers (Masakure and Henson 2005; Simmons et al. 2005). These interlinking contracts also help contracting parties share risk. Therefore, it is assumed that the Trader variable has a positive effect on the probability and level of adoption of SAPs.

In most developing countries, self-protection and risk sharing via informal insurance is the most common approach to reducing exposure to risk, as extended family or friends share resources when risks occur (Fafchamps and Lund 2003; Fafchamps and Gubert 2007). This informal insurance can take the form of friendship or kinship networks. Households with greater numbers of relatives (Kinship) are therefore more likely to adopt new technologies because they are able to experiment with technologies without excessive exposure to risk. However, having more relatives may reduce incentives for hard work and induce inefficiency, such that farmers may exert less effort to invest in technologies. This is the dark side of social capital in the form of kinship. The expected sign on the kinship coefficient is therefore indeterminate.

Government indicators. As discussed above, governance indicators include government effectiveness (Extenskill) and political connections (Connection) variables. Bad governance, in the form of recruiting poorly-skilled civil servants, leads to inefficient and ineffective bureaucracy. In most developing countries, including Tanzania, agricultural inputs and supply of credit are delivered to rural farmers through government's local bureaucracy, so the inefficiency of the governance system affects farmers in terms of costly access to agricultural input and credit (Zerfu 2010). This affects the return from technology adoption and, hence, discourages adoption of technologies.

Often agricultural extension agents are mandated to deliver and implement agricultural-related services and goods. Households' evaluation of the competence of civil servants will thus be shaped by the extension agents they interact with. When households deal with competent extension agents, they are likely to acknowledge the competence of the agents and may develop confidence to adopt technologies, believing competent agents will provide better services.

Although we are not aware of empirical evidence of the impact of government effectiveness and political connections on technology adoption, empirical evidence in Kaufmann et al. (2007) and Zerfu(2010) support a positive role of these factors on production efficiency in firms' performance. Thus, we anticipate a positive effect on adoption and intensity of adoption.

Government support (Govtsup). In developing countries, it is not uncommon for governments and international organizations to provide aid and/or subsidies when crop production fails (social safety nets (social insurance). Such support, if properly implemented, can help farm households smoothen consumption and maintain productive capacity by reducing the need to liquidate assets that might otherwise occur without it (Barrett 2005c; Tadesse and Shively 2009). The expected sign on the government support coefficient is positive.

Market and plot access. The distance to markets (Mktdist) and plot access (distplot) can influence farmers' decision making in various ways. Better access, apart from influencing availability of technology, can influence the use of output and input markets, and the availability of information and support organizations (e.g., credit institutions), as well as the opportunity costs of labor (Jansen et al. 2006; Wollni et al. 2010; Pender and Gebremedhin 2007). It can also increase the amount of labor and/or capital intensity by raising output to input price ratios (Binswanger and McIntire 1987). The hypothesis here is that the further away a village or a household lies from input and output markets (Mktdist**)**, the smaller the likelihood that they will adopt new technology. Thus, this variable is expected to have a negative impact on the probability and level of adoption of SAPs.

Land tenure (Tenure)**.** A number of studies have demonstrated that security of land ownership has a substantial effect on the agricultural performance of farmers (Besley 1995; Kassie and Holden 2008; Deininger et al. 2009). Better tenure security increases the likelihood that farmers will capture the returns from their investments. As a result, demand for short-term inputs (e.g., fertilizer) will increase as well. In this paper, this variable is proxied by plot tenure status (1 is owned by farmer, and zero otherwise). We hypothesized that this variable positively influences investments whose benefits are captured in the long run (CT, SWC, and manure), but that its effect on short-term inputs (CF and improved seeds) and practices (intercropping and crop rotations) is ambiguous.

In an area where land is scarce and search costs are high, tenants are likely to apply more short-term inputs on rented plots than owned plots because of the threat of eviction from use of the plot (Kassie and Holden 2008).

Physical capital. This variable is represented by livestock ownership, farm size, income, and value of major farm equipment and household furniture. Wealthier households are better able to bear possible risks associated with adoption of practices and may be more able to finance purchase of inputs, such as fertilizer and improved seeds. Crop-livestock interaction is a common practice in developing countries, where livestock serve as source of manure and draft power, and crop enterprises generate fodder for livestock. Following Matuschke and Qaim (2008), we included in the regression equations current household expenditures as proxy for the income level of the farm households.[5] The expected sign on the coefficients on livestock (Livestock), income (Expenditure) and asset value (Assetvalue) is positive. On the other hand, households with relatively large holdings may follow an extensification path (using less-intensive farming methods) compared to those who have smaller land holdings (providing basic sustenance). Therefore, the coefficient sign on the farm size variable (Totfarmsize) is indeterminate.

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[5] The use of current income as a covariate variable may be sub-optimal, but is still justifiable because poverty traps are widespread in developing countries, particularly among smallholder farmers (e.g., Barrett 2005b; Woolard and Klasen 2005). Poverty traps imply that households with initially low-income levels remain low-income households over a long period.

Off-farm activity participation (Salary). Economic incentives play an important role in the adoption of SAPs, although their effects may be complex and subtle (Lee 2005). Household access to alternative sources of employment, and the labor return from it, are likely to influence positively and negatively the adoption of SAPs (Mahmoud and Shively 2004; Pender and Gebremedhin 2007: Wollni et al. 2010). Households that have alternative sources of income may be better able to adopt technologies, since they may have better access to information about new technologies or the capacity to finance investments. On the other hand, off-farm activities may divert time and effort away from agricultural activities, reducing investments in technologies and the availability of labor. The hypothesized effect of the salary variable on adoption is ambiguous. This variable is defined as equal to 1, if the household has salaried employment members, and zero if otherwise.

Human capital. Household characteristics, such as education level of household head (Educ), age (Age), family size (HHsize), and gender of household head (Gender), may affect decisions to adopt SAPs because of the imperfect markets (de Janvry et al. 1991; Pender and Gebremedhin 2007; Nyangena 2011). Households with more education may have greater access to non-farm income and thus be more able to purchase inputs. Educated farmers may also be more aware of the benefits of modern technologies and may have a greater ability to decode new information, search for appropriate technologies to alleviate their production constraints, and analyze the importance of new technologies (Pender and Gebremedhin 2007; Kassie et al. 2011).

On the other hand, more educated households may be less likely to invest in labor-intensive technologies and practices, since they may be able to earn higher returns on their labor and capital if they are used in other activities (Pender and Gebremedhin 2007). Thus, the probability and level of adoption increase with the education level of the farmers.

Age means more exposure to production technologies and environments, and greater accumulation of physical and social capital. However, age can also be associated with loss of energy and short-planning horizons, as well as being more risk averse. Thus, the impact of age on technology adoption is indeterminate.

It has been argued that women have less access to critical farm resources (land, labor, and cash) and are generally discriminated against in terms of access to external inputs and information (De Groote and Coulibaly 1998; Quisumbing et al. 1995). The sign of the coefficient on the gender variable (1 equals male, and 0 otherwise) will be positive.

Plot variables are also included in our model. Previous studies have found plot slope, plot altitude, and plot size to be a positive and significant determinants of soil conservation and soil fertility management practices (Amsalu and de Graaff 2006; Bekele and Darke 2003; Marenya and Barrett 2007; Neill and Lee 2001). We also include district dummies to capture spatial or regional differences.

3.2. Descriptive Statistics

Definitions and summary statistics of the variables used in the analysis are given in table 1. We considered seven SAPs in this study: legume intercropping, legume crop rotations, conservation tillage (zero / minimum tillage), soil and water conservation, animal manure, chemical fertilizers, and improved seeds. Sampled households practiced legume intercropping and legume crop rotations on about 46 percent and 17 percent of the plots, respectively.

<<Table 1 here>>

Of the total plots intercropped, more than 99.6 are maize and legumes. Maize is often rotated with legumes, such as haricot beans and pigeonpeas. The major legume grown is haricot beans, cultivated in 37 percent of plots, followed by pigeonpeas at 15 percent. Of the total plots (1539) cultivated, 81 percent of plots were planted with maize and legume crops.

Conservation tillage is used on about 11 percent of plots. Farmers used this practice on 10 percent of their plots before the 2008–2009 crop season. Only 4 percent of plots were treated with chemical fertilizers, while about 23 percent received manure. Relative to other technologies and practices, farmers used more improved seeds - planted on about 67 percent of the plots. However, a high percentage of farmers planted improved varieties without chemical fertilizers, most likely because they were using other soil-fertility enhancing practices. In addition, about 92% of their plots fall under good to medium fertile soil (see Table 1). Farmers combined improved seed with SAPs on 75 percent of plots while 25 percent were cultivated with no SAPs. About 52 and 28 percent of plots have improved maize and legume varieties, respectively. SWC investment existed on nearly 18 percent of cultivated plots. The dominant SWC practices considered in this study are terracing (9 percent), plant barriers (18 percent), and stone bunds (3 percent).

Although additional rigorous analysis is required, it is evident that SAPs impact on the net value of crop production[6]. Figures 1–7 show cumulative density functions for the net value of crop production per acre (hereafter, crop production value) with and without SAPs.

<<Figures 1-7 are here>>

As illustrated in the figures, the cumulative distribution of crop production value of plots with SAPs is entirely to the right of that without SAPs. This indicates that crop production value with SAPs unambiguously holds first-order stochastic dominance over non-SAPs, except for plots with chemical fertilizer, where they are dominant at a lower crop production value.

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[6] This is the net of manure, seed, fertilizer, and chemical costs.

The Kolmogorov-Smirnov statistics test for cumulative distribution functions (CDFs), or the test for the vertical distance between the two CDFs, also affirms this result, except for chemical fertilizer and legume crop rotations plots (table 2). Similarly, a significant decrease in the cost of pesticides is observed on plots cultivated with LI, LCR, CT, SWC, and animal manure (see table 3). Intercropping can suppress weed growth because of canopy cover, LCR can break disease and weed cycles, and crops treated with CF and animal manure can compete well because of an increase in organic matter and soil fertility. In the long run, such practices can have positive environmental impacts. Note that chemical expenditures increase with improved seeds and CF use, most likely because such technologies are recommended with chemical packages.

<<Table 2 here>>

<<Table 3 here>>

These results, however, must be interpreted with caution because crop productivity and input use may also be influenced by plot, weather and household characteristics, apart from adoption of technologies. The fact that we did not control these characteristics may affect the results from crop production value and input expenditures analysis.

4. Results and Discussion

In this section, we discuss results obtained from the multivariate probit models (Table 4). For comparison purposes, random effects probit models were estimated although results not reported to conserve space.[7] The regressions are estimated at the plot level.

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[7] For comparison purposes, household random effects probit models were estimated although results not reported to conserve space.We have multiple plot observations per household. Random effects models are appropriate when some households have a single plot like in our case. The same variables turned out to be significant in both models.

The likelihood ratio test ($chi^2(21)$) = 238.80, *p-value* < 0.0001) for independence between the disturbances is strongly rejected, implying correlated binary responses between different SAPs and supporting the use of a MVP model. A detailed correlation matrix is presented in table 6 and discussed below.

The results suggest that both socioeconomic and plot characteristics are significant in conditioning the households' decisions to adopt SAPs. The MVP model shows that the probability of adoption of LI, CT, and SWC is more common in areas and/or years where rainfall is unreliable (in terms of timelines, amount, and distribution), perhaps because rainfall stimulates weed growth and high rainfall can cause water logging on plots where SWC is practiced. This result corroborates the findings by Jansen et al. (2006) that conservation tillage is less common where rainfall is higher. Because the performance of these technologies and practices varies (given characteristics of land, climate, agriculture, farmer, etc.), the adoption of these practices also vary, depending on climate variability. For instance, Kassie et al. (2008; 2009) found that SWC practices, such as stone bunds, provide higher crop returns per hectare in drier areas than in wetter areas, due to moisture conservation benefits.

The negative association between adoption of improved seeds and a low rainfall index shows that farmers avoid risks by using traditional varieties, instead of investing in expensive inputs in the presence of shocks and the absence of reliable insurance mechanisms. On the other hand, LI, CT, and animal manure use is more likely to be adopted by farmers who have experienced pest-disease infestations. But these same farmers are less likely to adopt improved crop varieties, for the same explanation as above.

In addition, we tried to estimate village fixed effects, however the program could not be able to converge as a result we estimated the program without village fixed effects.

Consistent with earlier work on technology adoption (e.g., Arellanes and Lee 2003; Gebremedhin and Swinton 2003; Tenge et al. 2004; Jansen et al. 2006; Kassie et al.2009; Nyangena 2011; Kabubo-Mariara and Linderhof 2011), land tenure influences adoption of SWC, CT, and animal manure, which is more common on owner-cultivated plots than on rented in (or borrowed) plots. This may be due to tenure insecurity. Given the fact that the benefits from long-term investments (CT, SWC, and manure) accrue over time, this inter-temporal aspect suggests that secure land access or tenure will impact the adoption decisions positively. On the other hand, consistent with Kassie and Holden (2008), farmers are more likely to use CF on rented in plots than on their own plots, also perhaps due to insecurity of tenure. Because the opportunity cost of using the land is typically lower for tenants, as opposed to owners, rental contracts (particularly with fixed or cash rent) induce overuse of the unpriced attributes of land (soil fertility) by using more chemical fertilizer (Allen and Lueck 1992; 1993).[8] Alternatively, farmers prefer to use long-term soil fertility enhancements on their own plots, and short-term soil fertility augmentations on rented in plots.

Results show that access to market and plot influences farmers' adoption decisions. We found that households located closer to markets are more likely to use LI and CT, but less likely to use CF. Distance from plot to residence also influences adoption decisions of LI, LCR, animal manure, which is more common on closer plots while CF use is common on distant plots. Transporting manure is more difficult to distant plots, compared to chemical fertilizer. Studies from elsewhere have shown a negative relationship between market access and CT and animal manure (Jansen et al. 2006; Pender and Gebremedhin 2007). Similarly, Kassie et al. (2009) found a positive association between chemical fertilizer use and plot distance.

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[8] The data did not differentiate between sharecropping and fixed-rent contracts.

The probability of adopting LI, SWC, animal manure, and CF is affected by households' participation in at least one rural institution or group. Similar results are found in several previous studies (Kassie et al. 2009; Wollni et al. 2010; Nyangena 2011). Furthermore, the probability of adoption of capital-intensive technologies, improved seeds, and CF increase with the number of traders who farmers know in and outside the village. This is likely because in developing countries, where most markets are imperfect, interlinked contracts may provide credit, inputs, information, and stable market-outlet services to farmers. However, the negative relationship between CT and number of relatives and traders is difficult to explain.

The results also uncover that more highly skilled civil servants enhance the likelihood of adopting CT, SWC, and improved seeds. These practices are relatively knowledge-intensive and require considerable management input. This underscores the importance of improving the competence of civil servants at the local administrative levels to speed up the adoption process of technologies.

In terms of household characteristics, the size of the family has a positive effect on the adoption of manure. A possible explanation is that collecting manure and transporting it to the fields is relatively labor intensive. Family size can determine availability of labor. Marenya and Barrett (2007) observed a similar result in Kenya. Older farmers are significantly less likely to use improved crop varieties and LI, perhaps because young farmers are stronger (better able to provide the labor needed by productivity-enhancing technologies and practices) and have longer planning horizons, and thus are less risk averse. In addition, if households have members with salaried employment, they are less likely to adopt CF, SWC, and CT.

The farmers that believe in government support during crop failure are more likely to use CT, probably because the benefit of new technology is uncertain and farmers want to be insured if they adopt new technologies. On the other hand, those who have less trust in government support are more likely to use crop- and risk-diversifying practices (such as LI), believing that government support may not fulfill households' food diversity needs.

The decision as whether to or not to adopt improved seeds, CF, and animal manure is positively and significantly influenced by livestock ownership. Manure availability obviously depends on the size of the herd a household owns because livestock waste is the single most important source of manure for small farms in the study area. Although increasing the number of livestock might not be a feasible solution, introducing high-yield breeds and improved forage legumes can increase livestock products, including manure (Kassie et al. 1999). The coefficient on asset ownership is positive and significant in CT, CF, and improved seeds regressions.

Similar to findings by Pender and Gebremedhin (2007), we find that households that own less land are more likely to adopt LI, CT, and CF for a particular plot. These findings suggest that shortage of land, due to population pressure, causes farmers to intensify agricultural production, using land-saving and yield-augmenting technologies. (This is in line with Boserup's hypothesis on the correlation between population density, land conservation, and property rights.)

Plot characteristics are also significant determinants of adoption decisions. LI, SWC, CT, LCR, and improved seeds are more common on larger plots. However, CF use is inversely related to plot size. The slope of a plot is a significant determinant of adoption of SWC, LI, LCR, and CF. In particular, we found that the likelihood of adopting CF is less likely on plots with moderate to steep slopes, while the likelihood of adopting SWC and LI is more likely. We also found that SWC and CF are more likely to be adopted on plots with poor fertile soils, and LI is more likely on plots with moderately fertile soils. With regards to soil depth, results indicate that improved seeds and SWC are more likely to be used on soil of medium depth. LCR is significantly lower with poor fertile soils and moderately sloped plots. These results imply that, for sustainable agricultural practices to be successful, they must address site-specific characteristics, since these conditions determine the need for adoption, as well as the type of technology adopted.

Adoption also varies by districts. The negative coefficients for Mvomero and Kilosa dummies for adoption of animal manure, SWC, and improved seeds suggest a lower probability of adoption if a farm household is located in these districts, rather than in Karatu districts (reference district). We find that farmers in Mvomero and Kilosa are less likely to use animal manure, SWC, and improved seeds than farmers in Karatu. However, farmers in Mvomero are more likely to use CF than farmers in Kilosa. Similarly, farmers in Mbulu are also less likely to use LCR, CF, and improved seeds, but they are more likely to use animal manure and LI. Kilosa farmers also use less significantly LCR and CT, compared to Karatu farmers. These results likely reflect unobservable spatial differences.

Finally, the correlation between the error terms of the seven adoption equations are reported in table 6. We find that some practices are complementary, while others have substitutability or compete for the same scarce resources. The correlation coefficients are statistically different from zero in 11 of the 21 cases, confirming the appropriateness of the multivariate probit specification.[9]

<<Table 4 here>>

<<Table 5 here>>

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[9] These results can be improved further if a combination of more than two technologies is considered. Yu et al. (2008) showed that the simple correlation between two technologies, ignoring other technologies, is misleading. They found that, as the number of bundled technologies increases, they are increasingly likely to be complementary with another, even if subsets are substitutes when viewed in isolation.

<<Table 6 here>>>

5. Conclusions and Implications

In sub-Saharan Africa, where farming is characterized by poor soil fertility condition and low levels of agricultural technology use, understanding the probability of adoption of productivity and sustainability enhancing practices is a policy issue. This paper uses detailed multiple plot observations to investigate the factors that influence farmers' decisions to adopt sustainable agricultural practices by utilizing multivariate probit regression model.

While there is heterogeneity with regard to factors that influence the choice of any of the seven practices[10], our results underscore the importance of rainfall, pest, and disease shocks; social capital in the form of membership in rural institutions, number of traders that farmers know; skill of local government agents; plot tenure status; asset ownership; and opportunity cost of labor on farmer decision to adopt SAPs. Plot and demographic variables also have heterogeneous impacts on adoption of various sustainable agricultural practices.

The significant role of rainfall shocks on adoption of CT, SWC, LI, and improved seeds suggests the need for proper geographical targeting in the promotion and adoption of practices by policymakers and development agencies.

Government effectiveness enhances the likelihood that farmers will invest in CT, SWC, and improved seeds, highlighting the importance of improving the skill of civil servants to avoid inefficiency and ineffectiveness that increases distrust and transaction costs.

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[10] Conservation tillage (CT), soil and water conservation (SWC), legume intercropping (LI), legume crop rotation (LCR), chemical fertilizer (CF), manure, and improved seeds.

We find, as have others, that tenure security is important for adoption of CT, SWC, animal manure and CF, indicating that public policies that increase security in land tenure are likely to create to adopt long-term land enhancing investments because farmers can enjoy benefits for over a long period of time.

Our results suggest that, in the context of our study area, the probability of a farmer adopting LI, manure, CF and SWC increases with participation in local collective action institutions. Similarly, the adoption of CF and improved seeds is likely to increase with increased market integration proxied here using number of traders that farmers know in their vicinity. These findings suggest that in order to enhance the adoption of these practices, local rural institutions and service providers need to be supported because they effectively assist farmers in providing credit, inputs, information, and stable market outlets.

Finally, adoption of sustainable agricultural practices can be affected by other factors, such as profitability, risk associated with adoption of technologies, and their ability to generate immediate benefits to meet urgent livelihood needs of the resource poor farmers. Future studies need to examine the productivity, risk, environmental, and welfare implications to individual and combinations of sustainable agricultural practices.

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Table 1. Definition of Variables and Descriptive Statistics

Dependent variables		**Mean**	**Std. Dev.**
Legume intercropping (LI)	Plots received legume intercropping (1 = yes; 0 = no)	0.46	0.50
Conservation tillage (CT)	Plots received conservation tillage (1 = yes; 0 = no)	0.11	0.31
Soil and water conservation (SWC)	Plots received SWC practice (1 = yes; 0 = no)	0.18	0.39
Animal manure	Plots received animal manure (1 = yes; 0 = No)	0.23	0.42
Improved seeds	Plots received improved seeds (1 = yes; 0 = No)	0.67	0.47
Legume crop rotations (LCR)	Plots received legume crop rotations (1 = yes; 0 = no)	0.17	0.37
Chemical fertilizer (CF)	Plots received chemical fertilizer (1 = yes; 0 = no)	0.04	0.20

Explanatory variables			
Plot characteristics			
Plotsize (acre)	Plot size (acre)	1.92	2.57
Tenure	Plot ownership (1 = owned; 0 = rented in)	0.89	0.31
Plotdist	Plot distance to dwelling (in walking minutes)	27.21	36.78
Godfertplt (ref)	Farmers' perception that plot has good fertile soil (1 = yes; 0 = no)	0.20	0.40
Modfertplt	Farmers' perception that plot has moderately fertile soil (1 = yes; 0 = no)	0.72	0.45
Porfertplt	Farmers' perception that plot has poor fertile soil (1 = yes; 0 = no)	0.08	0.28
fltslpplt (ref)	Farmers' perception that plot has gentle slope (1 = yes; 0 = no)	0.39	0.49

Modslpplt	Farmers’ perception that plot has moderate slope (1 = yes; 0 = no)	0.51	0.50
Stepslpplt	Farmers’ perception that plot has steep slope (1 = yes; 0 = no)	0.10	0.29
Shwdepplt(ref)	Farmers’ perception that plot has shallow deep soil (1 = yes; 0 = no)	0.08	0.27
Moddepsolplt	Farmers’ perception that plot has moderate deep soil (1 = yes; 0 = no)	0.67	0.47
Depsolplt	Farmers’ perception that plot has deep soil (1 = yes; 0 = no)	0.25	0.44
Socio-economic characteristics			
Kinship	Number of relative that farmer has inside the village (Number)	8.56	15.96
Connections	Household has relative in leadership position (1 = yes; 0 = no)	0.26	0.44

Trader	Number of traders that farmer knows (number)	5.69	7.11
Distext	Distance to agricultural extension office (in walking minutes)	77.75	72.08
Mktdist	Distance to main market (in walking minutes)	134.92	94.46
Totfarmsize	Total farm size (acre)	4.03	4.29
Expenditure	Household income (‘000 TSh*)	2115.2	233.8
Extenskill	Farmers confident in skill of extension agents (1 = yes; 0 = no)	0.61	0.49
Assetval	Total asset value of major farm equipment and household furniture ('000 TSh)	432.12	2322.10
Pestsdisease	Pests and disease are key problems (1 = yes; 0 = no)	0.64	0.48
Salary	Household member has salaried	0.14	0.35

	employment (1 = yes; 0 = no)		
HHsize	Total family size (number)	5.53	2.39
Gender	Gender of household head (1 = male; 0 = female	0.88	0.33
Age	Age of household head (years)	45.89	14.26
Educ	Education level of household head (years of schooling)	1.46	0.83
Govtsup	Household can rely on government during crop failure (1 = yes; 0 = no)	0.35	0.50
Fertavial	Timely availability of fertilizer is a problem (1-yes; 0=no)	0.21	0.41
Livestock	Total number of livestock owned (number)	10.32	16.93
Rainfalindex	Rainfall satisfaction index	0.37	0.33
Group	Participation in farmers' group or association (1 = yes; 0 = no)	0.29	0.46

* Tsh = Tanzanian shillings

District dummies		
Karatu (ref.)	Karatu District (1 = yes; 0 = no)	0.23
Mbulu	Mbulu District (1 = yes; 0 = no)	0.26
Mvomero	Mvomero District (1 = yes; 0 = no)	0.20
Kilosa	Kilosa District (1 = yes; 0 = no)	0.31
Number of plot (household) observation	1539(681)	

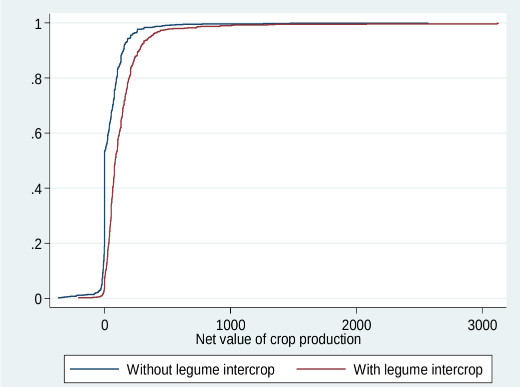

Figure 1. Impact of legume intercrop on net value of crop production(' 000 TSh/acre)

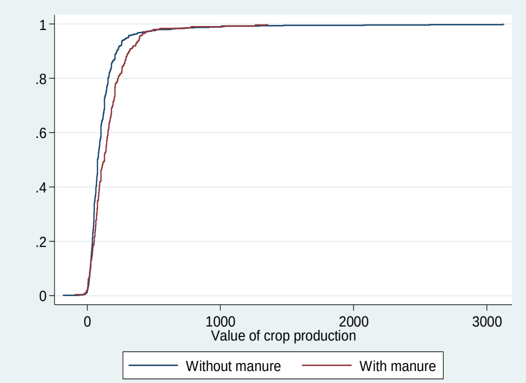

Figure 2. Impact of manure on net value of crop production ('000 TSh/acre)

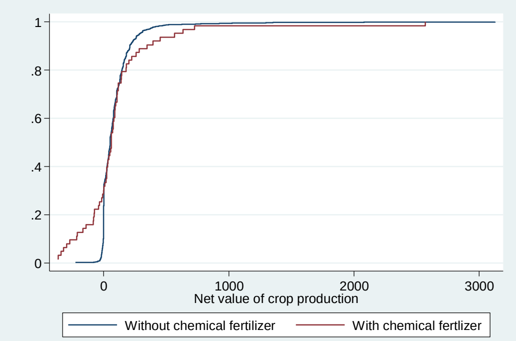

Figure 3. Impact of chemical fertilizer on net value of crop production(' 000 TSh/acre)

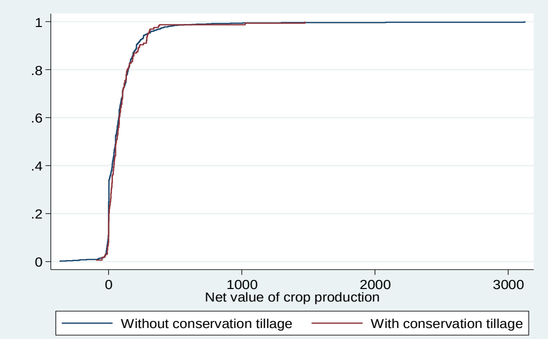

Figure 4. Impact of conservation tillage on net value of crop production ('000 TSh/acre)

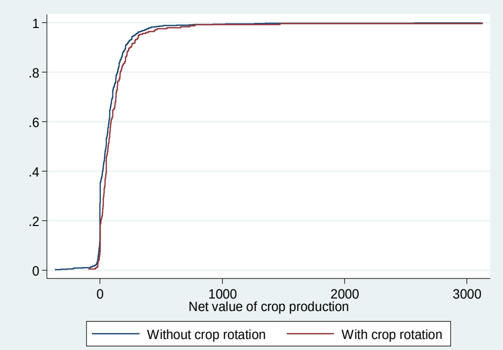

Figure 5. Impact of legume crop rotation on net value of crop production('000 TSh/acre)

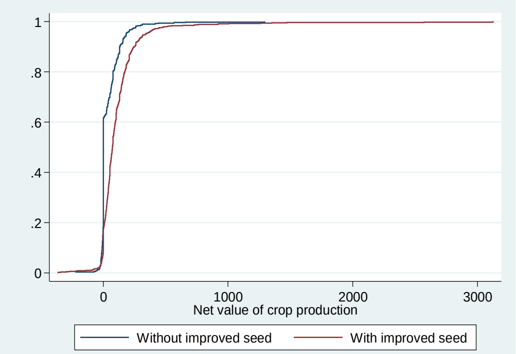

Figure 6. Impact of improved seed on net value of crop production ('000 TSh/acre)

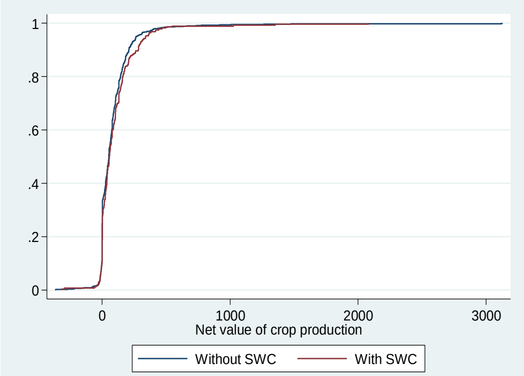

Figure 7. Impact of soil and water conservation on net value of crop production ('000 TSh/acre)

Table 2. Kolmogorov-Smirnov statistics test for cumulative yield distribution

SAP type	Distribution
Legume intercrop (LI)	0.2444 (p = 0.000)***
Animal manure	0.2474 (p = 0.000)***
Improved seeds	0.2762 (p = 0.000)***
Chemical fertilizer (CF)	0.1471 (p = 0.317)
Soil and water conservation (SWC)	0.0615 (p = 0.440)
Conservation tillage (CT)	0.1059 (p = 0.087)*
Legume crop rotation (LCR)	0.0522 (p = 0.636)

Table 3. Impact of sustainable agricultural practices on chemical expenditures (TSh/acre)

SAP	Adoption	Mean expenditure	Diff.	Observations
Legume intercrop	Yes	375.6	-1534.984	706

	No	1910.6	(504.3)***	833
Legume crop rotations	Yes	352.4	-1022.8	254
	No	1375.2	(345.3)**	1285
Conservation tillage	Yes	161.9	-1172.5	168
	No	1334.4	(316.2)***	1371
Animal manure	Yes	346.8	-1119.2	357
	No	1466.0	(365.1)***	1182
Soil and water conservation	Yes	1068.0	-169.1	280
	No	1237.16	(511.2)	1259
Improved seeds	Yes	1519.7	941.7	1027
	No	578.00	(419.1)**	512
Chemical fertilizer	Yes	19466.9	19039.95	63
	No	427.0	(5920.20)***	1476

Tsh = Tanzanian shillings

Table 4. Results of the Multivariate Probit Model

CONSERVATION TILLAGE				SOIL AND WATER CONSERVATION				LEGUME INTERCROP			
	Coeff.	*Std. err.*	*P-value*		*Coeff.*	*Std. err.*	*P-value*		*Coeff.*	*Std. err.*	*P-value*
Household characteristics and endowments											
Rainfalindex	-1.626	0.225	**0.000**	Rainfalindex	-0.360	0.142	**0.011**	Rainfalindex	-0.345	0.121	**0.004**
Pestdiseas	0.711	0.138	**0.000**	Pestdiseas	0.132	0.103	0.200	Pestdiseas	0.163	0.083	**0.050**
Extenskill	0.299	0.121	**0.014**	Extenskill	0.290	0.098	**0.003**	Extenskill	-0.041	0.080	0.605
Connection	0.120	0.128	0.349	Connection	0.176	0.104	**0.092**	Connection	-0.022	0.084	0.792
Group	-0.014	0.119	0.910	Group	0.329	0.095	**0.001**	Group	0.234	0.079	**0.003**
Kinship	-0.039	0.009	**0.000**	Kinship	0.002	0.004	0.634	Kinship	0.006	0.004	0.188
Trader	-0.030	0.010	**0.001**	Trader	-0.005	0.007	0.442	Trader	0.000	0.005	0.973
Insurance	0.792	0.145	**0.000**	Govtsup	-0.089	0.100	0.371	Govtsup	-0.218	0.083	**0.008**
Mktdist	-0.003	0.001	**0.000**	Mktdist	0.000	0.000	0.840	Mktdist	-0.002	0.000	**0.000**
Distext	0.001	0.001	0.243	Distext	-0.002	0.001	**0.006**	Distext	0.000	0.001	0.623
Fertavial	0.751	0.137	**0.000**	Fertavial	0.252	0.110	**0.022**	Fertavial	-0.053	0.101	0.596

Salary	-0.704	0.188	**0.000**	Salary	-0.268	0.142	**0.060**	Salary	-0.068	0.125	0.589
lnHHsize	-0.144	0.124	0.244	lnHHsize	-0.008	0.098	0.934	lnHHsize	0.046	0.085	0.585
Gender	0.267	0.167	0.110	Gender	-0.001	0.133	0.995	Gender	-0.045	0.115	0.695
lnAge	-0.288	0.200	0.150	lnAge	0.341	0.171	**0.046**	lnAge	-0.281	0.133	**0.035**
Educ	-0.117	0.084	0.162	Educ	0.022	0.070	0.751	Educ	-0.104	0.055	**0.059**
Livestock	0.004	0.003	0.192	Livestock	0.000	0.003	0.963	Livestock	0.004	0.002	0.116
lnFarmsize	-0.498	0.114	**0.000**	lnFarmsize	-0.074	0.091	0.414	lnFarmsize	-0.460	0.068	**0.000**
lnAssetval	0.289	0.052	**0.000**	lnAssetval	0.022	0.036	0.537	lnAssetval	-0.008	0.032	0.804
lnexpenditure	0.163	0.086	**0.057**	lnexpenditure	0.101	0.070	0.148	lnexpenditure	0.031	0.061	0.615
Plot characteristics											
Tenure	0.448	0.181	**0.013**	Tenure	0.389	0.152	**0.010**	Tenure	0.002	0.118	0.984
lnPlotsize	0.408	0.097	**0.000**	lnPlotsize	0.158	0.070	**0.024**	lnPlotsize	0.395	0.056	**0.000**
Plotdist	0.001	0.001	0.650	Plotdist	-0.001	0.001	0.357	Plotdist	-0.004	0.001	**0.000**
Modfertplt	0.191	0.148	0.196	Modfertplt	0.065	0.125	0.602	Modfertplt	0.229	0.099	**0.021**
Porfertplt	-0.332	0.265	0.211	Porfertplt	0.507	0.189	**0.007**	Porfertplt	0.036	0.154	0.815
Modslpplt	0.145	0.117	0.212	Modslpplt	0.240	0.099	**0.015**	Modslpplt	0.140	0.080	**0.082**

Stepslpplt	-0.824	0.311	**0.008**	Stepslpplt	0.459	0.182	**0.012**	Stepslpplt	0.341	0.140	**0.015**
Moddepsolplt	-0.047	0.273	0.864	Moddepsolplt	0.342	0.185	**0.064**	Moddepsolplt	0.155	0.138	0.258
Depsolplt	0.137	0.272	0.614	Depsolplt	-0.004	0.199	0.985	Depsolplt	-0.093	0.147	0.525
District dummies											
Mbulu	0.095	0.170	0.576	Mbulu	0.000	0.124	0.999	Mbulu	0.345	0.118	**0.003**
Mvomero	0.203	0.161	0.208	Mvomero	-0.600	0.131	**0.000**	Mvomero	-0.918	0.117	**0.000**
Kilosa	-0.676	0.172	**0.000**	Kilosa	-1.828	0.160	**0.000**	Kilosa	-0.793	0.110	**0.000**
Constant	-5.962	1.430	0.000	Constant	-4.416	1.127	0.000	Constant	1.507	0.940	0.109

	ANIMAL MANURE				**CHEMICAL FERTILIZER**				**IMPROVED SEEDS**		
	Coeff.	***Std. err.***	***P-value***		***Coeff.***	***Std. err.***	***P-value***		***Coeff.***	***Std. err.***	***P-value***
Household characteristics and endowments											
Rainfalindex	0.010	0.149	0.949	Rainfalindex	-0.321	0.221	0.146	Rainfalindex	-0.240	0.120	**0.045**
Pestdiseas	0.511	0.119	**0.000**	Pestdiseas	0.090	0.160	0.576	Pestdiseas	-0.188	0.082	**0.022**
Extenskill	0.031	0.100	0.756	Extenskill	0.150	0.171	0.379	Extenskill	0.298	0.077	**0.000**
Connection	0.018	0.104	0.862	Connection	0.060	0.193	0.754	Connection	-0.008	0.085	0.926
Group	0.386	0.098	**0.000**	Group	0.390	0.133	**0.003**	Group	0.088	0.078	0.261

Kinship	0.005	0.004	0.203	Kinship	-0.010	0.007	0.145	Kinship	-0.001	0.004	0.834
Trader	0.003	0.007	0.699	Trader	0.020	0.007	**0.008**	Trader	0.009	0.005	**0.077**
Govtsup	0.095	0.096	0.319	Govtsup	-0.055	0.163	0.737	Govtsup	-0.102	0.081	0.209
Mktdist	0.000	0.000	0.962	Mktdist	0.002	0.001	**0.003**	Mktdist	0.000	0.000	0.466
Distext	-0.001	0.001	0.323	Distext	-0.002	0.001	0.158	Distext	0.000	0.001	0.892
Fertavial	-0.031	0.128	0.807	Fertavial	-0.268	0.230	0.244	Fertavial	0.091	0.099	0.354
Salary	-0.189	0.140	0.177	Salary	-0.595	0.280	**0.033**	Salary	0.000	0.120	0.999
lnHHsize	0.317	0.120	**0.008**	lnHHsize	-0.026	0.173	0.881	lnHHsize	-0.046	0.088	0.601
Gender	-0.067	0.142	0.638	Gender	-0.202	0.188	0.283	Gender	0.017	0.112	0.881
lnAge	-0.111	0.167	0.508	lnAge	0.154	0.265	0.560	lnAge	-0.480	0.128	**0.000**
Educ	-0.004	0.063	0.955	Educ	0.289	0.152	**0.057**	Educ	-0.085	0.052	**0.098**
Livestock	0.010	0.003	**0.002**	Livestock	0.010	0.004	**0.018**	Livestock	0.007	0.003	**0.005**
lnFarmsize	0.047	0.088	0.592	lnFarmsize	-0.339	0.132	**0.010**	lnFarmsize	-0.487	0.073	**0.000**
lnAssetval	0.043	0.039	0.275	lnAssetval	0.177	0.052	**0.001**	lnAssetval	0.030	0.031	0.337
lnexpenditure	0.050	0.074	0.499	lnexpenditure	0.003	0.137	0.982	lnexpenditure	0.237	0.062	**0.000**
Plot characteristics											

Tenure	0.533	0.162	**0.001**	Tenure	-0.669	0.187	**0.000**	Tenure	-0.039	0.116	0.737
lnPlotsize	0.051	0.071	0.469	lnPlotsize	-0.416	0.120	**0.001**	lnPlotsize	0.305	0.055	**0.000**
Plotdist	-0.005	0.002	**0.034**	Plotdist	0.004	0.002	**0.009**	Plotdist	0.001	0.001	0.540
Modfertplt	0.150	0.140	0.282	Modfertplt	0.111	0.214	0.604	Modfertplt	0.031	0.096	0.745
Porfertplt	0.188	0.207	0.365	Porfertplt	0.726	0.292	**0.013**	Porfertplt	-0.064	0.145	0.656
Modslpplt	-0.073	0.099	0.463	Modslpplt	-0.250	0.149	**0.095**	Modslpplt	-0.053	0.080	0.507
Stepslpplt	0.075	0.195	0.699	Stepslpplt	-0.933	0.325	**0.004**	Stepslpplt	-0.225	0.128	**0.079**
Moddepsolplt	-0.021	0.178	0.907	Moddepsolplt	-0.171	0.269	0.525	Moddepsolplt	0.314	0.133	**0.018**
Depsolplt	-0.030	0.194	0.878	Depsolplt	-0.234	0.297	0.430	Depsolplt	0.060	0.142	0.675
District dummies											
Mbulu	1.134	0.127	**0.000**	Mbulu	-0.903	0.506	**0.074**	Mbulu	-0.603	0.123	**0.000**
Mvomero	-1.305	0.189	**0.000**	Mvomero	0.904	0.213	**0.000**	Mvomero	-0.512	0.125	**0.000**
Kilosa	-0.850	0.136	**0.000**	Kilosa	-0.319	0.286	0.265	Kilosa	-0.392	0.117	**0.001**
Constant	-3.137	1.134	**0.006**	Constant	-4.509	2.416	**0.062**	Constant	-0.614	0.949	0.518

LEGUME CROP ROTATION			
	Coeff.	***Std. err.***	***P-value***
Household characteristics and endowments			
Rainfalindex	0.473	0.156	**0.002**
Pestdiseas	-0.115	0.113	0.309
Extenskill	-0.052	0.110	0.635
Connection	-0.151	0.126	0.232
Group	0.001	0.104	0.989
Kinship	0.003	0.003	0.331
Trader	0.007	0.006	0.283
Govtsup	-0.219	0.118	**0.063**
Mktdist	0.000	0.001	0.623
Distext	0.001	0.001	0.399
Fertavial	0.176	0.122	0.149
Salary	0.223	0.161	0.166
lnHHsize	0.063	0.118	0.595

Gender	-0.087	0.154	0.575
lnAge	0.155	0.194	0.425
Educ	-0.067	0.075	0.371
Livestock	0.005	0.003	**0.092**
lnFarmsize	0.173	0.083	**0.036**
lnAssetval	-0.068	0.039	**0.081**
lnexpenditure	0.036	0.076	0.635
Plot characteristics			
Tenure	0.243	0.174	0.163
lnPlotsize	-0.256	0.076	**0.001**
Plotdist	0.004	0.001	**0.015**
Modfertplt	-0.115	0.120	0.339
Porfertplt	-0.667	0.273	**0.015**
Modslpplt	-0.234	0.108	**0.031**
Stepslpplt	0.037	0.168	0.827
Moddepsolplt	-0.105	0.182	0.566

Depsolplt	0.012	0.197	0.951
District dummies			
Mbulu	-0.904	0.168	**0.000**
Mvomero	-0.388	0.145	**0.008**
Kilosa	-0.811	0.148	**0.000**
Constant	-1.547	1.327	0.244
Regression diagnostics			
LR test of rho = 0: chibar2(01)			249.51***
Log pseudolikelihood			-3818.100
Wald chi2(224)			2062.99***
Number of observations			1539

Table 5. Correlation Coefficients for MVP Regression Equations (p-value in parentheses)

	ρ_{LI}	ρ_{CT}	ρ_{Manure}	ρ_{LCR}	ρ_{CF}	ρ_{SWC}
ρ_{CT}	**0.21(0.00)**					
ρ_{Manure}	**0.35(0.00)**	0.10(0.26)				
ρ_{LCR}	**-0.3(0.00)**	-0.16(0.17)	**-0.39(0.00)**			
ρ_{CF}	-0.03(0.75)	**-0.24(0.10)**	-0.07(0.57)	-0.15(0.31)		
ρ_{SWC}	0.03(0.59)	**0.36(0.00)**	**0.11(0.09)**	0.01(0.91)	-0.07(0.52)	
ρ_{seed}	**0.50(0.00)**	-0.02(0.81)	**0.13(0.00)**	**-0.17(0.00)**	**0.42(0.00)**	-0.03(0.59)