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Abstract

Soil fertility depletion is considered the main biophysical limiting factor to increasing per capita food production for most smallholder farmers in Africa. The adoption and diffusion of sustainable agricultural practices (SAPs), as a way to tackle this impediment, has become an important issue in the development policy agenda for sub-Saharan Africa. This paper examines the adoption decisions for SAPs, using multiple cross-sectional plot-level observations, collected in 2010 from 681 farm households and 1,539 plots, in 4 districts and 88 villages of rural Tanzania. We employ a multivariate probit technique to model simultaneous adoption decisions by farm households. Our study reveals that rainfall shocks, insects and disease shocks, government effectiveness, tenure status of plot, social capital, plot location and size, and asset ownership, all influence the adoption decision of sustainable practices. Policies that target SAPs and are aimed at organizing farmers into associations, improving land tenure security, and enhancing skills of civil servants can increase the likelihood that smallholder farmers will adopt SAPs.

Key Words: sustainable practices, multiple adoption, multivariate probit, Tanzania

JEL Classifications: C01, O55, Q01, Q16

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Introduction

Most countries in sub-Saharan Africa, including Tanzania, heavily depend on agriculture that is dominated by subsistence smallholder farmers. The fate of the agricultural sector directly affects economic growth, food security, poverty alleviation, and social welfare. The performance of agriculture in this region has not lived up to expectations, characterized by decades of ups and downs. Its low level of productivity is emphasized by the statistic that while the sector employs about 67 percent of labor force, it contributes only about 17 percent of the total gross domestic product (World Bank 2000).

Continued decline of soil fertility (depletion of soil nutrients and organic matter), low and poorly distributed rainfall, poor resource endowments, lack of or inadequate institutions, little or no use of fertilizer, production risk, and endemic crop and livestock diseases are major causes of the low and decreasing performance of sub-Saharan Africa's agricultural sector (Binswanger and Townsend 2000; Rosegrant et al. 2001; Pender, Place, and Ehui 2006; Ajayi 2007; Misiko and Ramisch 2007). Soil fertility depletion is considered the main biophysical limiting factor for increasing per capita food production for most of the smallholder farmers in Africa. The average annual nutrient balance for the region for the period 1983–2000 was estimated to be minus 22–26 kilograms of nitrogen (N), minus 6–7 kilograms of phosphorus (P), and minus 18–23 kilograms 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 kilograms per hectare of cultivated land, much lower than in other developing countries (Morris et al. 2007). In our study of 1,539 plots, in 4 districts (Karatu, Mbulu, Mvomero, and Kilosa, discussed below), merely 4 percent of the plots received chemical fertilizer, despite the fact that 52 percent of the plots were planted with improved maize varieties.

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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 (Arellanes and Lee 2003; Ruben and Pender 2004, Pender, Place, and Ehui 2006; Misiko and Ramisch 2007).

The adoption and diffusion of specific sustainable agricultural practices (SAPs)[1] 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. These practices are conservation tillage, legume intercropping, legume crop rotations, improved crop varieties, use of animal manure, complementary use of organic fertilizers, and soil and stone bunds[2] (De Souza et al. 1999; Kassie and Zikhali 2009; Lee 2005; Wollni et al. 2010).

The potential benefits of SAPs lie not only in conserving but also in enhancing the natural resources (e.g., 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 can reduce the yields of certain crops, but not others.

Notwithstanding their benefits, the adoption rate of these technologies and practices is still low in rural areas of developing countries (Somda et al. 2002; Neill and Lee 2001, Tenge et al. 2004; Wollni et al. 2010; Kassie et al. 2009; Jansen et al. 2006), despite a number of national

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[1] Sustainable agriculture can be broadly defined as an agricultural system involving a combination of sustainable production practices in conjunction with the discontinuation or reduced use of production practices that are potentially harmful to the environment (De Souza et al. 1993; Lee 2005). More specifically, the Food and Agricultural Organization (FAO) argues that sustainable agriculture consists of five major attributes: 1) it conserves resources, and 2) it is environmentally non-degrading, 3) technically appropriate, and 4) economically and 5) socially acceptable (FAO 2008).

[2] See De Souza et al. (1999) and Lee (2005) for a detailed list and definitions of sustainable agricultural practices.

and international initiatives to encourage farmers to invest in them. The same is true in 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 erosion continues to be a problem (Mbaga-Semgalawe and Folmer 2000; Tenge et al. 2004). Moreover, relatively little empirical work has been done to formally examine the socioeconomic factors that influence 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 data set, generated by Selian Agricultural Research Institute (SRAI) of Tanzania in collaboration with the International Maize and Wheat Improvement Center (CIMMYT), to identify the key factors influencing adoption of several agricultural technologies and practices, and their impact on household welfare in the maize-legume cropping system zones. The specific objective of the paper is to use multiple plot observations to jointly analyze the factors that facilitate and impede the probability of adopting SAPs in the rural villages of Tanzania. The adoption decisions in question relate to legume intercropping (LI), legume crop rotations (LCR), animal manure, conservation tillage (CT, 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, there is much less research on the impact of governance indicators (government effectiveness or performances and political connection), kinship, rainfall shocks, insects and diseases shocks, and farmers' trust of government support during crop failure. Second, to the best of our knowledge, no other study has comprehensively and rigorously analyzed the adoption of SAPs in Tanzania. The existing studies in Tanzania (e.g., Mbaga-Semgalawe and Folmer 2000; Isham 2002; Tenge et al. 2004) assessed the determinants of a single technology adoption (fertilizer or soil and water conservation structures), which ignored complementarities and/or substitutabilities. They also did not take into account important variables, such as plot characteristics and those mentioned above. Unlike these and other recent similar studies (e.g., Marenya and Barrett 2007), we were able to capture plot specific attributes and analyze multiple adoption decisions with our rich data set. Third, there are limited adoption studies on conservation tillage, legume intercropping, and legume crop rotation in Africa in general and in Tanzania in particular. This article contributes to these gaps as well.

1. Conceptual Framework and Econometric Strategy

Farmers are more likely to adopt a mix of technologies to deal with a multitude of agricultural production constraints. 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 decisionmakers who are often faced with technology alternatives that may be adopted simultaneously and/or sequentially as compliments, 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 under consideration, this approach may under- or over-estimate the influences of various factors on the adoption decisions.

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 conditional on the adoption decision (Dorfamn 1996; Wu and Bacok 1998; 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 a multivariate one and attempting univariate modeling excludes useful economic information contained in interdependent and simultaneous adoption decisions.

This study adopts the 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 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:

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

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

where $j = 1, ...m$ denotes the type of SAP. 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 independently and identically distributed 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 the seven latent equations, which represent unobserved characteristics for the same individual.

1.1 Data and Description of Variables

The data used in the analysis came from detailed household and plot survey of 700 farm households and 1,589 plots (defined on the basis of land use), in 88 villages in 4 districts of Tanzania.[3] The survey conducted in November and December 2010.

In the first stage in the sampling procedure, we selected districts in Tanzania based on their maize-legume production potential: two districts, Karatu and Mbulu, from the high-potential northern zone; and two, Mvomero and Kilosa, from the low-potential eastern zone. Each of the two zones was assigned 350 households, for a total of 700. The 350 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. Trained enumerators collected a wide range of information on the households' production activities, plot-specific characteristics, including SAP adoption and demographic and infrastructure information for each household and village. 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.

The enumerators also collected a number of other plot attributes:

- Soil fertility, where farmers ranked their plots as "poor," "medium," or "good (A dummy variable was set equal to 1 for the selected rank and zero for the others)
- Soil depth, where farmers ranked their plots as "deep," "medium deep," or "shallow" (A dummy variable was set equal to 1 for the selected rank and zero for the others)
- Plot slope, where farmers ranked their plots as "flat," "medium slope," or steep slope"
- Plot size in acres
- Distance of the plot from the household dwelling, in minutes walking

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[3] As a result of missing values for some of the explanatory variables, the numbers of observations used in the final sample are 681 households and 1,539 plots.

Other information collected at the plot level was tenure status of plots, crops grown, crop production estimates, labor inputs associated with each type of agricultural activity, fertilizer usage, and seed types.

Key socioeconomic elements collected about the household include age, gender, education level, family size, asset ownerships, participation in extension and training services, membership in farmers' organizations, consumption expenditures, distance a household lies from input and output markets and extension offices, whether households believe they can rely on government support 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 and outside the village, production constraints (such as crop pests, diseases, and input availability), crop and livestock marketing data, and how much land a households owns.

Information was also collected on governance indicators, such as government effectiveness4 and political connection (Kaufmann et al. 2007). Empirical evidences support the positive role of government effectiveness and political connection on economic growth and firm's investment performance (Faccio 2006; Dixit 2004; Zerfu 2010). Recent literature in new institutional economics suggests that formal institutions provided by the state are not the only ones that matter for economic development (Dixit 2004). Informal institutions, such as political connections—which are a 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 office 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 local government staffs, including extension workers. Farmers were asked to rank their confidence (on a scale of 1 to 7, where 7 means high confidence) in the ability of civil servants to do their jobs. The responses were recoded, where 1 indicates confidence in the qualification of civil servants (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.

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[4] 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).

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 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.5 Responses to each of the questions (yes or no) were coded as favorable or unfavorable 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.6 The data also includes non-rain shocks, such as crop pests and diseases occurrence within the last 10 years.

1.2 Explanation of Variables and Hypotheses

Following the adoption literature (e.g., Bandiera and Rasul 2006; Pender and Gebremedhin 2007; Bluffstone and Köhlin 2011; Marenya and Barrett 2007; Wollni et al. 2010), the explanatory variables included in our regression analysis and their hypothesized effect on adoption of SAPs are discussed below.

S**hocks**. 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, favorable 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

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

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

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 market 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 colleagues, 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 all seven SAPs. The number of traders that a farmer knows (Trader) is included because interlinked contracts are common in areas 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 friendships 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 as much risk and may also enable them to access more labor. However, having more relatives may reduce incentives for hard work and induce inefficiency, so that farmers may exert less effort to invest on technologies. This is the dark side of social capital in the form of kinship. The expected sign on the kinship coefficient is indeterminate.

Government indicators. As discussed above, governance indicators include government effectiveness (Govteffect) and political connection (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 bureaucracy is transferred to 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. Extension visits per se may not matter for technology adoption, but farmers trust in the skill of extension workers and others does.

Although we are not aware of empirical evidence of the impact of government effectiveness and political connection on technology adoption, empirical evidence in Kaufmann et al. (2007), Faccio (2006), and Zerfu (2010) support a positive role of government effectiveness and political connection on production efficiency in firms' performance. Thus, the government effectiveness and connection variables have 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. Such support properly implemented can help farm households smooth 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 (Mktdist). The distance to markets (Mktdist) and plot access (dstplot) 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; Jacoby et al. 2002; 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 (farm chemicals, labor) 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 in 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.[7] 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.

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

[7] Using 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.

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 otherwise.

Human capital. Household characteristics, such as education level of household head (Educ), age (Age), family size (Fsize), 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.

2. Descriptive Statistics

Definitions and summary statistics of the variables used in the analysis are given in table 1. The SAPs we considered in this study include legume intercropping, legume crop rotations, conservation tillage (zero or reduced 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. Of the total plots cultivated, 81 percent of plots were planted with maize and legume crops. Of these, about 69 percent and 53 percent are planted either as a pure stand of maize or legumes, or as intercrops, respectively.[8]

Of the total plots intercropped, more than 99.6 are maize and legumes. Maize is often rotated with legumes, such as haricot beans and pigeon peas. The major legume grown is haricot beans, cultivated in 37 percent of plots, followed by pigeon peas at 15 percent.

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: about 67 percent of plots were planted with them. It seems that farmers plant improved varieties without chemical fertilizer, most likely because they are using other soil-fertility enhancing practices instead of CF. Some 75 percent of plots with improved seed included other SAPs, and 25 percent were cultivated with no SAPs, including chemical fertilizer. About 52 and 28 percent of plots have improved maize and legume varieties, respectively. Soil and water conservation investment existed on nearly 18 percent of cultivated plots. The dominant SWC practices considered in this study are terracing (9 percent), live (plant or tree) barriers (18 percent), and stone bunds (3 percent).

Although additional rigorous analysis is required, SAPs impact the net value of crop production[9] and costs of chemical insecticides and herbicides. Figures 1–7 show cumulative density functions for the net value of crop production per acre (hereafter, crop production value) with and without SAPs.

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

[8] The sum will not add to 81% because of intercropping.

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

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.

The Kolmogorov-Smirnov statistics test for CDFs (cumulative distribution functions), 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 chemical insecticides and herbicides 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.

These results, however, must be interpreted with caution because crop productivity and input use may also be influenced by plot 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.

3. Multivariate Probit (MVP) Model Results and Discussion

In this section, we discuss results obtained from the multivariate probit models. (See table 4) For comparison purposes, we have reported estimates from random effects probit models.[10] (See table 5) In most cases, the same variables turned out to be significant in both models. Results are discussed based on MVP estimates. The regressions are estimated at the plot level.

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.

The results suggest that both socioeconomic and plot characteristics are significant in conditioning the households' decisions to adopt SAPs. The MVP model exudes that the

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[10] We have multiple plot observations per household. Random effects models are appropriate when some households have a single plot. Fixed effects model application requires a minimum of two observations per household, but in our sample, some households have a single plot. Our analysis shows that the likelihood ratio test of the null hypothesis that the correlation between two successive error terms for plots (rho) belonging to the same household is significantly different from zero, justifying application of random effects model (see table 5).

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 with the findings by Jansen et al. (2006) that zero or minimum 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 certain practices can be greater in areas of marginal rainfall and/or in areas where climate variability is high. 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 impacts.

The negative association between improved seeds and a low rainfall index exudes that farmers avoid risks by using local seed varieties, instead of investing in expensive inputs in the presence of other shocks and the absence of reliable insurance mechanisms. Promoting improved seeds along with moisture-conserving technologies, such as conservation agriculture, may help farmers avoid risks related to adoption of improved seeds. On the other hand, LI, CT, and animal manure use is more likely by farmers who have experienced crop diseases and pest infestations, but they are less likely to adopt improved crop varieties, for the same explanation as above.

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 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 (e.g., soil fertility) by using more chemical fertilizer (Allen and Lueck 1992; 1993).[11] Alternatively, farmers prefer to use long-term soil fertility enhancements on their own plots, and short-term soil fertility augmentations on rented in plots.

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

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. Travel time from plot to residence also influences LI, LCR, animal manure, and CF, which is more common on closer and 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.

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 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 condition 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.[12]

4. 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 fertility- and productivity-enhancing practices is becoming a more important issue. This paper uses detailed multiple plot observations to investigate the factors that influence farmers' decisions to adopt sustainable agricultural practices by utilizing a cross-sectional multivariate probit regression models.

While there is heterogeneity with regard to factors that influence the choice of any of the seven practices,[13] our results underscore the individual importance of rainfall, pest, and disease shocks; social capital in the form of membership in rural institutions and number of traders that farmers know; skill of local government agents; plot tenure status; asset ownership; and opportunity cost of labor on adoption decision. 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 to target 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 technology adoption transaction costs. 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

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[12] 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.

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

are also incentives 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 increased, if the farmer is a member of farmers' group or association. Similarly, the adoption of CF and improved seeds is likely to increase with the number of traders that farmers know. These findings suggest that in order to enhance the adoption of these practices, local organizations 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 impact on poverty alleviation. Future study is necessary to examine the productivity, risk, environmental, and welfare implications to individual and combinations of sustainable agricultural practices.

Figures and Tables

Figure 1. Impact of Legume Intercropping on Net Value of Crop Production (000 Tsh/acre)

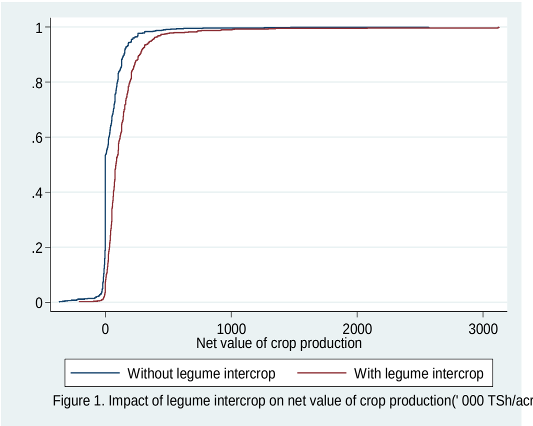

Figure 2. Impact of Manure on Net Value of Crop Production (000 Tsh/acre)

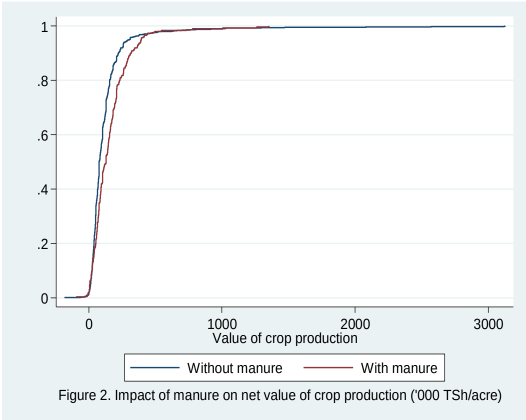

Figure 3. Impact of Chemical Fertilizer on Net Value of Crop Production (000 Tsh/acre)

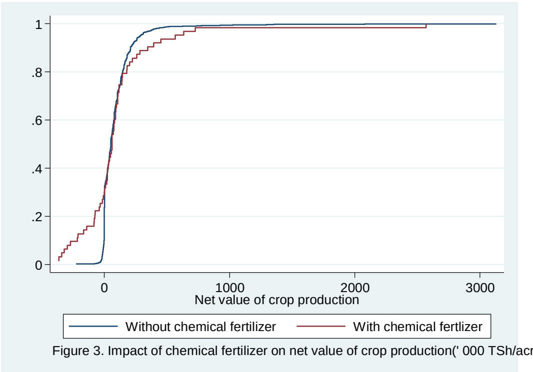

Figure 4. Impact of Conservation Tillage on Net Value of Crop Production (000 Tsh/acre)

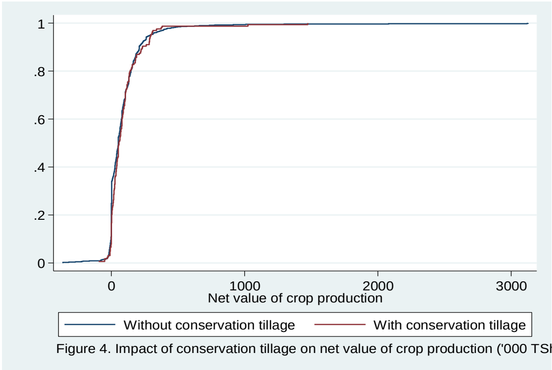

Figure 5. Impact of Legume Crop Rotation on Net Value of Crop Production (000 Tsh/ acre)

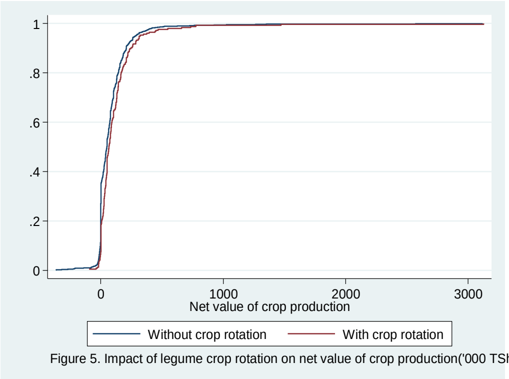

Figure 6. Impact of Improved Seeds on Net Value of Crop Production (000 Tsh/acre)

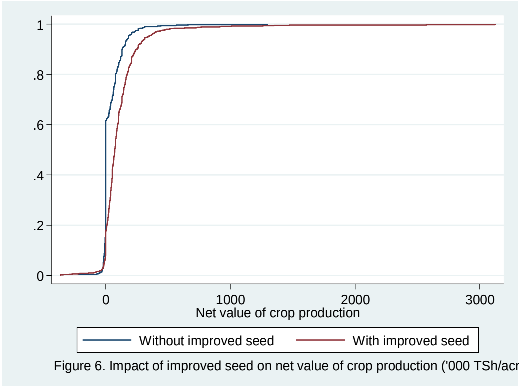

Figure 7. Impact of Soil and Water Conservation on Net Value of Crop Production (000 Tsh/acre)

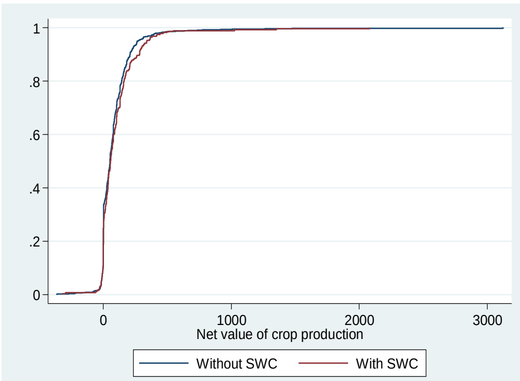

Figure 7. Impact of soil and water conservation on net value of crop production ('000 TSh/acre)

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			
Relative	Household received extension training on conservation tillage(1 = yes; 0 = no)	8.56	15.96
Connection	Household has relative in leadership	0.26	0.44

	position (1 = yes; 0 = no)		
Trader	Number of traders that farmer knows (number)	5.69	7.11
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
Staffskill	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 employment (1 = yes; 0 = no)	0.14	0.35
Fsize	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
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	

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 (LI)	Yes	375.6	-1534.984	706
	No	1910.6	(504.3)***	833
Legume crop rotations (LCR)	Yes	352.4	-1022.8	254
	No	1375.2	(345.3)**	1285
Conservation tillage (CT)	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 (SWC)	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 (CF)	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**
Pestdisease	0.711	0.138	**0.000**	Pestdisease	0.132	0.103	0.200	Pestdisease	0.163	0.083	**0.050**
Govtefect	0.299	0.121	**0.014**	Govtefect	0.290	0.098	**0.003**	Govtefect	-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
Govtsup	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
lnFsize	-0.144	0.124	0.244	lnFsize	-0.008	0.098	0.934	lnFsize	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**
Livestockno	0.004	0.003	0.192	Livestockno	0.000	0.003	0.963	Livestockno	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**
Pestdisease	0.511	0.119	**0.000**	Pestdisease	0.090	0.160	0.576	Pestdisease	-0.188	0.082	**0.022**
Govtefect	0.031	0.100	0.756	Govtefect	0.150	0.171	0.379	Govtefect	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
lnFsize	0.317	0.120	**0.008**	lnFsize	-0.026	0.173	0.881	lnFsize	-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**
Livestockno	0.010	0.003	**0.002**	Livestockno	0.010	0.004	**0.018**	Livestockno	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**
Pestdisease	-0.115	0.113	0.309
Govtefect	-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
lnFsize	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
Livestockno	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. Results of the Random Effects Models

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	-11.688	1.654	0.000	rainfalindex	-1.300	0.657	0.048	rainfalindex	-0.401	0.172	0.020
Pestdisease	6.238	1.024	0.000	Pestdisease	0.647	0.474	0.173	Pestdisease	0.233	0.119	0.050
Govtefect	2.168	0.860	0.012	Govtefect	1.216	0.449	0.007	Govtefect	0.014	0.113	0.902
Connection	0.681	0.853	0.425	Connection	0.772	0.511	0.131	Connection	-0.088	0.124	0.478
Group	-0.965	0.856	0.259	Group	0.983	0.453	0.030	Group	0.240	0.116	0.039
Kinship	-0.263	0.085	0.002	Kinship	0.002	0.017	0.912	Kinship	0.007	0.004	0.074
Trader	-0.167	0.084	0.048	Trader	-0.003	0.031	0.911	Trader	0.000	0.008	0.987
Govtsup	5.924	0.836	0.000	Govtsup	-0.971	0.477	0.042	Govtsup	-0.284	0.116	0.015
Mktdist	-0.022	0.004	0.000	Mktdist	0.001	0.002	0.665	Mktdist	-0.002	0.001	0.002
distext	0.003	0.005	0.547	distext	-0.006	0.004	0.104	distext	0.000	0.001	0.575
Fertavial	3.281	0.893	0.000	Fertavial	-0.120	0.575	0.834	Fertavial	-0.155	0.142	0.277
Salary	-4.267	1.340	0.001	Salary	-0.338	0.627	0.590	Salary	-0.062	0.168	0.710
lnFsize	0.016	1.160	0.989	lnFsize	0.264	0.474	0.577	lnFsize	0.063	0.119	0.599
Gender	1.292	1.206	0.284	Gender	0.292	0.634	0.645	Gender	-0.042	0.160	0.795
lnAge	-0.686	1.417	0.629	lnAge	0.966	0.755	0.201	lnAge	-0.295	0.185	0.111
Educ	-1.818	0.636	0.004	Educ	0.089	0.327	0.785	Educ	-0.095	0.073	0.196
Livestockno	0.016	0.019	0.384	Livestockno	0.001	0.012	0.913	Livestockno	0.004	0.004	0.290
lnFarmsize	-2.443	0.753	0.001	lnFarmsize	-0.219	0.339	0.518	lnFarmsize	-0.574	0.100	0.000
lnAssetval	1.967	0.402	0.000	lnAssetval	-0.030	0.164	0.857	lnAssetval	-0.016	0.044	0.719
lnexpendit~e	0.788	0.665	0.236	lnexpendit~e	0.080	0.346	0.816	lnexpendit~e	0.027	0.086	0.751
Plot characteristics											
Tenure	1.870	1.056	0.076	**Tenure**	**-0.095**	**0.482**	**0.844**	Tenure	0.098	0.149	0.511

lnPlotsize	0.760	0.409	0.063	lnPlotsize	0.374	0.200	0.061	lnPlotsize	0.530	0.074	0.000
Plotdist	0.006	0.009	0.507	Plotdist	-0.013	0.005	0.009	Plotdist	-0.006	0.001	0.000
Modfertplt	1.764	0.821	0.032	Modfertplt	0.252	0.444	0.570	Modfertplt	0.317	0.127	0.013
Porfertplt	-1.223	1.500	0.415	Porfertplt	0.730	0.651	0.262	Porfertplt	0.081	0.201	0.688
Modslpplt	-0.092	0.695	0.895	Modslpplt	1.035	0.360	0.004	Modslpplt	0.147	0.108	0.173
Stepslpplt	-6.124	3.388	0.071	Stepslpplt	1.018	0.521	0.051	Stepslpplt	0.362	0.175	0.039
Moddepsolplt	1.303	1.647	0.429	Moddepsolplt	0.277	0.465	0.552	Moddepsolplt	0.188	0.182	0.302
Depsolplt	1.392	1.708	0.415	Depsolplt	-0.057	0.565	0.920	Depsolplt	-0.037	0.197	0.851
District dummies											
Mbulu	0.429	1.107	0.698	Mbulu	-0.113	0.563	0.841	Mbulu	0.387	0.168	0.021
Mvomero	2.454	1.106	0.026	Mvomero	-1.726	0.625	0.006	Mvomero	-1.199	0.180	0.000
Kilosa	-4.219	1.528	0.006	Kilosa	-8.760	0.895	0.000	Kilosa	-1.006	0.165	0.000
Constant	-40.246	10.397	0.000	Constant	-9.587	5.351	0.073	Constant	1.719	1.326	0.195
Regression diagnostics											
LR test of rho = 0: chibar2(01)			220.25***	LR test of rho = 0: chibar2(01)			329.07***	LR test of rho = 0: chibar2(01)			43.87***
Log pseudolikelihood			-203.140	Log pseudolikelihood			-383.790	Log pseudolikelihood			-806.903
Wald chi2(31)			226.71***	Wald chi2(31)			150.94***	Wald chi2(30)			219.29***
Number of observations			1539.000	Number of observations				Number of observations			1539.000
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	0.142	0.332	0.668	rainfalindex	-0.337	0.504	0.504	rainfalindex	-0.256	0.152	0.092
Pestdisease	0.702	0.256	0.006	Pestdisease	0.212	0.343	0.537	Pestdisease	-0.252	0.104	0.015
Govtefect	0.073	0.225	0.747	Govtefect	0.218	0.331	0.509	Govtefect	0.348	0.099	0.000
Connection	0.057	0.254	0.822	Connection	0.165	0.336	0.623	Connection	0.008	0.109	0.940
Group	0.601	0.239	0.012	Group	0.572	0.309	0.064	Group	0.098	0.102	0.339

Kinship	0.004	0.008	0.586	Kinship	-0.014	0.019	0.474	Kinship	-0.003	0.003	0.431
Trader	0.005	0.018	0.789	Trader	0.024	0.019	0.205	Trader	0.012	0.007	0.087
Govtsup	0.053	0.233	0.820	Govtsup	-0.213	0.366	0.562	Govtsup	-0.130	0.102	0.202
Mktdist	-0.001	0.001	0.658	Mktdist	0.003	0.002	0.092	Mktdist	0.000	0.001	0.599
distext	0.000	0.002	0.934	distext	-0.001	0.002	0.643	distext	0.000	0.001	0.964
Fertavial	0.101	0.280	0.719	Fertavial	-0.265	0.415	0.522	Fertavial	0.109	0.127	0.389
Salary	-0.343	0.314	0.274	Salary	-0.965	0.668	0.149	Salary	-0.007	0.149	0.964
lnFsize	0.575	0.253	0.023	lnFsize	-0.074	0.317	0.815	lnFsize	-0.050	0.106	0.642
Gender	-0.116	0.353	0.742	Gender	-0.272	0.412	0.510	Gender	-0.043	0.143	0.764
lnAge	-0.088	0.389	0.822	lnAge	0.263	0.575	0.648	lnAge	-0.576	0.168	0.001
Educ	0.117	0.152	0.443	Educ	0.443	0.277	0.110	Educ	-0.076	0.066	0.253
Livestockno	0.014	0.007	0.035	Livestockno	0.010	0.012	0.395	Livestockno	0.008	0.004	0.021
lnFarmsize	0.067	0.190	0.726	lnFarmsize	-0.444	0.246	0.071	lnFarmsize	-0.560	0.086	0.000
lnAssetval	0.082	0.086	0.339	lnAssetval	0.225	0.138	0.105	lnAssetval	0.033	0.041	0.417
lnexpendit~e	0.035	0.166	0.830	lnexpendit~e	0.013	0.253	0.960	lnexpendit~e	0.260	0.077	0.001
Plot characteristics											
Tenure	1.010	0.309	0.001	Tenure	-0.695	0.310	0.025	Tenure	0.015	0.140	0.915
lnPlotsize	0.259	0.124	0.038	lnPlotsize	-0.348	0.168	0.039	lnPlotsize	0.381	0.064	0.000
Plotdist	-0.010	0.003	0.001	Plotdist	0.006	0.003	0.046	Plotdist	0.000	0.001	0.761
Modfertplt	0.418	0.237	0.078	Modfertplt	0.381	0.372	0.305	Modfertplt	0.023	0.113	0.836
Porfertplt	0.383	0.363	0.291	Porfertplt	1.166	0.545	0.032	Porfertplt	-0.037	0.176	0.832
Modslpplt	0.028	0.209	0.893	Modslpplt	-0.407	0.277	0.142	Modslpplt	-0.049	0.096	0.607
Stepslpplt	0.016	0.353	0.963	Stepslpplt	-1.201	0.579	0.038	Stepslpplt	-0.293	0.156	0.060
Moddepsolplt	0.086	0.340	0.800	Moddepsolplt	-0.405	0.455	0.373	Moddepsolplt	0.310	0.159	0.052
Depsolplt	0.074	0.358	0.835	Depsolplt	-0.633	0.515	0.219	Depsolplt	0.046	0.171	0.789
District dummies											
Mbulu	1.978	0.337	0.000	Mbulu	-1.146	0.687	0.095	Mbulu	-0.717	0.157	0.000

Mvomero	-2.583	0.537	0.000	Mvomero	1.068	0.425	0.012	Mvomero	-0.563	0.160	0.000
Kilosa	-1.518	0.356	0.000	Kilosa	-0.522	0.489	0.286	Kilosa	-0.473	0.150	0.002
Constant	-5.736	2.615	0.028	*Constant*	-6.729	4.085	0.100	*Constant*	-0.400	1.173	0.733
Regression diagnostics											
LR test of rho = 0: chibar2(01)			98.90***	LR test of rho = 0: chibar2(01)			15.72***	LR test of rho = 0: chibar2(01)			21.04***
Log pseudolikelihood			-456.220	Log pseudolikelihood			-156.620	Log pseudolikelihood			-874.730
Wald chi2(31)			85.11***	Wald chi2(31)			40.390	Wald chi2(30)			123.27***
Number of observations			1539.000	Number of observations			1539	Number of observations			1539.000

LEGUME CROP ROTATION

	Coeff.	**Std. err.**	**P-value**
Household characteristics and endowments			
Rainfalindex	0.692	0.254	0.006
Pestdisease	-0.234	0.176	0.183
Govtefect	-0.099	0.165	0.550
Connection	-0.224	0.192	0.243
Group	-0.071	0.171	0.676
Kinship	0.004	0.006	0.443
Trader	0.009	0.010	0.347
Govtsup	-0.301	0.177	0.089
Mktdist	0.001	0.001	0.548
distext	0.000	0.001	0.807
Fertavial	0.300	0.199	0.132
Salary	0.252	0.254	0.319
lnFsize	0.090	0.175	0.607

Gender	-0.153	0.227	0.501
lnAge	0.234	0.284	0.410
Educ	-0.068	0.109	0.529
Livestockno	0.007	0.005	0.141
lnFarmsize	0.265	0.137	0.053
lnAssetval	-0.084	0.066	0.206
lnexpendit~e	0.030	0.129	0.816
Plot characteristics			
Tenure	0.294	0.243	0.227
lnPlotsize	-0.371	0.101	0.000
Plotdist	0.005	0.002	0.015
Modfertplt	-0.234	0.176	0.184
Porfertplt	-0.869	0.355	0.014
Modslpplt	-0.209	0.161	0.194
Stepslpplt	0.232	0.254	0.362
Moddepsolplt	-0.027	0.263	0.917
Depsolplt	0.109	0.283	0.701
District dummies			
Mbulu	-1.117	0.264	0.000
Mvomero	-0.508	0.236	0.031
Kilosa	-1.044	0.244	0.000
Constant	-2.028	2.028	0.318
Regression diagnostics			
LR test of rho = 0: chibar2(01)			25.55***
Log pseudolikelihood			-379.900
Wald chi2(31)			52.04**
Number of observations			1539.000

Table 6. Correlation Coefficients for MVP Regression Equations

	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)

	ρ_{LI}	ρ_{CT}	ρ_{Manure}	ρ_{LCR}	ρ_{CF}	ρ_{SWC}
ρ_{CT}	**0.17 (0.01)**					
ρ_{Manure}	**0.32 (0.00)**	**0.12 (0.10)**				
ρ_{LCR}	**0.14 (0.00)**	-0.01 (0.94)	-0.04 (0.56)			
ρ_{CF}	-0.02 (0.84)	-0.1 (0.50)	0.04 (0.70)	0.05 (0.58)		
ρ_{SWC}	0.04 (0.54)	**0.32 (0.00)**	0.08 (0.18)	0.03 (0.66)	-0.01 (0.44)	
ρ_{seed}	**0.49 (0.00)**	-0.02 (0.73)	**0.19 (0.00)**	**0.15 (0.00)**	**0.38 (0.00)**	-0.02 (0.66)

Notes: p-value is in parentheses. Bold indicates significant value.

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