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Authors Author Affiliation and Contact Information
Hailemariam Teklewold[1], Menale Kassie[2] and Bekele Shiferaw[3]

[1]PhD Candidate at University of Gothenburg, School of Business, Economics and Law, Department of Economics, PO Box 640, SE 405 30, Gothenburg, Sweden. Tel: +46 76 5843729; e-mail: Hailemariam.Teklewold@economics.gu.se.
[2]Scientist-Agricultural & Development Economist at CIMMYT (International Maize and Wheat Improvement Center), Nairobi, Kenya; e-mail: m.kassie@cgiar.org.
[3]Director of the Socioeconomics Program at CIMMYT (International Maize and Wheat Improvement Center), Nairobi, Kenya; e-mail: b.shiferaw@cgiar.org.

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[1]PhD Candidate at University of Gothenburg, School of Business, Economics and Law, Department of Economics, PO Box 640, SE 405 30, Gothenburg, Sweden. Tel: +46 76 5843729; e-mail: Hailemariam.Teklewold@economics.gu.se.
[2]Scientist-Agricultural & Development Economist at CIMMYT (International Maize and Wheat Improvement Center), Nairobi, Kenya; e-mail: m.kassie@cgiar.org.
[3]Director of the Socioeconomics Program at CIMMYT (International Maize and Wheat Improvement Center), Nairobi, Kenya; e-mail: b.shiferaw@cgiar.org.

Abstract

Sustainable agricultural practices (SAPs) that lead to an increase in productivity are central to the acceleration of economic growth; this will alleviate poverty and help to overcome the recurrent food shortages that affect millions of households in Africa. However, the adoption rates of SAPs remain below expected levels. This paper analyzes the factors that facilitate or impede the probability and level of adoption of interrelated SAPs, using recent data of multiple plot-level observations. Multivariate and ordered probit models are applied to the modeling of adoption decisions by farm households facing multiple SAPs which can be adopted in various combinations. The results show that there is a significant correlation between SAPs, suggesting that adoptions of SAPs are interrelated. The analysis further shows that both the probability and the level of decisions to adopt SAPs are influenced by many factors: a household's trust in government support, credit constraint, spouse education, rainfall and plot-level disturbances, household wealth, social capital and networks, including the number of traders known by a farmer in his vicinity, his participation in rural institutions, and the number of relatives he has inside and outside his village, labor availability, and plot and market access. These results imply that policy makers and development practitioners whose aims are to strengthen local institutions and service providers, maintain or increase household asset bases, and establish and strengthen social protection schemes, can speed up the adoption of SAPs.

JEL classification: Q01, Q12, Q16, Q18

Keywords: Multiple adoption; Sustainable Agricultural Practices; Multivariate probit; Ordered probit, Ethiopia

1. Introduction

Sustainable agricultural practices (SAPs) that lead to an increase in productivity are central to the acceleration of economic growth; this will alleviate poverty and help to overcome the recurrent food shortages that affect millions of households in Africa. Despite the improvements made over the last four decades in the agricultural sector, a combination of declining soil fertility, population growth, low uptake of external inputs, and climate disruption has resulted in a dramatic fall in per capita food production (Pretty et al., 2011). This has led to more hunger and poverty in the region. As population growth continues, arable land is shrinking in many areas, meaning that the extensification path and the practice of letting the land lie fallow for long periods are rapidly becoming impractical, thereby making continuous cropping a common practice in many densely-populated areas. This has resulted in a vicious circle of low agricultural productivity, inadequate investment in sustainable intensification options, increasing land degradation, and reduced capacity of farm households to manage climatic variability and change.

The adoption and diffusion of SAPs have become an important issue in the development-policy agenda for sub-Saharan Africa (Scoones and Toulmin, 1993; Lee, 2005; Ajayi, 2007), especially as a way to tackle these impediments. The Food and Agriculture Organization (FAO) argues that sustainable agriculture consists of five major attributes: (1) it conserves resources, (2) it is environmentally non-degrading, (3) it is technically appropriate, (4) it is economically and (5) socially acceptable (FAO, 1989). Accordingly these practices broadly defined may include conservation tillage, legume intercropping, legume crop rotations, improved crop varieties, the use of animal manure, the complementary use of inorganic fertilizers, and soil and stone bunds for soil and water conservation (D'Souza et al., 1993; Lee 2005, Kassie et al., 2010; Wollni et al., 2010).

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 Ethiopia, 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. 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). A better understanding of constraints that condition farmers' adoption behavior is therefore important for designing promising pro-poor policies that could stimulate the adoption of SAPs and increase productivity. Past research also focused on the adoption of component technologies in isolation, while farmers typically adopt and adapt multiple technologies as complements, substitutes, or supplements that deal with their overlapping constraints. In addition, technology adoption decisions are path dependent: the choice of technologies adopted most recently by farmers is partly dependent on their earlier technology choices. Analysis made without controlling for technology interdependence and simultaneous adoption in complex farming systems may underestimate or overestimate the influence of various factors on the technology choice made (Wu and Babcock, 1998).

The present paper contributes to the growing economic literature on sustainable agriculture in the following ways: first, our analysis uses a comprehensive large household- and plot-level survey conducted recently in maize-legume farming systems of Ethiopia; second, we consider methods that recognizes the interdependence between different practices and that jointly analyze the decision to adopt multiple SAPs, including maize-legume rotation, conservation tillage, modern crop varieties, inorganic fertilizer, and manure; third, using recent data from

the maize-legume farming system in Ethiopia, we concentrate on the relative importance of social capital and network, market transaction costs, confidence in the skill of extension agents, reliance on government support, (social insurance), household wealth, individual rainfall stress and plot-level incidence stresses, in determining the probability and level of adoption of SAPs; fourth, we extend the focus from the probability of an adoption decision to the extent of adoption as measured by the number of SAPs adopted.

2. Econometric framework

As discussed below in section 4.1, farmers adopt a mix of technologies to deal with a multitude of agricultural production constraints. This implies that the adoption decision is inherently multivariate, and attempting univariate modeling would exclude useful economic information about interdependent and simultaneous adoption decisions (Dorfman, 1996). The econometric specification of this paper consists of two parts: in the first part we examine the determinants of multiple adoption decisions of SAPs, using a multivariate probit model (MVP); in the second part, we analyze the determinants of the levels of SAPs adopted, using pooled and random effects ordered probit models.[1]

2.1 A multivariate probit model

In a single-equation statistical model, information on a farmer's adoption of one SAP does not alter the likelihood of his adopting another SAP. However, the MVP approach simultaneously models the influence of the set of explanatory variables on each of the different practices, while allowing for the potential correlation between unobserved disturbances, as well as the relationship between the adoptions of different practices (Belderbos et al., 2004). One source of correlation may be complementarities (positive correlation) and substitutabilities (negative correlation) between different practices (Ibid). Failure to capture unobserved factors and

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[1] The structure of the data, multiple plot observation per households allows us to apply panel data models. We are not aware of a panel data command for multivariate probit model.

interrelationships among adoption decisions regarding different practices will lead to bias and inefficient estimates (Greene, 2008).

The observed outcome of an SAP adoption can be modeled following random utility formulation. Consider the ith farm household $(i = 1,..., N)$ which is facing a decision on whether or not to adopt the available SAP on plot p $(p = 1, ..., P)$. Let U_0 represent the benefits to the farmer from traditional management practices, and let U_k represent the benefit of adopting the kth SAP: $(k = R,V,F,M,T)$ denoting choice of crop rotation (R), improved crop variety (V), inorganic fertilizer (F), manure use (M) and reduced tillage (T). The farmer decides to adopt the kth SAP if $Y_{ipk}^* = U_k^* - U_0 > 0$. The net benefit ($Y_{ipk}^*$) that the farmer derives from the kth SAP is a latent variable determined by observed household, plot and location characteristics (X_{ip}) and unobserved characteristics (u_{ip}):

$$Y_{ipk}^* = X_{ip}'\beta_k + u_{ip} \qquad (k = R,V,F,M,T) \qquad (1)$$

Using the indicator function, the unobserved preferences in equation (1) translate into the observed binary outcome equation for each choice as follow:

$$Y_k = \begin{cases} 1 & if \quad Y_{ipk}^* > 0 \\ 0 & otherwise \end{cases} \qquad (k = R,V,F, M,T) \qquad (2)$$

In the multivariate model, where the adoption of several SAPs are possible, the error terms jointly follow a multivariate normal distribution (MVN) with zero conditional mean and variance normalized to unity (for identification of the parameters) where $(u_R, u_V, u_F, u_M, u_T) \sim MVN(0, \Omega)$ and the symmetric covariance matrix Ω is given by:

$$\Omega = \begin{bmatrix} 1 & \rho_{RV} & \rho_{RF} & \rho_{RM} & \rho_{RT} \\ \rho_{VR} & 1 & \rho_{VF} & \rho_{VM} & \rho_{VT} \\ \rho_{FR} & \rho_{FV} & 1 & \rho_{FM} & \rho_{FT} \\ \rho_{MR} & \rho_{MV} & \rho_{MF} & 1 & \rho_{MT} \\ \rho_{TR} & \rho_{TV} & \rho_{TF} & \rho_{TM} & 1 \end{bmatrix} \qquad (3)$$

Of particular interest are the off-diagonal elements in the covariance matrix, which represent the unobserved correlation between the stochastic components of the different types of SAP. 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 the choice of alternative SAPs.

2.2 An ordered probit model

Because the MVP model specified above is only concerned with the probability of adoption of SAPs, no distinction is made between, for example, those farmers who adopt one practice and those who use multiple SAPs in combination. In the case of multi-SAP adoption, defining a cut-off point between adopters and non-adopters is the main problem in examining the factors influencing the level of adoption of SAPs (Wollni et al., 2010). In our case, many farmers will not adopt the whole package, some applying only a mix of some SAPs on their farms but not others. As a result, for SAPs as a package, it is difficult to quantify the extent of adoption, for instance by the fraction of area under SAPs, as is usually done in adoption literature. To overcome this problem, following D'Souza et al., (1993) and Wollni et al., (2010), we use the number of SAPs adopted as our dependent variable. The information on the number of SAPs adopted could have been treated as a count variable. Count data is usually analyzed using Poisson regression model but the underlying assumption is that all events have the same probability of occurrence (Wollni et al., 2010). However, in our application the probability of adopting the first SAP could differ from the probability of adopting a second or third practice, given that in the latter case the farmer has already gained some experience with an SAP and has been exposed to information about the practice. The number of SAPs adopted by farmers is an ordinal variable, hence the use of an ordered probit model in the estimations. The model involves a different latent variable for the frequency function of SAPs (T*). As mentioned above, the ith farm household $(i = 1,…, N)$ decides to

adopt a certain number of SAPs on plot p $(p = 1, ..., P)$ based on the maximization of an

underlying utility function: $T_{ip}^* = X_{ip}' \alpha + \varepsilon_{ip}$ $\qquad$ (4)

where X_{ip} is a vector of household, plot and location characteristics; α is a vector of

parameters to be estimated; and ε_{ip} is unobserved characteristics. The farmer decides to

adopt an additional SAP if the utility gained from adopting it is higher than the utility of not

adopting it. Since the utility level of individual farmer T_{ip}^* is unobserved, the observed level

of SAPs T_{ip} is assumed to be related to the latent variable T_{ip}^* in the following way

(McKelvey and Zavoina, 1975):

$T_{ip} = j$ if and only if $\mu_j \leq T_{ip}^* < \mu_{j+1}$ for j=0,...,J $\qquad$ (5) $\qquad$ where J is the

number of SAPs adopted; $\mu_j, ..., \mu_{J+1}$ are threshold levels that are empirically estimated. This

equation states that if the number of SAPs T_{ip}^* is between μ_0 and μ_{J+1}, the response to the

question on the number of SAPs adopted is equal to j ($T_{ip} = j$). Parameter vectors α and

μ are estimated by maximum likelihood.

The data set consists of single and multiple plots per household. There could therefore be a

correlation among plot observations within a household, which could affect standard errors

and bias-estimated coefficients. The management of one plot within the same household may

affect the management of other plots. A method that accounts for such correlation in single

and multiple plot-level data is the random effect ordered probit model.[2] In the random effect

ordered probit model, the error term ε_{ip} in equation 4 will be decomposed into $\eta_i + e_{ip}$,

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[2] 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 the application of random effects model.

where e_{ip} is a normally distributed random error – with mean 0 and variance σ_e - capturing unmeasured effects on the level of SAPs; and η_i is an individual specific heterogeneity and is distributed normally with mean 0 and variance σ_η.

3. **Study areas and sampling**

The data used for this study is based on a farm-household survey in Ethiopia conducted during the period October - December 2010 by the Ethiopian Institute of Agricultural Research (EIAR) in collaboration with the International Maize and Wheat Improvement Center (CIMMYT), to identify the key factors influencing the simultaneous adoption of several agricultural technologies and practices, and the impact of these on household welfare in the maize-legume cropping system zones. The sample covers a total of 898 farm households and 4, 050 farming plots. In this study, we focused on maize plots (1, 616) because maize is the largest cereal commodity in terms of its share of total cultivated area, total production, and role in direct human consumption. It accounts for more than 50% of the total cultivated land and 76% of the total consumption of own production. A multistage sampling procedure was employed to select peasant associations (PAs)[3] from each district, and households from each PA. First, based on their maize-legume production potential, nine districts were selected from three regional states of Ethiopia: Amhara, Oromia and SNNRP Region. Second, based on proportionate random sampling, 3-6 PAs in each district, and 16-24 farm households in each PA were selected.

a) Data and descriptive statistics

A structured questionnaire was prepared, and the sampled respondents were interviewed by experienced interviewers under close supervision by researchers from CIMMYT and EIAR. The questionnaire consisted of detailed enquiries about household, plot and village data

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[3]These are the lowest administrative structure in Ethiopia.

including input and output market access, household composition, education, assets ownership, herd size, various sources of income, participation in credit markets, membership of formal and informal organizations, trust, stresses, participation and confidence in extension services, cropping pattern, crop production, land tenure, adoption of SAPs and a wide range of plot-specific attributes.

Dependent variables

For each plot, the respondent recounted the type of SAPs practiced: maize-legume rotation, conservation tillage, manure, modern crop seeds, and inorganic fertilizers.

The maize-legume rotation system (temporal diversification) is one option for sustainable intensification that can help farmers to increase crop productivity through N fixation and also help to maintain productivity in a changing climate that could bring new pests and diseases due to warmer weather (Delgado et al., 2011). Maize-legume crop rotation was practiced on about 23.2% of the plots during the cropping season considered for this analysis.

Conservation tillage is part of a sustainable agricultural system, as soil disturbance is minimized and crop residue or stubble allowed to remain on the ground with the accompanying benefits of better soil aeration and improved soil fertility. Minimum soil disturbance requires less traction power and less C emissions from the soil (Delgado et al., 2011). In our case, conservation tillage practices entails reduced tillage (only one pass) and/or zero tillage and letting the stubble lie on the plot. Conservation tillage is used on 36.3% of maize plots.

Manure use refers to the application of livestock waste on the farming plot. It is a major component of a sustainable agricultural system with the potential benefits of long-term maintenance of soil fertility and supply of nutrients, especially nitrogen (N), phosphorus (P) and potassium (K). The average quantity of manure used in our sample was about 1.25

tons/ha. However, the quantity of manure conditional on manure use is 5 tons/ha. Of the total maize plots, about 27.3% plots received manure.

The introduction of modern maize varieties could improve food security and income for a rapidly-growing population by improving productivity. The National Maize Research Project of Ethiopia has recommended a number of improved maize varieties adapted to the different maize agro-ecologies of the country. Yet the area covered with modern maize varieties is still only around 50% in our sample and about 52.5% of the maize plots covered by improved maize varieties.

On the other hand, the average inorganic fertilizer used for maize in the study areas is 43 kg N/ha. and 13 kg P/ha. About 67% of the maize plots received fertilizer and farmers who use fertilizer applied 57 kg N/ha. and 18 kg P/ha. This is very low compared to the official extension recommendation of 92 kg N/ha. and 69 kg P/ha. About 67.3% of the maize sample plots treated with inorganic fertilizer.

Independent variables

The adoption models include several explanatory variables based on economic theory and previous empirical adoption studies (D'Souza et al., 1993; Neill and Lee, 2001; Arellanes and Lee, 2003; Lee, 2005; Marenya and Barrett 2007; Knowler and Bradshaw, 2007; Kassie et al., 2010; Wollni et al., 2010). The description and the summary statistics of the variables are given in table 1.

<div align="center">

[Table 1]

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Farm and household characteristics

We include several plot-specific attributes, including soil fertility[4], soil depth[5], plot slope[6], plot tenure status and spatial distance of the plot from the farmer's home (walking distance in minutes). On average, landowners operate on four plots of about 0.5 ha each, and these plots

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[4] the farmer ranked each plot as "poor", "medium" or "good"

are often not spatially adjacent (as far as 5 hours walking time away). The variable distance to the plot is an important determinant of the adoption of SAPs because of increased transaction costs on the farthest plot, particularly the cost of transporting bulky materials/inputs. For instance, plots treated with manure are closer to the residence (about 6 minutes away on foot) than plots that are not treated with manure (about 13 minutes away on foot). Distant plots usually receive less attention and less-frequent monitoring such as watching and guarding, particularly for maize and legume crops which are edible at green stage, and hence farmers are less likely to adopt SAPs on such plots.

With respect to socio-demographic characteristics we control those relevant to adoption decision, such as family size, age, sex, and education level of the household head and spouse. About 92% of the sample households have a male head. The number of years of education range from 2 to 4 years across the study areas with only 55% of the heads having had at least primary education. However, farm technology adoption decisions cannot be made only by the head of the household but must be part of an overall household strategy (Zepeda and Castillo, 1997). Therefore we also include education of the spouse when we examine the role of human capital in the adoption of SAPs. The average years of the spouse's education are about 1.3, with only 30% of spouses having had at least primary education.

Input-output market access

Access to market variables are directly associated with the transaction costs that occur when households participate in input and output marketing activities. Transaction costs are barriers to market participation by resource-poor smallholders, and are factors responsible for significant market failures in developing countries (Sadoulet and de Janvry, 1995). Market access is measured here by distance to the input markets (in minutes walking time) and by means of transportation used to output markets, a dummy variable equal to 1 if farmers are

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[5] the farmer ranked each plot as "deep", "medium deep" or "shallow"
[6] the farmer ranked each plot as "flat", "medium slope" or steep slope"

walking to the market, and to zero if farmers use other transportation systems (such as vehicle, bicycle or cart). The average walking distance to input markets is about one hour, and only 56% of households use different transportation means (vehicle, bicycle or cart) to visit the market. Distance to market and poor access to transportation can negatively influence the smallholder's adoption of SAPs, through increasing travel time and transport costs.

Resource constraints

As a measure of wealth of the household, we include the total value of all non-land assets, livestock ownership (in Tropical Livestock Units (TLU)) and farm size. We also include a dummy variable equal to one if the household receives a remittance in the form of cash and/or participates in off-farm work as an indicator for working capital influencing adoption. Farm size is often thought to be a prerequisite for obtaining credit. In Ethiopia, farmers must have at least 0.5 ha. under maize to participate in the credit scheme for maize (Doss, 2006).

A credit constraint is usually frequently mentioned in technology adoption literature. In order to understand whether a farmer has access to credit we followed the Feder et al., (1990) approach of constructing a credit-access variable. This measure of credit tries to distinguish between farmers who choose not to use available credit, and farmers who do not have access to credit. This idea is often valid on the grounds that many non-borrowers do not borrow because they actually have sufficient liquidity from their own resources, and not because they cannot obtain credit, while some cannot borrow because they are not creditworthy, do not have collateral, or fear risks (Feder et al., 1990; Doss, 2006). In this study, the respondent is asked to answer two sequential questions: whether credit is needed or not, and if yes, whether credit is obtained for farming operations or not. The credit-constrained farmers are then defined as those who need credit but are unable to get it (30%). Accordingly, the credit-unconstrained farmers are those who do not need credit (40%) and those who need credit and are able to get it (30%).

Stresses

Smallholder farming in Ethiopia is often subject to environmental disturbances such as extreme weather events: drought, waterlogging, floods, untimely or uneven distribution of rainfall, incidence of pest and diseases, and frost. Understanding the impact of these disturbances on the adoption of SAPs is relatively neglected. These stresses and others erode the confidence of farmers in adopting technology. This study includes self-reported rainfall and plot-level crop-production disturbances, to measure the farm-specific experience related to them. The rainfall disturbance variable is based on respondents' subjective rainfall satisfaction in terms of timeliness, 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. Responses to each of these questions (either 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 one and the worst equal to zero[7]. Plot-level disturbance is captured by the three most common stresses affecting crop production: attacks by pests and diseases, water logging, drought, and frost and hailstorm stress. The effect of these disturbances on the adoption of SAPs depends on the type of SAP. For instance, farmers may be less likely to adopt those SAPs that involve cash expenditure, such as fertilizer and seed varieties, compared to SAPs (e.g. manure, or crop rotation) that do not.

We also control for the possible role of farmers' perception of government assistance, by including a dummy variable taking the value of one if the farmer can rely on government support when events beyond their control occur and cause output or income loss. In the developing world where production risks are high due to a number of factors (e.g. unreliable

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[7]Actual rainfall data was preferable, but getting reliable data in most developing countries including Ethiopia is difficult.

rainfall, incidence of pests and diseases), farmers are less likely to adopt technologies in the absence of farm insurance to smooth consumption during crop failure, and this is true in Ethiopia. Social safety nets/insurance, if properly implemented, can build farmer confidence so that he invests despite uncertainty, and can help farm households to smooth consumption and maintain productive capacity by reducing the need to liquidate assets that might otherwise occur, (Barrett 2005). Thus government support can positively influence the adoption of SAPs.

Social capital

In addition to the classic household characteristics and endowment variables, the survey also collected variables related to social capital and networks that can influence technology adoption decisions (Isham, 2002; Bandiera and Rasul, 2006; Marenya and Barrett, 2007). Social capital literature treats social networks as a means to access information, secure a job, obtain credit, protect against unforeseen events, exchange price information, reduce information asymmetries and enforce contracts (Barrett , 2005; Fafchamps and Minten, 2002). In this study, detailed questions were asked in order to identify different social networks. We distinguished three social networks and capital: first, a household's relationship with rural institutions in the village, defined as whether the household is a member of a rural institution or association, such as input supply and labor sharing; second, a household's relationship with trustworthy traders, measured by the number of trusted traders inside and outside the village that the respondent knows; and third, a household's kinship network, defined as the number of close relatives that the farmer can rely on for critical support in times of need. Such classification is important, as different forms of social capital and networks may affect the adoption of SAPs in various ways, such as through information sharing, stable market outlets, labor sharing, the relaxing of liquidity constraints, and mitigation of risks.

Extension

Extension is a source of information for many farmers, either directly, through contact with extension agents, or indirectly, through farmers who have prior exposure transmitting information to other farmers. The former is measured by the frequency of extension contact related to SAP activities, while the latter is a purposeful way of gathering information which includes that acquired from the social network. Given the fact that many of the extension agents are also involved in other activities, such as input delivery service, administering credit provision and collection of repayment, farmers may question the skill of extension agents to provide updated information. Hence we assess the perception of farmers regarding the skill of extension workers through attitudinal questions with a seven-point Likert scale (where 7 means high confidence). To reduce measurement error, the responses are recoded into a dummy variable where 1 indicates confidence in the qualification of extension agents (slightly agree to strongly agree) and 0 indicates lack of confidence (strongly disagree to indifferent).

4. Results and discussions

4.1 Conditional and unconditional adoption

The joint and marginal probability distribution of plots for the five SAPs is presented in table 2. Of the 1,616 plots considered in the analysis, about 1,509 plots benefited from one or more than one SAP and all five SAPs were applied in only 10 plots. Inorganic fertilizer was predominantly used by the sample households. It was used as a single technology on 11% of plots, in combination with modern seed varieties on 16% of plots, and in combination with conservation tillage and modern seed varieties on 10% of plots. Manure alone was adopted on 5% of the plots, in combination with organic fertilizer on 4% of plots, and together with improved variety and inorganic fertilizer on 3% of plots. Similarly, 5%, of the plots benefited from crop rotation jointly with improved seeds and inorganic fertilizer, 4%, from improved seeds, inorganic fertilizer and conservation tillage, and 2% from only crop rotation.

[Table 2]

Although the statistics on the joint and marginal probabilities provide interesting results, the sample unconditional and conditional probabilities for adoption also highlight an interesting indication of the existence of possible interdependence across the five SAPs (Table 3). To mention some results, the unconditional probability of a plot with inorganic fertilizer is 67.3%. However, this probability of adoption is significantly increased to 78.1%, 73.2% and 76.4% conditional on the adoption of one practice (seed variety), two practices (rotation and seed variety), and three practices (rotation, seed variety and conservation tillage), respectively. Interestingly, the conditional probability of a plot with inorganic fertilizer is significantly lower if farmers are adopting manure (one practice-48.2%), jointly manure and conservation tillage (two practices- 38.3%) and three practices (manure, seed variety and conservation tillage - 49.2%). The probability of the use of inorganic fertilizer is reduced by more than 25% when households applied manure, suggesting substitutability between manure and inorganic fertilizer.

[Table 3]

While a more in-depth multivariate analysis is required, a non-parametric maize net-income distribution analysis showed that SAPs impact the net value of maize production. The cumulative distribution of the net value of maize production on plots with legume rotation (C), chemical fertilizer (F), improved maize seeds (V), manure use (M) and conservation tillage (T) dominates the maize net-income cumulative distribution on plots without these SAPs. This is shown by the graphs (Figures 1-5) of the cumulative density function (CDF) of maize net income of plots with SAPs being constantly below or equal to that of plots without these practices. Confirming the above result, the Kolmogorov-Smirnov statistics test[8] for equality of net maize-production value-distribution function also showed that the maize net incomes across each SAP do not have the same distribution function. Although rigor analysis is important, this is an important economic incentive for farmers to adopt SAPs.

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[8] The test result is not shown here for the sake of space.

4.2 Regression results

4.2.1 Adoption decisions: MVP model results

The MVP model is estimated using maximum likelihood method on plot-level observations.[9,10] The model fits the data reasonably well – the Wald test of the hypothesis that all regression coefficients in each equation are jointly equal to zero is rejected. As expected, the likelihood ratio test [$\chi2(10) = 119.553$, p=0.000)] of the null hypothesis that the covariance of the error terms across equations are not correlated is also rejected. This is supported by the correlation between error terms of the adoption equations reported in table 4. The estimated correlation coefficients are statistically significant in six of the ten pair cases, where three coefficients have negative and the remaining three have positive signs. In addition to supporting the use of the MVP, this also shows the interdependence of practices in that the probability of adopting a practice is conditioned by whether a practice in the subset has been adopted or not. These results agree with the conditional and unconditional adoption probabilities reported in table 3 above. The result shows that improved crop variety is complementary with crop-rotation, commercial fertilizer and manure. The correlation between improved crop variety and chemical fertilizer adoption is the highest (41%). On the other hand, manure is a substitute for commercial fertilizer, crop rotation and conservation tillage. The substitution between manure and chemical fertilizer contradicts the finding of Marenya and Barrett (2007) where they found complementarity. The cross-technology correlation may have an important policy implication in that a policy change that affects one SAP can have spillover effects to other SAPs.

[Table 4]

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[9] The results are obtained with a Stata routine due to Cappellari and Jenkins (2003).

[10] For comparison, we also estimated five independent random effects univariate probits. For readability the results are not shown here but are available upon request. In brief, the qualitative results are similar with MVP results.

Furthermore, the MVP coefficient estimates (Table 5) show that the estimated coefficients differ substantially across the equations, indicating the appropriateness of differentiating between practices. In order to formally test this, we estimated a constrained specification with all slope coefficients forced to be equal. The likelihood ratio test statistic was ($\chi^2(168)=$ 1516.41, p=0.000), decisively rejecting the null hypothesis of equal-slope coefficients. This result strongly indicates the heterogeneity in adoption of SAPs and, consequently, supports a separate analysis instead of aggregating them into one SAP variable.

[Table 5]

The MVP model results show that the spouse's (woman's) education level has a positive impact on the adoption of commercial fertilizers and conservation tillage. The result is of particular interest in developing countries where the role of women in agricultural investment and/or farm planning business is not widely recognized.

The mode of transportation to output market influences the likelihood of adoption of improved variety and conservation tillage. Households which use a vehicle, bicycle, or cart are more likely to adopt improved variety and conservation tillage. This suggests that improving the road infrastructure and access to a public transportation system is important in facilitating adoption, through facilitating product transport, reducing the cost of the farmer's time and enabling him to obtain timely market information.   However, we should note that owning a means of transportation and using public transport may also have   a wealth or liquidity effect in the sense that those who own a means of transportation and are able to use public transport may also have more cash income to finance the purchase of technologies. The impact of transaction costs related to the distance from residence to input market has a mixed effect. Distance to the input market has a negative and significant effect on the adoption of improved crop varieties. This is the usual inverse relationship between input demand and transaction costs. It reflects the difficulty of remote households in accessing and implementing new technologies. Distance to the input market, on the other hand, has a

positive and significant effect on the adoption of conservation tillage practices. This is probably because as transaction costs to the input market increase, farmers may opt for a non-external inputs option such as conservation tillage practice.

Wealth, as measured by the value of major household and farm equipment influences positively the adoption of modern crop varieties, commercial fertilizer and conservation tillage. This is probably because wealthier farmers may have the capacity to purchase external inputs and may be more able to take risks. Similarly, livestock ownership positively influences the adoption of manure farming because livestock waste is the single most important source of manure for small farms in most parts of Ethiopia. This finding is in agreement with that of Marenya and Barrett (2007), and is an indication of the positive complementarity between livestock and crop enterprises as a means of generating synergetic production with the goal of utilizing the products of one for the growth of the other (Marenya and Barrett, 2007; Hilimire, 2011). Credit constraint negatively influences investment in modern crop varieties and commercial fertilizers, and this suggests that liquidity-constrained households (those who need credit but are unable to find it) are less likely to adopt SAPs that require cash outlay.

The results further underscore the importance of rainfall and plot-level stresses (pests or disease, waterlogging and frost) in explaining adoption of SAPs. A higher value of the rainfall index is a positive occurrence, and thus the probability of adoption of commercial fertilizer and crop-rotation is high in areas/years where rainfall is reliable in terms of timing, amount and distribution. Kassie et al., (2010) and Pender and Gebremedhin (2007) found that commercial fertilizers provide a higher crop return per hectare in wetter areas than in drier areas and suggest the need for careful agro-ecological targeting in the development, promotion and scaling up of sustainable practices. Similarly, adoptions of crop rotation and modern crop varieties are negatively and significantly influenced by waterlogging and frost

stress. The incidence of pest and disease attacks influences positively the adoption of conservation tillage practice.

The hypothesis that social capital affects positively the probability of the adoption of SAPs is confirmed. The probability of adopting crop-rotation and conservation tillage practices is affected by a households' participation in a rural institution or group, and by the number of relatives inside and outside the village that farmers can rely on for critical support in times of need.   Likewise, adoption of crop rotation, modern crop varieties and manure farming increases with the number of traders inside and outside the village. With scarce or inadequate information sources and imperfect markets, social networks such as traders and farmers' associations or groups facilitate the exchange of information, and enable farmers to access inputs on schedule and overcome credit constraints. This finding suggests that in order to enhance the adoption of maize technology, local rural institutions and service providers need to be supported because they can effectively assist farmers in providing credit, inputs, information, and stable market outlets.

Those households who trust in government support when crops fail are likely to adopt modern crop varieties and commercial fertilizer, probably because the benefit of new technology is uncertain, and farmers want to have insurance if they adopt new technologies. On the other hand, those who have less trust in government support are more likely to adopt practices that use local resources such as manure. The results also reveal that more highly-skilled extension agents enhance the likelihood of the adoption of conservation tillage practice. This practice is relatively knowledge-intensive and requires considerable management input. However, the frequency of extension contact has no impact on adoption of this practice. This may indicate that it is not the frequency of extension contact per se which affects adoption, but the quality of the extension services.

Consistent with earlier work on technology adoption (e.g., Kassie et al., 2010; Jansen et al., 2006) land tenure influences the adoption of the use of animal manure, which is more common on owner-cultivated plots than on rented plots. This may be due to tenure insecurity. Given the fact that the benefits from long-term investments (e.g. manure) accrue over time, this inter-temporal aspect suggests that secure land access or tenure will impact positively on adoption decisions.

With respect to plot characteristics, the analysis shows that the use of commercial fertilizers is less likely on plots with good soil quality, while the use of manure is more likely. The propensity to adopt commercial fertilizers is more likely on plots with a steep slope, while the practice of conservation tillage is more likely on flat plots. However, the probability of the adoption of commercial fertilizers increases on distant flat plots (see interaction term). The result suggests the tradeoff of using commercial fertilizers on steep nearby plots and distant flat plots. Although the use of fertilizers on distant flat plots can prevent nutrient erosion, it can increase transaction costs. A similar result is found on the adoption of improved crop varieties.

4.2.2 Number of SAPs adopted: Ordered probit results

The estimation results of the pooled- and random-effects ordered probit model are given in table 6. Although the magnitude of coefficients is slightly different, the same variables were significant in both models.[11] The discussion of results is based on the pooled ordered probit model. [12]

[Table 6]

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[11] The null hypothesis that the inter-plot correlation ($\rho = \sigma_\eta / (\sigma_\eta + \sigma_e)$, where in the probit model σ_ε is close to 1) coefficient is zero is rejected $[\rho = 0.392(p = 0.000)]$. This result suggests the plot variance component is not negligible and consequently the random effects model is justified.
[12] The stata package does not have a command to compute marginal effects from the random effect ordered probit model.

The chi-squared statistic for the ordered probit model is 286.35 and is statistically significant, indicating that the joint test of all slope coefficients equal to zero is rejected. Results reveal that the number of SAPs adopted increases with family size and decreases with the age of the head of household. As in the adoption decision, the spouse's education level has a significant and positive effect on the level of SAP use. Each additional year of education of the spouse increases the probability of adopting more than two SAPs by 1.3%. The dummy variable for means of transportation to output market is significant and has a negative sign in the number of SAPs adopted. Farmers who do not have their own means of transportation or access to public transport are 9% less likely to adopt more than two SAPs.

Social capital variables such as a household's membership of a rural institution, a kinship network, and trust in traders, have a significant and positive effect on the number of SAPs used, with varying marginal probability effect however. If a household is a member of a rural institution or group, the probability of adopting more than two SAPs increases by 11%. As the number of relatives and traders known by the farmer increases, he is 0.3% and 0.6% more likely to adopt two or more SAPs, respectively. Extension contact on the practice of crop rotation has a positive marginal probability effect (0.6%) for adopting more than two SAPs. The value of the household's assets influences positively the adoption of more than two SAPs in farming plots. Note that in table 2 improved crop variety and commercial fertilizer are predominantly found in each mix of more than two SAPs. This result is consistent with the positive effect of wealth on the likelihood of adoption of SAPs. Households that experience plot-level stresses such as the incidence of frost and hailstorms are 8% less likely to apply more than one SAP on their farming plot than households who have not experienced these. Consistent with the probability of adoption of SAPs, a farmer's perception of government support in case of crop failure plays an important role in the number of SAPs adopted. In the study area, farmers who rely on governmental support during adverse conditions are 20% more likely to adopt more than two SAPs on their farms. The effect of this variable seems to

be more important on the adoption of externally purchased SAPs (such as improved seeds and commercial fertilizers).

Plot-related variables, such as plot access as measured by plot distance to residence, have a negative impact on the number of SAPs adopted. An increase of 10 minutes in the walking distance to the plot decreases adoption of more than two SAPs by 1%. Farmers are more likely to apply a greater number of SAPs on plots with shallow or medium-deep soil than on plots with deep soil, and on plots with poor soil rather than on plots with good or medium soil quality. These plots may need a combination of different types of SAPs to increase productivity.

5. Conclusions and implications

Increasing and sustaining agricultural productivity through investment in sustainable agricultural practices is important for the reduction of hunger and poverty in Ethiopia. In this study, we analyzed the probability and level of adoption of multiple SAPs by smallholder farmers in Ethiopia using plot-level observations. We used multivariate probit and ordered probit models to identify the factors that facilitate or impede the probability of the adoption of SAPs and the number of SAPs adopted on the plot. Our approach extends the existing empirical studies by allowing for correlations across SAPs and including new policy-relevant variables that affect adoption decisions.

The results show that there is a strong complementarity and substitutability between SAPs, indicating the interdependence of SAP adoption. Studies that consider the adoption of multiple SAPs in isolation could lose important cross-technology correlation effects, and potentially yield biased estimates. The cross-technology correlation may have important policy implications in that a policy change that can affect one SAP can have spillover effects to other SAPs.

Most importantly, the results show that the probability and extent of adoption of SAPs are influenced by several factors: social capital in the form of membership of rural institutions, credit constraint, spouse education, asset ownership, distance to markets, mode of transportation, rainfall and plot-level disturbances, the number of relatives and traders known by the farmer inside and outside his village, the farmer's belief in government support during crop failure, and confidence in the skill of extension agents. With respect to socio-demographic characteristics, the age of the household head and the size of the family influence the number of SAPs adopted.

The significant role of social capital on adoption suggests the need for establishing and strengthening local institutions and service providers to accelerate and sustain technology adoption. In a country where there is information asymmetry and where both input and output markets are missing or incomplete, local institutions can play a critical role in providing farmers with timely information, inputs (e.g., labor, credit, insurance) and technical assistance.

The importance of the value of assets and the availability of credit in influencing the purchase of inputs (crop varieties and fertilizer) calls for improving the credit delivery system in the country. Livestock ownership influences the adoption of the use of manure. 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.

The effects of rainfall disturbance on commercial fertilizer and maize-legume rotation adoption are also an important finding for targeting technologies, and for understanding the need to provide rainfall information in terms not only of amount but also of timing and distribution. Furthermore, the use of SAPs is associated positively with the farmer's reliance on government support during crop failure. This suggests that investment in public safety-net programs (public insurance) and risk-protection mechanisms can be expected to have a

positive impact on the adoption of SAPs. Investment in rural public education with special focus on women will facilitate the adoption of technologies and practices.

Finally, while there is ample evidence from on-station and on-farm experiments on the impact of SAPs on productivity (Nzabi et al., 2000; Bloam et al., 2009; Rockstrom et al., 2009; Ghosh et al., 2010), little is known about the associated effects under smallholder farmers' conditions. Although the results of this study can provide a useful insight for policy makers, further research that examines the productivity, risk, environmental, and welfare implications of the adoption of individual SAPs and combinations of SAPs, is important in filling the knowledge gap and in bringing a profound influence to bear on the formulation of farm policies.

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Table 1.   Definitions and summary statistics of the variables used in the analysis

Variables	Description	Mean	Std. Dev.
Household and farm characteristics			
FAMLYSZIE	Family size	6.84	2.83
SEX	1=if sex of the head is male	0.92	0.28
AGE	Age of the head	41.63	13.35
EDUCATHEAD	Years of education of the head	3.42	3.42
EDUCATSPOUS	Years of education of the spouse	1.41	2.85
PLOTDIST	Plot distance from home, minutes	11.26	27.43
RENTDPLT	1=if rented plot	0.15	-
SHALDEPT	1=if shallow depth of soil	0.20	-
MEDMDEPT	1=if medium depth of soil	0.44	-
GODSOIL	1=if good soil quality	0.40	-
MEDMSOIL	1=if medium soil quality	0.51	-
FLATSLOP	1=if flat plot slope	0.62	-
MEDMSLOP	1=if medium slope plot	0.33	-
Resource constraints			
FARMSIZE	Farm size, ha	2.22	2.88
ASSETVALUE	Total value of assets, Birr[13]	19543.41	50331.33
OTHERINCOM	1=if the household earns other income and transfers	0.65	-
TLU	Livestock herd size (tlu)	12.38	12.18
CREDIT	1=if credit is a constraint (credit is needed but unable to get)	0.30	-
Market access			
MEANSTRANS	1=if walking to marketing as means of transportation	0.44	-
WALKDIST	Walking distance to input markets, minutes	59.80	56.63
Social capital			
RELATIVE	Number of close relatives living in and outside the village	10.09	11.35
KNOWTRUST	Number of grain traders that farmers know and trust	2.45	4.00
MEMBER	1=if member in input/marketing/labor rural institutions/group	0.24	-
Extension service			
EXTMAZLEG	Frequency of extension contact on maize/legume varieties, days/year	7.26	18.13
EXTPEST	Frequency of extension contact on pest control, days/year	3.01	9.14
EXTROTAT	Frequency of extension contact on crop rotation, days/year	2.95	8.08
EXTTILAGE	Frequency of extension contact on tillage practices, days/year	3.37	12.39
CONFDNT	1=if confident with skills of extension workers	0.82	-
Stresses			
RAININDEX	Rainfall index (1= best)	0.52	0.30
PESTSTRES	1=if pest and disease stress	0.12	-
WATRLOGG	1=if water logging/drought stress	0.22	-
FROSTSTRES	1=if frost/hailstorm stress	0.06	-
RELYGOVT	1=if rely on government support in case of crop failures	0.39	-
Location dummies			
WESTSHOA	1=if west Shewa zone	0.21	-
EASTWELEGA	1=if east Welega zone	0.07	-
WESTARSI	1=if west Arsi zone	0.13	-
HADYA	1=if Hadiya zone	0.11	-
GURAGE	1=if Gurage zone	0.09	-
SIDAMA	1=if Sidama zone	0.10	-
EASTSHOA	1=if east Shewa zone	0.22	-
METEKEL	1=if Metekel	0.08	-

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[13]   1 Birr = 0.059 USD at the time of survey.

Plot observations	1,616
Household bservations	898

Table 2. Joint and marginal probabilities of adoption of SAPs

Percent adopting in:	Joint probability	Marginal				
		Rotation	Variety	Fertilizer	Manure	Tillage
Rotation only	1.58	1.58	-	-	-	-
Modern seed only	2.37	-	2.37	-	-	-
Inorganic fertilizer only	10.62	-	-	10.62	-	-
Manure only	4.92	-	-	-	4.92	-
Conservation tillage only	2.31	-	-	-	-	2.31
Rotation and seed	1.70	1.70	1.70	-	-	-
Rotation and fertilizer	2.31	2.31	-	2.31	-	-
Rotation and manure	1.03	1.03	-	-	1.03	-
Rotation and tillage	1.09	1.09	-	-	-	1.09
Seed and fertilizer	16.02	-	16.02	16.02	-	-
Seed and manure	2.00	-	2.00	-	2.00	
Seed and tillage	2.18	-	2.18	-	-	2.18
Fertilizer and manure	3.52	-	-	3.52	3.52	-
Fertilizer and tillage	5.58	-	-	5.58	-	5.58
Manure and tillage	3.16	-	-	-	3.16	3.16
Rotation, seed, fertilizer	4.25	4.25	4.25	4.25	-	-
Rotation, seed, manure	0.61	0.61	0.61	-	0.61	-
Rotation, seed, tillage	0.73	0.73	0.73	-	-	0.73
Rotation, seed, manure	0.49	0.49	-	0.49	0.49	-
Rotation, fertilizer, tillage	2.18	2.18	-	2.18	-	2.18
Rotation, manure, tillage	0.49	0.49	-	-	0.49	0.49
Seed, manure, tillage	1.40	-	1.40	-	1.40	1.40
Seed, fertilizer, manure	4.31	-	4.31	4.31	4.31	-
Seed, fertilizer, tillage	9.65	-	9.65	9.65	-	9.65
Fertilizer, manure, tillage	0.91	-	-	0.91	0.91	0.91
Rotation, seed, manure, tillage	0.55	0.55	0.55	-	0.55	0.55
Rotation, seed, fertilizer, manure	1.40	1.40	1.40	1.40	1.40	-
Rotation, seed, fertilizer, tillage	3.52	3.52	3.52	3.52	-	3.52
Rotation, fertilizer, manure, tillage	0.67	0.67	-	0.67	0.67	0.67
Seed, fertilizer, manure, tillage	1.27	-	1.27	1.27	1.27	1.27
All five	0.61	0.61	0.61	0.61	0.61	0.61
None (plot not received any of the practices)	6.61	-	-	-	-	-
Total	100.00	23.21	52.57	67.31	27.34	36.30

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Table 3. Unconditional and conditional adoption probabilities

	Rotation	Seed	Fertilizer	Manure	Tillage
$P(Y_k = 1)$	0.232	0.525	0.673	0.273	0.363
$P(Y_k = 1\|Y_R = 1)$	1	0.576*	0.665	0.251	0.424**
$P(Y_k = 1\|Y_V = 1)$	0.254	1	0.781***	0.231**	0.379
$P(Y_k = 1\|Y_F = 1)$	0.229	0.610***	1	0.196***	0.362
$P(Y_k = 1\|Y_M = 1)$	0.213	0.444***	0.482***	1	0.331
$P(Y_k = 1\|Y_T = 1)$	0.271**	0.548	0.672	0.249	1
$P(Y_k = 1\|Y_R = 1, Y_V = 1)$	1	1	0.732*	0.236	0.405
$P(Y_k = 1\|Y_R = 1, Y_F = 1)$	1	0.634***	1	0.205**	0.453***
$P(Y_k = 1\|Y_R = 1, Y_M = 1)$	1	0.542	0.542***	1	0.396
$P(Y_k = 1\|Y_R = 1, Y_T = 1)$	1	0.549	0.710	0.235	1
$P(Y_k = 1\|Y_V = 1, Y_F = 1)$	0.238	1	1	0.185***	0.315
$P(Y_k = 1\|Y_V = 1, Y_M = 1)$	0.260	1	0.627	1	0.306
$P(Y_k = 1\|Y_V = 1, Y_T = 1)$	0.271	1	0.756***	0.192***	1
$P(Y_k = 1\|Y_F = 1, Y_M = 1)$	0.240	0.576	1	1	0.263***
$P(Y_k = 1\|Y_F = 1, Y_T = 1)$	0.286**	0.617***	1	0.141***	1
$P(Y_k = 1\|Y_M = 1, Y_T = 1)$	0.255	0.422***	0.383***	1	1
$P(Y_k = 1\|Y_R = 1, Y_V = 1, Y_F = 1)$	1	1	1	0.205**	0.422
$P(Y_k = 1\|Y_R = 1, Y_V = 1, Y_T = 1)$	1	1	0.764*	0.213	1
$P(Y_k = 1\|Y_R = 1, Y_V = 1, Y_M = 1)$	1	1	0.635	1	0.365
$P(Y_k = 1\|Y_R = 1, Y_F = 1, Y_M = 1)$	1	0.635	1	1	0.404
$P(Y_k = 1\|Y_R = 1, Y_F = 1, Y_T = 1)$	1	0.591	1	0.183**	1
$P(Y_k = 1\|Y_R = 1, Y_M = 1, Y_T = 1)$	1	0.500	0.553	1	1
$P(Y_k = 1\|Y_V = 1, Y_F = 1, Y_M = 1)$	0.264	1	1	1	0.248***
$P(Y_k = 1\|Y_V = 1, Y_F = 1, Y_T = 1)$	0.274	1	1	0.125***	1
$P(Y_k = 1\|Y_V = 1, Y_M = 1, Y_T = 1)$	0.302	1	0.492***	1	1
$P(Y_k = 1\|Y_F = 1, Y_M = 1, Y_T = 1)$	0.368**	0.544	1	1	1
$P(Y_k = 1\|Y_V = 1, Y_F = 1, Y_M = 1, Y_T = 1)$	0.323	1	1	1	1
$P(Y_k = 1\|Y_R = 1, Y_F = 1, Y_M = 1, Y_T = 1)$	1	0.476	1	1	1
$P(Y_k = 1\|Y_R = 1, Y_V = 1, Y_M = 1, Y_T = 1)$	1	1	0.526	1	1
$P(Y_k = 1\|Y_R = 1, Y_V = 1, Y_F = 1, Y_T = 1)$	1	1	1	0.147**	1
$P(Y_k = 1\|Y_R = 1, Y_V = 1, Y_F = 1, Y_M = 1)$	1	1	1	1	0.303

Y_k is a binary variable representing the adoption status with respect to practice k (k = Rotation (R), seed variety (V), fertilizer (F), manure (M), conservation tillage (T)).

*, ** and *** indicate statistical significance difference at 10, 5 and 1% respectively. The comparison is between unconditional probability and conditional probability in each practice.

Table 4. Estimated covariance matrix of the regression equations (standard errors in parenthesis) between SAPs using the MVP joint estimation model

	ρ_R	ρ_V	ρ_F	ρ_M
ρ_V	0.117 (0.044)***			
ρ_F	0.066 (0.064)	0.408 (0.057)***		
ρ_M	-0.091 (0.049)*	0.115 (0.046)***	-0.460 (0.059)***	
ρ_T	0.047 (0.054)	-0.001 (0.048)	0.051 (0.067)	-0.083 (0.047)*

Likelihood ratio test of: $\rho_{RV} = \rho_{RF} = \rho_{RM} = \rho_{RT} = \rho_{VF} = \rho_{VM} = \rho_{VT} = \rho_{FM} = \rho_{FT} = 0$

$$\chi^2 (10) = 119.553$$

Prob> 0.0000

*,** and *** indicate statistical significance at 10, 5 and 1% respectively

Table 5. Multivariate probit model results (Robust standard errors)

Variables	Rotation Coeff	SE	Variety Coeff	SE	Fertilizer Coeff	SE	Manure Coeff	SE	Tillage Coeff	SE
Household and farm characteristics										
FAMLYSZIE	-0.008	0.017	0.048	0.016	-0.006	0.026	0.028	0.017	0.019	0.020
SEX	0.026	0.139	0.181	0.146	0.308	0.216	-0.159	0.144	-0.052	0.161
AGE	-0.005	0.004	-0.001	0.003	-0.002	0.005	-0.002	0.003	0.0001	0.004
EDUCATHEAD	0.001	0.014	-0.002	0.013	0.017	0.021	-0.006	0.013	-0.023	0.016
EDUCATSPOUS	0.015	0.015	0.019	0.014	0.072***	0.026	-0.001	0.012	0.036**	0.017
DIST	-0.018	0.014	-0.008	0.010	-0.011	0.010	0.013	0.011	0.005	0.008
RENTD	0.073	0.372	0.359	0.357	0.439	0.318	-0.902*	0.520	-0.057	0.352
SHALWDEPT	0.104	0.113	0.005	0.106	0.297*	0.168	0.081	0.115	0.199	0.130
MEDUMDEPT	0.176*	0.098	0.134	0.090	0.173	0.136	0.066	0.094	0.138	0.115
GOODSOL	-0.027	0.179	-0.167	0.154	-0.514***	0.207	0.358**	0.167	-0.317*	0.173
MEDMSOL	-0.076	0.180	-0.092	0.146	-0.281	0.201	0.234	0.167	-0.274	0.172
FLATSLOP	0.225	0.203	-0.126	0.176	-0.796**	0.279	0.321	0.224	0.325*	0.188
MEDMSLOP	0.102	0.209	-0.244	0.180	-0.634**	0.279	0.172	0.228	0.463***	0.186
GODSOL X DIST	0.021*	0.013	-0.018**	0.008	-0.006	0.011	-0.007	0.007	-0.001	0.006
MEDMSOL X DIST	0.018	0.013	-0.014*	0.008	-0.008	0.009	-0.012	0.008	-0.001	0.006
RENTD X GODSOL	0.141	0.402	-0.145	0.391	0.066	0.378	0.175	0.557	0.055	0.387
RENTDX MEDSOL	-0.191	0.397	-0.228	0.371	-0.019	0.382	0.595	0.546	-0.172	0.388
FLATSLP X DIST	-0.006	0.012	0.024**	0.011	0.021**	0.011	-0.012	0.011	-0.004	0.008
MEDMSLP X DIST	0.002	0.012	0.028***	0.011	0.016	0.011	-0.027*	0.016	-0.002	0.008
Market access and resource constraints										
MEANSTRANS	-0.060	0.086	-0.157**	0.083	-0.124	0.101	0.034	0.084	-0.292***	0.104
WALKDIST	-0.001	0.001	-0.001*	0.001	0.000	0.001	0.0001	0.001	0.002*	0.001
FARMSIZE	-0.034	0.034	-0.001	0.014	0.009	0.029	-0.025	0.018	0.013	0.017
ASSETVALUE	0.172	0.860	1.562**	0.806	7.932***	1.956	-1.248	0.912	3.493***	1.488
OTHERINCOM	0.192**	0.098	-0.069	0.082	-0.143	0.128	0.112	0.085	-0.070	0.108
TLU	0.002	0.005	-0.004	0.003	0.002	0.008	0.012***	0.005	-0.002	0.006
CREDIT	-0.078	0.102	-0.170**	0.092	-0.318**	0.166	0.038	0.149	0.023	0.120
Social capital and extensions										
RELATIVE	0.005*	0.003	0.001	0.003	0.003	0.004	-0.004	0.003	0.013***	0.004
KNOWTRUST	0.017*	0.010	0.019**	0.010	0.006	0.014	0.019**	0.010	0.005	0.012
INPUTMEMBER	0.283***	0.097	0.143	0.099	0.073	0.136	-0.157	0.101	0.364***	0.123
CONFDNT	0.035	0.115	0.061	0.100	0.085	0.127	-0.047	0.098	0.232*	0.134
Stresses										
RAININDEX	0.278*	0.171	-0.230	0.154	0.430**	0.229	0.186	0.150	-0.291	0.188
PESTSTRES	0.081	0.123	0.037	0.125	-0.092	0.179	-0.026	0.119	0.230*	0.137
WATRLOGG	-0.294***	0.116	-0.075	0.101	0.087	0.159	0.010	0.101	-0.022	0.122
FROSTSTRES	-0.117	0.191	-0.430***	0.156	-0.089	0.258	-0.094	0.151	0.020	0.179
RELYGOVT	-0.057	0.092	0.253***	0.082	6.973***	0.381	-0.459***	0.086	-0.009	0.096
CONSTANT	-0.428	0.365	0.339	0.332	-0.549***	0.502	-0.626*	0.356	-0.059	0.401
Joint-significance of location variables: χ^2 (7)	37.06		63.90		96.74		19.13		46.05	
Prob. $> \chi^2$ (7)	0.000		0.000		0.000		0.008		0.000	
Sample size = 1616			Wald χ^2 (221)	= 2302.48;		Prob. $> \chi^2$ = 0.000				

*,** and *** indicate statistical difference at 10, 5 and 1% respectively; SE is robust standard error;   Other non-significant control variables include: EXTMAZLEG, EXTPEST, EXTROTAT EXTTILAGE..

Table 6. Ordered probit results

Variables	Coefficients		Prob(Y=0|X)	Prob(Y=1|X)	Prob(Y=2|X)	Prob(Y=3|X)	Prob(Y=4|X)	Prob(Y=5|X)	Coefficients	
				Marginal effects					Random effects ordered probit model	
FAMLYSZIE	0.025*	(0.014)	-0.002*	-0.006*	-0.001	0.006*	0.003*	0.0002	0.036**	(0.018)
AGE	-0.005*	(0.003)	0.0005*	0.001*	0.0001	-0.001*	-0.001*	0.00005	-0.007*	(0.004)
EDUCATSPOUS	0.036***	(0.009)	-0.003***	-0.008***	-0.001*	0.008***	0.004***	0.0003**	0.044***	(0.013)
MEANSTRANS	-0.248***	(0.070)	0.022***	0.059***	0.005	-0.058***	-0.026***	-0.002**	-0.324***	(0.088)
RELATIVE	0.007***	(0.003)	-0.001***	-0.002***	-0.0002*	0.002***	0.001***	0.0001**	0.008**	(0.003)
KNOWTRUST	0.021***	(0.007)	-0.002***	-0.005***	-0.001*	0.005***	0.002***	0.0002**	0.025***	(0.008)
INPUTMEMBER	0.301***	(0.089)	-0.023***	-0.069***	-0.016**	0.070***	0.036***	0.003**	0.425***	(0.114)
EXTROTAT	0.017***	(0.007)	-0.001**	-0.004***	-0.0004	0.004***	0.002***	0.0001**	0.018**	(0.009)
ASSETVALUE (10^{-6})	2.268***	(0.697)	-0.199***	-0.537***	-0.058*	0.533***	0.241***	0.020**	3.006***	(0.890)
FROSTSTRES	-0.228**	(0.112)	0.024*	0.055**	-0.003	-0.053**	-0.021**	-0.002**	-0.227*	(0.136)
RELYGOVT	0.551***	(0.069)	-0.046***	-0.126**	-0.023***	0.126***	0.063***	0.006***	0.855***	(0.090)
DIST	-0.002*	(0.001)	0.0001*	0.0004*	0.00004	-0.0004*	-0.0002*	-0.00002	-0.003**	(0.001)
RENTD	-0.017	(0.079)	0.002	0.004	0.0004	-0.004	-0.002	0.0002	-0.161*	(0.095)
SHALDEPT	0.202**	(0.094)	-0.016***	-0.047**	-0.010	0.047	0.023**	0.002*	0.254**	(0.115)
MEDMDEPT	0.213***	(0.078)	-0.018***	-0.050***	-0.006*	0.050***	0.023***	0.002**	0.236**	(0.096)
GODSOIL	-0.196*	(0.110)	0.018*	0.046*	0.004	-0.046*	-0.020**	-0.002	-0.191	(0.142)
MEDMSOIL	-0.216**	(0.105)	0.019**	0.051**	0.006	-0.051**	-0.023**	-0.002*	-0.217	(0.138)
FLATSLOP	0.177	(0.153)	-0.016	-0.042	-0.003**	0.042	0.018	0.001	0.178	(0.177)
MEDMSLOP	0.138	(0.149)	-0.012	-0.032	-0.005**	0.032	0.015	0.001	0.161	(0.171)
Joint-significance of location variables: $\chi^2(7)$	40.86								49.23	
Prob. $> \chi^2(7)$	(0.000)								(0.000)	
μ_1	-1.757***	(0.293)							-2.331***	(0.371)
μ_2	-0.660**	(0.289)							-0.912**	(0.359)
μ_3	0.495*	(0.291)							0.561	(0.356)
μ_4	1.560***	(0.295)							1.921***	(0.358)
μ_5	2.742***	(0.324)							3.444***	(0.390)
Log-likelihood	-2154								-2089	

*, ** and *** the null-hypothesis is rejected at a level of significance of $p = 0.10$, 0.05 and 0.01. Figures in parenthesis are robust standard errors; Other non-significant control variables include: SEX, EDUCATHEAD, WALKDIST, EXTMAZLEG, EXTPEST, EXTTILAGE, CONFDNT, FARMSIZE, OTHERINCOM, TLU, CREDIT, RAININDEX, PESTSTRES, WATRLOG.

Fig 1. Cumulative distribution for the impact of crop rotation on   maize net income
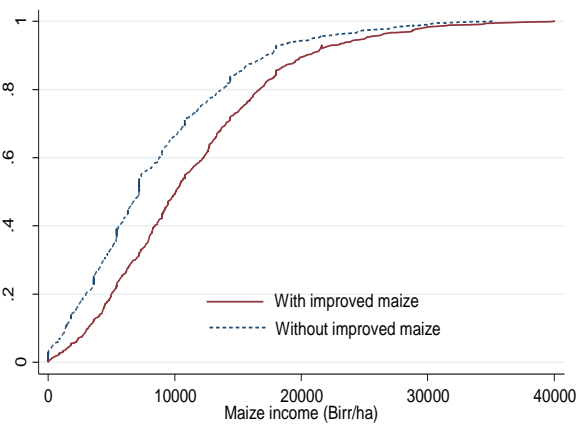
Fig 2. Cumulative distribution for the impact of improved crop seed on   maize net income
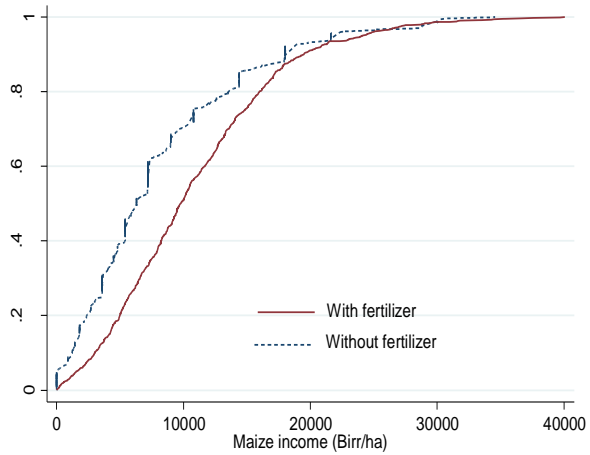
Fig 3. Cumulative distribution for the impact of inorganic fertilizer on maize net income
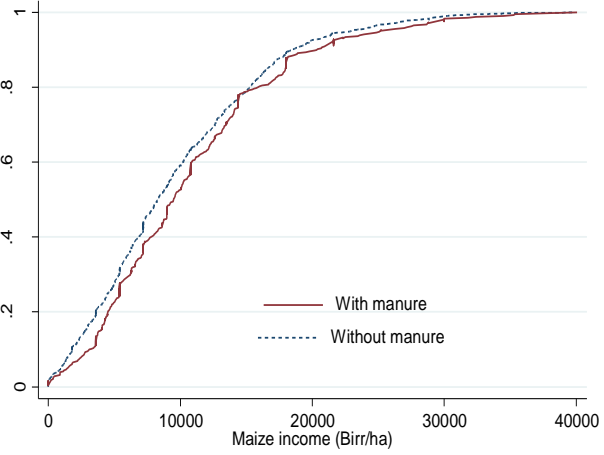
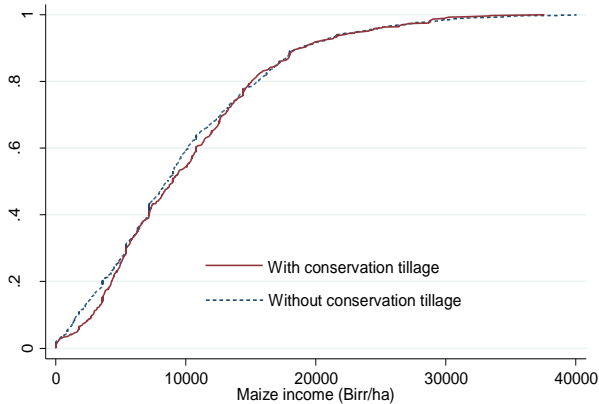Fig 4. Cumulative distribution for the impact of manure use on maize net income

Fig 5. Cumulative distribution for the impact of conservation tillage on maize net income