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Adoption and economics of multiple sustainable intensification practices in Ethiopia: Evidence from panel data

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Abstract

This paper examines adoption and impacts of combinations of cropping system intensification practices - cropping system diversification, conservation and modern varieties - using nationally representative panel farm household survey data collected in 2010 and 2013 in Ethiopia. We adopted a multinomial endogenous switching regression in an impact evaluation framework to control for selection bias caused by observed and unobserved heterogeneities. The results show that conservation tillage, cropping system diversification, and modern varieties increase household income when they are adopted individually as well as in combination. However, the impact is greater when they are adopted in combination. We find 'win-win' outcomes - the highest payoffs and the lowest applications of agro-chemicals - when all these intensification practices are adopted jointly. The results suggest that policies and programs aimed at promoting adoption of multiple cropping system intensification practices can have both economic as well as environmental benefits.

Introduction

Adoption and diffusion of natural resource management practices for the sustainable intensification of food systems has long been and continues to be a major concern in developing countries. It is widely recognized that in Ethiopia, with a predominant agricultural base economy, a growing population will demand a substantial increase in food production than the country has ever produced before. Meeting this demand will put a pressure on the agricultural resource base that is already under significant strain. Unsustainable farming activities have severely depleted soil nutrients throughout much of the Sub-Saharan Africa region (Sanchez 2002, FAO 2003). Addressing these challenges effectively require pursuing strategies on adopting various agronomic practices to build sustainable agricultural systems which leverage the available natural resources and underpin agriculture to deliver output growth and environmental sustainability (Pretty 1999; FAP 2011; Montpellier Panel 2013; Abraham et al 2014). The application of sound agricultural intensification practices is an increasingly important component of such investment for retaining ecological integrity and ensuring that the food systems are resilient enough to absorb shocks and stresses and avoid degradation of land and water resources (World Bank 2006).

One desirable goal of sustainable agricultural intensification is the ability to increase water retention in soils and manipulate soil organic matter dynamics via management practices to help soil conservation, to ensure the sustainable productivity of agro-ecosystems, and to increase the capacity of the soils to act as a sink for, rather than a source of, atmospheric carbon (Fernandes et al. 1997; Pretty, 1999; Lee, 2005; Woodfine, 2009; Snapp et al. 2010; Jhamtani, 2011). To be sustainable, an agroecosystem requires production systems that are resilient to natural stressors such as disease, pests, drought, and low soil fertility (Heinemann et al., 2013). The key principles for sustainability are in fact to integrate biological and ecological process such as nutrient recycling, nitrogen fixation, soil regeneration, predation and parasitism into food production processes; and minimize the use of non-renewable (Altieri, 1995; Pretty, 1999; Abraham et al., 2014). Environmental benefits of sustainable agricultural intensification include, among others, improved water quality and pollination due to reduced agro-chemical use, better carbon sequestration, enhanced biodiversity and improved soil condition (Uematsu and Mishra, 2012).

The concern about sustainable intensification of the agricultural system has brought attention on the Millennium Development Goals that specifically target the reduction of poverty where poverty is explicitly linked to the environment and the sustainable management of land and natural resources. Sustainable agricultural intensification is fundamental to ensuring adequate food and fiber production there by a sustainable and increasingly productive agricultural base is essential for household food security (World Bank 2006; Wollni et al., 2010). Amid the consideration of sustainable agricultural intensification for their various contribution and the potential constraints to expand sustainable farming, the importance of adoptions of multiple intensification agronomic practices on farm income and their effect on the use of agro-chemicals is generally overlooked in the economics literature.

In this study we highlighted the agricultural production systems in Ethiopia that emphasize nutrient recycling and water management and enhance farm incomes and affect the demand for agro-chemicals – via adoption of modern maize varieties, residue retention conservation tillage and cropping system diversifications. Cropping system diversification as a strategy of reducing risk by planting different crop species can stabilize yields over the long term, provide a range of dietary nutrients, and maximize returns with low levels of technology and limited resources. In drought-prone areas using low-input regimes with little supplemental water, these characteristics maximize labor efficiency per unit area of land, minimize the risk of catastrophic crop failure due to drought or severe pest attack, and guarantee the availability of food at medium to high levels of species productivity (World Bank, 2006). In most developing countries, the levels of organic matter using crop residues and other forms of plant biomass which have other priority uses are often insufficient. Under these conditions, conservation or minimum tillage significantly reduces soil carbon oxidation following the planting of each crop and can also significantly reduce soil erosion (Pieri et al., 2002). Combining cropping system diversification with conservation tillage can result in significant synergy to increase nutrient and water use efficiencies, suppress weeds, pests and diseases and improve crop productivity (Piha, 1993). The availability of modern technology such as modern crop varieties that are able to adapt and be productive under climate change scenarios will be especially important to enhance total agricultural biomass for farmers.

In the past few years, researchers have progressively extended the technology adoption theory in both static and dynamic dimensions to account for a richer variety of technology adoption behaviors (see the surveys in Feder et al., 1985; Doss, 2006; Knowler and Bradshow, 2007). One salient area of research on technology adoption that is not studied very well is that of multiple technology adoption (Teklewold et al., 2013; Wu and Babcock, 1998). One of the most interesting aspects of multiple technology adoption is the motivation behind the decision to adopt more than one technology. Adoption of a combination of technologies is quite common in many farming systems to address multiple constraints such as weeds, pest and disease infestations, and low soil fertility (Dorfman, 1996; Khanna, 2001, Moyo and Veeman, 2004). Khanna (2001) pointed out that recognition of the inter-relationships between multiple technologies while analyzing their adoption decisions is important for obtaining consistent impact estimates of adoption. Modeling technology adoption and impact analysis in a multiple technology choice framework is therefore important to understand the processes, determinants, and impacts of technology options (Dorfman, 1996). A better understanding of the effect of combination of intensification practices on farm income and demand for agrochemicals can inform policies for sustainable agricultural intensification.

Because the commitment to sustainable agricultural system is becoming an important agenda for central and local policy makers in Ethiopia (Holden and Lunduka 2012; Snapp et al., 2010; Abraham et al 2014), much effort has been devoted to evaluation of adoption and impacts of sustainable agricultural intensification (Gebremedhin and Scott, 2003; Kassie et al. 2010; 2011; Teklewold et al., 2013). While the empirical literature on technology adoption is relatively rich for Ethiopia, evidence is considerably more limited on a single cross-sectional data which do not allow analyzing the various aspects of adoption and impacts of multiple cropping intensification practices by controlling for the confounding effects of household level unobservable. If unobserved individual specific (and time constant) effects affect the outcome variable, and are correlated with the model regressors, regression with cross sectional data analysis does not identify the parameters of interest (Dustmann, and Rochina-Barrachina 2007). The estimated parameters are likely to be biased as a consequence of failing to control potential endogeneity caused by time-invariant unobservable household specific effects. Controlling for unobserved heterogeneity helps to achieve more accurate prediction. Considerably, less attention has also been paid to provide a detail analysis on long term impact to enable us to better understand the effects of various combinations of intensification practices and to establish a strong and robust empirical basis for improved agricultural management.

Therefore, building on Teklewold et al (2013) to motivate the empirical work in the context of a multiple technology adoption model, this paper aims to contribute to adoption and impact literature using a comprehensive nationally representative panel data collected in 2010 and 2013. We specifically evaluate the impact of combinations of multiple intensification practices (such as cropping system diversification, conservation tillage, modern seeds and inorganic fertilizers) on net farm income (net of fertilizer, seeds, pesticides and hired labour) and N fertilizer and pesticides (agro-chemicals) use..

We use recent development in econometrics to model observed and unobserved individual heterogeneity in a panel data setting. This household and plot panel nature of the data allows us to control for time-invariant household, community, and institutional characteristics using a household fixed effects models. In addition we extend binary sample selection method to panel data multinomial sample selection to control potential sample selection bias. From our econometric estimates, we compute the average net crop income effects for each combination of SIPs. We confirm the results of previous study. A combination of intensification practices has improved household income with lower demands for agro-chemicals. This result has important policy implications for designing technology generation and promotion.

Data and Descriptive Statistics

The data source for this study is the two rounds of the Ethiopia farm household survey conducted in 2010 and 2013. The survey were carried out by the International wheat and maize improvement center (CIMMYT) in conjunction with Ethiopian Institute of Agricultural Research (EIAR) through the 'Sustainable Intensification of Maize-Legume Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA) program. The surveys were designed to study options for production and technology adoption constraints in Ethiopia using detailed data on production and other socio-economic characteristics at household, plot, and village level for the 2009/2010 and 2012/2013 cropping season. The survey covered around 1,534 households with an average of 2.99 maize plots in 2010 and 1,444 households with 2.75 maize plots in 2013 respectively[1].

The survey asked farmers about the various intensification practices for each plot in both years. Our dependent variable in this study include legume-maize intercropping and crop rotations, which we call cropping system diversifications (D), minimum tillage (T) defined as either reduced tillage (only one oxen-plough pass) or zero tillage combined with letting the residue remain on the plot and improved maize seeds (V). Descriptive statistics of the three practices considered in both years is presented in Table 1. Of the total maize plots, cropping system diversification is adopted on 17% of the plots in 2010 and increased to half of the plots in 2013. This increase is most striking. Almost 30% of the maize plots received minimum

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[1] See Kassie et al (2015) for detailed sampling procedures.

tillage practice in 2010, but this coverage is reduced lower than 20% in 2013. Among maize growing plots, the proportion of plots with improved maize seeds. All differences between the two years are statistically significant at the 1% level.

Table 2 presents the different combinations of cropping intensification practices and presents the proportion of adoption in both countries. Analysis of adoption of the three intensification practices lead to eight combinations from which the farmer able to choose. Of the total maize plots in Ethiopia about 26% didn't receive any of the intensification practices ($V_0D_0T_0$) in 2010. But this rate is significantly reduced to 11% in 2013. Contrary to this, simultaneous adoption of all practices ($V_1D_1T_1$) increases from 3% in 2010 to 5% in 2013 cropping season. Another interesting result is that adoption of package that contains only improved seed ($V_1D_0T_0$) is significantly decreased respectively from 32% in 2010 to 30% in the 2013 season. However, this adoption rate increases when a farmer adopts a package that contains a combination of improved seeds and cropping system diversification ($V_1D_1T_0$) or both cropping system diversification and conservation tillage ($V_1D_1T_1$).

Table 3 presents the adoption of a given practices conditional on the adoption of a single or combination of other types of practices. The adoption of cropping system diversification decreases conditional on adoption of conservation tillage alone or in combination with improved variety. The same is true for adoption of conservation tillage where its adoption decreases when only cropping system diversification is adopted or when it is combined with improved seed. The result might indicate substitutability between these two practices. This result is of interest to enhance adoption of external inputs such as improved seeds by designing a package of these inputs with other sustainable intensification practices such as conservation tillage and cropping system diversification.

The mobility of individual farm household's in terms of their adoption status can best be described using adoption transition matrix. The transition matrix in Table 4 shows the change in household's adoption status of the three cropping intensification practices between 2010 and 2013 cropping season. Twenty nine percent of farmers who didn't adopt cropping system diversification in 2010, had adopted it in 2013, while around fifty five percent of adopters in 2010 had dis-adopted the practice by 2013. The percentage of continuing adopters and non-adopters of cropping system diversification are 45 and 71, respectively, a fact captured by the immobility index value of 1.16. Similar adoption and dis-adoption situation is also observed for the other practices. The percentage of new entrants to adoption (dis-adoption) of conservation tillage and improved variety between 2010 and 2013 cropping season are 72 (18), 34 (71) and 17(40), respectively. Furthermore, 82 and 29% of adopters of conservation tillage and improved variety, respectively, were still continuing adoption, whereas continuing dis-adoption of conservation tillage and improved variety are observed by 28 and 66% of households during the panel period, respectively. The dependence of household adoption/dis-adoption status of all the crop intensification practices in 2013 on the status in 2010 (and vice versa) is also confirmed by the high Chi-squared value, which allows us to reject the null hypothesis of independence between the two years at the 1% significance level.

The above discussion sheds light on adoption and dis-adoption of system of crop intensification practices; it doesn't dwell on providing information related to factors affecting choice of a single or combination of farming practices. We draw on a rich set of literature on technology adoption to select a comprehensive set of drivers that are known to affect farmers' decision on technology adoption in our econometric analysis (D'Souza et al., 1993; Fuglie, 1999; Neill and Lee, 2001; Arellanes and Lee, 2003; Gebremedhin and Scott, 2003; Lee, 2005; Bandiera, and Rasul, 2006; Marenya and Barrett 2007; Knowler and Bradshaw, 2007; Ricker-Gilbert and Jayne, 2009; Wollni et al., 2010; Kassie et al., 2010; 2011; Holden and Lunduka, 2012). According to this literature, factors affecting adoption and our outcome variables include natural capital (soil depth, slope, fertility); social capital and social protection (membership in input/marketing group, number of traders farmers know and trust, number of relatives outside the village, expected government support in case of crop failure); shocks (plot level crop production disturbances such as pests, diseases, water logging and drought); governance indicator (household confidence in the skills of extension workers); physical capital (farm size, livestock size, farm and household assets); access to services and constraints (distance to main market and input, extension office, access to credit and fertilizer subsidy); human capital (family size, household head education, gender and age); plot distance to dwelling; and location variable (altitude).

Table 5 provides the definitions of the variables used in our analysis and the mean values for the entire sample of maize farms in Ethiopia for the 2010 and 2013 cropping season. The last column in each country box shows *t*-statistics or z-statistics that compare means of the 2010 and the 2013 observations. While most of the variables are straightforward, some may require explanation. We focus on describing those variables that are not common in the adoption and impact literature. A detailed description of these variables is available in Kassie et al. (2012) and Teklewold et al. (2013).

The average proportion of cereal crop area allocated to maize production significantly rises between 2010 and 2013 from 31% to 42% in Ethiopia. A credit constraint is usually common in technology adoption literature. In order to understand whether farmer has access to a source of cash we followed Feder et al. (1990) approach of constructing credit access variable. This measure of credit tries to distinguish between farmers who choose not to use available credit and farmers who did not have access to credit. This idea is often valid on the ground that as 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 credit worthy (Feder et al., 1990; Doss, 2006). In this study, the respondents were asked to respond to the two sequential questions: whether or not they needed credit for farming operations, and, if so, whether or not they obtained the credit they needed. The credit constrained farmers are thus defined as those farmers who needed credit but were unable to get it.

In addition to the basic household characteristics and endowment information collected, each wave of the panels contains variables related to social capital which can influence technology adoption decisions (Isham 2002; Bandiera and Rasul, 2006; Marenya and Barrett, 2007; Kassie et al., 2013). The social capital literature treats social networks and social spillovers, consisting of trust, networks of cooperation, reciprocity and safety-nets, as a means to facilitate the exchange of information, obtain credit, shocks protection and reduction of information asymmetries (Barrett 2005; Fafchamps and Minten 2002). We define three social capital and networks variables: a household's relationship with rural institutions in the village (1 if the household is a member of a rural institution/association and zero otherwise); a household's relationship with trustworthy traders (proxied by the number of trusted traders outside the village whom the respondent knows); and a household's kinship network (measured by the number of relatives that the farmer can rely on in times of need outside the village). Such classification is important, as different forms of social capital and networks may provide different services to farmers. The same characteristics of social capital that can effectively provide the above services might have the potential to cause negative consequences in another situation by acting as a barrier to social inclusion and social mobility; and by dividing rather than unifying communities or societies (Wall et al., 1998; DiFalco and Bulte, 2011). The expected effect of social capital and networks variables on the adoption decision is therefore indeterminate a priori.

Social capital has relational, material and political aspects and therefore cannot be measured by a single indicator (Martin et al., 2004), we distinguished three social networks and capital:- a household's affiliation to rural institutions in the village (1 is if the household is a member of a rural institution/association and 0 if otherwise); a household's network with trustworthy traders (proxied by the number of trusted traders in and outside the village whom the respondent knows); and a household's kinship network (measured by the number of close relatives that the farmer can rely on for support in times of need). Such classification is important as different forms of social capital and networks may affect household food security in various ways such as through information sharing, stable market outlets, labor sharing, the relaxing of liquidity constraints and mitigation of risks.

The political connection variable, reflecting access to social networks, is constructed as 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. Respondents in Ethiopia have lower political connections (around 55% in both survey years) . Connections with local administrators and agricultural officials may lead to better access to technologies, credit, and farm tools supplied by the public institutions and may also have remittance or cash transfer effect. Thus political connections will have a positive effect on the likelihood of adoption but remittance or cash transfer effect may reduce the incentive to work hard, particularly on labor demanding investments such as water and soil conservation measure.

The plot level shock is captured by four most common stresses such as pest and disease pressure; water logging and drought affecting crop production at farm plot level. The individual plot level shocks are constructed to measure the farm-specific experience related to various stresses in the preceding season affecting crop production. The effect of these shocks on the adoption of a combination of system of crop intensification practices depends on the type of practices contained in the set. 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. This contains the elements of protection of shocks which is intended to keep away farmers against risks such as lost income or devastation from crop failures or ensure a minimum level of economic well-being. In most of the developing world where production risks are high due to a number of factors, farmers are less likely to adopt technologies with adverse risk characteristics. If insurance mechanisms such as subsidies and productive safety net programs are available to smooth consumption during crop failure, they can choose farming approaches that have greater risk (but greater returns) because insurance reduces the risk faced by the farmers. In 2010, 73 of households in Ethiopia, respectively, rely on government assistance. Three years later 78% of Ethiopian farmers in the study areas, respectively believe in government support.

Agricultural extension services are the major source through which many agricultural innovations are channeled. We control for different access to extension services by walking distance to the nearest extension offices. However, access to extension services per se may not have a favorable impact on technology adoption, as this depends on the skill of the extension workers and the quality of information provided to farmers. Unlike previous adoption studies, we include respondents' perception of the skill of extension workers in providing the required services, by including a dummy variable that takes a value of one if the farmer indicates confidence in the skill of extension agents and zero otherwise. In 2010, 82% of households, respectively, in Ethiopia are confident with the capabilities of the extension agents; by 2013 this percentage has declined to 76% in Ethiopia.

Econometric framework

In this study we used a multinomial endogenous switching regression model with fixed effects to account for how adoption of an alternative combination of intensification practices impacts on net crop income[2] and agro-chemical use. There are several issues need to be addressed in the econometrics strategy to investigate the role of a combination of intensification practices s on various farm outcome. Adoption of a combination of intensification practices may not be random, but farmers endogenously self-select themselves into adoption/non-adoption decisions, so decisions are likely to be influenced by unobservable characteristics (for example expectation of yield gain from adoption, managerial skills, motivation) that may be correlated with the outcomes of interest. In many problems of applied econometrics, the presence of unobserved heterogeneity in the equation of interest is a problem in the empirical applications. This is a well-known sample selection bias problem where straightforward regression analysis leads to inconsistent estimators. Selection bias is an inevitable problem in many empirical researches that uses retrospective data. Thus requires employing a selection correction method – computing an inverse Mills ratio using the theory of truncated normal distribution (Lee 1983; Bourguignon et al., 2007). The inverse Mill's ratios calculated from

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[2] This is based on the gross value of maize production (but gross value of maize and legume production if there is spatial cropping system diversification) net of fertilizer, seed, pesticides, and hired labor costs.

the multinomial logit models are then added as additional regressors to the outcome equations reducing the bias from not accounting for selection into the adoption decisions.

Secondly, if the unobserved individual effects are correlated with the explanatory variables in the first step then the multinomial logit specification may give inconsistent results. This is likely to be the case as unobserved individual effects such as skills, motivation and sociability are likely to influence the likelihood of adoption of multiple SIPs. Mundlak (1978) proposed a method to overcome this problem that accounts for the correlation between the explanatory variables and the individual effects by modeling the relationship explicitly. This approach takes the group means of the time varying explanatory variables in the adoption equations and includes them as additional explanatory variables in the multinomial logit model as a proxy for removing the time invariant individual effects. Modeling this dependence allows for unbiased estimation of the parameters, regardless of whether or not the explanatory variables, and the individual effects are independent in the equations (Ebbes et al., 2004). In the second step we applied fixed effect regression model in our net farm income estimation.

Following Lee (1983), Dubin and McFadden (1984), Dustmann and Rochina-Barrachina (2007), and Wooldridge (2010) the underlying decision process of cropping system diversification, conservation tillage, inorganic fertilizer and improved maize varieties is explicitly modeled using a multinomial logit model to deal with these sample selection issues. It is assumed that cropping system diversification, conservation tillage and improved maize seeds are jointly determined in a multinomial selection process. To illustrate this multinomial selection process, our sample is partitioned according to eight mutually exclusive combination of cropping system diversification, conservation tillage, inorganic fertilizer and improved maize seeds outcomes (Table 2).

Let y_{it} represent a choice variable that assumes the values 1, 2, . . . , 8 corresponding to the sixteen combination of intensification practices regimes. We can equivalently define indicator variables corresponding to these sixteen regimes: $y_{itj} = 1[y_{it} = j]$. Following Wooldridge (2010; pp 653-654), we specify that $P(y_{it} = j | x_{it}, \varepsilon_{it}) = P(y_{it} = j | x_i, \varepsilon_i)$, j = 1, 2, . . . , 8 is determined according to a multinomial logit model with unobserved individual effects:

$$P(y_{it} = j | x_i, \varepsilon_i) = \frac{\exp(x_i \beta_j)}{\sum_{m=1}^{j} \exp(x_i \beta_j)} \qquad (1)$$

where x_{it} is a vector of observed exogenous variables (household, plot and location characteristics) in the model for which there are observations for $\forall\, i$ and t, x_i is the vector of all observation for x_{it} for the i^{th} individual with the associated parameter of coefficient β_j and ε_i is unobserved heterogeneity. The model is then estimated by a maximum likelihood function (Green 2003).

In the first stage of our panel data estimation of the endogenous switching regression model, we estimate a pooled multinomial logit model augmenting with Mundlak (1978) approach to capture the correlations between regressors and individual effects. From these estimation results we derive the appropriate Inverse Mills Ratio (IMR) variables that will be added as additional explanatory variables in the second stage outcome equations. We followed Wooldridge (2010) in assuming that the conditional distributions of $\varepsilon_i | x_i$ and $\varepsilon_i | \bar{x}_i$ are the same, where $\bar{x}_i$ is time averages of variables in x_i. This equality of conditional distributions implies:

$$P(y_{it} = j | x_i) = P(y_{it} = j | x_{it}, \bar{x}_i) \qquad \forall i \text{ and } t.$$

The assumed multinomial selection model generates probabilities according to:

$$P_{itj} = P(y_{it} = j | x_{it}, \bar{x}_i), \qquad j = 2, \ldots, 8$$

$$= \theta(x_{it}, \bar{x}_i, \beta_j)$$

$$P_{it1} = 1 - \sum_{j=2}^{16} P_{itj}$$

where β_j is the multinomial logit parameter vector for outcome j.

Therefore, the inverse Mill's Ratio (λ_{itj}) is defined as the ratio between the standard normal probability distribution function and the standard normal cumulative distribution function evaluated at each $x_{it}\beta$ for y_{itj}.

Outcome equations

To determine the impact of combination of cropping system diversification, conservation tillage, inorganic fertilizer and improved seeds on outcome (net maize income), the relationship between the outcome variables and a set of exogenous variables *Z* (plot, household and location characteristics) is estimated by fixed effect model for the chosen package. In our packages of intensification practices specification (Table 1), the reference category, i.e., non-adoption of practices ($D_0T_0V_0\,F_0$) is denoted j=1. At least one intensification practice is used in the remaining packages (j=2, . . .,8). The outcome equation for each possible regime *j* is given as:

$$\begin{cases} \text{Regime}\,1: Q_{it1} = Z_{it}\alpha_1 + u_{it1} \quad \text{if } \mathrm{y}_{\mathrm{it}} = 1 \\ \vdots \qquad\qquad \vdots \\ \text{Regime}\,\mathrm{J}: Q_{itJ} = Z_{it}\alpha_J + u_{itJ} \quad \text{if } \mathrm{y}_{\mathrm{it}} = J \end{cases} \tag{2}$$

where $Q_{ijt}'s$ are the outcome variables of the i^{th} farmer in regime *j* at time t and the error terms $(u_{itj}'s)$ are distributed with $E(u_{itj}|X,Z)=0$ and $\mathrm{var}(u_{itj}|X,Z)=\sigma_j^2$. Q_{itj} is observed if and only if package *j* is used. The error term u_i is comprised of unobservable individual effects c_i and a random error term e_{it}. If the $\varepsilon's$ and $\mathrm{u's}$ are not independent, the OLS estimates in (2) will be biased. A consistent estimation of α_{j} requires inclusion of the selection correction terms of the alternative choices in (2). In the multinomial choice setting, there are J-1 selection correction terms, one for each alternative package. The second stage equation of the multinomial endogenous switching regression in (2) is respecified as:

$$\begin{cases} \text{Regime}\,1: Q_{it1} = Z_{it}\alpha_1 + \sigma_1\hat{\lambda}_{it1} + u_{it1} \quad \text{if } y_{it} = 1 \\ \vdots \qquad\qquad \vdots \\ \text{Regime}\,\mathrm{J}: Q_{itJ} = Z_{it}\alpha_J + \sigma_J\hat{\lambda}_{itJ} + u_{itJ} \quad \text{if } \mathrm{y}_{\mathrm{it}} = J \end{cases} \tag{3}$$

where σ_j is the parameter of coefficients for $\hat{\lambda}_{itj}$ showing the covariance between $\varepsilon's$ and $u's$. To control for potential omitted variable bias caused by the error term u_i, being correlated with the explanatory variables, a fixed effect model is estimated. In this specification, the unobserved effects are removed from the model by taking the panel level averages of the explanatory variables. Estimated standard errors in (3) are bootstrapped to account the bias in the standard errors caused by the generated regressors due to the two stage estimation procedure.

A necessary identification restriction for the multinomial selection framework is that at least one of the explanatory variables included in the multinomial logit equation is excluded from the outcome equation (Billari and Borgoni, 2005). The reason for this exclusion restriction is that the inverse Mill’s ratio is a non-linear function of the explanatory variables in the multinomial logit equation; thus, the second stage equation (net farm income equation) is identified because of this non-linearity. However, the non-linearity of the inverse Mill’s ratio is not normally tested or justified. Therefore, in order to make the source of identification clear, it is advisable to have an explanatory variable in the multinomial logit equation, which is not included in the second stage outcome equation (Greene, 2003). The explanatory variables that are only included in the multinomial logit specification to meet this exclusion restriction are walking distance to input markets, number of close relatives outside the village, walking distance to an extension office, number of grain traders that a farmer knows and trusts, believe in government support in case of crop failure, if household has relative in leadership position and farmers' confidence in the skills of extension workers. It is assumed that these variables influence adoption of package of intensification practices and have no direct effects on incomes except through adoption. We conduct a simple post estimation test to check the validity of the instruments and the results confirm that, in nearly all cases, these variables are jointly significant in the adoption equations but not in the net income regression equations (see Table 6). A simple correlation analysis between these instruments and outcome variable also shows that there is insignificant correlation.

Estimation of Average Treatment Effects

From the econometric approach outlined above there are several quantities that we may be interested. The estimands that are most commonly of interest are the average treatment effect on the population (ATE), the average treatment effect on the treated (ATT), and the average treatment effect on the untreated (ATU). The ATE is the unconditional average adoption effect which answers the question of how, on average, the net maize income would change if everyone in the population of interest had been assigned to a particular combination of intensification practices relative to if they had all received none of the practices. The ATT and ATU answers the question of how the average outcome would change if everyone who received one particular treatment had not received any treatment.

The ATE of package (j) versus package (1) is defined in equation (2) as:

$$ATE = E(Q_{itj} - Q_{it1} | Z = z_{it}) = Z_{it}(\alpha_j - \alpha_1) \qquad \text{for j = 2, . . ., 8} \qquad (4)$$

In observational studies where the investigators have no control over the assignment of the package of intensification practices, the adoption status is likely to be dependent on outcomes and thus a biased estimator of the ATE. However, the ATT and ATU is used to compare expected net maize income of adopters and non-adopters with the counterfactual hypothetical case that adopters did not adopt and vice versa, respectively. Following Carter and Milon (2005) and Di Falco et al. (2011), the expected net maize income under the actual and counterfactual hypothetical cases are computed as follows, by applying equations (3).

Adopters with adoption (actual): $E(Q_{itj} \mid y_{it} = j) = Z_{itj}\alpha_j + \sigma_j \lambda_{itj}$ (5)

Non-adopters without adoption (actual): $E[Q_{it1} \mid y_{it} = 1] = Z_{itj}\alpha_1 + \sigma_1 \lambda_{it1}$ (6)

Adopters had they decided not to adopt (counterfactual): $E[Q_{it1} \mid y_{it} = j] = Z_{itj}\alpha_1 + \sigma_1 \lambda_{itj}$ (7)

Non-adopters had they decided to adopt (counterfactual): $E[Q_{itj} \mid y_{it} = 1] = Z_{itj}\alpha_j + \sigma_j \lambda_{it1}$ (8)

Equations (5) and (6) represent the expected outcomes of adopters and non-adopters that were actually observed in the sample, whereas equations (7) and (8) denote the counterfactual expected outcomes of adopters and non-adopters, respectively. These expected values are used to compute unbiased estimates of the effects of adoption on adopters and on non-adopters. The average intensification practices adoption effect on the adopters (ATT) is defined as the difference between equations (5) and (6):

$$ATT = [Q_{itj} \mid y_{it} = j] - E[Q_{it1} \mid y_{it} = j] = Z_{it}(\alpha_j - \alpha_1) + \lambda_{itj}(\sigma_j - \sigma_1) \quad (9)$$

Similarly, the average effects of adoption of intensification practices on non-adopters (ATU), i.e., the effects of adoption on those who do not adopt if they did adopt, is computed as the difference between equations (7) and (8):

$$ATU = E[Q_{itj} \mid y_{it} = 1] - E[Q_{it1} \mid y_{it} = 1] = Z_{it}(\alpha_j - \alpha_1) + \lambda_{it1}(\sigma_j - \sigma_1) \quad (10)$$

The A*TT* and A*TU* parameters give the expected outcome effect of adoption, controlling for selection bias on a randomly chosen household from the groups who adopt and do not adopt combination of intensification practices, respectively.

The effects of adoption are likely to be heterogeneous: adopters and non-adopters may not benefit in the same way from adoption even if they have the same observed characteristics due to other endogenous determinants of the outcome variables (e.g., ability, motivation). This can be tested by taking the difference between equations (9) and (10). Carter and Milon (2005) called this a transitional heterogeneity effect.

Estimation results

Impacts of multiple intensification practices

In the second stage, we estimate the fixed effects regression on net crop income, N use and pesticide application for each package of combination of practices taking care of the selection bias correction terms from the first stage. We don't present the result and provide a detail here for the sake of space and because the paper has a focus on analyzing the impact of alternative combination of intensification practices not on dealing the determinants of net crop income and agro-chemicals use. But the result could be available upon the request of the authors.

However, it is worth mentioning that many of the selection correction terms are at least weakly significant at the 10% level, suggesting that these packages of practices will not have the same effects on non-adopters should they chooses to adopt, as it will on adopters. This is an evidence of self-selection in the adoption of package of practices. It is also that a good number of variables in the fixed effect model have shown significant correlation with the outcome variables and there are differences between the outcome equations coefficients among the different package adopter groups. This illustrates the heterogeneity in the sample with respect to crop net income and demand for N and pesticide. The intra-class correlation in the fixed effect model indicates that 18-27% of the variance in net income equation, 16-35% of the variance in pesticide equation and 25-42% of the variance in N use equations is due to differences across panels. This means that the variation in each model coming from cross-sectional data is higher than that coming across time. Hence, we can say that the higher proportion of the variation in the model is caused in part by the individual heterogeneity.

From the fixed effects regression estimates, we derive the unconditional and conditional average effect of adoption of various combination of improved seeds, conservation tillage and cropping system diversification[3]. The unconditional average effect is presented in Table 7. The unconditional average effects indicate that adopters of any of the intensification practices in isolation or in combinations earn more net crop income, on average, than non-adopters. This trend is also observed for N use and pesticide application, except that non-adopters use more pesticide than adopters of $V_0D_1T_0$, $V_1D_1T_0$ and $V_0D_1T_1$; and more N than adopters of pesticide $V_0D_1T_0$, $V_0D_0T_1$, $V_0D_1T_1$, and $V_1D_1T_1$. This naive comparison would drive misleading conclusion because the approach doesn’t consider that the difference in the outcome variables may be cause by observable and unobservable characteristics.

On the other hand, Table 8, 9 and 10 presents the true average adoption effects of net crop income, N use and pesticide application, respectively, under actual and counterfactual conditions. In the upper panel of these tables, the outcome variables of farm households who adopted the packages are compared with the outcome variables if the farm households had not adopted. This is done by applying eq. (9). We also present the average treatment effects for the untreated in lower panel of these tables where the outcome variables of farm households who don’t adopted the packages are compared with the outcome variables if the farm

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[3] As a robustness check, we replicate our estimation procedure using the pooled model specification and estimate the average treatment effects. The results don’t change much (detailed estimation results from the pooled multinomial endogenous switching regression is available upon request the authors).

households had adopted by applying eq. (10). In order to determine the average adoption effects we compare columns A and B, D and E, and G and H of Table 8, 9 and 10. Columns C, F and I of Table 8, 9 and 10 presents the impacts of adoption of combinations of intensification practices on crop income, pesticides and fertilizer use, computed as the difference between the above columns, respectively.

Results show that the adoption of either any of the intensification practice in isolation or a combination of them provides higher net crop income compared with non-adoption (Table 8). In all counterfactual cases, farm households who actually adopted would have earned less if they did not adopt (see column B of Table 8 of adopters row). Importantly, it is interesting to note that irrespective of the type of practices, as the number of practices in the combination increases the increment of net income raises as well. The largest income (240 USD/ha) is obtained from adoption of modern seeds jointly with cropping system diversification and conservation tillage ($V_1D_1T_1$). Adoption of modern seed in isolation provides the highest net income than adoption of other intensification practices in isolation. Adoption of modern seeds in combination with cropping system diversification also provides the highest income compared with income obtained from a combination of any two practices. Similar trend is also observed for the average treatment effects of the untreated. For the counterfactual condition of adoption by farm households that did not actually adopt, these households would have earned more if they did adopt (see column A of Table 8, the non-adopters row). Importantly, again, the net income increase as the number of practices included in the combination increases. Adoption of improved seed in isolation or in combination with cropping system diversification has a positive impact on farm income compared with adoption of any other single practice or any other two practices, respectively. The highest payoff (232 USD/ha) is achieved from adopting a combination of three practices - modern seeds, conservation tillage and cropping system diversification.

On inputs use, the counterfactual analysis shows that adoption of modern seeds and conservation tillage in isolation or in combination significantly increased the application of pesticide (Table 9). The use of more pesticides with the adoption of improved seed is probably because farmers would like to avoid risk, as high yielding varieties may be susceptible to pest outbreaks (Jhamtani, 2011). The notion that conservation tillage may increase pesticide application to compensate for less tillage (Fuglie, 1999) is observed in this study. However, this effect is offset by the adoption of cropping system diversification. The results show that the adoption of cropping system diversification in isolation or combined with modern varieties or conservation tillage significantly reduced the average pesticide application of adopters and also non-adopters, if they did adopt. This result implies that adopters would have applied more pesticides, had they not adopted, whereas non-adopters would have used less had they adopted. These results confirm the role of cropping system diversification in suppressing pests, diseases and weeds infestations. Thus, system diversification can be considered a risk management strategy particularly when the adoption of modern inputs such as improved crop varieties is considered in the farming system.

With regard to fertilizer use, we found that, for farmers who adopted package that contains modern varieties ($V_1D_0T_0$) the average nitrogen (N) application is significantly higher than it would have been if the adopters had adopted $V_0D_0T_0$ (Table 10). This is probably due to the complementarity between improved maize variety adoption and fertilizer use. A similar trend is also observed even when either cropping system diversification or conservation tillage is combined with modern varieties. However, consistent with our expectation, the demand for N fertilizer declines with adoption of either cropping system diversification or conservation tillage or a combination of the two. We also observed that conservation agriculture which is defined as the synergy between cropping system diversification and conservation tillage (FAO 2012) helps to offset the high demand for fertilizer due to adoption of modern varieties. These results are consistent with the ecological role of cropping system diversification and conservation tillage, such as reducing nitrogen application because of biological nitrogen fixation via legumes, buildup of soil fertility via enhanced soil organic matter and with previous empirical studies, such as Wu and Babcock (1998), who found in the Central Nebraska basin that farmers took nutrient credits from cropping system diversification adoption, and Teklewold et al. (2013) who found in Ethiopia that rotation systems reduced N fertilizer application. In this regard, our results suggest that cropping system diversification do not benefit farmers in reducing their production costs and also do exhibit environmental benefit, as nitrogen application declines with system diversification.

Conclusions

Increasing and sustaining food productions that do not compromise environmental integrity is a scientific and policy challenge that must be met to sustain and increase the net societal benefits of intensive agricultural production (Power 1999; Altieri 1999; Tilman et al., 2002). In this regard, sustainable crop intensification practices such as minimum tillage and crop diversifications combined with modern external input such as improved seeds is considered as an intensification that allow producers achieving sustainable food security and income for present and future generations while maintaining or improving the ecosystem services (Röling and Pretty. 1997). Thus the factors that derives farmers' decision to adopt sustainable crop intensification practices either individually or in combination, and theirs effects on net crop income and intensity of input use are fundamental questions which must be analyzed for designing agricultural development and ecosystems services conversing strategies. The purposes of this paper are to improve understanding of farmers' adoption decisions of individual and combined SIPs and to understand their effects on crop income and input using nationally representative comprehensive household-plot level panel data collected in 2010 and 2013 in rural Ethiopia. We developed a multinomial endogenous switching regression methodology, where selectivity is modeled as a multinomial logit and fixed effects model in the second stage including the self-selection bias correction terms.

With regards to the results of adoption effects of cropping system diversification, conservation tillage and modern seeds, the following conclusions can be derived. First, adoption of cropping system diversification with or without modern seeds increases income and reduces pesticides use. The highest crop income was achieved when farmers adopted cropping system diversification, conservation tillage and modern seeds jointly rather than in isolation; and the demand for pesticide due to adoption of modern seed and conservation tillage was reduced when farmers adopted cropping system diversification. This is a win-win outcome where the information can help in formulating and packaging extension information related to promotion of conservation agriculture jointly with modern inputs such as improved crop varieties. Second, the demand for fertilizer due to adoption of modern seeds was reduced with adoption of cropping system diversification and conservation tillage with significant increments in crop income. As in the pesticide results, the reduction in fertilizer use was achieved when farmers adopted cropping system diversification and conservation tillage in combination rather than individually This is also another win-win outcome. This result implies that adoption of conservation agriculture with modern external inputs, in addition to improving household food security through increasing income and reducing production costs, also has environmental benefits in terms of reducing external off-farm inputs use.

Hence, policies that helps to facilitate the scale up of these practices are more likely to be successful because these intensification practices provide tangible benefits to the individual household or community by emphasizing enhanced agricultural productivity, food security, and income, rather than by controlling land degradation per se (World Bank 2006).

Our adoption model results revealed that farmers' decision on the various combinations of conservation tillage, cropping system diversifications and modern seeds is influenced by observable plot, and household and village characteristics. These include plot level characteristics and manager of the plot, social capital in the form of membership of rural institutions, the number of relatives and traders known by the farmer outside his village, market access, wealth, credit, age, family size, confidence in the skill of extension agents, social protection in the form of farmers' confidence on government support during times of crop failure. Analyzing the effect of these variables can be used to target policies aimed at increasing adoption rates of these intensification practices. For example, the significant role of social capital and extension services suggests the need for establishing and strengthening local institutions, service providers and extension systems to accelerate and sustain the adoption. In a country where there is information asymmetry and 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, and insurance), and technical assistance. Furthermore, the adoption of cropping system diversification alone or jointly with conservation tillage in Ethiopia is more likely on owner cultivated plots than on rented in plots suggesting a number of supplementary policy measures that guarantee long term tenure security. The positive association between adoption of intensification practices and farmer's reliance on government support during crop failure 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 agricultural practices.

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Table 1. Definition and summary statistics of choice and impact variables

Variables	Definition	Ethiopia 2010	Ethiopia 2013	Ethiopia Average
Choice variables				
Improved variety	Improved maize variety adopted (1=if yes; 0 = no)	0.550	0.655	0.599***
Cropping system diversification	Maize was rotated/intercropped with a legume crop (1=if yes; 0 = no)	0.172	0.502	0.325***
Conservation tillage	Conservation tillage practice adopted (1=if yes; 0 = no)	0.297	0.188	0.247***
Impact variables				
Maize income	Net maize production value (USD/ha)	471.72 (278.40)	488.60 (297.58)	479.66 (287.69)***
Chemical	Pesticide application (lit./ha)	0.21 (0.89)	0.16 (0.88)	0.18** (0.89)
Fertilizer	Nitrogen application (kg/ha)	29.36 (38.60)	38.95 (44.24)	33.86*** (41.62)

*, ** and *** indicate that the difference between the two years is statistically significant at 10%, 5% and 1% level, respectively. Numbers in parenthesis are standard deviation.

Table 2. Frequency (%) distribution of sustainable crop intensification practices packages used on maize plots in Ethiopia

Choice (j)	SIPs package$^{\Psi}$	Improved variety (V)		Cropping system-diversification (D)		Conservation tillage (T)		Frequency (%)		
		V_1	V_0	D_1	D_0	T_1	T_0	2010	2013	Average
1	$V_0D_0T_0$		√		√		√	26.31	10.90	19.15***
2	$V_1D_0T_0$	√			√		√	31.87	30.58	31.27*
3	$V_0D_1T_0$		√	√			√	6.76	15.98	11.04***
4	$V_0D_0T_1$		√		√	√		9.77	2.06	6.19***
5	$V_1D_1T_0$	√		√			√	5.32	23.74	13.88***
6	$V_1D_0T_1$	√			√	√		14.85	6.28	10.87***
7	$V_0D_1T_1$		√	√		√		2.11	5.60	3.74**
8	$V_1D_1T_1$	√		√		√		3.01	4.85	3.86***

$^{\Psi}$Each element in the SIPs combinations (package) consist of a binary variable for a SIP /Cropping system diversification (D), Conservation tillage (T), and Improved variety (V)/, where the subscript refers 1= if adopted and 0 = otherwise.

*, ** and *** indicate that the difference between the two years is statistically significant at 10%, 5% and 1% level, respectively.

Table 3. Sample conditional and unconditional adoption probabilities of sustainable crop intensification practices in Ethiopia

	Improved variety	Cropping system diversification	Conservation tillage
$P(Y_k = 1)$	59.9	32.5	24.7
$P(Y_k = 1 \mid Y_V = 1)$	100.0	29.6***	24.6
$P(Y_k = 1 \mid Y_D = 1)$	54.6***	100.0	23.4*
$P(Y_k = 1 \mid Y_T = 1)$	59.8	30.8**	100.0
$P(Y_k = 1 \mid Y_V = 1, Y_D = 1)$	100.0	100.0	21.8***
$P(Y_k = 1 \mid Y_V = 1, Y_T = 1)$	100.0	26.2***	100.0
$P(Y_k = 1 \mid Y_D = 1, Y_T = 1)$	50.8***	100.0	100.0

Y_k is a binary variable representing the adoption status with respect to choice k (k = Cropping system diversification (D), Conservation tillage (T) and Improved variety (V)).

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

Table 4. Transition matrix in and out of adoption and dis-adoption of cropping intensification practices in Ethiopia

2010			2013								
			Cropping system diversification			Conservation tillage			Improved variety		
			Adopter	Non-adopter	Total	Adopter	Non-adopter	Total	Adopter	Non-adopter	Total
Ethiopia	Adopter,	N (%)	783 (44.8)	964 (55.2)	1747 (100.0)	1319 (82.2)	286 (17.8)	1605 (100)	333 (28.7)	827 (71.3)	1160 (100.0)
	Non-adopter	N (%)	162 (28.7)	403 (71.3)	565 (100.0)	507 (71.7)	200 (28.3)	707 (100.0)	393 (34.1)	759 (65.9)	1152 (100.0)
	Total	N (%)	945 (40.9)	1367 (59.1)	2312 (100.0)	1826 (79.0)	486 (21.0)	2312 (100.0)	726 (31.4)	1586 (68.6)	2312 (100.0)
			X^2=40.060; p-value<0.000			X^2=32.420; p-value<0.000			X^2=7.847; p-value<0.005		

Note: Top number is cell frequency and bottom number is cell percentage (in parentheses)

Table 5. Explanatory variables by year

Variables	Definition	Ethiopia		
		2010	2013	T/Z value$^{\Psi}$
Gender	1=if gender of household head is male	0.94	0.94	0.026
Age	Age of household head (years)	42.43 (12.5)	42.13 (12.44)	1.089
Hhsize	Total family size (number)	6.78 (2.56)	6.96 (2.49)	-3.301***
Educhd	Education level of household head (years of schooling)	3.06 (3.35)	3.06 (3.35)	0.185
Totfarmsize	Farm size, ha	2.61 (1.89)	2.38 (2.02)	5.369***
Propcereal	Proportion of area covered with other cereal crops	0.69 (0.24)	0.58 (0.29)	19.932***
Credit	1=if credit is a constraint (credit is needed but unable to get)	0.62	0.50	11.286***
Tlu	Livestock size (in tropical livestock unit)	5.23 (3.15)	5.97 (3.28)	-10.624***
Assetval	Value of farm & household assets (USD)	1060.65 (3012.03)	1516.29 (3313.85)	-6.664***
Ox0	1=if household own no oxen	0.16	0.20	-4.839***
Ox1	1=if household own only one ox	0.23	0.19	4.729***
Ox2	1=if household own more than a pair of oxen	0.61	0.62	-0.199
Vilmktdist	Walking distance to village markets, km	0.09 (0.74)	0.09 (0.74)	1.717
Manmktdist	Walking distance to main markets, km	0.45 (1.23)	0.45 (1.23)	1.112
Distinput	Walking distance to input markets, km	1.54 (4.80)	1.54 (4.80)	1.789
Group	1=if member in input/marketing/group	0.20	0.29	-9.924***
Kinship	Number of close relatives living outside the village	11.42 (14.26)	17.56 (21.85)	-13.218***
Trader	Number of grain traders that farmers know and trust	2.50 (4.11)	1.87 (3.01)	8.016***
Connections	1=if household has relative in leadership position	0.55	0.56	-1.131
Yearlived	Number of years the household has lived in the village	36.65 (13.94)	38.35 (14.23)	-5.581***
Distext	Walking distance to extension agents office, km	0.16 (0.58)	0.16 (0.58)	1.979
Extenskill	1=if confident with skills of extension workers	0.82	0.76	6.298***
Govtsup	1=if believe in government support in case of crop failure	0.73	0.78	-5.000***
Pests	1=if pest is a key problem	0.04	0.05	-2.691***
Disease	1=if disease is a key problem	0.04	0.06	-3.838***
Waterlog	1=if waterloging is a key problem	0.03	0.04	-1.805**
Drought	1=if drought is a key problem	0.14	0.12	3.012***
Plotdist	Plot distance from home, minutes	11.08 (17.61)	11.08 (17.61)	4.786
Tenure	1=if owned and cultivated by the household	0.81	0.88	-7.926***
Shalwdepsolplt[a]	1=if farmers' perception that plot has shallow depth soil	0.23	0.18	5.838***
Moddepsolplt[a]	1=if farmers' perception that plot has moderately deep soil	0.34	0.26	8.401***
Godfertplt[b]	1=if farmers' perception that plot has good fertile soil	0.47	0.53	-6.327***
Modfertplt[a]	1=if farmers' perception that plot has moderately fertile soil	0.46	0.39	6.954***
Flatslop[c]	1=if farmers' perception that plot has flat slop	0.67	0.69	-1.367*
Modslpplt[c]	1=if farmers' perception that plot has moderately steep slop	0.29	0.27	2.756***
Manureuse	1=if manure use	0.34	0.33	0.549
Altitude	Altitude (meter above sea level)	1773.42 (264.22)	1773.42 (264.22)	-0.282
Plot/Household observations		4587/1534	3982/1444	

[a] Reference group is plot with deep depth soil; [b] Reference group is plot with poor fertile soil: [c] Reference group is plot with steep slope; *, **, *** and NS indicate that the difference between the two years is statistically significant at 10%, 5% and 1% level and non-significant, respectively. Numbers in parenthesis are standard deviation; $^{\Psi}$The differences in means are obtained by subtracting means for 2010 year from those for 2013 year. T-test is used to compare the differences for continuous variables. The test on the equality of proportions is used to compare the differences for binary variables and Z-score is used.

Table 7. The unconditional average effect of adoption of improved maize variety (V), cropping system diversification (D) and conservation tillage (T) in Ethiopia (results from fixed effect estimation)

Country	SIPs package	Income		Pesticide application		Fertilizer application	
		Net maize income (USD/ha)	Adoption effects	Pesticide (Lit./ha)	Adoption effects	N (kg/ha)	Adoption effects
Ethiopia	$V_0D_0T_0$	391.56 (1.06)	-	1.11 (0.002)	-	14.93 (0.15)	
	$V_1D_0T_0$	552.36 (0.27)	160.80 (1.09)***	1.50 (0.0001)	0.384 (0.002)***	27.47 (0.15)	12.54 (0.21)***
	$V_0D_1T_0$	507.501(0.81)	115.94 (1.34)***	1.02 (0.001)	-0.099 (0.002)***	8.03 (0.29)	-6.90 (0.17)***
	$V_0D_0T_1$	494.40 (0.50)	102.83 (1.17)***	1.50 (0.0001)	0.384 (0.002)***	11.62 (0.09)	-3.32 (0.17)***
	$V_1D_1T_0$	599.39 (0.58)	207.83 (1.21)***	1.05 (0.001)	-0.065 (0.002)***	23.19 (0.33)	8.26 (0.36)***
	$V_1D_0T_1$	597.95 (0.43)	206.39 (1.15)***	1.75 (0.0002)	0.63 (0.002)***	21.40 (0.25)	6.47 (0.29)***
	$V_0D_1T_1$	543.70 (0.71)	152.13 (1.28)***	1.07 (0.001)	-0.049 (0.002)***	4.39 (0.02)	-10.54 (0.15)***
	$V_1D_1T_1$	632.50 (1.98)	240.94 (2.24)***	1.11 (0.002)	-0.003 (0.003)	1.99 (0.002)	-12.93 (0.15)***

Note: figures in parenthesis are standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1% level, respectively.

Table 8. Average expected net maize income (USD/ha) with adoption of SAPs effects (results from fixed effect estimation)

Sample	Outcome	Ethiopia		
		Adoption status		Adoption Effects
		Adopting (j= 2,. . .,8)	Non-Adopting (j=1)	
		A	B	C
Adopter	$E(Q_j\|I=2)$	550.89 (0.31)	380.64 (1.82)	170.25 (1.85)***
	$E(Q_j\|I=3)$	507.49 (2.45)	387.86 (3.12)	119.63 (3.98)***
	$E(Q_j\|I=4)$	500.43 (2.30)	401.92 (4.88)	98.51 (5.39)***
	$E(Q_j\|I=5)$	604.73 (0.95)	388.86 (2.69)	215.87 (2.85)***
	$E(Q_j\|I=6)$	592.86 (1.13)	398.93 (3.03)	193.93 (3.23)***
	$E(Q_j\|I=7)$	602.60 (3.22)	401.87 (5.28)	200.73 (6.19)***
	$E(Q_j\|I=8)$	643.32 (9.55)	402.85 (4.79)	240.47 (10.69)***
Non- adopter	$\mathrm{E}(\mathrm{Q}_j\|\mathrm{I}=1)$	504.24 (0.57)	401.70 (2.68)	155.66 (2.80)***
	$\mathrm{E}(\mathrm{Q}_j\|\mathrm{I}=1)$	518.07 (2.33)	401.70 (2.68)	116.36 (3.55)***
	$\mathrm{E}(\mathrm{Q}_j\|\mathrm{I}=1)$	493.07 (1.09)	401.70 (2.68)	91.37 (2.89)***
	$\mathrm{E}(\mathrm{Q}_j\|\mathrm{I}=1)$	577.83 (1.87)	401.70 (2.68)	176.13 (3.26)***
	$\mathrm{E}(\mathrm{Q}_j\|\mathrm{I}=1)$	567.95 (1.56)	401.70 (2.68)	166.25 (3.09)***
	$\mathrm{E}(\mathrm{Q}_j\|\mathrm{I}=1)$	572.13 (1.84)	401.70 (2.68)	170.43 (3.25)***
	$\mathrm{E}(\mathrm{Q}_j\|\mathrm{I}=1)$	633.34 (3.76)	401.70 (2.68)	231.64 (4.62)***

Note: ‘j’ represents package of SAPs shown in table 1; figures in parenthesis are standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1% level

Table 9. Average expected pesticide application (lit./ha) with adoption of SAPs effects in Ethiopia (results from fixed effect estimation)

Sample	Outcome	Ethiopia		
		Adoption status		Adoption Effects
		Adopting (j= 2,. . .,8)	Non-Adopting (j=1)	
		D	E	F
Adopter	$E(Q_j \vert I=2)$	1.50 (0.00002)	1.11 (0.002)	0.389 (0.002)***
	$E(Q_j \vert I=3)$	1.01 (0.003)	1.11 (0.004)	-0.096 (0.006)***
	$E(Q_j \vert I=4)$	1.50 (0.0003)	1.16 (0.007)	0.345 (0.007)***
	$E(Q_j \vert I=5)$	1.05 (0.002)	1.09 (0.004)	-0.046 (0.004)***
	$E(Q_j \vert I=6)$	1.74 (0.002)	1.10 (0.004)	0.635 (0.005)***
	$E(Q_j \vert I=7)$	1.05 (0.006)	1.12 (0.008)	-0.065 (0.009)***
	$E(Q_j \vert I=8)$	1.08 (0.009)	1.09 (0.007)	-0.011 (0.011)
Non- adopter	$E(Q_j \vert I=1)$	1.49 (0.0002)	1.15 (0.004)	0.349 (0.004)***
	$E(Q_j \vert I=1)$	1.01 (0.003)	1.15 (0.004)	-0.136 (0.005)***
	$E(Q_j \vert I=1)$	1.50 (0.0004)	1.15 (0.004)	0.351 (0.004)***
	$E(Q_j \vert I=1)$	1.07 (0.002)	1.15 (0.004)	-0.084 (0.005)***
	$E(Q_j \vert I=1)$	1.74 (0.001)	1.15 (0.004)	0.587 (0.004)***
	$E(Q_j \vert I=1)$	1.06 (0.003)	1.15 (0.004)	-0.091 (0.005)***
	$E(Q_j \vert I=1)$	1.11 (0.003)	1.15 (0.004)	-0.035 (0.005)***

Note: ‘j’ represents package of SAPs shown in table 1; figures in parenthesis are standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1% level

Table 10. Average expected nitrogen fertilizer application (kg./ha) with adoption of SAPs effects in Ethiopia (results from fixed effect estimation)

Sample	Outcome	Ethiopia		
		Adoption status		Adoption Effects
		Adopting (j= 2,. . .,8)	Non-Adopting (j=1)	
		G	H	I
Adopter	$E(Q_j \| I=2)$	25.97 (0.42)	17.01 (0.30)	8.96 (0.51)***
	$E(Q_j \| I=3)$	7.03 (0.24)	14.99 (0.40)	-7.96 (0.47)***
	$E(Q_j \| I=4)$	12.02 (0.72)	16.99 (0.26)	-4.96 (0.77)***
	$E(Q_j \| I=5)$	22.86 (0.37)	17.60 (0.45)	5.26 (0.58)***
	$E(Q_j \| I=6)$	16.04 (0.59)	11.57 (0.32)	4.46 (0.68)***
	$E(Q_j \| I=7)$	20.76 (3.12)	30.76 (0.22)	-9.99 (3.13)***
	$E(Q_j \| I=8)$	15.07 (0.67)	22.49 (0.45)	-7.41 (0.80)***
Non- adopter	$E(Q_j \| I=1)$	30.71 (0.11)	19.29 (0.25)	11.42 (0.27)***
	$E(Q_j \| I=1)$	8.28 (0.19)	19.29 (0.25)	-11.02 (0.32)***
	$E(Q_j \| I=1)$	15.11 (0.31)	19.29 (0.25)	-4.19 (0.42)***
	$E(Q_j \| I=1)$	24.64 (0.87)	19.29 (0.25)	5.34 (0.91)***
	$E(Q_j \| I=1)$	22.69 (0.43)	19.29 (0.25)	3.39 (0.50)***
	$E(Q_j \| I=1)$	7.06 (0.08)	19.29 (0.25)	-12.24 (0.27)***
	$E(Q_j \| I=1)$	13.99 (0.29)	19.29 (0.25)	-5.31 (0.38)***

Note: ‘j’ represents package of SAPs shown in table 1; figures in parenthesis are standard errors;

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