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Adoption and Impacts of Sustainable Agricultural Practices on Maize Yields and Incomes: Evidence from Rural Zambia

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Abstract

This paper uses a multinomial endogenous treatment effects model and data from a sample of over 800 households and 3,000 plots to assess the determinants and impacts of adoption of sustainable agricultural practices (SAPs) on maize yields and household incomes in rural Zambia. Results show that adoption decisions are driven by household and plot level characteristics and that the adoption of a combination of SAPs raises both maize yields and incomes of smallholder farmers. Adoption of improved maize alone has greater impacts on maize yields, but given the high cost of inorganic fertiliser that limits the profitability of adoption of improved maize, greater household incomes are associated rather with a package involving SAPs such as maize–legume rotation and residue retention.

Keywords: *Incomes*; *maize yields*; *multinomial endogenous treatment effects*; *sustainable agricultural practices*; *Zambia*.

JEL classifications: *O13, Q1, Q12, Q16*.

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1. Introduction

Low soil fertility is one of the major constraints to agricultural productivity in Africa (Vanlauwe and Giller, 2006; Beedy *et al.*, 2010). Degraded and infertile soils resulting from continuous mono-cropping and insufficient recycling of organic matter coupled with rainfall variability and frequent dry spells have led to low crop yields in most of Africa (Ngwira *et al.*, 2012) and exacerbated poverty, food insecurity and child malnutrition.

Sustainable agricultural practices (SAPs) offer a potential solution to some of these problems by improving soil fertility, sequestering carbon for climate change mitigation, and increasing crop yields and incomes. Broadly defined, SAPs may include crop rotation or intercropping with legumes, conservation tillage, residue retention, improved crop varieties, complementary use of organic fertilisers, and soil and stone bunds for soil and water conservation (Lee, 2005; Woodfine, 2009; Branca *et al.*, 2011). In this paper we focus on three SAPs and combinations of them that relate to maize, a major crop in Zambia: maize–legume rotation, improved maize varieties, and residue retention. These three practices are the major practices included in Zambia's conservation promotion policies (see section 2).

Maize–legume rotation has a number of benefits for both farmers and the environment, including soil improvement through nitrogen-fixation, reduction of disease, weed and insect populations, and increases in the soil-carbon content, which helps to mitigate the effects of climate change (Hutchinson *et al.*, 2007; Andersson *et al.*, 2014). Residue retention involves the accumulation of organic matter and, to a certain extent, minimum soil disturbance (conservation tillage) and offers additional benefits of improved soil fertility and crop yields. Moreover, it reduces soil and water losses, improves infiltration, reduces soil temperatures and, in time, improves soil fertility (CFU, 2007).

Although SAPs offer a number of benefits, there is limited empirical evidence on the determinants of their adoption and/or their impacts on smallholder welfare. A recent study by Arslan *et al.* (2013) on the adoption intensity of conservation agriculture (CA) in Zambia is the first attempt to comprehensively assess the factors that affect the intensity of adoption of SAPs. However, they only investigate the determinants and intensity of adoption (minimum tillage and crop rotation), and do not assess the effects on either crop yields or the welfare of the smallholder farmers. Similarly, Grabowski *et al.* (2014) assess only the determinants of the adoption of minimum tillage among cotton growing farmers in Zambia without looking at its impact on yields. Haggblade *et al.* (2010) give a good overview of the adoption and impact studies of CA in Zambia, where they show that CA has the potential to increase yields and incomes for farmers. However, despite the potential complementarity of maize–legume rotation, residue retention and improved maize, very few studies have simultaneously analysed the adoption and impacts of these three practices on smallholder farmer's welfare. Recent studies on adoption of SAPs use multivariate or seemingly unrelated multivariate probit regression models (Marenya and Barrett, 2007; Kassie *et al.*, 2013; Teklewold *et al.*, 2013a; Kamau *et al.*, 2014) to assess factors that affect adoption but do not analyse the impacts of (combinations of) these SAPs on crop yields and incomes of smallholder farmers. To our knowledge, the only studies that assess the impact of SAPs in Africa are by Teklewold *et al.* (2013b) and Kassie *et al.* (2014) in Ethiopia and Malawi, respectively. However, Ethiopia has different ecological conditions and agricultural policies compared to Zambia (e.g. the seed sector is more liberalised in

Zambia than in Ethiopia), hence the impact of these SAPs may be different. We also include residue retention as one of the three SAPs as very little empirical evidence exists on the effects of residue retention (or a combination of residue retention with other SAPs) on crop yields and incomes. Neither Teklewold *et al.* (2013b) nor Kassie *et al.* (2014) have analysed the adoption and/or impacts of residue retention.

This paper contributes to the emerging body of literature on SAPs by identifying the factors that affect the decisions to adopt individual practices of maize–legume rotation, residue retention and improved maize as well as the combination of the three practices and their impact on smallholder farmers' welfare in Zambia. We model the adoption of these practices as a multinomial selection process where the expected benefits of SAPs induce the adoption decisions. We specifically use a multinomial endogenous treatment effects model (Deb and Trivedi, 2006b) to account for selection bias due to both observed and unobserved heterogeneity and to assess the differential impacts of the adoption of single as well as multiple SAPs. In assessing the adoption decisions, the multinomial endogenous treatment effects model allows the modelling of interdependency among the different SAPs. Compared with the computationally cumbersome multinomial endogenous switching regression model used by Teklewold *et al.* (2013b) and Kassie *et al.* (2014), the multinomial endogenous treatment effects model is easier to implement and also allows the distribution of the endogenous treatment (adoption of SAPs) and outcomes (income and yield) to be specified using a latent factor structure, thereby allowing a distinction to be made between selection on unobservables and selection on observables (Deb and Trivedi, 2006b). In addition, the paper uses comprehensive plot-level data combined with household level characteristics. The combination of plot and household level data allows us to build a panel which in turn helps to control for selection and endogeneity bias that may arise due to correlation of unobserved heterogeneity and observed explanatory variables.

The next section gives a background of SAPs in Zambia, while section 3 presents the data and description of variables. Section 4 describes the multinomial endogenous treatment effects model, followed by section 5 which presents the empirical results. The last section provides conclusions and implications.

2. Background of SAPs in Zambia

SAPs in Zambia have been promoted as a package under the practice known as Conservation Agriculture (CA), or Conservation Farming (CF) as well as through the promotion of improved crop varieties. CA in Zambia involves a package of several practices that includes land preparation in the dry season using minimum tillage systems, crop residue retention, seeding and input application in fixed planting stations, and crop rotations that include legumes (Haggblade and Tembo, 2003; CFU, 2007). The promotion of CA started in the 1990s as a result of ecological and economic challenges (Arslan *et al.*, 2013).

After Zambia's independence, agricultural production increased due, *inter alia*, to the expansion of the cultivated area, support for maize marketing, and extensive fertiliser and input subsidies (Baudron *et al.*, 2007). However, this encouraged continuous maize mono-cropping and a heavy application of inorganic fertilisers that resulted in soil degradation (Haggblade and Tembo, 2003; Andersson and D'Souza, 2013). These unsustainable agricultural practices coupled with the removal of maize subsidies and liberalisation of maize marketing in 1991 led to a decline in maize productivity, increasing rural poverty and food insecurity (Baudron *et al.*, 2007;

Andersson and D'Souza, 2013). It was in response to the above problems that the adoption of SAPs was encouraged in Zambia.

In Zambia, empirical evidence shows that CA is essential for smallholder agricultural production to be sustainable and to achieve broad based objectives of increasing crop yields, mitigating climate change and attaining food security (Haggblade *et al.*, 2010; Umar *et al.*, 2011; Arslan *et al.*, 2013). Adoption of improved crop varieties is the other SAP considered in this study (Lee, 2005). Improved maize varieties have been available in Zambia since the 1960s and were introduced to smallholder famers around the 1970s and to date about 60% of Zambian smallholders use improved maize seed (Kumar, 1994; Tembo and Sitko, 2013).

There are strong complementarities among the three practices (crop rotation, improved varieties and residue retention). Maize–legume crop rotation, which is one of the options for sustainable intensification, plays a vital role in fixing atmospheric nitrogen in the soil that is vital for increased maize production. The practice is also essential in controlling weeds, especially striga,[2] which is notorious in fields were maize mono-cropping is the major practice. In the Southern province of Zambia, Thierfelder and Wall (2010) found that maize yields after growing sunhemp (a legume) were 74% higher than the yields in mono-cropped maize plots. The two practices are interrelated because the average yield per hectare is larger when both are adopted than when they are used in isolation. Similarly, the residues from both the production of legumes and improved maize improve soil fertility and moisture retention and increase soil organic matter once they are incorporated into the soil, which is beneficial for the production of both crops. Most African farmers face liquidity constraints (Marenya and Barrett, 2007), hence technologies such as maize–legume rotation can be used as a substitute for inorganic fertilisers (Kamau *et al.*, 2014) or complements, especially when it comes to producing hybrid maize.

Sustainable agricultural practices should be able to meet the current and future societal needs for food and fibre and for ecosystem services and for healthy life by maximising the net benefit to society when all costs and benefits of the practices are considered (Tilman *et al.*, 2002). Therefore, sustainability is not only about ecology, but it also includes food security and economic aspects such as increased income and reduced poverty. With the growing population in Zambia, food production has to increase to meet the demand for food and one way to achieve this is the maintenance of high maize yields. Recent studies on adoption and impact of improved maize varieties in Zambia on smallholder farmers' wellbeing (e.g. Mason and Smale, 2013; Smale and Mason, 2014), show that improved maize varieties tend to increase crop yields, food security and household income. Moreover, the Zambia Agricultural Research Institute (ZARI) has released several improved maize varieties that are high yielding, early maturing, and are specifically adapted to each of the three agro-ecological zones of the country. For this reason, we consider improved maize varieties as being one of the sustainable agricultural practices.

Additionally, as mentioned above, improved maize varieties (e.g. hybrids) require the use of complementary inorganic fertilisers, hence introducing improved varieties together with soil fertility enhancing practices such as residue retention and maize–legume rotation may reduce the need for fertiliser. Most recent studies (e.g. Vanlauwe

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[2] Striga, locally known as *kamfiti*, (witch weed in English) competes for soil nutrients with maize plants.

et al., 2014) recommend the use of supplementary fertilisers for SAPs such as CA to work properly. They explain that the use of fertiliser results in the production of more stover which implies more organic matter in the soil.

In addition to the CA programme, a Fertiliser Support Programme (FSP) was reintroduced in Zambia in 2002 (MACO, 2008). The main objective of the FSP was to improve household and national food security, incomes, accessibility to agricultural inputs (seed and fertiliser) by smallholder farmers and building capacity of the private sector to participate in the supply of agricultural inputs. The FSP evolved into the current Farmer Inputs Support Programme (FISP) in 2008 with the view of enhancing diversification of the agricultural inputs (e.g. inclusion of legumes). Under this subsidy[3] programme, each beneficiary farmer receives 200 kg of fertiliser and 10 kg of hybrid maize seed. This programme has not led to heavy application of inorganic fertilisers and a return to maize mono-cropping. A recent study by Levine and Mason (2014) shows that FISP did not crowd out SAPs such as maize–legume rotation, although it had a small significant crowding out effect on minimum tillage, implying that farmers are still using these practices despite fertiliser subsidies.

3. Conceptual and Econometric Framework

Agricultural technologies are usually introduced in packages that include several components. These components may complement each other, or may be adopted independently (Feder *et al*., 1985). In most cases, farmers adopt a combination of technologies to deal with a whole range of agricultural production constraints including low crop productivity, droughts, weeds, pests and diseases. The model developed by Feder (1982) presents one of the first attempts to deal with interrelations in the adoption of multiple agricultural technologies. In recent years, more studies have looked at the joint estimation of multiple agricultural technologies (e.g. Byerlee and De Polanco, 1986; Dorfman, 1996; Marenya and Barrett, 2007). In this study, we utilise the random utility framework in modelling the adoption of the SAPs.

Here we focus on technology adoption as a choice over eight alternatives involving our three focus SAPs (crop rotation, improved varieties and residue retention): (i) No adoption; (ii) maize–legume rotation only; (iii) improved maize varieties only; (iv) residue retention only; (v) maize–legume rotation and improved maize; (vi) maize–legume rotation and residue retention; (vii) improved maize and residue retention; and (viii) maize–legume rotation, improved maize and residue retention. We presume that the farmer chooses the SAPs combination that maximises utility subject to land availability, labour, input costs and other constraints. More formally, we assume that farmers aim to maximise their utility V_{ij} by comparing the utility provided by alternative varieties. A farmer i will therefore choose any practice j, over any alternative practice k, if $V_{ij} > V_{ik}, k \neq j$.

Farmers often self-select into the adopter/non-adopter categories and endogeneity problems may arise because unobservable factors may be correlated with the outcome variables (yields and total household income). For instance, farmers may decide to adopt a technology based on unobservable factors such as their innate managerial and technical abilities in understanding and using the technology (Abdulai and

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[3] We don't conduct a detailed analysis of effects of subsidies on the beneficiaries in Zambia, but for details, see e.g. Mason and Smale (2013) and Smale *et al*. (2014).

Huffman, 2014) and failure to account for this may overstate or understate the true impact of the SAPs.

To effectively assess the adoption and impact of SAPs in a joint framework, we adopt a multinomial[4] endogenous treatments effect model proposed by Deb and Trivedi (2006a,b). The model accounts for both the interdependence of the adoption decisions and selection bias as a result of observed and unobserved characteristics. Adoption decisions are modelled in a mixed multinomial logit selection model in the first stage and in the second stage, OLS is used with selectivity correction to estimate the impacts of SAPs on maize yields and household income.

In addition, we exploit plot-level information to deal with the issue of farmers' unobservable characteristics that are likely to affect our results. In recent studies, plot level data have been used to construct a panel and to control for farm-specific effects (e.g. Udry, 1996; Kassie *et al.*, 2008; Di Falco and Veronesi, 2013). Because of the complexity of including standard household fixed effects in a multinomial endogenous treatment effects model, we follow Mundlak (1978) to control for unobserved heterogeneity that may be correlated with observed explanatory variables. We include on the right-hand side of each equation the mean value of plot-varying explanatory variables. The approach relies on the assumption that unobserved effects are linearly correlated with the means of the plot-varying explanatory variables.

3.1. Multinomial endogenous treatment effects model

The multinomial endogenous treatment effects model consists of two stages. In the first stage of the model, a farmer chooses one of the eight SAP bundles mentioned above. Following Deb and Trivedi (2006a,b), let V_{ij}^* denote the indirect utility associated with the jth SAP bundle, $j = 0, 1, 2, \ldots, J$ for household i:

$$V_{ij}^* = z_i'\alpha_j + \sum_{k=1}^{J} \delta_{jk} l_{ik} + n_{ij} \tag{1}$$

where $\mathbf{z}_i$ is a vector of household, social capital, trust and plot-level covariates discussed in section 4.2; α_j is the vector of corresponding parameters to be estimated; n_{ij} are the independently and identically distributed error terms; l_{ik} is the latent factor that incorporates the unobserved characteristics common to the household's adoption of SAPs and outcomes (maize yields and household income), such as the management and technical abilities of the farmers in understanding new technologies, and the transaction costs incurred as a result of poor access to input markets because of infrastructural constraints (Abdulai and Huffman, 2014). Following Deb and Trivedi (2006b), let $j = 0$ denote non-adopters and $V_{i0}^* = 0$. While V_{ij}^* is not observed, we observe the choice of SAP bundle in the form of a set of binary variables d_j and these are collected by a vector, $\mathbf{d}_i = d_{i1}, d_{i2}, \ldots, d_{iJ}$. Similarly, let $\mathbf{l}_i = l_{i1}, l_{i2}, \ldots, l_{iJ}$. Then the probability of treatment can be written as:

$$\Pr(\mathbf{d}_i|z_i, \mathbf{l}_i) = g\left(z_i'\alpha_1 + \sum_{k=1}^{J} \delta_{1k} l_{ik} + z_i'\alpha_2 + \sum_{k=1}^{J} \delta_{2k} l_{ik} + \cdots + z_i'\alpha_J + \sum_{k=1}^{J} \delta_{Jk} l_{ik}\right) \tag{2}$$

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[4] We use the multinomial as opposed to the multivariate framework because the former has an advantage of evaluating alternative combinations of practices as well as individual practices.

where $\boldsymbol{g}$ is an appropriate multinomial probability distribution. Following Deb and Trivedi (2006b), we posit that $\boldsymbol{g}$ has a mixed multinomial logit (MMNL) structure defined as:

$$\Pr(\mathbf{d}_i|z_i,\mathbf{l}_i) = \frac{\exp(z_i'\alpha_j + \delta_j l_{ij})}{1 + \sum_{k=1}^{J}\exp(z_i'\alpha_k + \delta_k l_{ik})}. \tag{3}$$

In the second stage, we assess the impact of adopting the SAP bundle on two outcome variables: the natural logarithm of maize yields and total household income per capita. The expected outcome equation is formulated as:

$$E\big(y_i|d_i,\mathbf{x}_{i,}\mathbf{l}_i\big) = x_i'\beta + \sum_{j=1}^{J}\gamma_j d_{ij} + \sum_{j=1}^{J}\lambda_j l_{ij.} \tag{4}$$

In this equation, y_i is the welfare outcome for a household i; $\mathbf{x}_i$ represents exogenous covariates with parameter vectors β. Parameters γ_j denote the treatment effects relative to the non-adopters. Specifically, coefficients γ_j gauge the effects of SAPs on the welfare of farm households. If the decision to adopt SAPs is endogenous, assuming d_{ij} to be exogenous results in inconsistent estimates of γ_j. Since $E(y_i \mid \mathbf{d}_i, \mathbf{x}_i, \mathbf{l}_i)$ is a function of the latent factors l_{ij}, the outcome is affected by unobserved characteristics that also affect selection into treatment. When λ_j, the factor-loading parameter, is positive (negative), treatment and outcome are positively (negatively) correlated through unobserved characteristics; i.e. there is positive (negative) selection, with γ and λ the associated parameter vectors, respectively. Since the outcome variables are continuous, we assume that they follow a normal (Gaussian) distribution function. The resulting model was estimated using a Maximum Simulated Likelihood (MSL) approach.[5]

Although in principle the parameters of the model are identified even if the regressors in the treatment equations are identical to those used in the outcome equation, Deb and Trivedi (2006a) recommend the use of exclusion restrictions or instruments for a more robust identification; i.e. including regressors in the treatment equations that do not enter the outcome equation. For the multinomial treatment effects model to be identified, it is not strictly necessary that the vector of covariates includes additional variables not included in the outcome equation because the parameters of the semi-structural model can be identified through the non-linear functional form of the selection model. Although getting a valid instrument is empirically challenging, we use source of SAPs information as the instrumental variable, which is a binary variable that takes on a value of one if information was obtained from a demonstration plot, and zero if no information on SAPs was obtained. Though in most cases the primary source of information is usually through government extension agents, demonstration plots are also important sources of information on improved agricultural technologies. Demonstration plots are likely to encourage the adoption of SAPs as farmers are able to see the benefits rather than just hearing about them. This variable is likely to be correlated with the adoption of SAPs but is unlikely to have any direct effect on maize yields or household incomes except through adoption. Adegbola and Gardebroek (2007) show that access to information on improved agricultural

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[5] The model was estimated using the Stata command *mtreatreg*, which is an extension of the *treatreg* Stata command to a multinomial approach by Deb (2009) and 500 simulation draws were used.

technologies is vital in the adoption decision making process, and information variables have been used as valid instrumental variables for technology adoption studies in Africa (Di Falco *et al.*, 2011; Di Falco and Veronesi, 2013). We establish the admissibility of the instrument by performing a simple falsification test: if a variable is a valid selection instrument, it will affect the decision of adopting SAPs, but will not affect the outcome variables among non-adopting farm households (Di Falco *et al.*, 2011; Di Falco and Veronesi, 2013). The results show that information on SAPs can be considered a valid instrument: it is statistically significant in most equations of the decision to adopt SAP j (Table 1) but not of the yield and income equations (Table S4 in the online appendix).

There is a potential simultaneity between adoption of improved maize varieties and inorganic fertilisers (Smale *et al.*, 1995). To control for this, we included a variable (fertiliser use), which is the average fertiliser application rate at the village level. This variable is expected to be exogenous to maize variety adoption decisions at plot level. The decision on the amount of fertiliser to apply to each plot is made at the household level. Therefore, aggregating fertiliser application rates at village level implies that the household has no influence on the amount of fertiliser applied and therefore is exogenous at plot and household level.

4. Data, and Description of Variables

4.1. Sampling scheme

Our data come from a survey of 810 sample households and 3,750 maize plots conducted in January and February 2012 in the Eastern Province of Zambia. This was conducted by IITA and CIMMYT in collaboration with ZARI as part of a larger joint project entitled *Sustainable Intensification of Maize–Legume Systems for the Eastern Province of Zambia* (SIMLEZA). A survey questionnaire was prepared and administered by trained enumerators who collected data from households through personal interviews and observations. The survey was conducted in three districts (i.e. Chipata, Katete and Lundazi), which were targeted as the major maize and legume growing areas. In the first stage, each district was stratified into agricultural blocks (8 in Chipata, 5 in Katete and 5 in Lundazi) as primary sampling units. In the second stage, 41 agricultural camps were randomly selected, with the number of camps allocated proportionately to the selected blocks, and the camps selected with the probability of selection proportional to size. Thus, 17 camps[6] were selected in Chipata, 9 in Katete and 15 in Lundazi. A total sample of 810 households was randomly selected from the three districts, with the number of households from each selected camp being proportional to the size of the camp.

Apart from household level data (e.g. age and education of the household head, size of the household), the survey also collected plot level data which includes the distance of the plot from the homestead, land tenure, size of the plot, depth of the soil, soil fertility and slope of the plot. Data on crop yields, household income, and on the use of SAPs such as maize–legume rotation, residue retention and use of improved maize varieties were collected.

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[6] A camp is a catchment area made up of eight different zones consisting of villages and is headed by an agricultural camp officer. A block is made up of camps and is managed by an agricultural block officer.

Total household income includes income from crops, livestock and livestock products, and off-farm income (e.g. salaries, remittances, farm labour wage income, pension income and income from business). This provides a reliable indicator of economic well-being among smallholder farmers (Smale and Mason, 2014). Yield is defined as the total amount of maize harvested per hectare of land planted to maize in the growing season.

4.2. *Description of variables and hypotheses*

The factors that are likely to affect adoption and impact of SAPs include household and farm characteristics (Feder *et al*., 1985) (age of the household head, education, household size, gender of household head and farm size); social capital and trust (Narayan and Pritchett, 1999; Isham, 2002) (number of relatives in the village, membership of a farmers' association, number of grain traders that farmers trust, confidence in extension agents, trust in government support in case of crop failure); number of contacts with extension agents; crop stresses (rainfall index, pests and drought problems); plot characteristics (land tenure, plot distance from homestead, soil fertility, slope and soil depth); and location characteristics (district dummies, distance to output market and fertiliser markets).

4.2.1. *Household characteristics*

Feder *et al*. (1985) identify household size, age, education and gender of the household head as important household characteristics that influence decisions on adoption of modern agricultural technologies. Adoption of SAPs may be affected by age because older farmers are expected to be more experienced with regard to production technologies and may have accumulated more physical and social capital (Kassie *et al*., 2013). However, younger farmers may be more flexible in adopting innovations; hence the impact of age on technology adoption is indeterminate. Households with better education are expected to be more aware of the benefits of new technologies and more efficient in their farming practices (Pender and Gebremedhin, 2007). Similarly, size of the household is a factor that is often argued to be important in adoption decisions. Household size is usually used to proxy labour endowment (Pender and Gebremedhin, 2007), so that the larger the family, the more labour is available for agricultural production. Therefore the adoption of SAPs is expected to increase with both the level of education and size of the household. It is generally believed that women tend to adopt improved technologies at a lower rate than men (Doss and Morris, 2000) because they generally face constraints in terms of access to resources and time (Pender and Gebremedhin, 2007). We therefore hypothesise that female-headed households are less likely to adopt SAPs than their male counterparts.

The size of the farm and access to off-farm income are important measures of household wealth and can therefore influence the household decision-making process. Farmers can allocate a larger area to improved varieties only if they have enough land; therefore those with more land have a comparative advantage to adopt SAPs. However, households with relatively more land may use less-intensive farming methods than those with less land (Kassie *et al*., 2013). Hence the effect of farm size on the adoption of SAPs is indeterminate. Similarly, the effect of access to off-farm income on the adoption of SAPs could be positive or negative. Davis *et al*. (2009) review a number of papers on the impact of off-farm income on agriculture. They generally conclude that off-farm income has positive effects on agriculture. On the other hand, Mathenge *et al.* (2014) found that off-farm income was inversely related to hybrid maize seed use in Kenyan agricultural areas where farms were commercialising, intensification of maize production was relatively greater and labour constraints were binding.

4.2.2. *Social capital and trust*

Previous studies have shown that social capital plays a vital role in the adoption of agricultural innovations (e.g. Narayan and Pritchett, 1999; Isham, 2002). Social networks enable farmers to overcome credit and resource constraints and are central in facilitating the exchange of information, especially where there is inadequate information and imperfect markets (Kassie *et al.*, 2013). The number of relatives in and outside the village on whom a household can rely for critical support (kinship) is an important factor in technology adoption. Households with more relatives are therefore more likely to adopt new technologies because they are able to experiment with technologies without excessive exposure to risk. However, Di Falco and Bulte (2011) mention that kinship sharing may come at the expense of income growth, which may reduce the likelihood of modern agricultural technologies being adopted. Therefore we do not have a clear prior expectation on the effect of kinship. Membership of an agricultural or farmers' association reflects the intensity of contacts with other farmers, enabling them to learn from one another about new technologies (Adegbola and Gardebroek, 2007). We therefore envisage that the adoption of SAPs will increase with group membership. The number of trusted traders that a farmer knows not only reflects the degree of market integration and incentive for sustainable intensification but also captures interlinked contracts that are common in the presence of imperfect markets. The coefficient on the number of trusted traders is expected to be positive since they play a vital role in spreading information about technologies, and offer market-outlet services to farmers (Teklewold *et al.*, 2013a).

4.2.3. *Crop stresses*

Most countries in sub-Saharan Africa are subject to environmental problems such as droughts, uneven distribution of rainfall and pests. SAPs are vital in reducing the risks associated with droughts because, among other things, they conserve moisture (residue retention) and reduce weeds, pests and diseases (crop rotation). Therefore we posit that occurrences of drought will positively affect adoption of SAPs. To measure the adequacy and distribution of rainfall, a rainfall index was constructed following Quisumbing (2003) based on questions such 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 the questions (yes or no) were coded as favourable or unfavourable rainfall outcomes and averaged over the number of questions asked, so that the best outcome would be equal to one and the worst to zero. We expect the coefficient on the rainfall index to be positive. Since high rainfall may encourage weed growth (Kassie *et al.*, 2010), crop rotation, which reduces weeds, is especially expected to be positively associated with high levels of rainfall.

In the recent past, warmer weather has led to an increase in the number of pests and diseases and SAPs such as maize–legume rotation provide an economic alternative that can be used to maintain crop productivity (Delgado *et al.*, 2011). Kassie *et al.* (2013) explain that farmers tend to adopt practices that involve smaller cash outlays and low-risk technologies such as crop rotation in the presence of pests and diseases. However, SAPs such as residue retention have also been associated with an increase in diseases such as maize root rot (Govaerts *et al.*, 2007). We therefore hypothesise that pests will be positively associated with crop rotation and negatively related to residue retention and improved maize seeds.

4.2.4. Location characteristics

The distance to input and output markets reflects the transaction costs associated with buying inputs and taking produce to the market. Apart from affecting the access to the market, these distances can also affect the availability of new technologies, information and credit institutions (Kassie *et al.*, 2013). We therefore expect the relationship between the distance to the market and adoption of SAPs to be negative.

4.2.5. Access to extension services

Agricultural extension is proxied by the number of contacts farmers have with public and private extension agents and their confidence in their skills. The frequency of contacts is expected to have a positive effect on the adoption of SAPs based on previous studies on technology adoption (e.g. Adegbola and Gardebroek, 2007), reflecting exposure to information on SAPs. However, extension agents are involved in a lot of activities that include delivering inputs and administering credit, hence farmers may question their skills (Teklewold *et al.*, 2013a). Therefore, we hypothesise that confidence in the skills of extension agents (yes or no responses to the question of whether farmers trusted the skills of those agents working in their area) will be positively associated with adoption.

4.2.6. Plot characteristics

Finally, plot-level characteristics are significant determinants of adoption (e.g. Pender and Gebremedhin, 2007; Kassie *et al.*, 2008; Teklewold *et al.*, 2013a,b). The distance from the homestead is expected to reduce the likelihood of adoption for reasons explained above. In addition, plots that are further away may receive less attention and monitoring (Teklewold *et al.*, 2013a), making them more susceptible to pests and theft. Households that own land are expected to adopt modern agricultural technologies more easily as they do not run the risk of ending land rental. Other plot characteristics that are expected to influence adoption include farmers perception of the fertility of the plot (ranked as good, medium or poor), the slope of the plot (ranked as gentle, medium or steep) and soil depth (ranked as deep, medium or shallow). Poor soil fertility is expected to be positively associated with fertility enhancing practices such as maize–legume rotation and residue retention; the propensity to adopt SAPs such as improved maize is expected to be greater on plots with fertile soils, because most improved maize varieties require the application of expensive inorganic fertilisers which most rural farmers cannot afford (not all rural farmers have access to subsidies).

Plots with steep slopes are susceptible to wind and water erosion, so soil conservation practices such as residue retention, together with crop rotation are important in improving the structural stability and preventing run-off of soil nutrients (Anderson, 2009). We expect the coefficient on steep and moderate slopes to be positively associated with residue retention and crop rotation, but negative with improved maize seed. The depth of the soil gives an indication of the volume which can be utilised by the plant and which is conducive to moisture retention. This implies that the deeper the soil the better, hence we expect that deep and medium soils will increase the likelihood of SAPs being adopted.

The decision to adopt improved maize varieties is usually made jointly with the use of inorganic fertilisers (Kumar, 1994; Smale *et al*., 1995). Some studies in the region have also shown the importance of fertiliser in raising agricultural yields especially of maize (e.g. Duflo *et al*., 2008). On the other hand, maize–legume rotation and residue retention are essential in enhancing soil fertility and may be used as substitutes for inorganic fertilisers. We therefore expect the relationship to be positive with improved maize seed and negative with maize–legume rotation and residue retention.

5. Results and Discussion

5.1. *Descriptive statistics*

Summary statistics of the explanatory variables that are hypothesised to influence adoption are presented in Tables S1 and S2 in the online appendix. Table S1 presents the descriptive statistics for the variables used in the analysis disaggregated by district. Maize–legume rotation (11%) and residue retention (13%) were the most popular SAPs among adopters for individual components, and 51% in combination. Maize is usually rotated with legumes such as groundnuts, common beans, cowpeas and soybeans. Maize–legume rotation was the most common practice implemented in Chipata (13%) compared with 8% for Katete and 10% for Lundazi. The three SAPs were adopted simultaneously on about 13% of the 3,750 plots, whereas about 4% did not adopt any SAP. Lundazi district had the highest percentage of farmers (14%) who simultaneously adopted the three SAPs. About 64% of plots received improved maize varieties regardless of the adoption of other SAPs. However, farmers use improved maize alone on only 1% of total plots.

Considering the relationship between fertiliser and the other SAPs, the descriptive statistics show that adopters of maize–legume rotation and residue retention applied less fertiliser than non-adopters (see Table S3 in the online appendix). As expected, adopters of improved maize seeds applied more fertiliser than non-adopters, and when combined with (especially) legume rotation, the additional fertiliser use is reduced as the rotation substitutes for fertiliser.

The descriptive statistics also show that the welfare measures of interest in this study (maize yields and household income) are generally higher for Lundazi district (Table S1) and for multiple SAPs as compared with the individual SAPs (Table S2). The results also show that household income is highly correlated with the adoption of improved maize only and the combination of improved maize and residue retention.

5.2. *Determinants of adoption*

Table 1 presents parameter estimates of the mixed multinomial logit model which is equivalent to the first stage of our multinomial endogenous treatment effects model. The base category is non-adoption against which results are compared. The model fits the data very well with the Wald test, $\chi^2 = 86.37$; $P > \chi^2 = 0.000$ implying that the null hypothesis that all the regression coefficients are jointly equal to zero is rejected.

Table 1

Mixed multinomial logit model estimates of adoption of SAPs in eastern Zambia (baseline category is non-adoption of SAPs)

Variable	Residue retention	Maize–legume rotation	Maize–legume rotation and residue retention	Improved maize	Improved maize and residue retention	Improved maize and maize–legume rotation	Residue retention, maize–legume rotation and improved maize
Age of the household head	−0.01	0.00	0.01	0.00	0.00	0.00	0.01
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)*
Education of household head	0.06	0.08	0.13	0.06	0.13	0.11	0.20
	(0.03)*	(0.03)**	(0.03)***	(0.07)	(0.04)	(0.05)**	(0.03)***
Total household size	0.04	0.13	0.10	−0.21	0.10	0.16	0.13
	(0.04)	(0.04)***	(0.03)***	(0.09)**	(0.04)**	(0.05)***	(0.04)***
Gender of household head	−0.74	−0.63	−0.80	−0.13	−1.34	−0.06	−0.95
	(0.24)***	(0.24)**	(0.22)***	(0.49)	(0.27)***	(0.39)	(0.24)***
Total owned land in ha (cultivated)	0.11	0.07	0.15	0.21	0.14	0.06	0.18
	(0.04)**	(0.04)	(0.04)***	(0.06)***	(0.04)***	(0.06)	(0.04)***
Access to off-farm income	−0.41	−0.33	−0.53	0.72	−0.32	0.43	−0.40
	(0.22)*	(0.23)	(0.20)**	(0.49)	(0.25)	(0.36)	(0.22)*
Kinship	0.01	0.00	0.00	0.00	0.01	0.01	0.01
	(0.02)	(0.02)	(0.02)	(0.04)	(0.02)	(0.02)	(0.02)
Group membership	0.09	−0.51	−0.36	−0.08	0.21	0.71	0.89
	(0.4)	(0.39)	(0.36)	(0.75)	(0.50)	(0.85)	(0.45)**
Trust in government support	−0.32	−0.67	−0.73	−0.91	−0.75	−1.20	−0.75
	(0.29)	(0.29)**	(0.27)**	(0.48)*	(0.32)**	(0.38)***	(0.29)**
Number of traders	−0.03	−0.03	0.00	0.02	0.02	−0.06	0.00
	(0.03)	(0.03)	(0.02)	(0.04)	(0.03)	(0.05)	(0.03)
Confidence in skills of extension staff	−0.06	−0.53	−0.22	−0.14	−0.07	0.41	−0.16
	(0.3)	(0.3)*	(0.28)	(0.65)	(0.34)	(0.50)	(0.30)
Contacts with government extension agent	0.00	−0.03	0.01	0.02	0.01	−0.03	0.02
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)**

Table 1
(*Continued*)

Variable	Residue retention	Maize–legume rotation	Maize–legume rotation and residue retention	Improved maize	Improved maize and residue retention	Improved maize and maize–legume rotation	Residue retention, maize–legume rotation and improved maize
Contacts with government extension agent	0.00	0.00	0.00	−0.02	0.01	0.01	0.00
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)
Rainfall index	−0.04	0.32	−0.11	−0.21	−0.10	0.44	−0.35
	(0.22)	(0.23)	(0.20)	(0.44)	(0.26)	(0.37)	(0.22)
Pests are a problem	−0.69	−0.34	−0.80	−0.61	−0.18	−0.35	−0.66
	(0.29)**	(0.29)	(0.26)***	(0.55)	(0.33)	(0.44)	(0.29)**
Droughts are problem	1.02	1.28	0.95	0.06	1.39	0.13	0.99
	(0.51)	(0.51)**	(0.49)*	(1.17)	(0.55)**	(0.80)	(0.52)*
Ln distance to fertiliser markets	0.03	−0.11	−0.08	−0.23	−0.05	−0.12	−0.11
	(0.09)	(0.09)	(0.08)	(0.14)*	(0.10)	(0.12)	(0.09)
Ln distance to output market	−0.18	0.01	−0.08	0.15	−0.35	−0.19	−0.13
	(0.11)	(0.11)	(0.10)	(0.20)	(0.12)***	(0.15)	(0.11)
Katete	0.72	0.12	0.63	0.14	0.96	−1.18	0.47
	(0.37)**	(0.38)	(0.35)	(0.91)	(0.42)**	(0.84)	(0.37)
Lundazi	−0.98	−1.38	−1.97	0.16	−0.38	−0.79	−1.69
	(0.26)	(0.26)***	(0.23)***	(0.51)	(0.30)	(0.37)**	(0.26)***
Mundlak fixed effects							
Mean plot distance	0.10	−0.04	0.01	−0.11	0.08	−0.27	0.00
	(0.10)	(0.10)	(0.09)*	(0.20)	(0.12)	(0.16)	(0.10)
Mean land tenure	−1.21	−0.42	−0.79	−1.09	−1.42	−1.44	−1.03
	(0.46)**	(0.49)	(0.44)	(0.74)	(0.49)**	(0.58)**	(0.47)**
Mean good fertility	0.29	0.57	0.54	0.62	0.38	1.01	0.55
	(0.30)	(0.30)*	(0.27)**	(0.56)	(0.35)	(0.49)**	(0.31)*
Mean medium fertility	0.21	0.08	0.84	−0.39	0.30	0.37	0.82
	(0.28)	(0.29)	(0.26)***	(0.63)	(0.34)	(0.49)	(0.3)**

Table 1
(*Continued*)

Variable	Residue retention	Maize–legume rotation	Maize–legume rotation and residue retention	Improved maize	Improved maize and residue retention	Improved maize and maize–legume rotation	Residue retention, maize–legume rotation and improved maize
Mean gentle slope	−0.49	−0.13	−0.74	0.57	−0.57	−0.36	−0.97
	(0.54)	(0.55)	(0.49)	(1.03)	(0.61)	(0.9)	(0.53)*
Mean medium slope	−0.34	−0.31	−0.77	−0.27	−0.62	−0.13	−0.97
	(0.55)	(0.56)	(0.50)	(1.09)	(0.63)	(0.91)	(0.55)
Mean deep soil	0.25	0.27	0.16	0.06	0.74	1.97	0.52
	(0.37)	(0.38)	(0.34)	(0.72)	(0.45)	(0.78)**	(0.38)
Mean medium deep soil	0.48	0.29	0.60	−0.69	0.65	1.58	0.61
	(0.36)	(0.37)	(0.32)*	(0.73)	(0.44)	(0.78)**	(0.37)
Fertiliser rate	−0.00	−0.00	0.00	0.00	0.00	−0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Instrumental variable							
Had information on SAPs	0.49	0.80	0.88	−0.11	0.34	0.43	0.61
	(0.22)**	(0.23)***	(0.20)***	(0.47)	(0.26)	(0.34)	(0.23)**
Constant	3.21	2.04	4.01	0.44	2.26	−1.85	0.92
	(1.06)***	(1.07)*	(0.97)***	(1.98)	(1.23)*	(1.78)	(1.10)
Wald test $\chi^2 = 86.37$; $P > \chi^2 = 0.000$							

Notes: Sample size is 3,750 plots and 810 households and 500 simulation draws were used. ***$P < 0.01$, **$P < 0.05$, *$P < 0.1$. Robust standard errors in parentheses. Fixed effects at plot level are included.

The results show that adoption of most packages increases with household size. As expected, education is significantly and positively associated with most of the SAPs. Education plays an important role in technology adoption in that it enables households to interpret new information and understand the importance as well as benefits of adopting modern agricultural technologies. Our results suggest that female-headed households are less likely to adopt most of the SAP packages. This is consistent with the findings of some previous studies (e.g. Doss and Morris, 2000). This may reflect the fact that women have less access to resources, such as land, education and information on improved agricultural technologies (Doss and Morris, 2000)

Land is also important in technology adoption decisions, especially land-enhancing technologies such as SAPs. We find that households that have larger pieces of land are more likely to adopt SAPs than those with less land. Similarly, households who have rented pieces of land (land tenure) are less likely to adopt the SAP packages than those who have their own land. This result is consistent with a number of studies on technology adoption in Africa that have shown that land ownership has a significant effect on adoption decisions (e.g. Kassie *et al*., 2013; Teklewold *et al*., 2013a).

The results also show that access to off-farm income reduces the likelihood of adoption of certain SAP packages. This is consistent with Pender and Gebremedhin (2007) and Mathenge *et al*. (2014) who found a similar result. The relationship between off-farm income and technology adoption can be negative because off-farm activities divert time and effort away from agricultural activities, reducing investment in technologies and the availability of labour.

Farm households that have less trust in government support are more likely to adopt crop and risk diversifying practices believing that government support may not satisfy households' food diversity needs (Kassie *et al*., 2013). This is evidenced by the negative relationship between the government support variable and adoption of the all the SAPs (except residue retention). Consistent with earlier work on technology adoption (e.g. Adegbola and Gardebroek, 2007), contact with government extension agents has a positive and significant effect on the decision to adopt the package that includes the combination of all the SAPS, but not for all other combinations.

As expected, problems with pests are mainly associated with residue retention, maize–legume rotation and residue retention and the combination of all three SAPs. Research has shown that insect-pests may be sheltered in undisturbed soils and crop residues on the soil surface thereby being carried over from one season to another (Jat *et al*., 2013). Furthermore, Jat *et al*. (2013) explain that during the initial adoption of SAPs such as CA, higher incidences of insect-pests are possible when parasites or predators that would eliminate the pests are insufficient.

The results in Table 1 further show that occurrence of droughts is positively related to the adoption of maize–legume rotation only and in combination with residue retention and improved maize. This is consistent with the findings of a recent study in Zambia (Arslan *et al*., 2013) showing that SAPs such as CA are essential in mitigating risks from climate change. Crop rotation enables farmers to grow crops that can be harvested at different times and that may require different weather or environmental conditions. Residue retention on the other hand is vital in improving the soil and retaining moisture especially in drought prone areas. The result therefore suggests that farmers are adopting these practices to reduce the effects of droughts.

Distance to fertiliser and output markets influence the adoption of improved maize seed and combination of improved maize seeds and residue retention. This reflects the transaction costs of purchasing inputs so that the further away a farmer is from the market, the higher the transactions costs and consequently the lower the likelihood that they would adopt SAPs. Considering the plot characteristics, good soil fertility increases the adoption of the combination of maize–legume rotation and residue retention, improved maize and maize–legume rotation and a package of all the SAPs compared with those plots with poor soil fertility. However, this result should be interpreted with caution because good soil fertility may be endogenous to crop rotation and residue retention since these practices lead to an improvement in soil fertility. Without any information on plot history, causal inferences based on this result may be misleading. The likelihood of adoption of a package consisting of all the practices is lower on plots with gentle slopes compared with steep plots. However, the likelihood of adoption of a package of improved maize and maize–legume rotation or residue retention and maize–legume rotation is greater on plots with deep and medium deep soils.

5.3. Average treatment effects of SAPs

Table 2 presents the estimates of the impact of SAPs on maize yields and household incomes.[7] For comparison purposes, the outcome variables are estimated under the assumptions of exogenous and endogenous adoption decision of SAPs.

With the assumption of exogenous adoption of SAPs, the results show that, on average, adopters had higher yields than non-adopters and the results are positive and statistically significant for most of the packages. The results for income per capita are similar to those for the maize yields. Making causal inferences based on the assumption of exogenous SAPs may be misleading as it ignores the effect of unobserved confounders. The difference in welfare outcomes could be caused by unobservable characteristics of the farm households, such as their management abilities. We address this issue by estimating a multinomial endogenous treatment effects model.

The average adoption effects after controlling for unobserved heterogeneity show a somewhat different picture (Table 2). Generally, SAPs adopted in combination had a strong and positive impact on maize yields and household income compared to those adopted in isolation, except for the adoption of improved maize which out yielded the more comprehensive package consisting of improved maize, residue retention and maize legume–rotation. In addition, most of the factor loadings (λ) show evidence of negative selection bias suggesting that unobserved factors that increase the likelihood of adopting SAPs are associated with lower levels of welfare than those expected under random assignment to the SAPs adoption status. Positive selection bias is also evident in the income equation suggesting that unobserved variables increasing the likelihood of adopting residue retention are associated with higher levels of income.

The results show that, on average, the adoption of improved maize varieties significantly increases maize yields by about 90% and this is consistent with other studies on adoption and impacts of improved maize varieties (e.g. Mason and Smale, 2013). Considering the adoption of a combination of maize–legume rotation and residue retention and the package consisting of improved maize and residue retention, the average gain from adoption is about 67% and 57% increase in maize yields for adopters compared with that of non-adopters. The impacts of these packages are less than

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[7] The results for the two normal regressions (second stage) are presented in Table S5 in the online appendix. The results for the mixed multinomial treatment effects regressions are not presented to conserve space, but are available upon request.

Table 2

Multinomial endogenous treatment effects model estimates of SAPs impacts on maize yields and household income

Assumption	Package	Ln maize yield per ha	Ln household income per capita
Exogenous	Residue retention	26%	25%
		(0.14)*	(0.18)
	Maize–legume rotation	36%	48%
		(14)**	(0.18)**
	Improved maize	38%	26%
		(0.13)***	(0.16)
	Maize–legume rotation and residue retention	58%	50%
		(0.27)**	(0.34)
	Improved maize and residue retention	46%	50%
		(0.16)***	(0.2)**
	Improved maize and maize–legume rotation	17%	46%
		(0.22)	(0.27)*
	Residue retention, maize–legume rotation and improved maize	58%	62%
		(0.14)***	(0.18)***
Endogenous	Residue retention	43%	−12%
		(0.17)**	(0.22)
	Maize–legume rotation	−6%	29%
		(0.18)	(0.27)
	Improved maize	90%	54%
		(0.15)***	(0.19)**
	Maize–legume rotation and residue retention	67%	39%
		(0.29)***	(0.35)
	Improved maize and residue retention	57%	75%
		(0.20)***	(0.24)***
	Improved maize and maize–legume rotation	33%	69%
		(0.23)	(0.31)**
	Residue retention, maize–legume rotation and improved maize	80%	43%
		(0.17)***	(0.24)*
	Selection terms (λ)		
	Residue retention	−0.19	0.43
		(0.11)*	(0.15)**
	Maize–legume rotation	0.51	0.22
		(0.12)***	(0.24)
	Improved maize	−0.64	−0.37
		(0.1)***	(0.13)**
	Maize–legume rotation and residue retention	−0.10	0.12
		(0.10)	(0.10)
	Improved maize and residue retention	−0.11	−0.29
		(0.13)	(0.14)**
	Improved maize and maize–legume rotation	−0.18	−0.23
		(0.09)*	(0.16)
	Residue retention, maize–legume rotation and improved maize	−0.25	0.24
		(0.12)*	(0.18)

Notes: The baseline is farm households that did not adopt any SAP. Sample size is 3,750 plots and 810 households and 500 simulation draws were used. ***$P < 0.01$, **$P < 0.05$, *$P < 0.1$. Robust standard errors in parentheses. Fixed effects at plot level are included.

that of the adoption of improved maize only probably because some farmers may have accessed fertilisers through the government subsidy programme, which may have led to the increased yields.[8] This is consistent with the descriptive statistics showing that more inorganic fertilisers were applied to improved maize than other packages. Results further show that the implementation of a more comprehensive package consisting of all the three SAPs results in the yield effect of 80% (Table 2). Consistent with Arslan *et al.* (2015), we find no significant effect of maize–legume rotation on maize yields when implemented in isolation. Compared with the results under the exogeneity assumption, the estimates with the unobservable characteristics controlled for are generally higher, suggesting that failure to account for endogeneity would understate the true impact of adoption.

For income per capita, results show that, on average, adopters of a combination of SAPs had between 43% and 75% more income than non-adopters, with the package of improved maize and residue retention having the greatest income effect. Maize–legume rotation has a positive and significant effect (69%) on income when combined with improved maize. Interestingly, we find that the impacts of SAPs on income when all three SAPs are adopted as a package were lower than the returns from SAPs packages involving improved maize and maize–legume rotation or improved maize and residue retention. Contrary to the results found by Teklewold *et al.* (2013b), this suggests that adopting a more comprehensive SAPs package may not necessarily result in higher income than a package consisting of two SAPs. Similar findings are reported by Di Falco and Veronesi (2013) who show that implementing climate change adaptation strategies that are more comprehensive does not always translate into higher net revenues when compared with less comprehensive strategies.

6. Conclusions and Implications

6.1. Conclusions

In many developing countries, smallholder farmers face multiple constraints such as low soil fertility that lead to low yields and farm incomes. Previous studies have shown that adoption of SAPs can play an important role in alleviating some of these problems. However, in most studies, much attention has been given to the understanding of the determinants of adoption of multiple SAPs without analysing their effect on the welfare of farmers. This paper contributes to the empirical literature in this area by examining the determinants and impacts of the adoption of three interdependent SAPs (crop rotation, improved varieties and residue retention) and their combinations on maize yields and household incomes in rural Zambia using a multinomial endogenous treatment effects model and farm household survey data collected from a sample of over 800 households.

As in most adoption studies, we find that the decision to adopt is a function of household and plot-level characteristics. Specifically, the education of the household head, household size, farm size and the occurrence of droughts increase the likelihood of farm households adopting SAPs. On the other hand, the propensity to adopt reduced with gender of the household head, access to off-farm income and distance to input and output markets. The finding of a highly significant and positive association

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[8] Second stage estimates show that inorganic fertilisers had a positive and significant impact on maize yields.

between adoption of SAPs and the occurrence of droughts suggests that farmers may be using SAPs to mitigate the risks of rainfall variability and climate change.

On the impact of adoption of SAPs on welfare outcomes, the results show that sample selection bias results if the welfare equations are estimated without considering the adoption decision. The impact results also show that SAPs adopted in combination or as a package are more effective than those adopted in isolation. The adoption of the package that includes improved maize only and the bundle consisting of improved maize and residue retention resulted in the highest yield and income effects, respectively. Similarly, adoption of a comprehensive package of all the SAPs provides the second highest increase in yield. Although improved maize seed results in the highest benefits in farmers welfare, adoption of improved maize also entails the use of inorganic fertilisers which may be expensive for most small-scale farmers. The results of this study show that other relatively inexpensive soil enhancing practices, such as the combination of residue retention with crop rotation and a combination of these SAPs with improved maize can equally increase maize yields and incomes.

6.2. Policy implications

The impact estimates also highlight the fact that a more comprehensive package would not always result in greater benefits than less comprehensive packages. Consistent with the knowledge-intensive nature of most of the SAPs, the results suggest that improvement in education should be one of the strategies to improve adoption of SAPs. Moreover, removal of barriers to information would greatly help in encouraging adoption. It is also important for the actors involved in the design, promotion and dissemination of SAPs to find a suitable mix of these practices that will ensure an increase in maize productivity and incomes, while at the same time addressing issues related to inorganic fertiliser application, rainfall variability, droughts and climate change in Zambia.

In the wake of the ever increasing costs of external inputs such as inorganic fertilisers, there is need for policy-makers and researchers to look for cheaper methods of increasing yields and incomes for small-scale farmers. Adoption of improved maize varieties in combination with practices such as maize–legume rotation and residue retention can boost yields and farm incomes and should be promoted especially among resource poor farmers who cannot afford inorganic fertilisers.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Descriptive statistics by district.
Table S2. Descriptive statistics by adoption of SAPs.
Table S3. Fertilizer application by SAPs.
Table S4. Parameter estimates: Test on validity of selection instruments.
Table S5. Second stage estimates for maize yields and household income.

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