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Abstract

Climate change and variability and soil fertility depletion are among the main biophysical limiting factors for increasing per capita food production for smallholder farmers in developing countries. To tackle these challenges, the adoption of sustainable agricultural practices (SAPs), has become an important policy topic among donors and development agencies in developing countries. This paper examines the adoption decisions for SAPs, using recent primary data collected in 51 villages in 3 districts of Zimbabwe. The article employs a multivariate probit regression to model simultaneous interdependent adoption decisions by farm households. The analysis reveals that education, farm experience, farm size, income, access to information and agroecology influence the adoption of SAPs. Policies that are aimed at improving household income and enhancing access to information can increase the uptake of SAPs by smallholder farmers. Extension messages should aim to emphasize the complementarities between different SAPs. This information could help policy makers and extension agents to formulate and promote a package of SAPs.

Keywords: Sustainable agricultural practices, multiple adoption, multivariate probit, Zimbabwe

Introduction

Agricultural productivity in many developing countries including Zimbabwe is constrained by multiple and complex biophysical challenges, for example climate change and variability, low soil fertility, pest and disease prevalence (Shiferaw et al. 2014; Vanlauwe et al. 2014). In this connection, sustainable agricultural practices (SAPs) offers a practical pathway for farmers to enhance the productivity and resilience of agricultural production systems while conserving the natural resource base (The Montpellier Panel 2013; Teklewold et al. 2013; Kassie et al. 2013). The promotion of sustainable agricultural practices has become a major issue among donor, development and extension agencies to tackle the complex challenges affecting agriculture (Kassie et al. 2013). Examples of sustainable agricultural practices include conservation agriculture, agroforestry, legume intercropping, legume crop rotations, improved crop varieties, drought tolerant crop varieties, and integrated pest management, use of animal manure, and soil and water conservation (Pretty, Toulmin & Williams 2011; Kassie et al. 2013; Teklewold et al. 2013; The Montpellier Panel 2013; Vanlauwe et al. 2014).

Recent studies show that the adoption of SAPs provide higher yields and income (Teklewold et al. 2013; Manda et al. 2016). Despite the benefits of SAPs, their adoption rates remain low in sub-Saharan Africa (Kassie et al. 2015; Teklewold et al. 2013; Lee 2005). Understanding the factors that affect the adoption of SAPs can provide guidance into identifying key drivers and areas that enhance the use of these practices. However, the majority of earlier studies on the adoption of SAPs have focused on a single technology (Amsalu & Graaff 2007; Mazvimavi & Twomlow 2009; Arslan et al. 2014; Ghimire, Wen-chi & Shrestha 2015), ignoring complementarities and trade-offs between SAPs.

There is an emerging body of literature analysing the adoption of multiple sustainable agriculture practices (Jara-Rojas et al. 2013; Kassie et al. 2013; Teklewold et al. 2013; Kamau, Smale & Mutua 2014; Wainaina, Tongruksawattana & Qaim 2014; Kassie et al. 2015; Manda et al. 2016). Kassie et al. (2013) analysed the determinants of the adoption of four sustainable agriculture practices in Tanzania. Wainaina, Tongruksawattana & Qaim (2014) analysed factors influencing the adoption of seven SAPs among smallholder farmers in Kenya. In another study, Kassie et al. (2015) analysed the determinants of adoption of five SAPs in Ethiopia, Malawi, Kenya and Zambia. However, relatively little empirical work has been done to examine the factors that facilitate or constrain the adoption of multiple SAPs, especially conservation tillage, winter ploughing, staggered planting, drought tolerant varieties, integrated pest management, inorganic and organic fertilizers.

The contributions of this paper are threefold: First, we contribute to this strand of literature and analyse the adoption of seven SAPs among smallholder farmers in Zimbabwe -a different country context. This is important as the adoption of SAPs differ from one country to another, depending on local agro ecological, socioeconomic, and market conditions (Vanlauwe et al.

2014). Second, we consider different combinations of SAPs compared to earlier studies. Third, we identify complementarities and trade-offs between the seven SAPs.

The remainder of this article is organized as follows. In the next section we describe the methodology including the description of survey data. We then discuss the empirical model specification and estimation issues. Empirical results are presented and discussed. The last section concludes and discusses policy implications.

Methodology

Study area and sampling

The study used data from the baseline household survey conducted within the auspices of Extension and Training for Rural Agriculture (EXTRA) project in three districts of Zimbabwe namely Gokwe South, Kwekwe and Shurugwi. A stratified random sampling technique was used to select respondents. In the first stage, wards were selected with the objective to cover the varying agro ecological regions found in the district. In each ward all villages hosting the EXTRA project were listed and survey villages were chosen purposively to include diversity in agroecology. Once specific villages were selected, systematic random sampling at household level was done, whereby enumerators picked 6th or 7th homestead from the first point of entry in a particular village. From this sampling strategy, a total of 495 households were interviewed (Table 1). A pretested structured household questionnaire was administered to sampled households in March 2015 by trained enumerators. The questionnaire collected the following information: household demographics, crop and livestock production, sustainable agricultural technologies, income and access to information. In this article, we however analyse data from 398 households which had consistent responses on sustainable agricultural practices.

Table 1. Survey sample

District	Number of wards covered	Number of villages	Households interviewed
Shurugwi	2	12	81
Kwekwe	4	16	168
Gokwe South	6	23	246
Total	12	51	495

Description of the technologies

A total of seven sustainable agricultural practices (SAPs) were included in this study. These SAPs were sub-classified into climate risk management, crop protection and soil fertility management practices. The climate risk management practices included conservation agriculture, winter planting, staggered planting and drought tolerant varieties. The crop protection practice included in this study is integrated pest management. The last category was soil fertility management practices which included inorganic fertilizers and manure application. We hypothesized that farmers adopt SAPs that complement each other. We discuss each of these SAPs in the next sub-section.

Conservation agriculture is a practice that combines three principles: minimum tillage, permanent organic soil cover and crop diversification (including crop rotation) to sustainably improve farm productivity, profits and food security (Kassam et al. 2009; Arslan et al. 2014). Conservation agriculture offers sustainable farming options that address a broad set of farming constraints, such as low crop productivity, vulnerability to drought, limited access to draft power, soil degradation and loss of fertility (Kassam et al. 2009). The use of soil cover with crop residues or cover crops reduces soil moisture loss and increases infiltration. Crop rotation with nitrogen fixing legumes helps to improve soil fertility, crop diversity and to break the life cycle of pests and diseases. This helps to reduce farmers use of purchased external inputs (Teklewold et al. 2013). In this study, conservation agriculture adoption is defined as the practising of any of the three principles or any combination of the three. Winter ploughing is a practice where farmers till the land soon after harvesting to conserve moisture. This practice captures and conserves the first rains that fall in winter. Winter ploughing also prevents weeds, pests and diseases building up by breaking their life cycles. It is also thought to enable early planting due to early land preparation. During winter ploughing, crop residues are buried and when they decompose, they add organic matter to the soil. Staggered planting involves the planting of the same crop on different planting dates to hedge against the risk of poor crop germination and crop failure due to erratic and unreliable rainfall. Another climate risk management practice considered in this study is the use of drought tolerant varieties. The use of drought tolerant crop varieties is one of the strategies for managing water limitation in agriculture (Shiferaw et al. 2014). The use of drought tolerant varieties of maize have been found to have at least 30–40% yield advantage over other commercial varieties under severe stress, and similar performance under optimal conditions (Shiferaw et al. 2014; Xoconostle et al. 2010).

In terms of crop protection, farmers were asked whether they use integrated pest management. Integrated pest management are pest control strategies that tend to reduce costs of pesticide application through the use of non-chemical methods such as resistant varieties, maintaining clean fields, pheromone traps and chemical methods which avoid the use of same chemicals to control pest resistance (Kabir & Rainis 2015; The Montpellier Panel 2013). This SAP reduces the use of pesticides without causing harm to the yield and as such lowers production costs. Soil fertility management practices used in this study include inorganic fertilizer and manure application. Soil nutrient depletion is one of the major causes of low crop productivity and food insecurity in Africa (Shiferaw et al. 2014; Vanlauwe et al. 2014).The use of inorganic fertilizers and animal manure to improve nutrient supply and organic matter in the soil and is associated with yield increase.

Description of variables

The explanatory variables used in this study are drawn from adoption literature (Marenya & Barrett 2007; Mazvimavi & Twomlow 2009; Mariano, Villano & Fleming 2012; Kassie et al. 2013; Kamau, Smale & Mutua 2014; Kassie et al. 2015). We capture household characteristics by including age, gender, household size and education level of the household head. These variables are relevant in that they influence adoption decisions where there are market imperfections and institutional failures (Kassie et al. 2015). Older household heads tend to have more experience in production practices and of the local environment and a greater accumulation of physical and social capital, which enhances technology adoption. On the other hand, age can be associated with loss of energy, short-term planning and being more risk averse. Therefore the effect of age on technology adoption is ambiguous (Kamau, Smale & Mutua 2014; Kassie et al. 2015). Education may increase farmer's ability to acquire information and practice new technologies, and increase returns from the adoption of these technologies.

Farming experience is related to the history of past investments on the land and to knowledge gained through experience. Labour supply is captured by household size and full time labour. We expect households with greater availability of family labour to be more likely to adopt technologies, which requires farmers to carry out labour-intensive practices on their farms. We measured wealth using farm size, household income and cattle ownership. Wealth is expected to have positive effects on farmers' investment capacity and ability to bear risk and thus on the probability of adoption. However, the effect of wealth on some of the technologies is indeterminate because some investments such as conservation agriculture are known to be affordable to poorer households who lack draft power. Cattle ownership is also associated with the manure producing capacity of the household (Kamau, Smale & Mutua 2014).

In addition, we included a number of variables capturing access to information and social networks like public extension, mobile phone, farmer group, radio, television ownership, which are expected to have positive effects on farmers' ability to weigh the economic returns of each technology and thus on the probability of adoption (Wainaina, Tongruksawattana & Qaim 2014; Kassie et al. 2015). To capture agro-ecological variation across households, we include a dummy variable that equals one if the household is located in natural region III and zero in natural region IV. This classification is based on rainfall where natural region III receives higher rainfall than region IV (Ndlovu et al. 2014). We expect that households located in higher-rainfall areas (natural region III) may be less likely to adopt soil and water conservation technologies compared to households in drier natural region IV. Farmers residing in natural region III are more likely to adopt IPM because of higher incidence of pests and diseases. Cotton growers are more likely to adopt IPM because this technology was mainly promoted among cotton growers in the country. To control for this, we included a dummy variable capturing the growing of cotton in our model.

Estimation strategy

The estimation strategy is based on the premise that farmers are more likely to adopt a combination of sustainable agricultural practices (SAPs), which may be adopted simultaneously and/or sequentially as a complement or supplement to each other. Various empirical studies (Kassie et al. 2013; Teklewold et al. 2013; Jara-Rojas et al. 2013; Wainaina, Tongruksawattana & Qaim 2014; Kassie et al. 2015) argued that farmers usually consider a portfolio of SAPs and therefore the adoption decision is multivariate. Studies focusing on adoption of a single technology (Amsalu & Graaff 2007; Mazvimavi & Twomlow 2009; Arslan et al. 2014; Kabir & Rainis 2015; Ghimire, Wen-chi & Shrestha 2015) fail to consider the possible correlation/interdependence between different SAPs, thereby ignoring the fact that farmers are often faced by a set of choices. The use of univariate probit or logit models is inefficient when adoption decisions are inter-related since univariate models ignore the correlation in the error terms of adoption equations. The correlation arises because the same unobserved characteristics of farmers could influence the adoption decisions for different SAPs. Failure to capture such interdependence will lead to biased and inaccurate estimates.

We employ a multivariate probit (MVP) model that recognizes the correlation in the error terms of adoption equations and estimates a set of binary probit models (in our case seven probit models) simultaneously (Cappellari & Jenkins 2003; Kassie et al. 2015). Our MVP model consists of 7 binary choice equations, namely conservation agriculture, winter ploughing, staggered planting, drought tolerant varieties, integrated pest management, inorganic fertilizer, and use of animal manure. The MVP model is specified as:

$$y_{im}^{*} = \beta_m + X_{im} + \varepsilon_{im} \qquad m = 1,2 \ldots \ldots ,7 \qquad (1)$$

$$y_{im} = \begin{pmatrix} 1 \;\; if \; y_{im}^{*} > 0 \\ 0 \;\; otherwise \end{pmatrix} \qquad (2)$$

where y_{im}^{*} is a latent variable that captures the unobserved preferences associated with the choice of practice m. This latent variable is assumed to be a linear combination of observed characteristics, X_{im}, and unobserved characteristics captured by the stochastic error term, ε_{im}. The vector of parameters to be estimated is denoted by β_m. Given the latent nature of y_{im}^{*}, estimation is based on observable binary variables y_{im}, which indicate whether or not a farmer used a particular technology in the reference year.

The error terms ε_{im}, $m = 1,2 \ldots \ldots ,7$ are distributed multivariate normal each with mean 0 and a variance-covariance matrix V, where V has 1 on the leading diagonal, and correlations $\rho_{jk} = \rho_{kj}$ as off diagonal elements (Cappellari & Jenkins 2003):

$$V = \begin{pmatrix} 1 & \rho_{12} & \rho_{13} & \cdot & \cdot & \rho_{1k} \\ \rho_{21} & 1 & \rho_{23} & \cdot & \vdots & \rho_{2k} \\ \rho_{31} & p_{32} & 1 & \vdots & & \rho_{3k} \\ \vdots & \vdots & \vdots & 1 & \vdots & \rho_{4k} \\ & & & \cdot & 1 & \rho_{5k} \\ \rho_{j1} & \rho_{j2} & \rho_{j3} & \rho_{j4} & \rho_{j5} & 1 \end{pmatrix} \qquad (3)$$

where ρ (rho) denotes the pairwise correlation coefficient of the error terms corresponding to any two SAP's adoption equations to be estimated in the model (Kassie et al. 2015). In the presence of error terms correlation (ρ), the off-diagonal elements in the variance–covariance matrix of adoption equations become non-zero and Eq. (2) becomes an MVP model. In this model, ρ is not just a correlation coefficient, and carries more information. A positive correlation is interpreted as a complementary relationship, while a negative correlation is interpreted as being substitutes.

Results

Descriptive analysis

Table 2 shows the summary statistics of the seven sustainable agriculture practices and independent variables. Our study found out that 98% of the households were aware of the conservation agriculture technology. However, only 28% adopted the technology in the 2014/15 cropping season. We found out that all the sampled farmers in the three districts were aware of winter ploughing, staggered planting and drought tolerant varieties and 39%, 74% and 47% adopted these SAPs respectively. Although all the farmers were aware of integrated pest management, about 53% adopted this technology. Our study found out that all the sampled farmers were aware of use of inorganic fertilizers and manure. However, 56% and 71% adopted inorganic fertilizers and manure respectively. We find that most farmers were aware of the climate risk management, crop protection and soil fertility management strategies. These results may suggest that information is not a constraint for the adoption of these technologies. There are other factors constraining the adoption of conservation agriculture, winter ploughing, drought tolerant varieties, integrated pest management and inorganic fertilizers. Inorganic fertilizers are often expensive for poor smallholder farmers in Zimbabwe and this may be constraining its adoption. Vanlauwe et al. (2014) found that farmers in Africa apply 15 times less fertilizer and thus subsequently results in a huge yield gap.

The average age of the household head is 53 years. About 76% of the sample households are male-headed. The average educational attainment of household head is 8 years of education. Sampled households had on average 26 years of farming experience. These results suggest that the household heads were literate and have adequate farming experience. Education increases the farmer's ability to acquire information about appropriate technologies and farming experience reflects knowledge on farming techniques and local environmental conditions gained through experience, thus enhances adoption of SAPs. On average, households own seven acres of arable land. In terms of access to information, 92% of the household have access to public extension while 62% and 14 % own a radio and a television respectively. Thirty five percent of the sampled households belonged to a farmer group. About 33% of the households reside in natural region III, which receives relatively higher rainfall compared to natural region IV.

Table 2. Summary statistics of dependent and independent variables

Variable	Descriptions	Observations	Mean	Std. Dev.
Dependent variables				
Conservation agriculture		398	0.28	0.45
Winter ploughing		338	0.39	0.49
Staggered planting		348	0.74	0.44
Drought tolerant varieties		303	0.47	0.50
Integrated pest management		182	0.53	0.50
Inorganic fertilizer		370	0.56	0.50
Manure		389	0.71	0.45
Independent variables				
Age	Age of the household head (years)	398	53.42	15.73
Gender	0 if female; 1 if male	398	0.76	0.43
Education	Household head years of schooling	398	7.53	2.32
Farming years	Farming experience (years)	398	26.13	15.32
Household size	Number	398	6.20	2.84
Full time labour	Number	398	2.64	1.46
Job	Head main occupation (1=farmer)	398	0.76	0.43
Arable land	Arable land (acres)	398	7.40	5.25
Total income	Total household income (USD) log	398	6.76	1.12
Cattle	Own cattle (1=yes)	398	0.74	0.44
Public extension	Access public extension (1=yes)	398	0.92	0.27
Mobile phone	Own mobile phone (1=yes)	398	0.42	0.49
Farmer group	Belong to farmer group (1=yes)	398	0.35	0.48
Radio	Own radio (1=yes)	398	0.62	0.49
Television	Own television (1=yes)	398	0.14	0.35
Agroecology	Reside in natural region III (1=yes)	398	0.33	0.47
Cotton	Grew cotton (1=yes)	398	0.27	0.45

Econometric results

The likelihood ratio test for the overall correlation of error terms is significant: $X^2(21) = 47; p = 0.000$ and means the error terms across the adoption equations are correlated. The result support the application of the MVP model. We utilized the multivariate probit regression while controlling for demographic characteristics, such as age, gender and education (Table 3).

The coefficients that explain how each variable influence the probability of adopting each of these technologies are explained. The age of a farmer positively influenced the likelihood of adopting conservation agriculture and manure application. However, age squared has a negative and significant relation with the adoption of conservation agriculture. This result means that young farmers are more likely to adopt conservation agriculture but as farmers become too old the likelihood to adopt this technology falls. Older farmers are in most cases risk averse and less likely to adopt newer technologies compared to young farmers. Kamau, Smale & Mutua (2014) also found a similar result that young farmers are likely to adopt soil improving and natural resource management technologies. The econometric results also show that age squared has a positive effect on winter ploughing. This result suggest that young farmers are less likely to practice winter ploughing, but as they grow older and possibly amass draft power and farming equipment they start practising the technology.

Farming experience has a positive and significant relationship with inorganic fertilizer application. Farming experience usually increases the probability of technology adoption, because experienced farmers are more likely to have better access to information and knowledge of soil fertility technologies. In addition, farmers with better experience and information are most likely to take initiatives in adopting and testing new technologies. Targeting of such experienced farmers during the promotion of soil fertility technologies can, therefore, have a significant positive effect. One possible avenue to promote learning and increase adoption is to use inorganic fertilizer demonstration trials. Household size, which we use as an indicator of family labour availability has a positive and significant effect on the adoption of conservation agriculture and drought tolerant varieties. Full time labour has a negative and significant effect on conservation agriculture adoption. This is a bit surprising but can be explained by the fact that may be smallholder farmers are relying on part time labour on conservation agriculture than full time labour.

The result that when the head’s main occupation is farming reduces the likelihood of adopting winter ploughing is quite surprising. It might be because during winter, most farmers in the study area devote most of their time and labour for horticulture activities and some go for holidays in urban areas. This results in few farmers practising winter ploughing. We include farm size in the model to assess its effect on the probability of adopting sustainable agricultural technologies. The positive and significant sign on farm size indicated that as farm size increased, the likelihood of adopting winter ploughing, staggered planting and drought tolerant varieties increased. This result is consistent with Kassie, Shiferaw & Muricho (2011), Mariano, Villano & Fleming (2012) and Ghimire, Wen-chi & Shrestha (2015) who found that farm size positively influence technology adoption. Household income was found to increase the likelihood of adopting integrated pest management. This result is expected as this technology require purchased inputs - pesticides. Policies that are aimed at improving household income can increase the uptake of SAPs by smallholder farmers. One obvious data limitation is that we could not distinguish between farm and off-farm income. We suspect that the bulk of household income among the sampled farmers is coming from off-farm income.

Cattle ownership positively influenced the use of manure by smallholder farmers. This result may be associated with capacity to produce manure on-farm and is consistent with Kamau, Smale & Mutua (2014) who found that livestock had a significant effect on the use of soil amendments. However, cattle ownership has a negative influence on the adoption of integrated pest management. This could because cattle herding in summer may be diverting labour required for agricultural work such as crop protection. Access to public extension and television increased farmer’s likelihood of adopting staggered planting while mobile phone increased the likelihood of adopting drought tolerant varieties. These results underlie the importance of information access on promoting adoption of sustainable agricultural practices (Mariano, Villano & Fleming 2012; Ghimire, Wen-chi & Shrestha 2015). These results show that extension messages promoting the uptake of sustainable agricultural practices could be channelled through television and mobile phones. Access to radio reduced the likelihood of using inorganic fertilizers. Most of the study areas experienced erratic rainfall and midseason dry spells in the past season and farmers with radios could have accessed information in the midseason of the impending drought conditions and decided not to apply inorganic fertilizers fearing to burn the crops.

After controlling for the growing of cotton, results show that agroecology had a negative and positive effect on adoption of drought tolerant varieties and integrated pest management respectively. Farmers in the relatively wetter natural region 3 were less likely to adopt drought tolerant varieties. This is expected as farmers in areas that receive above average rainfall tend to grow long season crop varieties. Farmers residing in natural region 3 are more likely to adopt integrated pest management. This is because in the relatively wetter natural region 3, there are higher pest populations compared to dry natural region 4, which warrant high investments in pest management. The econometric results show that farmers growing cotton are likely to practise winter ploughing and staggered planting and less likely use manure.

Table 3. Coefficient estimates of the multivariate probit model

	Climate risk strategies				Crop protection	Soil fertility	
	CA	WP	SP	DTV	IPM	IF	MA
	b/se	b/se	b/se	b/se	b/se	b/se	b/se
Age	0.158**	-0.123*	0.064	-0.010	0.054	0.043	0.155*
	(0.077)	(0.070)	(0.074)	(0.063)	(0.072)	(0.071)	(0.084)
Age squared	-0.001*	0.001*	-0.001	-0.000	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Male head	-0.445	-0.264	0.567	0.061	0.113	0.600*	-0.165
	(0.328)	(0.371)	(0.366)	(0.340)	(0.342)	(0.338)	(0.417)
Household size	0.101*	0.056	-0.055	0.186***	-0.085	0.006	0.037
	(0.056)	(0.067)	(0.063)	(0.059)	(0.060)	(0.060)	(0.077)
Education	0.052	0.063	-0.044	-0.009	-0.001	0.047	0.036
	(0.053)	(0.057)	(0.058)	(0.051)	(0.058)	(0.050)	(0.062)
Farm experience	-0.012	-0.003	0.001	0.010	0.006	0.041**	-0.018
	(0.018)	(0.020)	(0.020)	(0.018)	(0.019)	(0.017)	(0.024)
Full time labour	-0.267**	-0.116	0.090	-0.123	0.071	0.034	0.047
	(0.109)	(0.116)	(0.108)	(0.101)	(0.104)	(0.109)	(0.135)
Job (1=farmer)	-0.256	-0.706**	-0.222	-0.057	0.008	0.319	-0.432
	(0.343)	(0.336)	(0.379)	(0.314)	(0.314)	(0.316)	(0.425)
Arable land	0.003	0.084**	0.084**	0.084***	0.025	0.008	0.010
	(0.031)	(0.033)	(0.038)	(0.032)	(0.031)	(0.031)	(0.043)
Income (log)	-0.080	-0.215	0.093	-0.106	0.493***	0.186	-0.179
	(0.138)	(0.142)	(0.146)	(0.135)	(0.146)	(0.132)	(0.163)
Cattle	0.140	0.367	-0.259	0.372	-0.545*	0.521	1.021***
	(0.326)	(0.346)	(0.346)	(0.314)	(0.326)	(0.319)	(0.377)
Public extension	0.186	0.457	1.244*	0.198	-0.758	-0.444	-3.957
	(0.662)	(0.631)	(0.651)	(0.730)	(0.740)	(0.767)	(109.850)
Mobile phone	0.187	0.234	0.210	0.539**	-0.402	-0.156	0.464
	(0.265)	(0.285)	(0.281)	(0.254)	(0.278)	(0.278)	(0.313)
Farmer group	-0.068	0.509	0.235	0.424	-0.366	0.473	0.186
	(0.289)	(0.323)	(0.317)	(0.303)	(0.297)	(0.320)	(0.427)
Radio	0.051	0.412	-0.446	0.127	-0.026	-0.529*	0.704
	(0.317)	(0.319)	(0.344)	(0.301)	(0.296)	(0.311)	(0.443)
Television	0.568	0.049	1.134**	0.344	0.201	0.153	-0.271
	(0.379)	(0.435)	(0.508)	(0.401)	(0.372)	(0.358)	(0.512)
Agroecology	0.090	0.274	0.168	-0.601**	0.995***	-0.434	0.759*
	(0.305)	(0.311)	(0.335)	(0.289)	(0.312)	(0.298)	(0.403)
Cotton	0.038	0.544*	0.740*	0.049	0.541	-0.335	-1.084***
	(0.309)	(0.330)	(0.393)	(0.317)	(0.331)	(0.306)	(0.376)
Constant	-4.669**	2.395	-2.967	-0.729	-3.228	-2.871	0.330
	(2.355)	(2.183)	(2.224)	(1.981)	(2.234)	(2.296)	(109.877)
N	132						
Wald chi2(126)	185.39***						
Log likelihood	-453.45						

*, **, *** significant at 10%, 5%, and 1% levels, respectively. Standard errors in parentheses. CA=conservation agriculture, WP=winter ploughing, SP=staggered planting, DTV=drought tolerant varieties, IPM=integrated pest management, IF=inorganic fertilizer and MA= manure.

Complementarities and substitutes

The binary correlations between the error terms of the seven adoption equations are presented in Table 4. These coefficients measure the correlation between the seven adoptions decisions after the influence of the observed factors are accounted for. We find that some practices are complements, while others are substitutes (compete for the same scarce resources). The correlation coefficients are statistically different from zero in 8 of the 21 cases, confirming the appropriateness of the multivariate probit model and technology adoption is not mutually independent.

The highest positive correlation (58%) is between conservation agriculture and use of manure. Conservation agriculture conserves soil and moisture, while manure increases soil fertility, so combining both could lead to synergies. The use of drought tolerant varieties is positively associated with winter ploughing. Both technologies are aimed at maximizing soil water use efficiency and complement each other. Apart from conserving moisture, winter ploughing also break pest and disease cycles. The use of drought tolerant varieties is positively associated with staggered planting. This is plausible as both technologies involve managing and conserving soil water. The positive correlation (43%) between integrated pest management and drought tolerant varieties shows the positive synergies between the two technologies. Drought tolerant varieties maximize soil water and integrated pest management protects the crop from pest and diseases winter ploughing is explained by the fact that both are crop protection technologies. The use of drought tolerant varieties is positively associated with manure application. Overall our results show that the use of drought tolerant varieties complements winter ploughing, staggered planting, integrated pest management and manure application. Extension messages should promote the use drought tolerant varieties alongside soil conservation, pest management and soil fertility technologies.

There are also a number of negative associations between adoption decisions, indicating technological substitutes. Conservation agriculture is negatively associated with staggered planting. In the majority of cases, the digging of planting basins and the actual planting (conservation agriculture) is done at the beginning of the rainy season thereby competing for the same scarce labour resource with staggered planting. Fertilizer and winter ploughing as well as fertilizer and staggered planting are found to be substitutes. This was not expected and the reasons for such relationship is not clear. This may be because the public extension heavily emphasize fertilizer use in its extension messages with minimal emphasis on winter ploughing and staggered planting. Wainaina, Tongruksawattana & Qaim (2014) argued that when farmers only get one information type, they get an incomplete picture and fail to exploit the synergies between different technologies. This might be the case for our results. The policy implication here is that extension staff need to promote all the different practices.

Table 4. Correlation coefficients for MVP regression equations

	ρ^{CA}	ρ^{WP}	ρ^{SP}	ρ^{DTV}	ρ^{IPM}	ρ^{IF}	ρ^{MA}
ρ^{CA}	1						
ρ^{WP}	0.250	1					
	(0.177)						
ρ^{SP}	-0.418**	-0.223	1				
	(0.182)	(0.159)					
ρ^{DTV}	0.230	0.343**	0.440**	1			
	(0.152)	(0.151)	(0.186)				
ρ^{IPM}	-0.157	0.289	-0.033	0.425***	1		
	(0.183)	(0.176)	(0.159)	(0.160)			
ρ^{IF}	0.134	-0.436***	-0.362**	-0.103	0.192	1	
	(0.156)	(0.165)	(0.182)	(0.148)	(0.168)		
ρ^{MA}	0.582**	0.001	-0.077	0.466**	0.176	-0.029	1
	(0.236)	(0.169)	(0.187)	(0.200)	(0.188)	(0.212)	

*, **, *** significant at 10%, 5%, and 1% levels, respectively. Standard errors in parentheses. CA=conservation agriculture, WP=winter ploughing, SP=staggered planting, DTV=drought tolerant varieties, IPM=integrated pest management, IF=inorganic fertilizer and MA= manure.

Likelihood ratio test for the overall correlation of error terms: chi2 (21) = 47.32 Prob > chi2 = 0.0009.

Conclusions and implications

This article examines factors affecting the adoption of multiple sustainable agricultural practices by smallholder farmers in Zimbabwe. We estimate multivariate probit regression to account for the possible correlation between different SAPs. From a policy perspective, understanding the determinants of SAP adoption could help design appropriate dissemination strategies. The empirical results show that various socio-economic, institutional and agro ecological influence smallholders farmers adoption decisions on SAPs. Empirical results show that young farmers are more likely to adopt conservation agriculture. This suggests that upscaling of conservation agriculture should target young farmers. It should be noted that the promotion of conservation agriculture should however not discriminate older farmers. Our result show that farming experience positively influences the adoption of inorganic fertilizers. The positive correlation between farming experience and the adoption of inorganic fertilizers suggests that increasing farmers' exposure and experience to soil fertility management practices through demonstration trials and other extension methods may accelerate the uptake of soil fertility technologies. The size of arable land positively influences the adoption of winter ploughing, staggered planting and drought tolerant varieties. Income influences the adoption of integrated pest management. Access to information through public extension and television positively influenced the adoption of staggered planting. Policies that are aimed at improving household income and enhancing access to information can increase the uptake of SAPs by smallholder farmers. These results also show that extension messages promoting the uptake of sustainable agricultural practices could be channelled through television and mobile phones

We found that there were complementarities between SAPs and in some cases substitutability effects. These correlations have two important implications for the promotion of SAPs in developing countries. Firstly, policy changes that affect adoption of a given SAP can have spill over effects on adoption of other SAPs. Therefore extension messages and promotions should emphasize the complementarities and substitutability between different SAPs to broaden farmer options. Secondly, information on which SAPs are adopted together and which individually, can help policy makers and extension agents to formulate a package of SAPs (Kassie et al. 2015). For example, farmers could harness maximum benefits if they apply manure to their conservation agriculture plots. Farmers could realize positive synergies if the adoption of winter ploughing, staggered planting, manure application and integrated pest management can each be combined with the planting of drought tolerant crop varieties. These use of drought tolerant varieties is crucial considering the recurrent drought occurring in Zimbabwe.

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