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Conservation agriculture, conservation farming and conventional tillage adoption, efficiency and economic benefits in semi-arid Zimbabwe

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Conservation practices can be of great importance in semi-arid regions for obtaining high crop yields and income, but adoption of the conservation practices, economic efficiencies and benefits remain unknown by most smallholders. The paper presents an overview of the adoption of conservation agriculture (CA), conservation farming (CF) and conventional tillage (ConvT), their technical efficiency and economic benefits. The study was carried out in Wards 4 and 17, Chimanimani District, Zimbabwe using a cross-sectional survey of 179 farmers involving participatory was used. A Stochastic frontier analysis (SFA) was used to determine relative technical efficiencies between CA, CF and ConvT farmers. Maximum likelihood estimation (MLE) technique was used to estimate Cobb-Douglas frontier production function. Gross margin (GM) analysis was employed to determine economic benefits by farmer category. Results showed that adoption was 59% for CF 20% for CA techniques and 69% for ConvT. SFA in R revealed that CF, CA and ConvT farmers were 87, 81 and and 64% technically efficient respectively. GM analysis showed that CF had the highest GM/ha of $99.88 and 196.20 with and without family labor cost respectively. This was followed by CA with GM/ha of $63.82 and 158.60.ConvT farmers had the least GM of -$25.16 and 65.20 with and without family labor cost. Most communal farmers considered ConvT to be a traditional practice; this could have been responsible for high adoption of the practice. Farmers showed a negative attitude towards CA despite the high labor requirements for CF. It is recommended that, of all the three practices in semi-arid regions, farmers use CF practice as it gives highest technical efficiency and GM.

Key words: Conservation agriculture, conservation farming, adoption, technical efficiency, stochastic frontier analysis.

INTRODUCTION

Conservation practices and conventional tillage (ConvT) have been common in Southern Africa for many years. ConvT has been the first practice and regarded as a traditional method of tillage in Africa. Matthew et al. (2012) found that ConvT led to rapid degradation of soil fertility and structure through loss of organic matter, giving higher input costs, increased runoff and excessive losses of soil and nutrients; key amongst these being soil degradation (Sperrati and Turmel, 2015). Ngwira et al. (2012) concluded that lower yields were obtained under ConvT than under conservation agriculture (CA).

Conservation agriculture (CA) and conservation farming (CF) have great potential of solving the above mentioned production problems of smallholder farmers in the dry parts of Africa (Haggblade and Tembo, 2003; Hobbs, 2007; Rockstrom et al*.,* 2009). They are popular alternatives which promise to utilize land and other resources in a sustainable manner (Nyamangara and Matizha, 2010). Various views are highlighted by researchers on sustainable agriculture based on CA and CF, from resource conservation, which range from low use of external inputs (Ouedraogo et at., 2001), through other various sustainable agriculture activities, to soil water and soil nutrient management (Pretty and Hine, 2000; Mashapa et al., 2013).

CA is a broader term that encompasses activities such as minimum tillage and zero tillage, tractor powered, animal powered and manual methods, integrated pest management, integrated soil and water management, and includes CF (Twomlow et al., 2008a). CF is a technology which uses planting basins and soil cover (Twomlow et al., 2008a; United Nations Food and Agriculture Organisation (FAO), 2011). It is a particular technology developed by Oldreive (1993). The CA Task Force for Zimbabwe (ZCATF) which was initiated in March 2004 outlined CA and CF components, and confirmed that digging planting basins using hoes, following principles like mulching and crop rotation, is termed CF (Protracted Relief Programme (PRP), (2005). Mazvimavi and Twomlow (2009) added that soil amendments like manure and inorganic fertilizers were incorporated precisely in the planting basins. Currently, the dominant CF technique adopted in Zimbabwe is the planting basin technique which concentrates limited water and nutrient resources applied (Thomlow, 2007). Specific examples of marked differences of CA from CF techniques include use of jab-planters, ripper tines, knife rollers and direct seeders (FAO, 2011). The principles of mulching, crop rotation and integrated pest management still apply. Farming communities' practices differ extensively. The variations can be influenced by farmer circumstances, the nature of the environmental factors prevailing in the area, and adoption. Thus, farmers may use very varied techniques to practise sustainable CA systems (Wall, 2007). This causes the interchangeable use of CA and CF.

ConvT is a standalone which is not confused with CA or CF. In this paper, ConvT involves using the mould-plough during land preparation to till the whole area to be planted, and then planting is done following behind the plough.

History from the 1960s shows that farmers in Chimanimani started using ripper-tines as a form of CA, to open up soil for planting purposes. A share mounted on ox-drawn mouldboard plough without a mouldboard was used. Hoes were used for digging small pits to capture rainwater in fields, as a basic CF technique, and for weed control. Mulches were mostly used in vegetable gardens. These technologies were mainly promoted in the study area by Agriculture Technical and Extension Services (AGRITEX). From 2000, there has been a series of upgraded initiatives introduced by Non Governmental Organizations (NGOs), state actors and various donors in partnership with lead Ministry of Agriculture, Mechanization and Irrigation Development of Zimbabwe to promote sustainable CA practices. CA techniques which have been promoted included no-till tied ridging; mulch ripping, no-till strip cropping, clean ripping, hand-hoeing or zero till, tied furrows (for semi-arid regions) and tied ridging (Mupangwa et al., 2006, Twomlow et al., 2006). The promotions would be expected to reduce the impact of adverse environmental factors which were becoming more and more severe, and also to increase crop yields (Twomlow et al., 2008b; Mazvimavi and Twomlow, 2009). However, these CA techniques were lowly adopted (Hobbs, 2007; Derpsch 2008; Gowing and Palmer, 2008) because rural farmers were lowly mechanized; lacked appropriate implements, technical information, and appropriate soil fertility management options (Twomlow et al*.,* 2006). These various factors prompted the need to venture into planting basins as improved initiatives of CF.

However, as long as there was enough production of staple food from CA and CF practices, the profitability aspect is usually never considered by most farmers in semi-arid regions; farmers may just have other goals like household food security, a stable income and minimizing risk of crop failure. There are not many studies known in literature done with a holistic approach to the technical efficiencies and economic benefits of CA, CF and ConvT practices and their relative adoptions in semi-arid parts of Zimbabwe. One previous study determined technical and economic efficiency of the CF techniques only, using the transcendental production function (Musara et al., 2012), while the other compared productivity and technical efficiency of CA with CF of maize using stochastic production frontier model (Mazvimavi et al., 2012). Most studies in literature simply consider CA without a further study on CF (Tsegaye et al., 2008, Gowing and Palmer, 2008; Mazvimavi et al., 2012).

The current study gives an overview of the technical efficiencies and economic benefits as well as adoption of

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CA, CF and ConvT as they are all practised in most semi-arid parts of Zimbabwe. This paper addresses the shortcomings in the use of CA and CF by basing their separation on the terminology used in literature (Twomlow et al., 2008a; ZCATF, 2009; FAO, 2011).

MATERIALS AND METHODS

The study on three practices: CA, CF and ConvT and their adoption, efficiency and economic benefits, was carried out in Chimanimani District.

Study area

Zimbabwe has five NRs (1-V). The study on was carried out in Chimanimani District, in Manicaland Province; the eastern province of Zimbabwe. Chimanimani District is characteristically known to have all the five agro-ecological or natural regions of the country. The specific wards under study were Ward 4 (Guhune) and Ward 17 (Biriiri). They fall in NR IV, which has been receiving mean annual rainfall below 500 mm in the last 10 years. The soils are sandy to sandy loams derived from granite rocks (IUSS Working Group WRB, 2007). Type of soil and gradient of an area has been known to offer incentives for adoption of soil conservation technologies due to increased danger of land degradation (Barungi et al., 2013).

Conservation practices

In the current study, CA refers to all the farmers who used ox-drawn equipment (ripper tines, direct seeders, or jab-planters), CF farmers are those who used only hand-hoe basins, and ConvT farmers are those who used mouldboard ox-drawn plough for ploughing the whole land during land preparation and covering seed when planting.

Research design and data

Ward 4 and Ward 17 were two wards purposively chosen for the study because of their highly variable annual rainfall of 460 to 600 mm (Moyo, 2000). The design was cross-sectional survey which included farmer- researcher-participatory action research approach. A cross-sectional survey was chosen for its low cost nature and ability to capture information at a given point in time. Pedzisa et al., 2010 found that the participatory approach encouraged greater knowledge-sharing among farmers, thus promoted grouping and adoption. A total of 2390 farming households were in the two wards and 200 farmers randomly sampled using random number tables based on the community household register intercept system (Mashapa et al., 2013). Each ward had 100 farmers sampled. Out of the total of 200 questionnaires, 179 representatives were valid for analysis because they provided all the information requested, and 21 had missing information. Structured questionnaires and face to face interviews were used to obtain data of household characteristics, technology adoption, practices, inputs, outputs, accessibility to extension services and markets. A structured questionnaire allowed data collection for quantitative analysis. A farmer could practise more than one technology and would therefore be considered as practising more than one technology. Almost all farmers in the study area were found growing maize under soil moisture conservation techniques. Although maize is a staple food crop in the area, there are other adaptable small grain crops like sorghum, finger millet and pearl millet grown in most dry parts of Zimbabwe.

Economic and econometric framework

Technical efficiency analysis

Economic efficiency can be defined as comprising two components. The first is technical efficiency which is defined as production of a maximum level of output from a given bundle of inputs (Alemdar and Oren, 2006). The second being allocative efficiency, defined as a combination of inputs that maximizes profits, given input prices. Economic efficiency is then defined by the product of technical and allocative efficiency.

Two approaches can be used in determining the level of a firm's technical efficiency in empirical work. One is a parametric approach, Stochastic Frontier, and another is non-parametric, Data Envelopment Analysis (DEA).

The stochastic frontier analysis (SFA) is based on the pioneering work of Aigner et al. (1977) and Meeusen and van de Broeck (1977). SFA been widely applied in estimating farm efficiencies (Onyenweaku and Ohajianya, 2005; Hussein et al, 2012, Samuel and Kelvin, 2013). The approach allows separation of the error term into two: One is associated with factors outside the farmers' control such as weather, pest and diseases; the other relates to farm specific conditions (Mohammed et al., 2013). In the current study, particularly SFA was used because it is very suitable for analysis of data from field trials where uncertainty is high due to such factors as weather, and also because the coefficients estimated in this study directly represent elasticity of production (Abedullah and Ahmad, 2006). However, to determine technical efficiency of farmers specifically practicing CA, CF and ConvT, the protocol of Rahman (2003) was used.

The stochastic frontier production function is defined after Rahman (2003) as:

$$Yi = f(X_i;\beta)\exp(v_i - u_i)\ \ i = 1,2,\ldots N \tag{1}$$

Where: Yi = possible production of i^{th} farm in kg; $f(X_i;\beta)$ = a suitable function of the vector X of inputs for the i^{th} farm, in this case a Cobb-Douglas production function was used; β = a vector of unknown parameters to estimated; v_i = random error with zero mean associated with random factors; u_i = non-negative random variables associated with farm's specific factors contributing to the farm not attaining maximum efficiency of production; N = number of farms in the sample

The random errors v_i are assumed to be independently and identically distributed as $N(0,\delta_v^2)$ random variables independent of the u_i's which are assumed to be non-negative truncations of the $N(0,\delta^2)$, that is, half-normal distribution. The Cobb-Douglas function was chosen because of its wide use in literature, easy of estimation and interpretation (Anyiro et al., 2012; Mango et al., 2015).

The following explicit function is estimated for CA, CF and ConvT farmers:

$$lnY_i = \beta_0 + \sum_{i=1}^{N}\beta_1\ lnX_i + v_i - u_i \tag{2}$$

Where, for farmer i, Y was the total quantity or value of maize produced in metric tonnes, X was the quantity or value of input j used, v_i was the two-sided error term and u_i was the one-sided error term representing technical inefficiency effects. The inputs were:

X_1 = maize area cropped in ha; X_2 = planted maize seed in kg; X_3 = amount of basal fertilizer in kg; X_4 = amount of top-dressing fertilizer

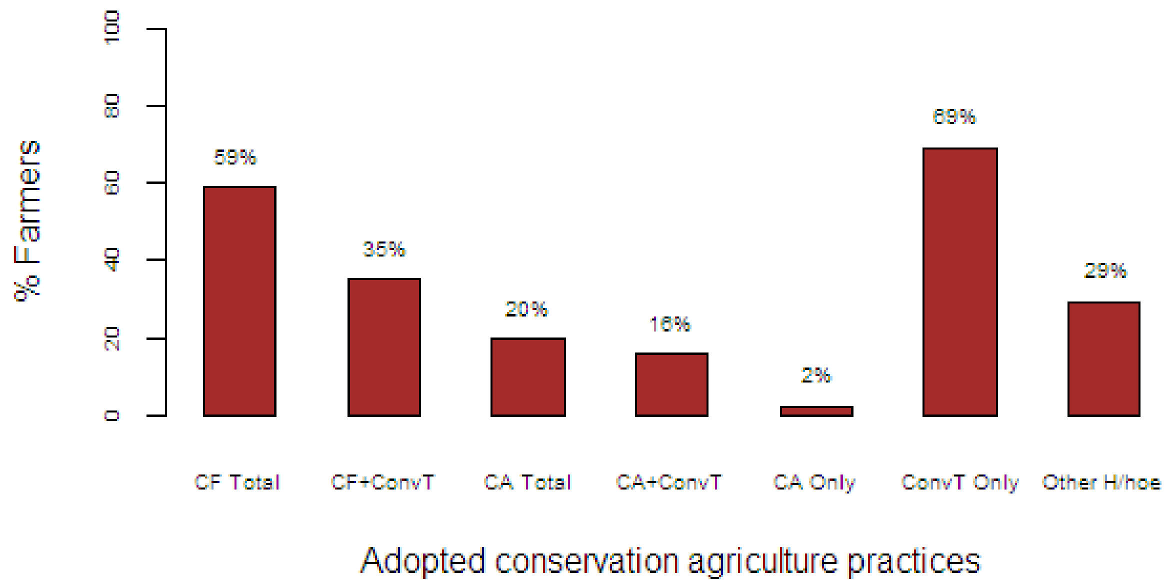

Figure 1. Adoptions of CA, CF and ConvT. Source: Survey data.

in kg; X_5 = amount of family labor used in maize production in hours.
The inefficiency model is specified as:

$$u_i = \delta_0 + \sum_{m=1}^{M} \delta_1 Z_m \quad (3)$$

Where Z_m are the inefficiency variables (m = 1,2,…M), and δ coefficients are unknown parameters to be estimated. These variables are described in the following paragraph: Education (number of years of schooling), household size (units of adult equivalents (AE)), household members away (AEs), access to credit (dummy, 1 for access and 0 for no access), gender (dummy, 1 for male and 0 otherwise), membership of a farmers' group (dummy, 1 for being a member of a group and 0, for non-member) and hired labor (dummy, 1 for use of hire labor, and 0 for non-use). A positive sign on the coefficient means the variable has a negative effect on efficiency while a negative sign of the coefficient means the variable reduces inefficiency.

Using MLE, the production and inefficiency models were estimated simultaneously in one stage using 'frontier package' in R (Coeli and Henningsen, 2013). MLE provides a consistent approach to parameter estimation problems. This means that MLE is effectively employed for use to give accurate estimates of many variables (Kadiri, 2014).

Economic analysis

This study used gross margin (GM) analysis to compare performance of CA, CF and ConvT. GM was shown without considering the cost of family labor because household had limited alternative for earning an income outside their farming, and thus the opportunity cost of their labor could just be evaluated in terms of leisure. Profit is the difference between total cost and total revenue. By definition, fixed costs do not vary with the amount of maize produced, the economic optimum could be obtained by maximizing the difference between total revenue and total variable costs per ha and this difference is known as the gross margin (Sibanda et al., 2016). Although various studies use GM to compare the economic benefits of alternative technologies to farmers (Chanie et al., 2014), not many studies have used GM analysis in evaluating CA practices, particularly in Zimbabwe. However, what can be termed accounting gross margin, which does not take account of the full opportunity costs of the resources, was used.

RESULTS

The study on adoption, efficiency and economic benefits of CA, CF and ConvT which were all practised in Chimanimani District during the survey period showed varying results.

Adoption of practices

General practice adoptions

Adoption of the practices is represented by a bar chart (Figure 1). The majority of farmers used ConvT only (69%), however, a sizeable proportion (59%) adopted CF. Farmers who adopted CF together with ConvT were over 30%, and there was also a group of farmers who used hand hoe but not strictly practising CF and these were 29%. CA (using ox-drawn or motorised equipment) had the least adoption rate (20%) whether as a standalone practice or in combination with ConvT.

Technical efficiency

Use of purchased inputs and productivity

Use of inputs for maize, and yields for each type of technology are presented (Table 1). ConvT had the

Table 1. Maize production and inputs used by farmer category.

Technology	Statistic	Maize area (ha)	Seed rate (kg/ha)	Basal fertilizer (kg/ha)	Topdressing (kg/ha)	Yield (MT/ha)
CA (N= 20)	Mean	0.18	22.30	55	49	0.90
	S.D	0.07	10.66	70.87	73.29	0.32
CF (N= 77)	Mean	0.23	22.70	20	82	0.96
	S.D	0.13	7.52	45.76	79.62	0.19
ConvT (N=82)	Mean	0.49	24.90	38	50	0.44
	S.D	0.31	12.80	50.10	70.85	0.50

MT = metric tons; Source: Survey data.

highest mean maize cropped area (0.49 ha) followed by CF (0.23 ha) and CA (0.18 ha) respectively. All farmers planted using seed rates which were below the recommended rate of 25 kg/ha. Farmers used rates of basal and top-dressing far below the extension service recommended rates of 200 and 150 kg/ha respectively.

Lowest yield level was obtained by ConvT farmers, whilst CF farmers had the highest (Table 1). There was a statistically significant ($P<0.01$) difference between mean yield for ConvT and the other practices (CA and CF), but the difference between mean yields for CF and CA was not statistically significant ($P>0.05$). Use of basal fertilizer was lowest among CF farmers.

Technical efficiency model

Production function

CA: only basal fertilizer had a positive and statistically significant influence on maize output. A 1% increase in use of basal fertilizer resulted in 0.45% increase in output, and this output response was inelastic. An inelastic response means that a change in input use results in less than proportionate change in the quantity of output while the opposite is true for an elastic response. Maize area, seed, top-dressing and family labor had no significant influence on maize output.

CF: Maize area and seed had a positive and statistically significant impact on output for CF, while basal fertilizer and labor had a negative and significant impact. A 1% increase in the area under maize resulted in 0.48% increase in output, and a 1% increase in basal fertilizer caused an output decrease of 0.11% under CF. Both relationships were inelastic. Top-dressing fertilizer had no significant influence on maize output.

ConvT: Top dressing fertilizer had a positive and statistically significant relationship with output for ConvT, while family labor and basal fertilizer had a negative but statistically significant impact on maize output. A 1% increase in top-dressing resulted in 0.78% increase in output, while a 1% increase in family labor use and basal fertilizer use caused 0.12 and 0.43% decrease in maize output, respectively. The output response to input use was inelastic in both cases, that is, a change in independent variables caused a less than proportionate change in the dependent variable. Maize area and seed had no significant influence on maize output under ConvT.

Returns to scale

A measure of returns to scale is obtained by calculating the sum of the input elasticities. Where the sum of input elasticities is equal to one, there are constant returns to scale. Increasing and decreasing returns to scale are displayed when the sum of elasticities are greater than one and less than one respectively. There were decreasing returns to scale for the three categories of farmers. However, CA and ConvT farmers had almost similar values for returns to scale (0.439 and 0.436 respectively).

Inefficiency model

All the inefficiency variables were not statistically significant for CA although they had different signs. Only about 11% of the 179 sampled farmers practised CA. The following variables had expected signs showing their positive effect on reducing technical inefficiency: group membership, number of non-resident members, gender (male farmers are more efficient than female farmers) and access to draft power. An increase in non-resident members improved technical efficiency since these households already had the largest size (a mean of 4.91 AE; Table 1).

For CF, all the variables in the efficiency model were statistically significant. Inefficiency reducing factors for CF were; number of family members away, gender (being male improves technical efficiency), group membership and level of household head education. Household size, gender and group membership had no influence on inefficiency for ConvT farmers. Draft power and level of education had a statistically significant reduction on

Table 2. MLE of the stochastic production frontier.

Variable		CA		CF		ConvT	
Production function		***Coeff.***	***S.E***	***Coeff.***	***S.E***	***Coeff.***	***S.E***
Intercept	β_0	0.362	0.937	2.537	1.286***	5.289	0.332***
ln Maize area	β_1	0.436	0.455	0.482	0.216***	0.090	0.081
ln Seed	β_2	-0.037	0.862	0.328	0.177***	0.120	0.078
ln Basal fertilizer	β_3	0.454	0.098***	-0.106	0.056**	-0.428	0.139***
ln Topdressing fertilizer	β_4	-0.121	0.196	-0.026	0.049	0.777	0.080***
ln Family labor	β_5	-0.339	0.279	-1.041	0.364***	-0.123	0.070**
Inefficiency model							
Intercept	δ_0	0.044	0.934	14.450	1.194***	1.755	1.000**
Hired labor	δ_1	0.115	0.286	-0.143	1.229***	-0.892	1.022
Credit access	δ_2	0.020	0.781	0.971	0.511**	8.311	1.637***
Farmer group	δ_3	-0.068	0.540	-7.140	0.684***	-2.404	1.610
Draft power	δ_4	-0.117	0.815	2.292	0.349***	-2.224	0.986**
Household size	δ_5	0.078	0.078	0.851	0.201***	-0.201	0.495
Gender	δ_6	-0.181	0.570	-6.980	0.683***	0.018	1.039
Education	δ_7	0.001	0.110	-2.323	0.157***	-0.667	0.362**
No. of members away	δ_8	-0.077	0.110	-1.590	0.254***	-1.431	0.554***
Variance parameters							
Sigma-squared		0.011		0.065		2.827	
γ		1.000		0.000		1.000	
λ		10000		0.0001		10000	
Log-likelihood function		25.66		-1.46		-8.817	
Mean technical efficiency		0.809		0.874		0.639	

Significance codes: 0.01***, 0.05**, 0.10*; Source: Survey data.

inefficiency, and credit had a statistically significant increase in technical inefficiency. CF had the highest mean technical efficiency of 87% followed by CA and ConvT with mean efficiencies of 81 and 64%, respectively (Table 2).

Model log-likelihood ratio test

Results of the log-likelihood ratio test rejected the no-efficiency model in favour of presence of inefficiency effects for all the three categories of farmers (Table 3).

Economic benefits

GM analysis

GM analysis was used to compare returns to the farmer for each farmer category (Table 4). CF had the highest GM/ha of $99.88 and 196.20 with and without family labor cost respectively, while CA with GM/ha had $63.82 and 158.60, respectively. ConvT farmers had a negative GM/ha of $25.16 with family labor cost and a positive GM/ha of $65.20 without family labor cost. CA and CF gavepositive (and almost the same level of) returns to purchased inputs and family labor. However, these figures were either below or equivalent to the average wage rate of $2/Md in the study area, and this was perhaps the reason why not many farmers in the survey used hired labor (32%). ConvT had the least and negative GM/ha as well as returns to purchased inputs and family labor. However, the gross margin would become positive if the cost of family labor was removed.

DISCUSSION

ConvT had the highest adoption of all the three. This was probably because it was the first known tillage practice and hence was regarded as a traditional practice by most farmers. Inevitably, the numbers of farmers practising ConvT was responsible for rapid land degradation (Abdullah, 2014). CF had higher adoption than CA (Figure 1). Lack of mechanized equipment limits adoption of some conservation practices. This outcome is confirmed by Baundron et al. (2015) who mentioned that lack of machinery has been one of the drivers of adoption of CF techniques in Southern Africa. Our study has results of 20% CA adoption which agree with Ngwira et

Table 3. The log-likelihood ratio test.

Category/practice	Model	DF	Log-likelihood value	DF	Chisq	P(>Chisq)
CA	1	7	12.17	10	26.66	0.000***
	2	17	25.66			
CF	1	7	-21.47	10	40.01	0.000***
	2	17	-1.46			
ConvT	1	7	-30.06	10	42.48	0.000***
	2	17	-8.82			

Model 1 = OLS (no technical inefficiency); Model 2 = Efficiency effects frontier; Significance codes: 0.01***, 0.05**, 0.10*; Source: Survey data.

Table 4. GM/ha budget for farmer categories based on average farmer.

Practice	CA	CF	ConvT
Gross income*	270	288	132
Less expenses			
Seed	35.68	36.32	39.84
Fertiliser	59.10	60.00	50.52
Total labor	111.40	91.80	66.80
Total costs that vary	206.18	188.12	157.16
GM ($/ha)			
With family labor cost	63.82	99.88	-25.16
Without family labor cost	158.60	196.20	65.20
Returns to inputs			
With family labor cost			
To purchased inputs ($/$)	0.67	1.04	-0.28
To family labor ($/Mds)	1.15	2.18	-0.75
Without family labor cost			
To purchased inputs ($/$)	1.67	2.04	0.72
To family labor ($/Mds)	2.85	4.27	1.95

*A local maize price of $300/MT, and a local hiring rate for labor of $2/day. Source: Survey data.

al. (2014) who found an adoption rate of 18.5% among smallholder farmers in Malawi. The area under CA which is reported in our findings (0.18 ha) also agrees with his findings (0.2 ha).

Many studies in literature have used the stochastic production frontier approach to estimate efficiencies for various production systems (Geta et al., 2010; Awunyo-Vitor et al., 2013, Yegon et al., 2015). From Table 2, the positive relationship between seed and output agrees with Awunyo-Vitor et al. (2013). However, this contradicts with Mazvimavi (2012) who found a negative influence of seed on maize output and positive influence on maize output under CA. The mean seed rate for CF farmers was below the recommended rate of 25 kg/ha (Table 1) and thus additional use of the input was likely to cause an increase in output. Some studies agree with the lack of seed influence on output as observed on CA and ConvT (Yegon et al., 2015). Using panel data in a study of smallholder maize production under CA and ConvT in Zimbabwe, Mazvimavi (2012) found a negative relationship between cropped land and output for CA, but a positive relationship for ConvT. Chirwa (2003) found a negative relationship between cropped area and output in a study of maize farmers in Malawi and notes that the relationship may be a result of area measurement errors.

Basal fertilizer had a statistically significant ($P<0.01$) influence on maize output under CA but negative influence for CF and ConvT. The results agree with studies done on CA and ConvT (Mazvimavi, 2012). The results (Table 2) confirm this where output elasticity with respect to basal fertilizer was greater and positive for CA (0.45) than for CF (-0.10) and ConvT (-0.42), which were negative and smaller. Geta et al. (2010) also found a significant influence of fertilizer on output. The negative influence of basal fertilizer on maize output under CF and ConvT needs further research to find if factors such as difference in land preparation depths between the technologies or other factors could have any influence on the effectiveness of the fertilizers. The lack of significant influence of top-dressing fertilizer on CF and CA could be caused by the fact that farmers used a quarter to a third of recommended rates, thus causing the inputs to have little effect (Table 1). Family labor had no influence on maize output under CA and CF but statistically significant, yet negative for both CF and ConvT (P<0.05) (Table 2). The results concur with the findings of Yegon et al. (2015) which also showed that labor was negatively related to output. The negative response to labor under ConvT agrees with Mazvimavi (2012) who found output elasticity with respect to labor positive for CA but negative for non-conservation farming.

All the inefficiency variables for CA were not statistically significant (Table 2). This could be a result of the very small proportion of CA farmers in the sample. Household size, gender and group had no influence on ConvT inefficiency. Inefficiency reducing factors for CF were number of household members away, hired labor, gender, group membership and level of household head education. Male farmers under CF were more efficient than women perhaps due to the strenuous nature of the practice. Chirwa (2003) found that female maize farmers were more efficient than men, though gender was not important in explaining efficiency. Number of family members away, access to draft power, and education reduced inefficiency for ConvT farmers. ConvT farmers had the largest number of non-resident members and second to CA farmers in terms of household head education. It was speculated that non-resident members away could be employed somewhere and thus they support farming activities by purchasing inputs. However, the matter was not conclusive as being away might increase inefficiency by less attention to the farm.

Other studies also found similar results regarding the effect of group membership and education on reducing inefficiency (Awunyo-Vitor et al., 2013; Yegon et al., 2015). Education is believed to reduce inefficiency by enabling farmers to try new innovations. This could be enhanced by group membership, allowing sharing of knowledge. Credit increased inefficiency for CF and ConvT farmers (Table 2). Although some farmers received credit, the credit was not linked to CA and was of small amounts. Access to draft power reduced inefficiency for ConvT practice but increased inefficiency for CF. ConvT farmers used the ox-drawn mouldboard plough and so, access to draft power was likely to reduce inefficiency. CF farmers basically used the hand-hoe, and access to draft power could lead to less output as less area was likely to be cropped. Geta et al. (2010) reported that access to draft power could reduce drudgery of operations.

While the efficiency figures appear to be high for smallholder farmers compared to other studies on technical efficiency (Table 2), they were quite plausible (Mazvimavi, 2012). Chirwa (2003) reported technical efficiencies as high as 76 and 79% for studies of smallholder maize farmers in Malawi. In the current study, the results of CF which have high technical efficiency agree with Musara et al. (2012). The technical efficiency for ConvT was within the range of 68% for both CA and ConvT (Mazvimavi, 2012). ConvT farmers were likely to be operating at a lower frontier compared to the two technologies. This could be seen from the mean yields for these technologies; ConvT maize yield was less than half of the CA technologies and the difference was statistically significant (P<0.05) (Table 1). This suggests that a technical change to adopt conservation agriculture would benefit the farmers (Mazvimavi, 2012).

Lack of significant influence on maize output for some variables like maize area, seed and labor on CA and variables in the inefficiency model could also be a result of small sample size for these farmers due to few farmers practising the technology in the area. Specification of the model could also limit significance tests (Coeli and Henningsen, 2013). Other variables which could be of interest were age of farmer, access to agricultural extension and level of off-farm income. The translog production function is a flexible functional form that takes care of interaction terms. However, the log-likelihood ratio test rejected the no-efficiency model in favour of presence of inefficient effects (Table 3) for all the three technologies.

Many studies use GM analysis to evaluate impact of interventions or new technologies on farmers. Memon (2015) used GM analysis to compare hybrid rice and other rice varieties in Pakistan. Although yields for hybrid variety were high, it fetched poor prices due to low quality, and farmers would face the challenge of buying seed every year. Chanie et al. (2014) used both econometric and GM analysis to compare performance of farmers participating in a research programme and non-participants in Ethiopia. The study showed that participants in the research programme had better productivity and GMs than non-participants.

GMs and returns to factors of production were highest for CA and CF farmers and least for ConvT farmers (Table 4). Tshuma et al. (2010) found that CA gives substantially higher gross margins than ConvT. The study confirms that CF demands more labor than CA.

Conclusions

The cross-sectional survey coupled with participatory approach revealed varied adoption results. CF had an adoption of 59% and CA had 20%. The majority of farmers (69%) engaged in convT only, and about 30% used a combination of the methods. Cobb-Douglas stochastic frontier production function was applied for the estimation of technical efficiency of CA, CF and ConvT. CF farmers were the most efficient farmers in terms of using their available resources. Their mean efficiency was 87%, followed by CA farmers who had 81%. ConvT farmers had the least mean efficiency (64%). Main sources of inefficiency were inadequate use of inputs (both organic and inorganic fertilizers), low household head education and inadequate family labor (CF). GM analysis showed that CF had the highest GM/ha of $99.88 and 196.20 with and without family labor cost respectively. This was followed by CA with GM/ha of $63.82 and $158.60 respectively. ConvT farmers had the least GM of -$25.16 and 65.20 with and without family labor cost. CF conserves nutrients, which makes it economically efficient, conserves moisture and soil which all make it a sustainable option in semi-arid regions. Based on these findings, the study therefore recommends use of CF practice as it gives highest yields and GM of all the three practices. The study is limited to maize in one district, yet Manicaland province has 7 districts. Further economic and econometric studies on other commonly grown crops like small grains in other districts be done to determine the most economically efficient crops to grow in dry regions.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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