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Productivity and profitability of maize-legume cropping systems under conservation agriculture among smallholder farmers in Malawi

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ABSTRACT

A study was conducted from 2014 to 2017 in Malawi to elucidate the short-term effects of maize-legume intercropping and rotation systems under conservation agriculture (CA) and conventional tillage (CT) on crop productivity and profitability. Twelve farmers hosted on-farm trials per district, in three districts, with each farmer having six plots. The design of the study was randomised complete block design arranged in a split plot fashion with tillage as main plot and cropping systems as sub-plots, with each farmer acting as a replicate. CA had 1400 and 3200 kg ha^{-1} more maize grain yield in the second and third seasons, respectively compared with CT. In the first two seasons, CT had 310, 180 and 270 kg ha^{-1} more cowpea, soybean and pigeon pea grain yields in Salima, Mzimba and Mangochi districts, respectively, compared with CA. Similarly, CA had 1100 and 950 kg ha^{-1} more groundnut grain yields than CT in Salima and Mzimba districts in the second and third seasons, respectively. Over the three-year study period, partial land equivalent ratio for maize ranged from 0.78 to 1.24. Largest net returns were achieved by intercropping maize with pigeon pea in Mangochi and rotating maize and groundnut in Mzimba and Salima districts.

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Conservation agriculture; maize yield; intercropping; crop rotation; partial land equivalent ratio; net returns

Introduction

Conservation agriculture (CA) is an ecosystem approach to sustainable agriculture and land management based on the practical application of three interlinked principles of: (i) continuous no or minimum mechanical soil disturbance (ii) permanent maintenance of soil much cover and (iii) diversification of cropping system through rotations and/or sequences and/or associations involving annuals and perennials, along with other complementary good agricultural production management practices (FAO 2019). In sub-Saharan Africa, CA is increasingly promoted by various international research centres, international non-governmental organisations (NGO), faith-based organisations and governments of southern Africa to overcome the problem of soil degradation, drought, low and unstable crop yields and high production costs. While efforts have endeavoured to implement all the three principles of CA, often one or two of these principles have been applied by smallholder farmers. Consequently, partial application of the principles of CA does not lead to the desired modification of various agro-ecological functions, such as soil health benefits, increased crop productivity and sustainability. While spreading of crop residues as soil surface mulch has been less of a problem, inclusion of a legume in crop rotation has been reported a major challenge by smallholder farmers in Malawi (Ngwira et al. 2014). In Malawi, farmers prioritise food security concerns above other farming objectives hence allocate larger proportions of their land holding to maize than other crops (Thierfelder et al. 2013; Umar 2014). Farmers also lack access to legume seed and stable and/or fair market for legume crops (Bwalya Umar et al. 2011).

Maize (*Zea mays*) accounts for more than 65% of land under cultivation in Malawi (MoAIWD 2018). Food security in resource-poor households is critically linked to the productivity and sustainability of maize-based cropping systems. However, the productivity of maize is hampered by declining soil fertility and low and variable rainfall. Inclusion of legumes in rotation or association with maize under CA is envisaged to play important roles because it breaks the continuous mono-cropping effects of maize. Legumes also play important roles in ensuring food security and increased income, suppressing weeds and fixing nitrogen (N) resulting in improved fertiliser use efficiencies (Snapp et al. 2010). It is also likely that CA plus legumes will help in adapting the production systems to climate change. However, key consideration is the choice of the legume crop species and varieties. Pigeon pea (*Cajanus cajan* (L.) Millsp) is one of the legume crops that have

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been shown to increase soil fertility and can potentially improve the productivity of CA-based systems due to its role in nutrient recycling resulting from its deep rooting system and also leaf litter fall that forms a thick layer on soil surface (Chikowo et al. 2004; Rusinamhodzi et al. 2017). Pigeon pea provides other socio-economic benefits, such as cheap source of protein, income from the sale of surplus, stems are a good source of fuelwood and also mitigates the risks of complete crop failure in bad seasons (Myaka et al. 2006). However, it is important to determine how pigeon pea can be effectively incorporated into the system in a way that will enhance adoption of the CA system. For example, in Mozambique and Tanzania, ratooning pigeon pea has been shown to reduce seed costs in subsequent years and the stumps and roots control erosion (Rusinamhodzi et al. 2012; Rusinamhodzi et al. 2017). The newly released medium duration pigeon pea varieties in Malawi are suitable to the length of the growing season and therefore escape the negative effects of goats that are left roaming after maize harvest. Successful dissemination and integration of pigeon pea in CA systems will require a better understanding of the complex interactions between priorities and objectives of farmers, partners involved in technology dissemination and socio-economic environment. In the same vein, soybean (*Glycine max* (L.) Merrill), groundnut (*Arachis hypogaea* L. Fabaceae) and cowpea (*Vigna unguiculata* (L.) Walp) are important legume crops with the potential for integration in CA systems because of high N fixation and biomass production (Kabambe et al. 2008; Mhango et al. 2013). However, the first step in the process of technology adoption is to get an understanding of what can be improved in the design of CA cropping systems for smallholder farmers in Malawi and southern Africa as a whole. It is envisaged that the modification and improvement of the CA system will enhance its agro-ecological benefits such as soil water conservation, improvement in soil fertility and reducing vulnerability of production systems to climate variability and change, among others. In addition, farmers adopt technologies that show immediate benefits in terms of yield and incomes. Therefore, the objective of this study was to elucidate the short-term effects of maize-legume intercropping and rotation systems under CA on productivity and profitability among smallholder farmers in Malawi.

Materials and methods

Description of study sites

This study was conducted for three years from 2014–2015 to 2016–2017 cropping seasons, in Ntiya and Mthiramanja Extension Planning Areas (EPA) in Mangochi district, Chinguluwe and Tembwe EPAs in Salima district and Manyamula and Zombwe EPAs in Mzimba district (Figure 1). Salima and Mangochi district fall within the low altitude sites with high rate of evapotranspiration, while Mzimba district is located in the medium altitude agro-ecological zone. All the EPAs are characterised by unimodal rainfall pattern with rainy season from November to April with a mean annual rainfall of about 800 mm. Mangochi district is more densely populated than Salima and Mzimba districts. Population density has implications for land holding sizes and the evolution of cropping systems in the study communities. Intercropping maize and pigeon pea has evolved as a common practice in Mangochi district, while rotating maize and cotton (*Gossypium hirsutum*) are also practised. Farmers in Salima district practise both intercropping and crop rotation. Apart from mono-cropped maize, farmers engage in cash crops such as cotton and groundnut. Farmers in Mzimba district grow tobacco (*Nicotiana tabacum*), groundnut and soybean in rotation with maize.

Initial soil samples were taken in 2014–2015 cropping season from on-farm trial sites on plot by plot basis and were analysed for pH (H_2O), organic carbon, phosphorus, potassium and total nitrogen. Soil analytical results show that all soils had a pH of above 5.5, implying no problems with acidity (Table 1). Except for Mangochi district, soil organic C was lower for Mzimba and Salima districts compared with the reported critical value of 0.8% for Malawi (Snapp 1998; Weil and Moghogho 2015). This implies that organic C levels in soils of studied areas in Mzimba and Salima fall below critical values adequate to maintain soil structure and support crop production (Snapp 1998). Therefore, agronomic practices aimed at enhancing soil organic C levels are recommended in the districts. Soil phosphorus (P) status at both sections was generally high above the critical value of 15 mg kg^{-1} (Aune and Lal 1997). This is in line with (Sillanpää 1982) who in a global survey found that Malawi soils are sufficient in P for maize production.

Experimental design

The study was conducted on-farm in three districts involving two EPAs per district and six farmers per EPA, with each farmer having six plots making a total of 216 plots and 36 farmers hosting trials. The design of the study was randomised complete block design (RCBD) arranged in a split plot fashion with tillage as main plot and cropping systems as sub-plots, with each farmer in an EPA acting as a replicate. Tillage treatments included conservation agriculture (CA) and conventional tillage (CT) while cropping systems studied were (i) mono-cropped maize in all the three districts; (ii) maize intercropped with grain

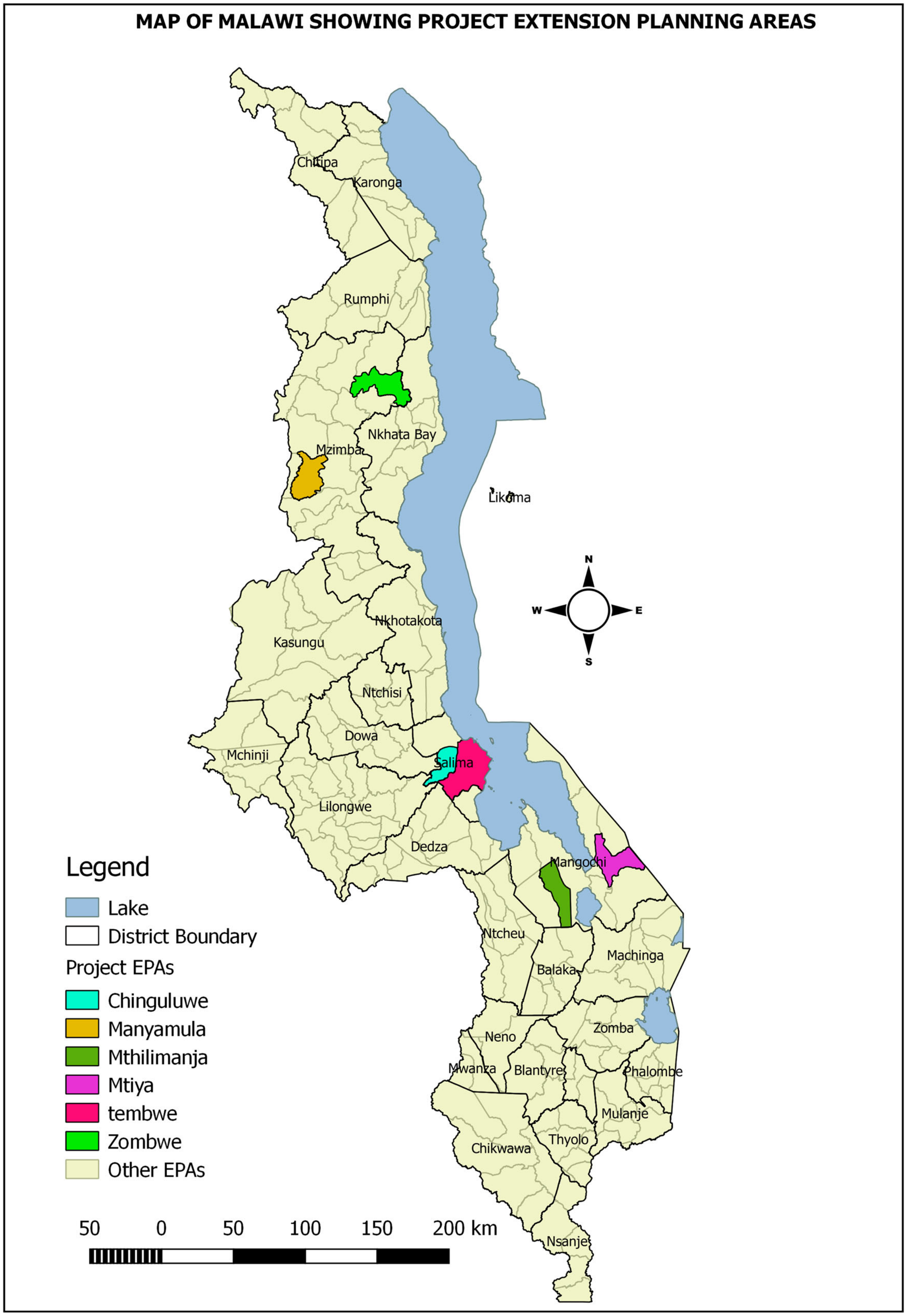

Figure 1. Map of Malawi showing study sites.

legumes i.e. soybean, cowpea and pigeon pea in Mzimba, Salima and Mangochi districts, respectively and (iii) maize in rotation with groundnut in all the three districts. The choice of legume crops under intercropping was based on farmers' own preferences which was largely dependent on land holding sizes and common cropping systems

Table 1. Initial soil chemical characteristics of the study areas.

	0–20 cm					20–40 cm				
District	pH	*P*(ug/g)	K (cmol/kg)	%N	% OC	pH	*P*(ug/g)	K (cmol/kg)	%N	% OC
Mangochi	5.68	105.68	0.77	0.09	1.00	5.61	86.82	0.47	0.10	1.11
Mzimba	5.96	41.93	0.46	0.04	0.49	5.84	29.54	0.42	0.03	0.37
Salima	5.95	67.15	0.71	0.06	0.71	6.07	58.18	0.66	0.07	0.78

practiced by the farmers in each district (Table 2). Main plot sizes consisted of 32 rows by 6 m long, while sub-plot sizes consisted of 8 rows by 6 m long.

Trial management

On-farm trials were managed by farmers in target communities with the support from extension officers who provided recommendations on the management of the plots. Scientific oversight was provided by research scientists and technicians. Monsanto hybrid maize DKC9089, which was farmers' choice, was planted at all sites. ICEAP00057 pigeon pea variety (which is of medium maturity), Sudan 1 cowpea variety and Makwacha soybean variety were used in intercropping systems with maize in Mangochi, Salima and Mzimba districts, respectively. GL24 groundnut variety was planted by the farmers in Salima district and CG7 groundnut variety was planted by farmers in Mzimba and Mangochi districts in rotation with maize. The choice of varieties by the farmers was largely based on their decision to avoid exposing the crops to terminal drought. All plots were seeded on the same day after the first effective rains in each year, defined as a rainfall greater than 30 mm after 15 November. Ridges in the conventional tillage practice were prepared by a hand hoe around October and planting was done using a hand hoe. All legumes were seeded at the same time with the maize crop. Ridge spacing was kept constant in all treatments: 75 cm between maize rows, 25 cm between planting stations and one plant per station giving a plant population of 53,333 plants per hectare. Similarly, one groundnut seed was planted per station at an intra-row spacing of 10 cm apart giving a plant population of 133, 333 plants per hectare. Intercropped legumes were seeded alongside each maize row planting two seeds spaced at 30, 10 and 90 cm for soybean, cowpea and pigeon pea, respectively. All treatments planted to maize received uniform fertiliser rate of 69 kg N ha^{-1} that was supplied as 100 kg of N: P: K ha^{-1} (23:21:0 + 4S) at seeding and 100 kg urea ha^{-1} (46% N) approximately three weeks after planting. Legumes did not receive any fertiliser. Weed control in conventional tillage plots was done manually as necessary. In CA fields, a tank mix of 2.5 l ha^{-1} glyphosate (N-phosphonomethyl) and 4 l ha^{-1} harness was applied as post-planting and pre-emergence herbicide, respectively followed by manual weeding when weeds were 10 cm tall or 10 cm in circumference.

Table 2. Description of treatments under on-farm.

Location	Main plot	Sub-plots
Mangochi	Conventional tillage	Mono-cropped maize Maize-pigeon pea intercropping Maize-groundnut rotation
	Conservation agriculture	Mono-cropped maize Maize-pigeon pea intercropping Maize-groundnut rotation
Mzimba	Conventional tillage	Mono-cropped maize Maize-soybean intercropping Maize-groundnut rotation
	Conservation agriculture	Mono-cropped maize Maize-soybean intercropping Maize-groundnut rotation
Salima	Conventional tillage	Mono-cropped maize Maize-cowpea intercropping Maize-groundnut rotation
	Conservation agriculture	Mono-cropped maize Maize-cowpea intercropping Maize-groundnut rotation

Harvest measurements

At physiological maturity, maize was harvested from four middle rows each 5 m long from each treatment and was used to extrapolate yields per hectare basis. The harvested cobs per plot were shelled to calculate grain yield that was then calculated on hectare basis at 12.5% moisture. All maize stalks and leaves without cobs were returned as surface mulch in CA plots and incorporated later into the soil during ridging in CT plots. For legumes, sequential harvesting from four middle rows of each sub-plot was carried out once the crop reached physiological maturity; pods were dried, shelled and dry grain weight was calculated on a hectare basis. The remaining biomass was returned as surface mulch in CA fields and incorporated during ridging in CT plots.

Partial land equivalent ratio

Land equivalent ratio (LER) was used to assess the efficiency of intercropping systems over sole cropping (Willey 1979). This is an area under sole cropping compared with the area under intercropping required to yield equal amounts at the same level of management.

The LER is a common approach to assess the land use advantage of intercropping (Willey and Rao 1980).

$$\mathrm{LER} \rightarrow \quad = \quad \rightarrow \quad \mathrm{LERa} + \mathrm{LERb} = \mathrm{Ia}/\mathrm{Sa} + \mathrm{Ib}/\mathrm{Sb}$$

Ia and Ib are the yields for each crop in the intercrop system, and Sa and Sb are the yields for each of the sole crops. LERa and LERb are the partial LER values for each species. An LER value higher than 1.0 indicates that there is a land use advantage for intercropping. However, in this study we considered calculating partial land equivalent ratio (pLER) values for maize crop only since it was the main food security crop and also the design of the study did not account for sole cropped pigeon pea, soybean and cowpea due to limited land to accommodate large trial sets. Partial land equivalent ratio (pLER) refers to the separate parts of the LER equation. Intercropping with two crops, such as maize and pigeon pea, is composed of two pLER values (maize and pigeon pea), which are added to give the total LER value. Partial land equivalent ratio values are used to assess the contribution of each crop towards total LER and are more detailed in terms of land use assessment.

Economic analysis

Economic performance of the systems was assessed using standard enterprise budgeting techniques to determine production costs and profitability. A partial budget analysis was performed using labour data and prices of all applied inputs (seed, herbicides, pesticides and fertilisers) from each of the plots during the entire period of the study. Labour data (in person hours and minutes) from three on-farm trials per site were obtained for each operation (laying crop residues, tillage, herbicide application, planting, fertiliser application, weeding, harvesting and threshing). Labour data and prices for inputs were recorded for each treatment separately. Variable costs were recorded by extension workers working with farmers over the life of the study. Net return (profit) ha^{-1} was estimated for each maize, cowpea and pigeon pea yield ($\mathrm{kg\ ha}^{-1}$) observation produced by each system based on average farm gate prices of US\$0.69, US\$0.71, US\$0.76, US\$0.64 and US\$0.24 in 2014/2015; US\$0.56, US\$0.69, US\$0.80, US\$0.60 and US \$0.30 in 2015/2016; US\$0.74, US\$0.25, US\$0.20, US\$0.25 and US\$0.31 in 2016/2017; for groundnut, cowpea, pigeon pea, soybean and maize, respectively and average variable costs for each treatment and year at each location (Bewick et al. 2008). Maize prices were converted from Malawi Kwacha kg^{-1} to U.S. dollars kg^{-1} using official exchange for this time posted by the Reserve Bank of Malawi (http://www.rbm.mw/archive_dfbr.aspx; accessed 18 June 2018). This ensured comparability on a standard dollar ha^{-1} basis for different systems. Maize prices were obtained from FAOSTAT (FAO 2019).

Statistical analysis

A linear mixed-effects model (REML procedure) (Coe 2002) was used to analyse data on maize and legume grain yields in the three seasons (2014–2017) from the on-farm trials. The effect 'farmer' was considered as a random effect since the farmers were randomly selected from a wider population of farmers in each EPA. The analysis of the mentioned crop yield data was performed separately for Mzimba, Salima and Mangochi districts because the districts were specifically chosen for investigation and may not be representative of all possible districts in the country. Statistical analyses were performed using Genstat version 18 (Genstat 2017). Grain yield data were tested for normality and homogeneity and showed normal population distribution and homogeneity of the variances.

Results

Rainfall

Daily rainfall was recorded in each site with a rain gauge. During the study duration (2014– 2017), average annual rainfall was 740, 916 and 982 mm for Mangochi, Mzimba and Salima districts, respectively (Figure 2). In the second season, Mangochi received approximately 366 and 282 mm less rainfall compared with the first and third seasons, respectively. In the third season, Mzimba received approximately 560 and 416 mm less rainfall with 9 and 27 days less compared with the first and second seasons, respectively. However, rainfall was well distributed in all the three seasons under study. Salima received approximately 883 and 789 mm less rainfall in the first and second seasons, respectively compared with the third season. While Salima received highest rainfall in the third season, the season was hit by dry spells during the vegetative phase of maize growth. Moreover, marked dry spells were experienced in the first season in Mangochi (27 days) and Mzimba (12 days) districts. According to the observations by farmers, the dry spells caused flower abortion in groundnut resulting in lower yields.

Crop yields

Analysis of variance showed that there were no significant differences on maize grain yield between CA and

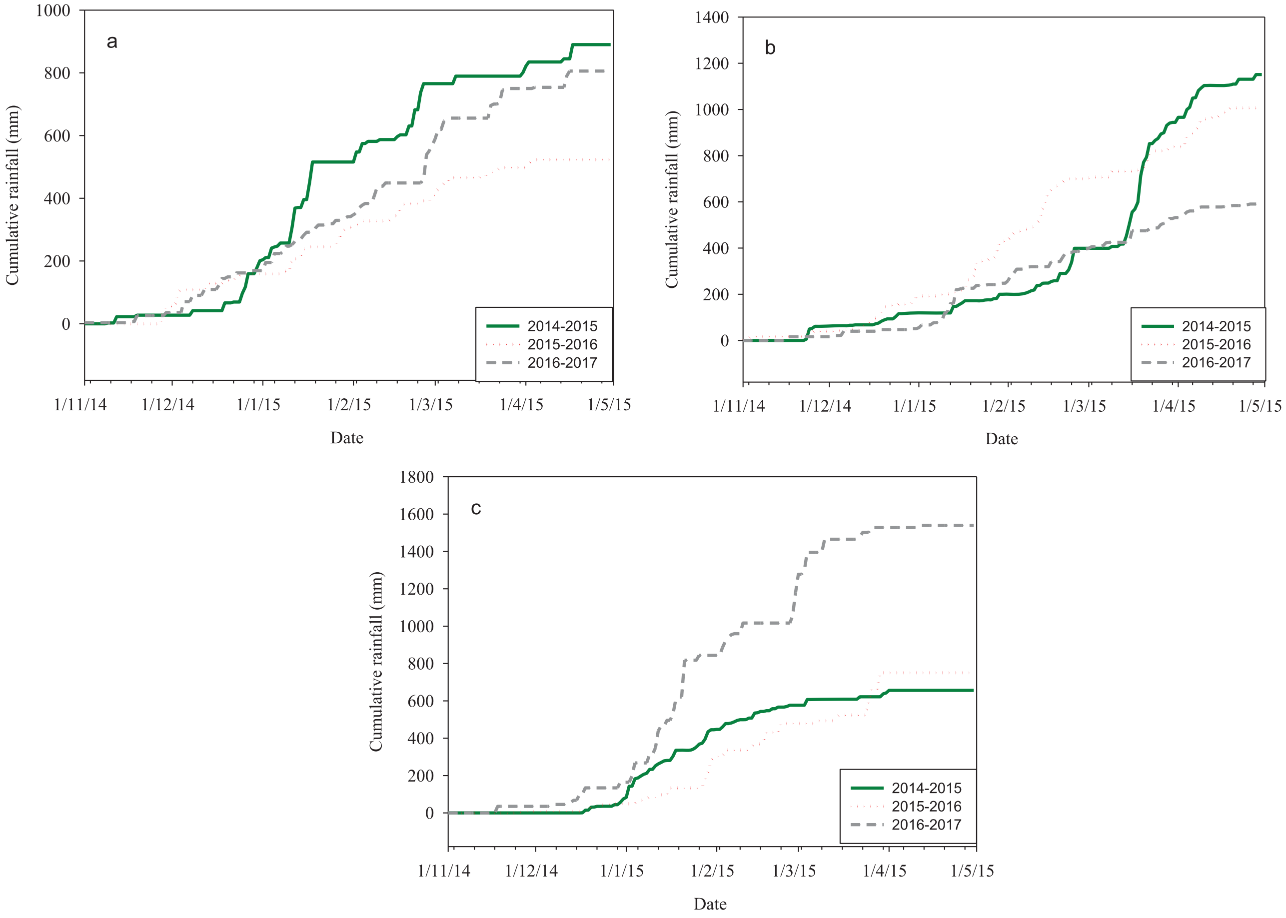

Figure 2. Cumulative rainfall (mm) for Salima, Mangochi and Mzimba for the three cropping seasons.

CT as well as between cropping systems in the first cropping season. In the second and third seasons, there were significant ($p < 0.05$) differences on maize grain yield between CA and CT in Salima district where CA had 1400 kg ha^{-1} and 3200 kg ha^{-1}, translating to 33% and 78%, respectively more grain yield compared with CT (Table 3). In the third season, there was significant ($p < 0.05$) interaction between tillage and cropping system in Mzimba. While there were no significant differences on maize grain yield between CA and CT for continuous sole maize and maize intercropped with soybean, rotating maize with groundnut had 1600 kg ha^{-1} more maize grain yield under CA than CT. For legumes, in the first season, there were significant differences ($p < 0.01$) on grain yields between CA and CT in Mzimba and Salima districts (Table 4). In the first season in Salima district, CT had 310 kg ha^{-1} more cowpea grain yield compared with CA. Similarly, soybean grain yields were significantly lower by 180 kg ha^{-1} under CA compared with CT in Mzimba district. In general, yields were low in the first season due to poor establishment of the legumes as farmers had not yet mastered the management of legumes especially in the CA fields. In the second season, CT had 270 kg ha^{-1} more pigeon pea grain yield than CA in Mangochi. While in the same season in Salima, CA had 1100 kg ha^{-1} more groundnut grain yield compared with CT. In the third season, CA had 950 kg ha^{-1} more groundnut grain yield than CT, while soybean grain yields were reduced by 170 kg ha^{-1} under CA compared with CT in Mzimba district.

Partial land equivalent ratio

Partial land equivalent ratio (pLER) values were calculated for maize crop only since it was the main food security crop and also the design of the study did not account for sole cropped pigeon pea, soybean and cowpea due to limited land to accommodate large trial sets. Partial land equivalent values varied with study locations and tillage systems. Over the three-year study period, pLER ranged from 0.78 to 1.24, suggesting that intercropped legumes offered minimal competition to maize (Figure 3). On average, pLER values for maize-pigeon pea, maize-soybean and maize-cowpea intercropping were 0.99, 1.11, 1.20 under CA and 0.90, 0.94 and 1.13 under CT, respectively.

Table 3. Maize grain yields (kg ha^{-1}) as influenced by tillage systems and cropping systems in Mangochi, Mzimba and Salima districts, 2014–2017.

		2014–2015			2015–2016			2016–2017		
		Tillage			Tillage			Tillage		
Mangochi	Cropping System	CT	CA	Mean	CT	CA	Mean	CT	CA	Mean
	Sole maize	3432	3465	3449	2326	3174	2750	5328	5379	5354
	Maize-ppea intercrop	3593	3565	3579	2774	2870	2822	5766	5595	5681
	Maize-Gnut Rot	-	-	-	2454	2358	2406	4758	4350	4554
	Mean	3513	3515		2518	2801		5284	5108	
		Tillage	Crop Syst	Till × Crop Syst	Tillage	Crop Syst	Till × Crop Syst	Tillage	Crop Syst	Till × Crop Syst
	p-Value	NS	NS	NS	NS	NS	NS	NS	NS	NS
	LSD (0.05)	464	492	696	372	456	645	790	968	1369
Mzimba	Cropping System	CT	CA	Mean	CT	CA	Mean	CT	CA	Mean
	Sole maize	3109	1700	2405	2796	2035	2416	5258	4856	5057
	Maize-soy intercrop	2413	2113	2263	3214	2285	2750	4005	4790	4398
	Maize-Gnut Rot	–	–	–	2804	4578	3691	4321	5960	5141
	Mean	2761	1907		2938	2966		4528	5202	
		Tillage	Crop Syst	Till × Crop Syst	Tillage	Crop Syst	Till × Crop Syst	Tillage	Crop Syst	Till × Crop Syst
	p-Value	NS	NS	NS	NS	NS	NS	NS	NS	0.05
	LSD(0.05)	529	561	793	1217	1559	2186	903	1106	1156
Salima	Cropping System	CT	CA	Mean	CT	CA	Mean	CT	CA	Mean
	Sole maize	3573	3041	3307	4743	5015	4879	3448	8442	5945
	Maize-cowpea intercrop	4026	2420	3223	3852	5890	4871	5001	7164	6083
	Maize-Gnut Rot	–	–	–	3826	5647	4737	3891	6339	5115
	Mean	3800	2731		4140	5517		4113	7315	
		Tillage	Crop Syst	Till × Crop Syst	Tillage	Crop Syst	Till × Crop Syst	Tillage	Crop Syst	Till × Crop Syst
	p-Value	NS	NS	NS	0.05	NS	NS	0.05	NS	NS
	LSD(0.05)	924	2040	2886	1177	1440	2038	2616	3204	4532

Note**:** maize-ppea = maize pigeon pea; maize-gnut = maize groundnut; maize-soy = maize soybean; till = tillage; crop syst = cropping systems

Profitability analysis

We present a combined profitability analysis for all the three seasons for each district (Table 5). Total variable costs were higher in CA systems than those of CT practices. On average, total variable costs under CA were US$509, US$573 and US$519 compared with US$475, US$525 and US$471 incurred under CT for Mangochi, Mzimba and Salima districts, respectively. Higher gross benefits under CA led to greater net returns than CT. Net returns under CA were US$852, US$560 and US $1060 compared with US$775, US$499 and US$651 obtained under CT for Mangochi, Mzimba and Salima districts, respectively. In Mangochi, highest net returns were realised by intercropping maize with pigeon pea both under CA and CT systems. Rotating maize and groundnut under CA were more profitable than other systems in Mzimba and Salima districts. Similarly, maize-pigeon pea intercrop produced highest benefit cost ratio of 2.40 and 2.66 under both CA and CT, respectively. Cost benefit ratios for maize-groundnut rotation were 1.89 and 2.70 for Mzimba and Salima districts, respectively.

Table 4. Legume grain yields (kg ha^{-1}) as influenced by tillage systems and cropping systems in Mangochi, Mzimba and Salima districts, 2014–2017.

		Tillage			Tillage			Tillage		
Mangochi	Cropping System	CT	CA	Mean	CT	CA	Mean	CT	CA	Mean
	Maize-ppea intercrop	1248	1216	1232	1334	1062	1198	1394	1248	1321
	Maize-Gnut Rot	471	586	528	1892	2899	2396	989	1650	1320
		Pigeonpea	Groundnut		Pigeonpea	Groundnut		Pigeonpea	Groundnut	
	p-Value	NS	NS		0.05	NS		NS	NS	
	LSD (0.05)	366	983		253	1261		313	913	
Mzimba	Cropping System	CT	CA	Mean	CT	CA	Mean	CT	CA	Mean
	Maize-soy intercrop	237	90	164	500	438	469	337	162	250
	Maize-Gnut Rot	1090	744	917	1196	783	990	1289	2243	1766
		Soybean	Groundnut		Soybean	Groundnut		Soybean	Groundnut	
	p-Value	0.01	NS		NS	NS		0.05	0.01	
	LSD(0.05)	91	981		931	762		153	728	
Salima	Cropping System	CT	CA	Mean	CT	CA	Mean	CT	CA	Mean
	Maize-cowpea intercrop	523	215	369	189	367	278	1099	1301	1200
	Maize-Gnut Rot	517	321	419	1041	2175	1608	1076	1249	1163
		Cowpea	Groundnut		Cowpea	Groundnut		Cowpea	Groundnut	
	p-Value	0.01	NS		NS	0.05		NS	NS	
	LSD(0.05)	197	317		397	907		319	949	

Note**:** maize-ppea = maize pigeon pea; maize-gnut = maize groundnut; maize-soy = maize soybean; till = tillage; crop syst = cropping systems

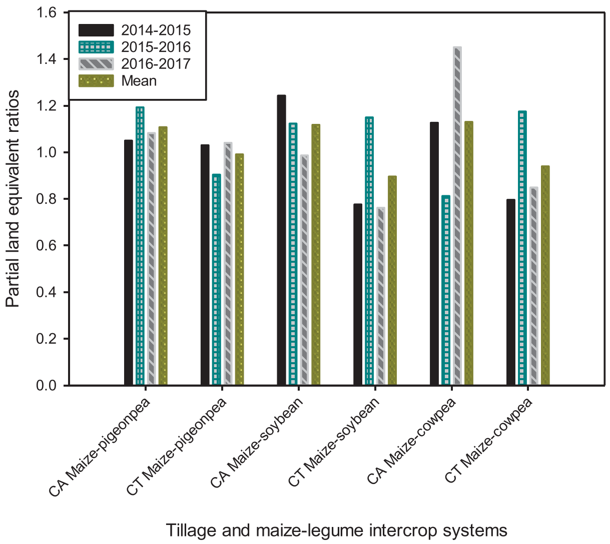

Figure 3. Partial land equivalent ratios (pLER) for maize intercropped with pigeonpea, soybean and cowpea in Mangochi, Mzimba and Salima districts, respectively, 2014–2017.

Discussion

Maize and legume yields

The results show seasonal effects on maize and legume yields (Tables 3 and 4). Although we did not quantify the effects of resource use efficiencies of these farmer-managed experiments, it can be assumed that low rainfall in the second season coupled with high temperatures in the low-altitude district of Salima could have resulted in high evapotranspiration culminating in higher soil water depletion patterns that resulted in maize stress hence low yields in conventionally tilled fields. This suggests that mulching in the CA plots assisted in the reduction of evapotranspiration compared with CT, thus conserving more soil moisture that probably increased crops' resilience to soil moisture stress hence higher maize grain yields. These results are in tandem with reports from elsewhere that showed more moisture conservation in CA fields due to no-till and mulching compared with CT (Roth et al. 1988; Govaerts et al. 2009; Thierfelder and Wall 2009).

The results of the current study suggest that benefits from crop rotation are realised from the better performance of legume crops during the previous cropping season (Table 3). The cumulative effect of biomass yields under CA from the first and second seasons might have contributed to more nutrients from both N fixation and biomass decomposition for the subsequent maize in the third season. Rotating groundnut with maize has been shown to improve maize grain yields in the subsequent season due to residual N addition (Mhango et al. 2013). Inclusion of legumes in maize-based systems either in intercropping or crop rotation has been shown to increase maize grain yields due to enhanced fertiliser use efficiencies (Snapp et al. 2010). In addition, crop rotations offer a number of ecosystem services that interact to boost crop yields, including breaking the pest and disease cycles, suppressing weeds, increasing biodiversity and recycling nutrients (Kassam et al. 2009). On average at all the study locations, maize grain yields were higher in the third cropping season compared with the first and second seasons. This could be due to improved management by farmers following a series of trainings in agronomic practices and CA practices, implying that benefits from CA implementation come after enhanced skills and knowledge by the farmers as well as the dedication of the extension workers working with farmers. In addition, improved 'soil fertility' due to physical, biological and chemical characteristics in CA as a result of no-tillage, crop residues retention and biologically fixed nitrogen from legume biomass led to more maize grain yields in CA systems than CT (Nyamangara et al. 2013; Ngwira et al. 2014).

These results show that intercropped legumes performed better under CT compared with CA (Table 4). These results confirm lack of experience by smallholder farmers to manage grain legumes in the early years of CA implementation. Similar results were obtained by (Naab et al. 2017) in North West Ghana under farmer-managed trials where CT had more soybean grain yields compared with CA. In their explanation, the authors attributed lower yields under CA due to lack of experience by farmers to manage legumes in the initial years of CA experimentation and ineffective herbicide application leading to more weeds that competed with crops for growth resources. However, for groundnut, grain yields were higher under CA compared with CT and this could be due to the differences in population densities. In CA groundnut is seeded 37.5 cm between rows compared with CT where it is seeded 75 cm between ridges, resulting in almost double population of groundnut under CA compared with CT. High population density ensures early ground cover resulting in better soil water conservation. In addition, high population reduces the incidence and occurrence of rosette disease due to restriction of aphids that transmit the virus causing the disease resulting in significant losses to groundnut production.

Maize productivity

In all the three seasons, intercropping maize with either pigeon pea or cowpea resulted in higher pLER values under CA than CT except for cowpea in the second

Table 5. Cost benefit analysis comparing conservation agriculture and conventional tillage cropping systems.

		CA				CT			
		Sole maize	Maize-pigeon pea	Maize-phase	Gnut-phase	Sole maize	Maize-pigeon pea	Maize-phase	Gnut-phase
Mangochi	Maize Yield (kg ha^{-1})	4006	4010	3354		3695	4044	3606	
	Legume Yield (kg ha^{-1})		1175		2275		1325		1441
	Gross benefits Maize ($US ha^{-1})	1155	1155	1033		1061	1165	1111	
	Gross Benefits Legume ($US ha^{-1})		674		1427		765		899
	Total Gross Benefits ($US ha^{-1})	1155	1829	1033	1427	1061	1930	1111	899
	Total input costs ($US ha^{-1})	365	404	380	249	237	333	255	181
	Total labour costs ($US ha^{-1})	109	135	110	338	168	194	173	360
	Total variable costs ($US ha^{-1})	474	539	435	587	405	527	428	541
	Net Benefits ($US ha^{-1})	681	1290	598	840	657	1402	683	358
	Benefit: Cost ratio	1.40	2.40	1.45	1.42	1.58	2.66	1.56	0.65
		Sole maize	Maize-soybean	Maize-phase	Gnut-phase	Sole maize	Maize-soybean	Maize-phase	Gnut-phase
Mzimba	Maize Yield (kg ha^{-1})	2864	3063	5269		3721	3211	3563	
	Legume Yield (kg ha^{-1})		230		1513		358		1243
	Gross benefits Maize ($US ha^{-1})	844	896	1620		1076	933	1096	
	Gross Benefits Legume ($US ha^{-1})		121		1050		179		814
	Total Gross Benefits ($US ha^{-1})	844	1017	1620	1050	1076	1112	1096	814
	Total input costs ($US ha^{-1})	420	482	447	249	291	411	322	181
	Total labour costs ($US ha^{-1})	109	135	112	338	168	194	173	360
	Total variable costs ($US ha^{-1})	529	617	558	587	460	606	494	541
	Net Benefits ($US ha^{-1})	315	400	1062	463	616	506	602	273
	Benefit: Cost ratio	0.51	0.60	1.89	0.87	1.27	0.82	1.19	0.54
		Sole maize	Maize-cowpea	Maize-phase	Gnut-phase	Sole maize	Maize-cowpea	Maize-phase	Gnut-phase
Salima	Maize Yield (kg ha^{-1})	5499	5158	5993		3921	4293	3859	
	Legume Yield (kg ha^{-1})		628		1712		604		1059
	Gross benefits Maize ($US ha^{-1})	1624	1531	1841		1123	1230	1185	
	Gross Benefits Legume ($US ha^{-1})		244		1075		259		691
	Total Gross Benefits ($US ha^{-1})	1624	1775	1841	1075	1123	1489	1185	691
	Total input costs ($US ha^{-1})	370	376	386	249	241	306	261	181
	Total labour costs ($US ha^{-1})	109	135	112	338	168	194	173	360
	Total variable costs ($US ha^{-1})	479	511	498	587	409	500	434	541
	Net Benefits ($US ha^{-1})	1146	1265	1344	487	714	989	752	150
	Benefit: Cost ratio	2.30	2.33	2.70	0.82	1.74	2.00	1.74	0.30

Note**:** Gnut-phase = groundnut phase.

season (Figure 3). The differences in pLER between CA and CT when maize was intercropped with cowpea could be explained in terms of efficient utilisation of water resources in intercrop systems. Similar results have been reported by (Chimonyo et al. 2018; Nelson et al. 2018) who demonstrated reduced competition for water resources between cereals and cowpea grown in intercrops. Pigeon pea shows slow growth in the initial stages of plant growth and takes over after maize has matured, thus offering little competition to maize (Sakala et al. 2000). Nonetheless, the high pLER values for maize obtained in this imply that intercropping was more efficient in these systems than mono-cropping. When assessing intercropping systems it is vital to take into consideration which crops are more preferable to the farmer. For example, maize is a food security crop for smallholder farmers in Malawi and any yield penalties emanating from intercropping arrangements are disadvantageous to farmers. This study has shown that all intercropping arrangements were more beneficial to farmers.

Profitability of the tillage and cropping systems

The higher total variable costs realised in CA systems could be due to the additional costs of purchasing herbicides and hiring knapsack sprayers (Table 5). However, farmers spent less days producing crops under CA compared with CT because farmers spent less time in land preparation and controlling weeds using herbicides. This is in contrast to other studies in Zambia and Zimbabwe that reported higher number of days spent on producing maize under CA compared with CT (Giller et al. 2009; Mazvimavi and Twomlow 2009; Umar 2014). This was due to the differences in CA systems being implemented in the countries of southern Africa. For example, in Zambia and Zimbabwe, CA systems promoted involve digging of planting basins that are more labour demanding compared with the no-till and dibble sticks being prasticed in Malawi. Inclusion of grain legumes in maize-based cropping systems has been demonstrated an attractive option for smallholder farmers than continuous sole maize.

Conclusion

CA practices tested in farmers' fields had improved maize grain yield, land equivalent ratio and higher economic gains compared with the CT systems in Malawi. Contrary to maize, grain legumes produced under intercropping with maize had higher yields under CT than CA systems, signifying a lack of knowledge by farmers to manage legume systems in the early years of CA implementation. Inclusion of legumes in maize-based systems was more profitable and lucrative than continuous sole maize although farmers need to grow legumes that are more adapted to their conditions. Although it can be argued that production costs can be offset by higher gross margins realised under CA systems, incurring additional capital costs can be a disincentive for adoption of CA for a majority of smallholder farmers in SSA and Malawi in particular. For adaptation and adoption of CA among farmers, there is a need to provide incentives to farmers in the early years of implementation as they gain knowledge and skills to make the system successful.

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