African Journal of Agricultural Research Vol. 7(26), pp. 3839-3846, 10 July, 2012
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/ AJAR11.1227
ISSN 1991-637X ©2012 Academic Journals

Full Length Research Paper

Effect of conservation agriculture management practices on maize productivity and selected soil quality indices under South Africa dryland conditions

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Accepted 21 May, 2012

Conservation agriculture experiment was conducted under irrigated and dryland conditions during 2007/2008-summer cropping season to determine a suitable soil-crop management practice for increase maize yield. The study consisted of tillage practices (conventional, minimum and zero), cropping systems (sole and intercrop plots) and fertilizer regimes (unfertilized control, low, adjusted low and optimum) as treatments. Minimum and zero tillage practices constituted the conservation agriculture tillage practices while supplementation of low fertilizer rate with seed inoculation using growth enhancing microbial inoculant constituted the adjusted low fertilizer rate. Fertilizer application gave a significant ($P < 0.05$) maize grain yield increase at both trial sites. Maize grain yield ranged from 1254 to 3683 kg ha^{-1} and from 1738 to 3199 kg ha^{-1} under supplementary irrigation and dryland non-irrigated condition, respectively. The highest maize grain yield obtained at optimum fertilizer rate did not differ significantly from that of adjusted low rate under dryland and inherent low soil nutrients condition. Although the adjusted low fertilizer rate gave no maize grain yield advantage over the low rate in soil with fairly high native nutrients, it however resulted in better crop responses and conservation of some of the soil properties studied under low-nutrients soil status. Zero tillage as a conservation agriculture practice gave the highest maize grain yield of 2805 and 2776 kg ha^{-1} under supplementary irrigation and dryland conditions, respectively. It also resulted in better conservation of soil nutrients resource than the conventional tillage practice.

Key words: Conservation agriculture, fertilizer regimes, cropping systems, maize yield, seed inoculation.

INTRODUCTION

Maize (*Zea mays* L.) is the most important cereal crop produced in Southern Africa (Fandohan et al., 2003). It constitutes the major food consumed in many rural homes; and widely grown by most farmers. However, the inherently infertile soil conditions on most smallholder farmlands (Odhiambo and Magandini, 2008) and the differences in soil and crop management practices by farmers often create huge yield gaps on such farmlands (Fanadzo et al., 2010). Hence, the consistently low maize yields on smallholder farmlands in many parts of Sub-Sahara Africa (SSA) is largely due to farmers' poor, ineffective and unsustainable land-use and crop management practices as well as extremely low to sometimes no fertilizer use (Mauricio, 2000; Mills and Fey, 2003; Machethe et al., 2004; Smaling et al., 2006). Commercial farms are similarly not completely shielded from the threat of low crop yield due to the increasing production challenges including changing climatic factors that predispose agricultural fields to increased biotic and abiotic stresses (Reynolds, 2010) and land degradation (Pimentel 2006). The current global warming, changing climatic pattern and increase cultivation of marginal lands accompanied by poor management further exacerbate the problem of food insecurity. The negative effects of these on crop yield is worse on smallholdings, due to farmers' limited resources and high input costs to cope with these production challenges (Machethe et al., 2004; Mweta et al., 2007). Notwithstanding the availability of numerous improved technologies, achieving increase maize yield remains a huge challenge in SSA. The assessment of strategies that could improve the efficient combination of available resources to achieve increase maize grain yield for millions of Africa's small-scale farmers and rural households that rely on maize, is thus crucial to addressing Africa's current soil fertility and food insecurity problems.

The way soils are managed can either improve or degrade soil quality indices (Gruhn et al., 2000; Sullivan, 2001). The use of simple implements by small-scale farmers results in minimal soil disturbances, a key principle of conservation agriculture. However, crop intensification under low or no nutrients input and poor land husbandry system as currently practiced by most small-scale farmers, could potentially aggravate soil degradation through nutrients loss (Westarp et al., 2004). The negative effects of soil degradation that characterize the functionality of traditional soil conservation and crop management practices (Abrams and Rue, 1988) following crop intensification, demands a more holistic approach to achieve increase and sustainable yields. Similarly, the deleterious effects of conventional tillage practice on soil, due to severe disturbance, further necessitate the adoption of conservation agriculture tillage practices such as ridging, minimum, zero and reduced tillage (Hellin, 2006). However, the low adoptions of conservation agriculture technologies may be related to its perceived poor understanding and non-adaptability to African farmers' prevailing practical realities (Gill et al., 2009). Smallholder farmers traditionally plant alternative crops with less nutrient demand as a management strategy to cope with loss in soil productivity (Ashby, 1985; Sillitoe and Shiel, 1999). They also employ techniques such as live barriers, rock walls, terraces, vegetated water ways and earth bunds (Suresh, 2000) as well as multi-storey cropping system to mitigate the impact of soil erosion.

In South Africa, various management strategies such as the production and use of plant growth boosters (Kutu and Asiwe, 2010; Baloyi et al., 2010) crop intensification coupled with increase fertilizer use and scaling-up of conservation agriculture (CA) practices (Thiombiano and Meshack, 2009) have gained increased attention in recent times. These are aimed at promoting better management of soil as a natural resource and also mitigate the negative impact of soil fertility decline and degradation problems that lead to low crop yields on farmlands. The sustainability of farmers' production practices in the 21st century and beyond will require clear understanding of the synergy between soil tillage and crop management options, so as to achieve high yield and sustainable crop production. Hence, the objective of the study was to assess available land husbandry practices and crop management options for increased maize yield and conservation of soil resources.

MATERIALS AND METHODS

Description of the sites

A conservation agriculture field trial was conducted during 2007/08-summer cropping season at two sites with varied soil characteristics under dryland conditions of South Africa. The sites namely Vaalharts experimental station (Latitude 27.95 S, Longitude 24.83 E, Altitude 1175 m) and a smallholder farmland at Eenzaam-Nebo (Latitude 24.57 S; Longitude 29.49 E; Altitude 1467 m) have mean annual rainfall of less than 620 mm. The Vaalharts site consists of sandy textured orthic A to red apedal B soil that belongs to the Hutton form and Vendersdorp family while Eenzaam site has red-brown to brown topsoil overlying freely drained, red apedal soil material with a medium base status and sandy loam texture that belongs to the Hutton form and Suurbekom family (Soil Classification Working Group, 1991). Pre-planting analysis of the surface 20 cm soil sample taken from Vaalharts gave soil test values of 5.6 % clay, pH (KCl) of 5.8, 0.23% organic carbon, 10.56 mg kg^{-1} mineral nitrogen (N) content and effective cation exchange capacity (ECEC) of 4.80 cmol[+] kg^{-1}. Similar sample from Eenzaam gave 15.2% clay, pH (KCl) of 3.89, 0.11% organic carbon, 12.86 mg kg^{-1} mineral N content and ECEC value of 2.80 cmol[+] kg^{-1}. Available phosphorus (P) content of 6.89 and 6.45 mg kg^{-1}, respectively for Vaalharts and Eenzaam sites were obtained prior to planting.

Conservation agriculture treatments

The CA treatments consisted of minimum and zero tillage practices with conventional (maximum) tillage practice treatment included as standard control. Different cropping systems (sole and intercrop) and fertilization regimes were assessed. The different fertilization regimes consisted of unfertilized control, low and optimum fertilization rates and an adjusted low fertilizer rates. Optimum fertilizer rate of 150 kg N, 60 kg P and 40 kg K ha^{-1} (designated F1) was applied while half of this rate (designated F2) was considered relatively close to what small-scale farmers will apply with minimal risk under dryland non-irrigated condition. The adjusted low rate implied improved F2 through seed inoculation (Si) using commercial B-Rus bacterial inoculants called Stimuplant to promote better crop growth; and designated F2+Si. The inoculant consisted of *Bacillus subtilis* (5×10^7 live cells/g) that are locally produced and marketed in the country as plant growth boosters. A paste of the inoculant mixed with powdered sticker (Stimulym) was prepared and thoroughly mixed with maize seeds to achieve good inoculation. Inoculated seeds were air-dried under shade and immediately planted. The tillage and cropping systems represented the main and subplots, respectively while fertilizer regimes constituted the sub-subplot. Each sub-subplot measured 30 m^2; and was replicated three times. Minimum tillage involved chisel-plough of the field to provide minimal soil disturbance for seeding, while the zero tillage involved the use of herbicide with minimal soil disturbance for seed sowing and fertilizer application. The conventional tillage treatment involved the use of chisel-plough followed by disc-plough and a wonder tiller to obtain clean, level and well-pulverized soil. Post-emergence weed control was achieved through light mechanical weeding. The assessment of relative conservation in this study was achieved by comparing the amount of soil water, pH, available P, biomass C, mineral N which is the sum of nitrate and ammonium N, exchangeable K and effective cation exchange capacity (ECEC); as well as maize grain yields in the different conservation agriculture treatments with the conventional tillage practice treatment after the crop were harvested. Soil moisture content was determined by loss on ignition method, pH in 1M KCl using a soil:solution ratio of 1:2.5 according to Non-Affiliated Soil Analysis Working Group (1990) while mineral N was determined according to Anderson and Ingram (1996). Similarly, available P and exchangeable K content were determined according to Bray and Kurtz (1945) and Okalebo et al (2002) procedures, respectively. The ECEC of each soil sample was estimated from the sum of exchangeable bases and acidity as described by Okalebo et al (2002) while biomass C determination was by fumigation-extraction method also described by Okalebo et

Table 1. Treatment effects on selected maize plant growth parameters and leaf area index.

Treatment	Plant height (cm)		Number of leaves per plant		Leaf area index	
	Vaalharts	Eenzaam	Vaalharts	Eenzaam	Vaalharts	Eenzaam
Tillage system						
Conventional	177.9	157.8	13.5	12.1	2.608	2.386
Minimum	175.2	157.8	13.6	12.2	2.503	2.423
Zero	175.1	147.0	13.2	12.0	2.621	2.179
SEM	5.51	6.87**	0.28	0.25	0.063	0.052
Cropping system						
Intercrop	179.1	154.1	13.4	12.0	2.676	2.309
Sole maize	173.0	154.2	13.6	12.2	2.479	2.338
SEM	2.51*	2.55	0.22	0.23	0.040*	0.033
Fertilizer regime						
Optimum	192.0	168.6	14.8	13.0	2.964	2.748
Adjusted low	187.3	161.2	14.2	12.2	2.768	2.357
Low	187.0	157.3	14.1	12.1	2.848	2.322
Control	137.9	129.3	10.7	11.1	1.729	1.867
SEM	3.13***	3.81***	0.32***	0.32***	0.036***	0.037***
Mean	176.1	154.2	13.5	12.1	1.263	1.271
CV %	5.3	7.4	7.0	8.0	8.5	8.8

Significant *; $P<0.05$, ***; $P<0.001$; SED = standard error of means; CV = coefficient of variation.

al. (2002).

Crop varieties and planting methods

Open pollinated maize seed variety ZM521 and certified disease-free hybrid white dry bean seeds variety PAN185 were planted as test crops. Maize was planted at 30 cm and dry bean at 10 cm intra-row spacing, while both crops were planted at 100 cm inter-row spacing. Maize and dry bean were planted at targeted population of 33, 333 and 238, 000 plants ha^{-1}, respectively under sole plots. One row of dry bean was planted between two maize rows to obtain a population of 204, 000 plants under intercrop. Only the trial at Vaalharts received regular supplementary irrigation (50 mm) with maize used as the indicator crop due to the sandy nature of the field. Irrigation was however terminated when crop attained 100% physiological maturity.

Data collection

Growth data that were collected from the trials included plant height, number of functional leaves per plant and leaf area at 100% tarseling. Leaf area index was calculated as a fraction of leaf area to land area while grain and stover yields were taken on both crops at harvest. The final grain yield of maize was adjusted to a 12.5% moisture content basis in line with the requirement from the South Africa maize industry. Land equivalent ratio (LER) for assessment of maize productivity under intercrop was calculated using the equation:

$$PLER_M = Y_{IM}/Y_{SM}$$

Where: $PLER_M$ = partial LER for maize, Y_{IM} = grain yield per unit area of intercropped maize, Y_{SM} = grain yield per unit area of sole crop maize (Ofori and Stern, 1987).

Data obtained from the trials were subjected to analysis of variance using Stat Graphics plus® version 5.0 while differences among treatment means were separated using Tukey HSD test at 5% level of significance.

RESULTS

Fertilizer application exerted significant ($P<0.001$) increases on maize plant height and the mean number of leaves produced per plant at both trial sites while the effects of tillage practices and cropping systems on LAI were variable (Table 1). Plant growth and vigour at the adjusted low rate were comparable to the optimum rate particularly under the rain fed condition. Intercropping significantly increased maize plant height and LAI at Vaalharts. The difference in mean plant height and number of leaves per plant across the two trial sites was significant ($P<0.001$); being generally higher across all treatments at Vaalharts than at Eenzaam.

Stover and total biomass yields were significantly ($P<0.001$) affected by fertilizer application while intercropping decreased maize yield component data though not significantly at Eenzaam site (Table 2). Neither tillage practice nor cropping system treatments exerted any consequential effects on maize plant population. Maize grain yield of 3683 kg ha^{-1} obtained at optimum the fertilizer rate did not differ significantly from 3029 kg ha^{-1} at adjusted low fertilizer rate from Vaalharts trial (Table 3). This is also true of Eenzaam trial under conventional tillage practice but resulted in significantly lower dry bean grain yield under dryland condition. There

Table 2. Yield component parameters (kg ha^{-1}) of maize as affected by different tillage treatments and crop production practices.

Treatment	Plant population (ha^{-1})		Stover yield		Total biomass	
	Vaalharts	Eenzaam	Vaalharts	Eenzaam	Vaalharts	Eenzaam
Tillage system						
Conventional	21458	19655	2436	2554	5666	5976
Minimum	20856	20496	2304	2493	5513	5906
Zero	21805	19823	2414	2112	5810	5652
SEM	1029	409	308	252	622	864
Cropping system						
Intercrop	21420	19669	2538	2432	5822	5804
Sole maize	21327	20314	2231	2341	5505	5885
SEM	840	334	125*	70	303	249
Fertilizer regime						
Optimum	21574	19977	3167	2973	7682	7259
Adjusted low	21667	19360	2662	2494	5844	6349
Low	21667	21436	2470	2462	6324	5915
Control	20586	19192	1240	1616	2803	3856
SEM	1188	472**	127***	148***	287***	359***
Mean	21373	19992	2385	2386	5663	5845
CV %	7.0	11.0	16.0	18.6	15.2	18.4

Significant *; $P<0.05$, ***; $P<0.001$; SED = standard error of means; CV = coefficient of variation.

Table 3. Grain yield (kg ha^{-1}) of component crops as affected by different tillage treatments and crop production practices.

Treatment	Maize grain		Drybean seed	
	Vaalharts	Eenzaam	Vaalharts	Eenzaam
Tillage practice (T)				
Conventional	2640	2646	246.6	587.3
Minimum	2604	2575	335.4	698.3
Zero	2805	2776	250.7	328.1
LSD	392	324	120.0	220.3
Prob	**ns**	**ns**	**ns**	**0.000**
Cropping system (Cs)				
Intercrop	2674	2575	164.4	245.7
Sole crop	2692	2756	390.7	830.1
LSD	321	466	98.6	179.8
Prob	**ns**	**ns**	**0.000**	**0.000**
Fertilizer regime (F)				
Optimum	3683	3199	180.1	496.1
Adjusted low	2766	3068	238.3	520.5
Low	3029	2658	366.1	718.5
Control	1254	1738	325.8	416.5
LSD	453	658	78.6	144.8
Prob.	0.000	0.000	0.011	0.032

dryland conditions. Zero tillage practice gave marginally higher maize grain yield than either minimum or was a strong correlation ($R^2 = 0.618$***) between leaf area index (LAI) obtained at 100% flowering and maize grain yield. Significant ($P<0.05$) locality × fertilizer regime interaction effects was obtained on maize grain yield (Figure 1) with a marginally lower coefficient of determination at Eenzaam ($r^2 = 0.879$ versus 0.899). All measured maize yield data under the CA practices were comparable but were insignificantly lower at Eenzaam than at Vaalharts.

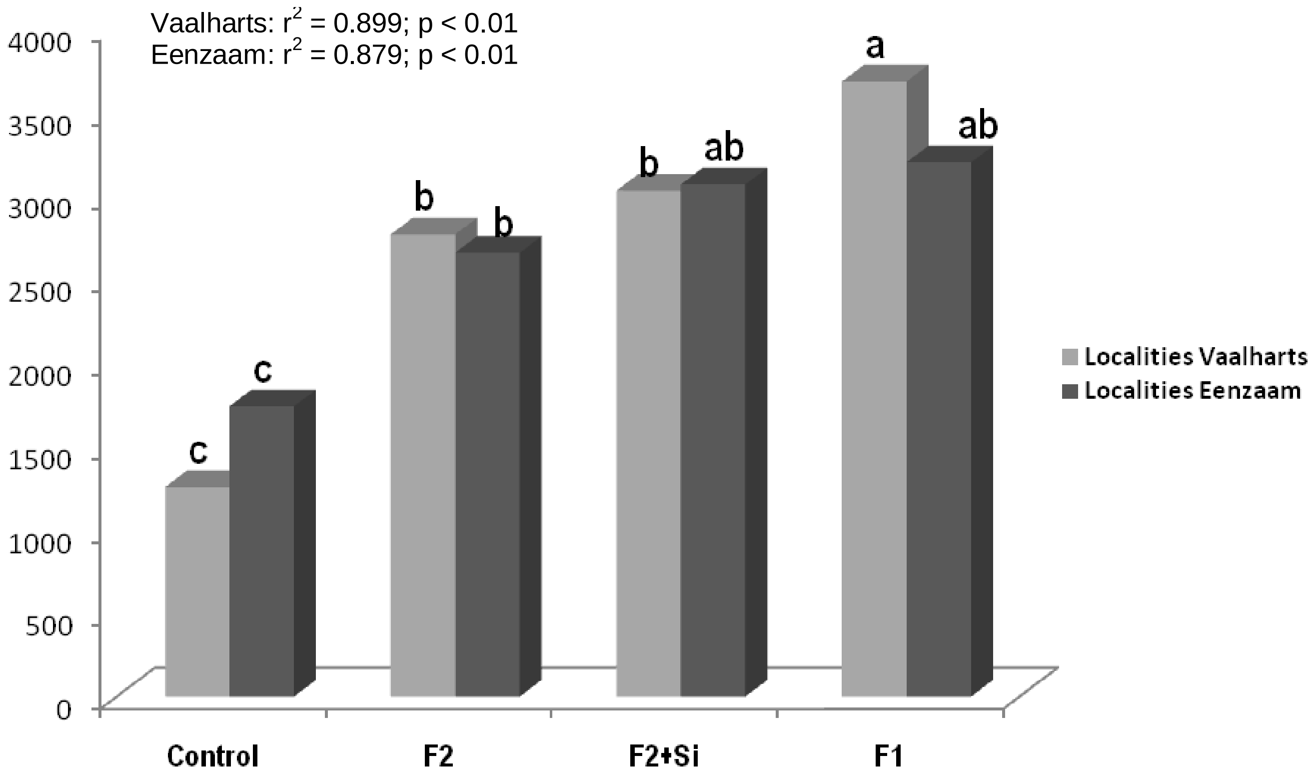

Figure 1. Significant locality x fertilizer interaction effect on maize grain yield (kg ha^{-1}).

Table 4. Partial land equivalent ratio (LER) of maize under different tillage treatments and fertilizer regimes.

Treatment	Locality		
	Vaalharts	Eenzaam	Mean
Tillage practice			
Conventional	1.044	0.976	1.010
Minimum	0.924	0.964	0.944
Zero	1.042	1.176	1.106
SEM	0.135	0.102	0.084
Fertilizer regime			
Optimum	1.024	0.756	0.890
Adjusted low	1.084	0.930	1.007
Low	1.031	1.050	1.041
Control	0.876	1.412	1.144
SEM	0.096	0.329	0.171
Mean	1.004	1.037	1.035
CV %	32.8	23.3	49.6

SED = standard error of means; CV = coefficient of variation.

The partial land equivalent ratios (PLERs) of maize for the two trial sites varied greatly across tillage practices and fertilizer regimes but are comparable (Table 4). A significant (P<0.05) locality × fertilizer regime interaction effect was obtained on partial LER for maize. There was a significant (P<0.001) difference in mean pH_{KCl}, total mineral N, percent organic and microbial biomass C contents obtained after harvest between the two trial sites (Table 5a). While the mean organic C content across all treatments decreased by approximately 27% at Eenzaam

Table 5a. Mean value of selected surface soil (0 to 20 cm) chemical properties after crop harvest at the two trial sites.

Trial site	$pH_{(KCl)}$	Mineral N	Bray-P1	Exch. K	Biomass C	% org. carbon	% moisture
		-----(mg kg^{-1})--------					
Eenzaam	4.33b	14.12a	8.27a	124a	0.118b	0.08b	4.95a
Vaalharts	6.30a	11.73b	8.23a	121a	0.126a	0.27a	3.24b

Figures followed by the same letter within same column did not differ significantly.

Table 5b: Selected surface soil (0-20 cm) properties as affected by conventional tillage and conservation agriculture tillage practices at the two trial sites

Site	% moisture	$pH_{(KCl)}$	% Org. C	Biomass C	Mineral N	Bray-P1	Exch. K	ECEC
					-------(mg kg^{-1})------			(cmol(+) kg^{-1})
Vaalharts								
CT	5.00b	6.29a	0.287c	0.096c	14.8b	37.03c	105b	3.645a
MT	5.32ab	6.26a	0.305b	0.121b	16.7ab	42.24a	115a	3.703a
ZT	5.53a	6.34a	0.330a	0.119a	18.3a	39.92b	118a	3.756a
SEM	0.23	0.05	0.011	0.012	1.10	0.92	2.8	0.11
Eenzaam								
CT	3.07a	4.46a	0.684b	0.090b	2.97b	4.18b	104b	1.863b
MT	3.13a	4.24b	0.695b	0.116a	3.54b	5.12a	105b	1.875b
ZT	3.23a	4.27b	0.760a	0.117a	4.40a	5.58a	118a	2.480a
SEM	0.17	0.03	0.02	0.014	1.79	0.86	4.6	0.18

Figures followed by the same letter within same column and trial site did not differ significantly CT, MT & ZT connote conventional tillage, minimum tillage and zero tillage, respectively.

after crop harvest, it increased by up to 17% at Vaalharts. The content of microbial biomass C after harvest was also marginally higher at Vaalharts than Eenzaam. Soil available P content was increased by approximately 19 and 28% at Eenzaam and Vaalharts, respectively after crop harvest possibly due to the residual effects of fertilizer application. Soil pH condition at both sites increased while the mineral N content however decreased after crop harvest. The different tillage treatments exerted variable effects on soil water and selected chemical properties at both trial sites with water and the content of organic carbon, soil microbial biomass C, extractable P and exchangeable K better conserved under zero and minimum tillage (Table 5b).

DISCUSSION

The significant increase in plant height and LAI obtained at Vaalharts under the intercrop plots may be attributed to the synergistic effect of supplementary irrigation and the positive contribution of transferred N fixed to the maize (Martin et al., 1991; Mudita et al., 2008; Kutu and Asiwe, 2010). The significant reduction in the mean plant population of maize recorded under the different fertilizer regimes in one of the trial site was associated to animal grazing following invasion. However, the comparable maize yields obtained under the different tillage and cropping systems at both sites despite the variable soil and supplementary irrigation at Vaalharts may be attributed to high and well distributed rainfall amount obtained during the growing season at Eenzaam, which favoured high crop yields. Similarly, the significant and comparative maize grain increases at the adjusted low fertilizer rate over low and unfertilized control in soil with inherent low soil nutrient status suggests that extra investment on less expensive plant growth booster by farmers such as the inoculants utilized in this study is advantageous. This is of significant benefits particularly to resource-poor farmers in view of the high cost of inorganic fertilizers (Kutu and Asiwe, 2010; Baloyi et al., 2010) and the associated risks of high inorganic fertilizer application rate under condition of changing climate and unpredictable rainfall pattern.

The higher stover and total grain yields obtained under intercrop than sole maize plots might be attributed to the elimination of shading effects as a result of simultaneous planting of both crops and possibly because of greater compatibility of the component crop (Kutu and Asiwe, 2010). However, the marginally lower yields on a much heavier texture soil at Eenzaam than Vaalharts under minimum and zero tillage as CA practices despite the favourable conditions during the season, may either be due to the reduced soil cover available to ensure sufficient soil moisture conservation or, higher soil clay content that possibly limited soil water availability to the growing maize crop. Although high clay content in soils typical of Eenzaam trial site has significant contribution to water retention (Reichert et al., 2010), the physiological processes of the growing maize plants and the prevailing environmental factors could possibly limit water availability and hence impact negatively on crop productivity (Wu et al., 2011).

The strong correlation between LAI and maize grain yield reported in this study is in agreement with previous study reported by Bavec and Bavec (2002) suggesting the importance of green leaf area for the maintenance of high grain yields (Kamara et al., 2003). Similarly, the significant interaction between trial sites and fertilizer regimes on maize grain yield suggests a positive influence of fertilizer application on grain yield at both trial sites, regardless of the variation in soil properties. The greater than 1.0 LER values for most intercrop treatment plots gave clear indication of the superiority of intercropping over sole cropping system in terms of the overall grain yield advantage. This is crucial for small-holder farmers whose primary aim is to produce for the family on the available small parcel of land.

The decrease in soil organic carbon content at the more arid and drier Eenzaam trial site after crop harvest might be attributed to the higher soil organic carbon mineralization rate coupled with the high incidence of animal grazing activities in the area that possibly limited the accumulation of plant residues on the field. Soil organic matter as a major pool of C, N, P and sulphur is the central indicator of soil quality that often change rapidly due to microbial immobilization and mineralization (Farguharson et al., 2003). Soil P increases reported in this study following crop fertilization agrees with earlier findings (Ishaq et al., 2002). Similarly, the increase in soil pH reported in this study agrees with previous studies, which was attributed to the application of inorganic fertilizer and addition of basic cations following decomposition of plant residues on the fields (Clark et al., 1998; Melero et al., 2007). The non-significant difference in the mean water content among the different tillage practices at Eenzaam may also be due to poor soil cover.

Conclusion

The study revealed maize yields increase following application of inorganic fertilizer, even at sub-optimal rates while supplementary addition of bacteria inoculant as plant growth booster not only enhanced maize response to low levels of fertilizer application but alsoincreased grain yield under inherently low soil nutrient condition. It also resulted in better conservation of most of the soil nutrients studied after crop harvest. The practice thus represents improved crop management and soil conservation strategy that could promote increase and sustainable maize production. Not only is the product cheap and affordable, its use is also simple and does not require specialized skill or equipment. When such innovation is combined with conservation agriculture practices such as minimum and zero tillage practices, it could result in better land husbandry option for the preservation of water and plant nutrients resources. Finally, results of the potential benefits of the use of bacteria inoculants such as locally produced in South Africa to promote plant growth and increase yields as reported in this study are in agreement with earlier findings. The adoption and use of such improved crop production practice by small-scale farmers as alternative to their current practice of low or no fertilizer application along with zero tillage as a CA practice could be beneficial in terms of maize yield increases and the conservation of soil resources.

ACKNOWLEDGEMENTS

This research was funded by Agricultural Research Council (ARC), South Africa through Parliamentary grant while technical support was provided by Mr. William Deale and Willie Jansen. Support from the Directorate of Research Administration and Innovation of University of Limpopo is also sincerely appreciated.

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