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Vol. 12(31), pp. 2524-2532, 3 August, 2017
DOI: 10.5897/AJAR2017.12289
Article Number: 0474F2465414
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Implications of tillage practices, management of soil surface and fertilizer application on sustainable dryland agriculture: A case study of Eastern Rwanda

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Received 7 March, 2017; Accepted 4 April, 2017

Conservation agriculture (CA) is becoming popular in sub-Saharan Africa as potential solution to soil degradation. However, most findings are based on large scale, mechanized agricultural production systems which are not easy to apply within the smallholder farmer's context. This study assessed the implications of tillage practices, management of soil surface and fertilizer application on sustainable dryland agriculture of Eastern Rwanda. The experimental design was Split Plot with 4 replications. The main plots were conventional tillage (CT) and no tillage (NT) and sub-plots were: Control, sole residues application (RR); residues application with inorganic fertilizers (RR+IF) and inorganic fertilizers (IF) applied alone. Inorganic fertilizers application increased bean grain and biomass yield by 103%. In no tillage inorganic fertilizers had higher maize grain and biomass yields whereas residues application had 68% higher maize grain and biomass yield in conventional tillage. The significant increase in organic carbon was observed in residues applied with inorganic fertilizers. There was a significant N decrease in all treatments however control and residues had the highest N pool compared to other treatments. Sole residues application and residues applied with inorganic fertilizers treatment increased significantly Available P. The use of inorganic fertilizers in conservation agriculture systems should be promoted as the engine toward successful of CA practices for Bugesera district conditions. These results provide a basis for conducting trade-off analyses to support the development of CA crop management and international development strategies based on available scientific evidence.

Key words: Conservation agriculture, no tillage, residues management, Bugesera District.

INTRODUCTION

Land degradation, depletion of soil fertility and weather variability remain major biophysical limitations to agricultural productivity (Wasige et al., 2014). According to Alam et al. (2014) soil tillage is an important factor affecting soil properties, increase crop yield up to 20% and it affects sustainable use of soil resources in general.

However, land preparation methods based on the conventional approach coupled with prolonged exposure of bare soil surface, causes soil degradation through accelerated soil and organic carbon losses (Baker et al., 2007). This leads further to physical, chemical and biological soil degradation as it was discussed by Thierfelder and Wall (2009).

The removal of crop residues from the fields has been reported as hastening the decline of soil organic carbon and loss of soil moisture when coupled with conventional tillage (Chivenge et al., 2007). Wasige (2013) found that mining of soil nutrients is extensive on many smallholder farms of East and Central Africa (ECA), which is triggered by continuous cropping, inadequate replenishment of soil nutrients in relation to plant demand, high rates of soil erosion, leaching and removal of crop residues from the fields. As a result, soil fertility has continued to decline to an extend that has made agriculture to these geographies a risky enterprise (Bidogeza et al., 2015).

Rwanda has high annual loss of nutrients which is estimated to beyond 40 kg N ha^{-1}, 6.6 kg P ha^{-1}, and 33.2 kg K ha^{-1} according to Nabahungu (2012). The variability in rainfall intensity and frequency has been observed globally during the past century (twentieth century), with Africa being the most affected. There are ever growing concerns that this change in weather variability will further threaten the welfare and food security of already highly vulnerable rural households in developing nations and pose a serious challenge to development efforts (Jones et al., 2015).

This situation raises the need for the use of sustainable practices of soil management to both increase crop productivity and safeguard the land resources for future generations. Conservation agriculture (CA), an approach to manage agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment has potential to sustain agricultural productivity. Key practices of CA in use include direct planting of crop seeds; covering soil permanently; using crop residues and cover crops; and crop rotation (Louwagie et al., 2009). Conservation agriculture can increase yield, maximizes soil infiltration and reduce soil erosion while conserving energy and labor (Kabirigi et al., 2015). Furthermore CA increases water use efficiency through conservation of soil moisture (Pretty et al., 2006).

However, CA has been, as well, reported as a complex and requires intensive community based extension. There have been debates on how CA would fit ecological and socio economic conditions for smallholder farming (Baudron et al., 2015). An example is the discoursed in Vanlauwe et al. (2014) on the appropriate use of fertilizer to enhance crop productivity as a fourth principle required to define CA in sub-Saharan Africa (SSA), which has been criticized by Sommer et al. (2014) as confusing element in CA. Based on this unconcluded debate, there is a need to examine CA with regard to crop productivity, profitability and soil quality under smallholder farmer's conditions.

The claims for the potential of CA in Africa are based on widespread adoption in the Americas, where the effects of tillage were replaced by heavy dependence on herbicides and fertilizers. The available evidence suggests virtually no uptake of CA in most SSA countries, with only small groups of adopters in South Africa, Ghana and Zambia. Additionally empirical evidence is not clear of which principle of CA contributes to the desired effects. In Rwanda the adoption rates have been low and promoting CA in Rwanda requires increasing knowledge and awareness to farmers with stronger research and wider demonstrations (Kabirigi et al., 2015). Hence, this paper has an objective to assess the effects of the integrating conventional and no tillage practices, soil surface management and fertilizer application on crop productivity and soils conditions in the drier parts of South-Eastern Rwanda.

MATERIALS AND METHODS

Study area

The study was conducted in RAB Karama Station, Bugesera District of Eastern Province in Rwanda (Figure 1). The area lies between latitudes 2.2315°S and longitude 30.1127°E with gentle topography between 1,290 m and 1,524 m above sea level. The annual average temperature is 21.4°C and average annual rainfall is 854 mm. Agriculture in the district is subsistence oriented and largely characterized by small size of landholding (0.75 ha on average) due to high density of human population. This subsistence agriculture involves livestock rearing and crop farming on small parcels. The district lies in Mayaga and peripheral Bugesera agro-climatic region which is driest agro-climatic region of Rwanda. The dominant soil is Oxisols, strongly weathered with poor agriculture value (Verdoodt and Van Ranst, 2003). In Bugesera, two plant formations remarkably dominate: the savannas with dense shrubs covering the hills, and the grassy savannas covering the dry valleys and the trays of the hills. Seasons in the districts are: (i) small dry season that goes from January to the mid-March, (ii) the big rain season runs from mid-March to mid-June, (iii) the long dry season covers mid-June to mid-October while, (iv) the short wet season starts from mid-October and ends in December.

Experimental design and layout

The experimental design was split plot with 4 replications and was carried out for 2 seasons; season A2014 and season B2014. The main plot was tillage system: Conventional tillage (CT) and No

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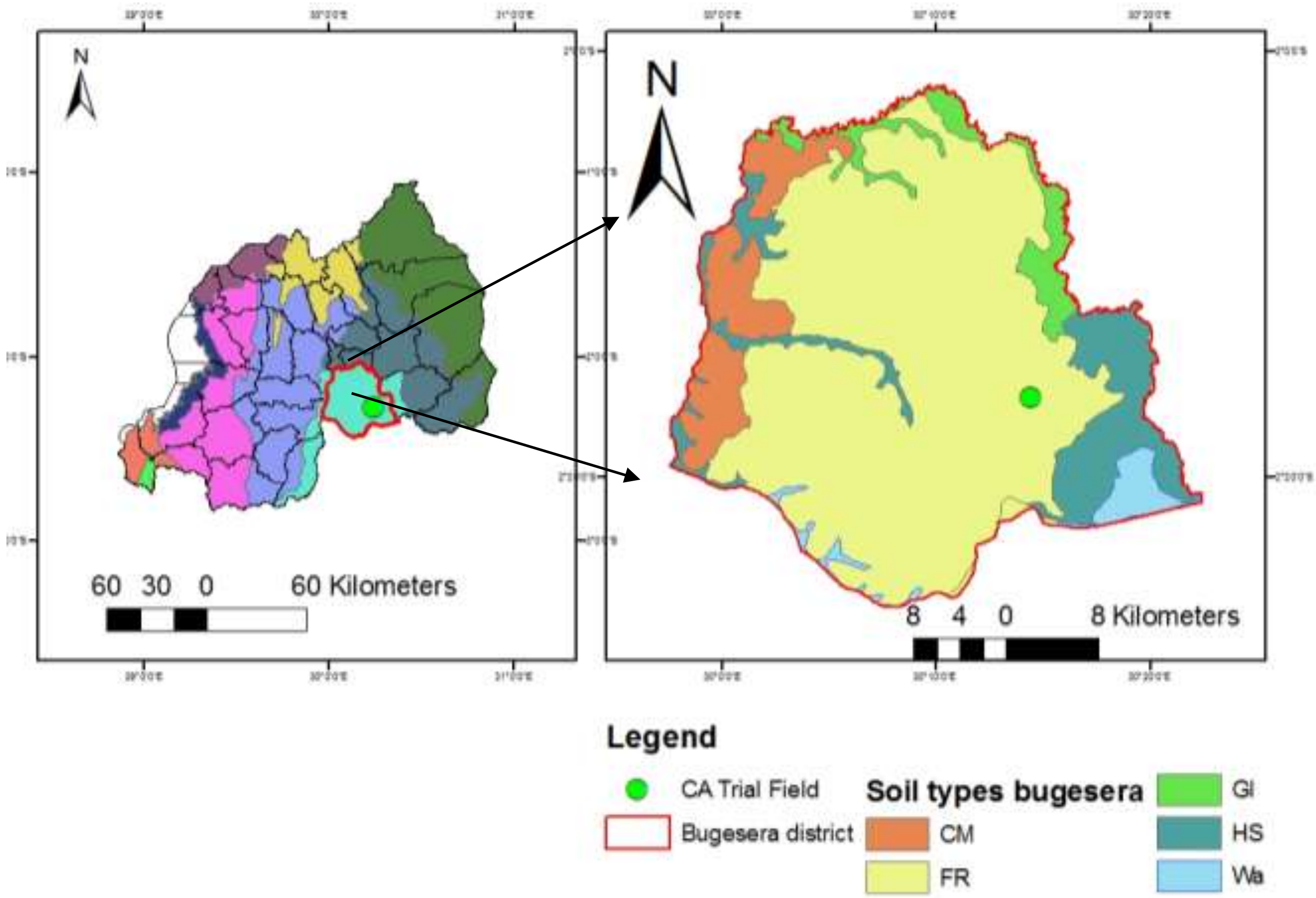

Figure 1. Map of Bugesera District showing research sites and their dominant soils (CM= Cambisols, FR=Ferralsols, GL=Gleysols, HS=Histosols, Wa=Water).

tillage (NT). Sub plot was control, sole residues application (RR); residues application with inorganic fertilizers (RR+IF) and inorganic fertilizers (IF) applied alone. Main and sub plot treatments were first combined and randomly assigned to plots within blocks. Blocking was done based on the field terrain/slope. The experiment was implemented using mirror rotation approach to allow assessment of maize and beans crops in the two seasons at the same time. This consisted of setting two plots per treatment adjacent to each other and alternating the two crops the following season. During the first season, residues were imported, and for the subsequent seasons, they were retained from the harvested crop. During the two seasons of trial bush beans (RWK 10) and Maize (ISARM 081) varieties were used as the test crops with spacing of 0.1 m within rows and 0.5 m between rows for beans and 0.25 m within rows and 0.75 m between rows for maize. The unit plot was 5 m by 5 m but at harvest last lines and 25 cm of edge of each line were considered as borders. The whole plant on plots were harvested by cutting at the ground level and weighed as fresh weight.

Soil sampling and analysis

At the beginning of the field trial, soils were sampled in each block following a zig-zag method at a depth of 0-30 cm to determine the pre-experiment physico-chemical characteristics of the soil. The soil samples were collected just before land preparation and one week to planting and fertilization in season A2014. This indicated the status before applying treatments while for evaluating the effect of treatments on soil properties samples were collected in an individual plot of each treatment taken at the end of the season. Laboratory soil samples analyses were done following standard methods. Soil organic carbon was determined using wet oxidation modified Walkley Black method as described by Skjemstad and Taylor (1999). Available P was determined using Mehlich III method (Sims, 2000) and Total N was determined using Kjeldahl method (Sims, 2000). Table 1 summarizes soil physical characteristics and chemical status before treatments application.

Rainfall distribution in RAB Karama Research Station in seasons A2014 and B2014

Figure 2 shows rainfall distribution in season A2014 and B2014 in RAB Karama research station where experiment was established. There were differences in total rainfall and distribution between seasons. The season A2014 had cumulative daily rainfall of 402.4 mm while in season B2014 had 320.6 mm.

RESULTS AND DISCUSSION

Effect on beans grain and biomass yield

The tillage method had a significant interaction ($p>0.05$)

Table 1. Soil fertility status before applying treatments.

Parameter	Units	Value	Comment
pH	pi	5.96	Moderately acid
Total N	%	0.2	Medium
OC	%	1.57	Average structural condition and stability
OM	%	2.71	Average structural condition and stability
Available P	mg.kg^{-1}	3.16	Very low
CEC	Cmol	7.7	Low
Sand	%	62.2	
Silt	%	22.1	
Clay	%	15.7	
Soil texture		Sandy loam	

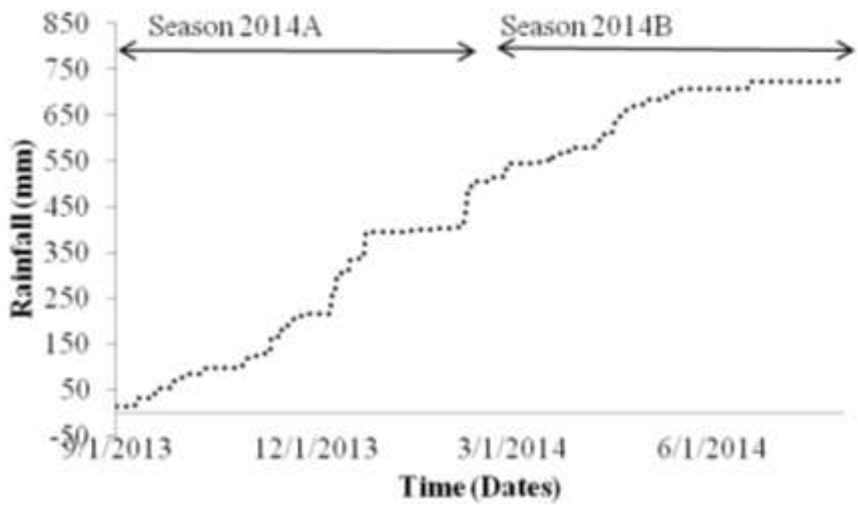

Figure 2. Cumulative daily rainfall during the study period (seasons A2014 and B2014). Source: RAB Karama Research Station.

with season where no tillage had higher bean grain and biomass yield in season A and conventional tillage had higher bean grain and biomass yield in season B (Figure 3). Residues application and inorganic fertilizers had also a significant effect on bean grain and biomass yield (Figure 3). Inorganic fertilizers recorded higher yield in season A while residues applied with inorganic fertilizers had higher grain (3.4 t ha^{-1}) and biomass (6.46 t ha^{-1}) yield in season B. In season A both control and sole residues application had lower yield while in season B the control had lower yield compared to the rest of treatments.

The lack of the effect of residues application in the first season was due to high carbon to nitrogen (C: N) ratio of the maize stover residues which were used in beans plots. Maize stovers having high C:N ratio, microbial decomposition can easily lead to nitrogen immobilization (Nicolardot et al., 2001; Bengtsson et al., 2003) because decomposing microorganisms use existing soil nitrogen for their metabolism thus depleting it in soils. Having the effect of CA treatments on yield is not usually obtained in shorter period since organic matter require time to build up however in lower rainfall areas with more level land and longer dry spells it is possible to obtain higher yield in short period as it has been reported by Araya et al. (2012).

Effect on maize grain and biomass yield

The interaction between tillage method, season and residues application was significant (p=0.001) on maize grain and biomass yield (Figure 4). In season A sole residues application treatment had higher (68% increase compared to the control) yield in conventional tillage method while in no tillage the highest maize grain and biomass yield was observed in inorganic fertilizers applied alone (3.3 t ha^{-1}). In season B residues applied with inorganic fertilizers had higher maize grain (2.4 and 2.3 t ha^{-1}) and biomass (4.2 and 3.9 t ha^{-1}) yield respectively for both conventional and no tillage method.

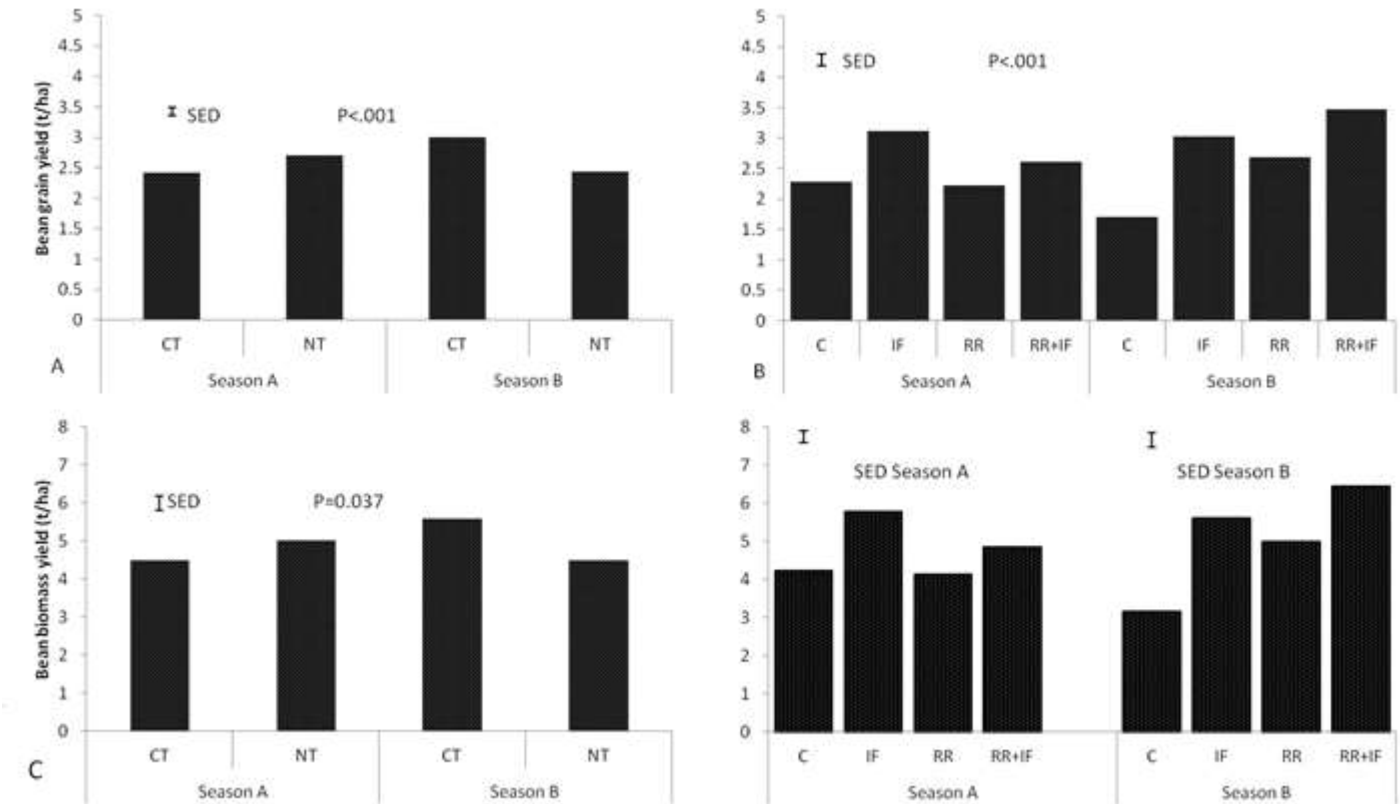

Figure 3. Effect of tillage method (A, C), residues and inorganic fertilizers (B, D) on bean grain yield (A, B) and bean biomass yield (C, D). C=Control, RR= residues retained, RR+IF=residues retained with inorganic fertilizers, IF=inorganic fertilizers, CT=conventional tillage, NT= no tillage. Vertical bar represent SED of Interaction tillage* Season (A, C) and SED of interaction Residues and inorganic fertilizers*Season (B, D).

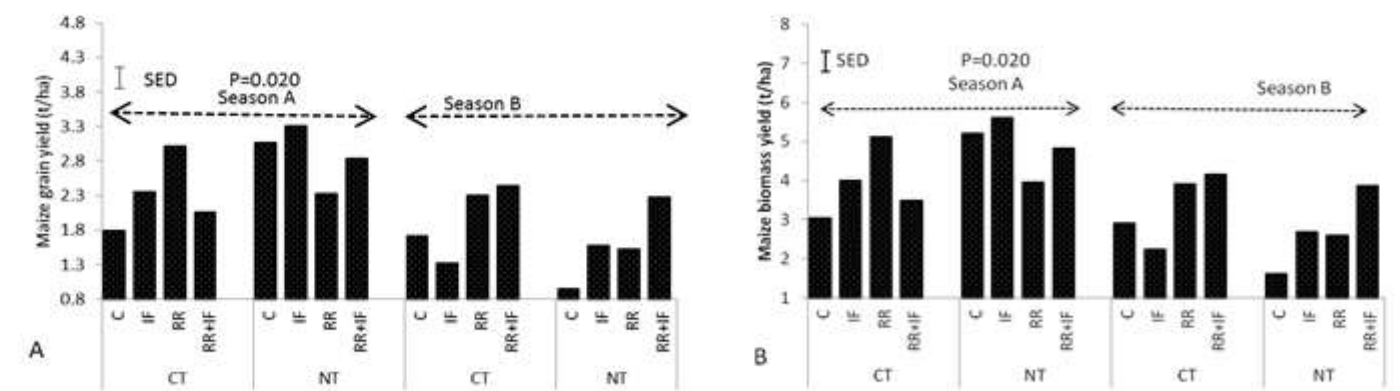

Figure 4. Effect of tillage method, residues and inorganic fertilizers on maize grain (A) and biomass (B) yield for seasons A2014 and B2014. C=Control, IF=Inorganic fertilizers, RA= Residues applied, RA+IF=Residues applied with inorganic fertilizers, vertical bar represent SED of interaction Tillage*Residues and inorganic fertilizers*Season.

The improvement in yields recorded in treatments that had residues applied with inorganic fertilizer can be endorsed to the enhanced water holding capacity as well as the improved nutrient retention and slow release over the season as it has been reported by Sun et al. (2014). Another factor resulted in the positive effect of residues application on maize biomass and grain yield is the type of residues used. Since beans residues were applied its

Table 2. Effect of tillage method, residues and inorganic fertilizers on soil organic carbon (%).

Tillage	Residues	Initial	Final SA	Changes SA	T test	Final SB	Changes SB	T test
CT	Control	1.574	1.592	0.019	NS	1.610	0.036	0.041*
	Residues	1.574	1.629	0.055	0.047*	1.621	0.048	0.013*
	Residues+IF	1.574	1.610	0.036	NS	1.569	-0.005	< 0.001**
	IF	1.574	1.596	0.023	NS	1.624	0.050	NS
NT	Control	1.574	1.597	0.024	NS	1.585	0.011	NS
	Residues	1.574	1.627	0.054	NS	1.596	0.023	NS
	Residues+IF	1.574	1.658	0.084	0.005*	1.585	0.012	0.013
	IF	1.574	1.604	0.030	NS	1.594	0.020	NS
	SED (T*R)		NS			NS		
	SED (T)		NS			NS		
	SED (R)		NS			NS		

CT= Conventional tillage, IF=Inorganic fertilizers, NS=Not significant, NT = No tillage, R=residue application, SA= Season A (A2014) and SB= Season B (B2014), T=Tillage method.

decomposition is faster and leads to high nitrogen mineralization as bean residues have narrow carbon to nitrogen ratio. Results from this study support Vanlauwe et al. (2014) who suggested that the appropriate use of fertilizer should be considered as a fourth principle of CA in order to enhance crop productivity in addition to three that currently define CA which are minimum disturbance of soil, keep soil cover and crop diversification. The early effects of tillage on yields can be attributed to the site potential as reported by Bayala et al. (2012) that conservation agriculture treatments have positive effects on yield in poor to medium soil quality than in high quality soils. This raises the need for assessment and understanding the effects of CA under different ecological and socio-economic conditions as suggested by (Giller et al., 2009).

Effect on organic carbon

The interaction effect of tillage and residues application on soil organic carbon was not significant (p>0.05) (Table 2). However sole residues application and residues applied along with inorganic fertilizers had a significant increase in soil organic carbon respectively in conventional and no tillage system in both season A and season B. In season B a significant decrease of soil organic carbon was observed in residues applied with inorganic fertilizers.

The increase in organic carbon in conventional tillage in residues retained treatments might be the consequence of turning down residues (Kushwa et al., 2016). Study by Margenot et al. (2017) reports that residue retention in no tillage system increases the accumulation of organic carbon in the top soil. Results from this study are in agreement with Mehmood et al. (2014) who reported 22% increase in organic carbon as result of residues application and tillage method. The significant effect of residues application on soil organic carbon was also observed by Khalid et al. (2014). In contrary results of Hobbs (2007) reported that residue application cannot increase soil organic carbon content as long as the soil is moldboard plowed. Reasons for contrasting results can be the results of differences in soil composition (texture and native organic matter content) as it has been highlighted by Singh et al. (2014) or plowing method used.

Effect on nitrogen

This study highlighted a nitrogen pool in all treatment as it is presented in Table 3. In season A, the highest Nitrogen pool was observed in control (-0.024%) and in sole residues application (-0.021%) in conventional tillage method while in no tillage method the highest pool was in inorganic fertilizers applied alone (-0.016%) and in control (-0.015%) treatments. In season B, the highest Nitrogen pool was observed in control in both conventional and no tillage methods.

The significant nitrogen decrease observed in this study explains how nitrogen is the nutrient required in high quantity since it is required for both crop growth and microbial activities. It has been reported by Giller et al. (2009) that large amounts of cereal residues with a high C:N ratio that are left on the soil surface temporarily result in reduced N in the soil. This suggest the application of N based inorganic fertilizers along with residues retention or growing a cover crop at the early stage of conservation agriculture system (Araya et al., 2016). Normally conventional tillage with residues

Table 3. Effect of tillage method, residues and inorganic fertilizers on Nitrogen (%).

Tillage	Residues	Initial	Final SA	Changes SA	T test	Final SB	Changes SB	T test
CT	Control	0.195	0.172	-0.024	< 0.001**	0.179	-0.017	< 0.001**
	Residues	0.195	0.174	-0.021	< 0.001**	0.186	-0.009	< 0.001**
	Residues+IF	0.195	0.184	-0.011	< 0.001**	0.179	-0.016	< 0.001**
	IF	0.195	0.178	-0.017	< 0.001**	0.191	-0.005	< 0.001**
NT	Control	0.195	0.181	-0.015	< 0.001**	0.184	-0.011	< 0.001**
	Residues	0.195	0.184	-0.011	< 0.001**	0.193	-0.003	< 0.001**
	Residues+IF	0.195	0.185	-0.011	< 0.001**	0.192	-0.004	< 0.001**
	IF	0.195	0.180	-0.016	< 0.001**	0.189	-0.007	< 0.001**
	SED (T*R)		NS			NS		
	SED (T)		NS			0.00263		
	SED (R)		NS			NS		

CT= Conventional tillage, IF=Inorganic fertilizers, NS=Not significant, NT = No tillage, R=residue application, SA= Season A (A2014) and SB= Season B (B2014), T=Tillage method.

Table 4. Effect of tillage method, residues and inorganic fertilizers on available P ($mg.kg^{-1}$).

Tillage	Residues	Initial	Final SA	Changes SA	T test	Final SB	Changes SB	T test
CT	Control	3.16	2.627[b]	-0.53	0.034*	4.204[a]	1.05	0.007*
	Residues	3.16	3.572[ab]	0.42	0.048*	4.82[a]	1.66	0.004*
	Residues+IF	3.16	3.861[ab]	0.70	0.001*	4.542[a]	1.39	< 0.001**
	IF	3.16	4.894[a]	1.74	< 0.001**	4.337[a]	1.18	0.009*
NT	Control	3.16	3.041[b]	-0.12	NS	4.037[ab]	0.88	0.002*
	Residues	3.16	2.956[b]	-0.20	NS	4.726[a]	1.57	0.004*
	Residues+IF	3.16	3.91[a]	0.75	0.033*	4.537[bc]	1.38	0.001*
	IF	3.16	4.822[a]	1.67	< 0.001**	3.692[c]	0.54	< 0.001**
	SED (T*R)		NS			NS		
	SED (T)		NS			NS		
	SED (R)		0.25			0.17		

CT= Conventional tillage, IF=inorganic fertilizers, NS=not significant, NT = no tillage, R=residue application, SA= Season A (A2014) and SB= Season B (B2014), T=tillage method.

retained should result in increased availability of nitrogen because plowing increase mineralization by exposing previously unexposed soil surface to microbial attack (Masvaya et al., 2017).

Effect on available phosphorous

No interaction observed between tillage method, residues and inorganic fertilizers application on available P. However sole inorganic fertilizers application had higher available P in season A compared to other treatments whereas in season B sole residues application had higher available P compared to the rest of treatments. Results generated a significant decrease of available P in control in season A. In season B the significant increase in available P was observed in all treatments as presented in Table 4.

One of factors affecting availability of P in the soil is the amount of clay present thus having high available P in residues application treatments may be attributed to the reduced soil erosion that preferentially removes colloidal fraction as it has been discussed by Agbede and Ojeniyi (2009).

The weak effect of residues and tillage method on available P may result from the lack of treatments effect on organic carbon but as well reflects the low P contribution in the form of retained residues (Margenot et al., 2017). The lack of the effect of residues of tillage method on the available p was also observed by Araya et al. (2016).

Conclusion

Our study evaluated the implication of tillage methods, inorganic fertilizers and residue application on maize and beans yield and on soil properties in Bugesera district located in Eastern province of Rwanda. Results evidenced that tillage methods, inorganic fertilizers and residues application had a significant effects on maize and bean yields as well as on soil properties. Sole residues application and sole inorganic fertilizers increased maize grain and biomass yield respectively in conventional tillage and in no tillage. Residues applied alone or in combination with inorganic fertilizers increased both organic carbon and available P. No tillage method is recommended for Bugesera semi-arid area of Rwanda but should be accompanied by residues retention and inorganic fertilizers. The right use of inorganic fertilizers is considered as the engine toward successful of implementation of conservation agriculture practices in Bugesera district conditions. Our results provide a basis for conducting trade-off analyses to support the development of CA crop management and international development strategies based on available scientific evidence.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

This research is a result of Masters Study in Kenyatta University, Integrated Soil Fertility (ISFM) program. Association for strengthening Agricultural Research in Eastern and Central Africa (ASARECA) provided fellowship which allowed me to stay in Kenyatta University and the payment of tuition fees. The field work was made possible with financial assistance from Sustainable Intensification of Maize Legume cropping systems for food security in Eastern and Southern Africa (SIMLESA) project.

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