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Medium-term effects of conservation agriculture on soil quality

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Inefficient management practices lead to soil organic matter depletion, structure breakdown and increased erosion. This has resulted into low crop yields of sub-Saharan Africa. Conservation agriculture (CA) is being considered as a potential system having the capability of improving soil quality and providing stable yields. A study was therefore conducted, at Chitedze Research Station-Malawi, to evaluate medium term effects of 5 years CA experiment potential in improving soil quality. The results indicated that chemical nutrient build up in CA is gradual and significant differences between treatments were realized from the 4th year of practicing CA. In the 5th year, CA treatments, on average registered 14 and 21% higher in pH and soil organic matter (SOM) respectively than in the common practice. A positive correlation (74%) between soil SOM and pH in the 5th year was observed. CA treatments had a range of 61.2 - 69.4% of the soil particles composed of soil aggregates greater than 2 mm in diameter compared to 30.1% under common practice by the 5th year. In the top 30 cm of the soil, 67 and 17 earthworm's' m^{-2} were recorded in CA and control, respectively. Maize yields were higher in the 5th year as compared to the 1st year. In all the parameters assessed, CA using maize - cowpea rotation treatment gave highest values. Conclusively, CA improves soil quality, especially when legumes are integrated.

Key words: Common practice, soil aggregate stability.

INTRODUCTION

Agricultural production in Malawi faces numerous problems which have resulted in the maize production being at less than 1.3 t ha^{-1} against the potential of 6 to 8 t ha^{-1} (Ellis et al., 2003). Soil degradation is one of the major constraints to maize production in Malawi, mainly due to poor soil management, deforestation and over grazing. Additionally, the current conventional agriculture techniques practiced by smallholder farmers are known

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to steadily deplete soil fertility, through erosion and loss of soil organic matter, thereby reducing the potential yield on the cultivated arable land (Joseph, 2008). Along with this, it is estimated that six hundred thousand tons of soil are moved manually each year to make ridges (FAO, 1993). Yearly movement of the soil through conventional crop production systems lead to declining productivity and soil degradation. Most operations following the initial ploughing tend to compact the soil, reduce water infiltration, soil aeration and organic matter content, and increase farming costs (Thierfelder and Wall, 2009). Consequently, soil movement leads into the disturbance of the habitat of soil micro flora and fauna and hence loss in microbial diversity (Ghabbour, 2010). This scenario has been worsened by climate change effects which have increased the occurrences of drought periods, combined with shifts and unpredictable rainfall patterns (IPCC, 2001).

A number of efforts have been initiated to address the problems of soil degradation particularly low soil fertility in Malawi. These included the studies which screened the potential of green manure crops as sources of green manure for maize (Gilbert, 1998). Other studies examined the suitability of these legumes in intercrops with maize (Ngwira et al., 2012). Maize pigeon pea intercropping has shown consistent N contribution of a minimum of 27 kg ha^{-1} from natural leaf fall without significant reduction in maize yield (Sakala, 1994). Crop rotation with velvet beans, soybean has also shown positive contribution to soil fertility (Kumwenda, 1997). Despite all these innovations, the current soil organic matter (SOM) inputs (from leguminous trees in fallows, tree leaf litter, cereal, legume crop residues, animal manures and composts) are insufficient to maintain SOM levels in most smallholder farm soils because it is not possible to grow and produce enough biomass to maintain SOM.

Conservation Agriculture (CA) is one of the climate smart agriculture systems which offer renewed hope for the smallholder production in Malawi. Through practicing minimum tillage, soil cover and integration of legumes, as CA principles, it would enhance build-up of both organic matter and soil microbes due to reduced erosion (Thierfelder and Wall, 2012). CA allows for improved water infiltration, water holding capacity and subsequent increased yields of maize (Thierfelder and Wall, 2009). Thus, CA is considered to be one of the agricultural systems with the potential of positively contributing to climate change adaptation and mitigation strategies. Based on this assumption, a study was carried out in a long term CA trial to understand the trends of soil quality improvement in maize based cropping systems in the first 5 years considered as a medium term period.

MATERIALS AND METHODS

Site description

The study was conducted in an ongoing CA trial that was planned for a long term study. The trial is situated at Chitedze Agriculture Research Station located at an altitude of 1145 m above sea level, 14°S latitude and 34°E (Thierfelder and Wall, 2012). Chitedze is a representative of the Lilongwe plain, which is a major maize producing region of Malawi. The terrain is flat to gently undulating and soils are ferruginous Latosols, which are deep and drain freely (Brown and Young, 1965). The soils have been described as having a well-developed structure containing dark to reddish brown top soil with pH ranging from 4.5 to 6.0. Mean annual temperature ranges from 18 to 21°C (Ngwira et al., 1989).

Chitedze Research station receives unimodal type of rainfall that normally starts in November and ends in March. The area receives on average 800 to 900 mm of rainfall, annually. The rainfall data for the first year (2007) and fifth (2011) year of trial implementation show that more annual rainfall was observed during 2007/2008 cropping season (1090.9 mm) and the least rain amount of 743.8 mm fell in the fifth cropping season - (2010/2011) (746.7 mm), with more rains received in the months of December and January (Figure 1).

Experimental treatments

The long term conservation agriculture experiment was laid out in a complete randomized block design with eight treatments (Table 1) replicated four times. Vegetable materials were consisted of maize (*Mays zea*), cowpea (*Vigna unguiculata*), pigeon pea (*Cajanus cajan*) and velvet bean (*Mucuna pruriens*).

The long term CA trial has a main plot size of 24 m x 13.5 m making a total of 18 rows with an area of 324 m^2. The net plot size is 20 m x 7.5 m (10 rows giving a total area of 150 m^2). All crop residues after the first year were retained in the plot of treatments 2 to 8, but removed in the Control plot (Treatment 1) following the common practice of farmers in Central Malawi where crop residues from the previous year's crops are either burned or grazed.

Soil sampling

Soil sampling was done at the end of each experimental cropping season, 2007 and 2011. Soil samples were taken in all the treatments and replicates. In each plot the soil was sampled at five soil depth points (0 – 10 cm, 10 – 20 cm, 20 – 30 cm, 30 – 60 cm and 60 - 90 cm) and at 3 randomly selected sampling points with an Eldeman soil auger. A composite sample from each depth was then obtained, giving rise to 5 samples, from respective depth, per plot. The soil samples were air dried and, except for the determination of aggregate stability, sieved to pass through a 2 mm sieve.

Soil pH and soil organic matter

Soil pH was determined in water (1:2.5 H_2O) (Wendt, 1996). Soil samples were analysed for total soil organic carbon using the Walkley and Black method as described by Anderson and Ingrams (1993) and the soil organic matter was derived from total organic carbon.

Soil aggregate stability

Soil aggregate stability was determined using soils from the 0 - 10 cm soil layer, in the 1st (2007) and the 5th year (2011) of the trial. Soil aggregate stability was determined using the Dry and Wet Sieving method as described by Kemper and Rosenau (1986). In the laboratory, 50 g of the soil with aggregates ranging between 10 mm to greater than 2 mm in diameter was placed on top of a set of 5 sieves (8, 4, 2, 1 and 0.5 mm), saturated with water for about

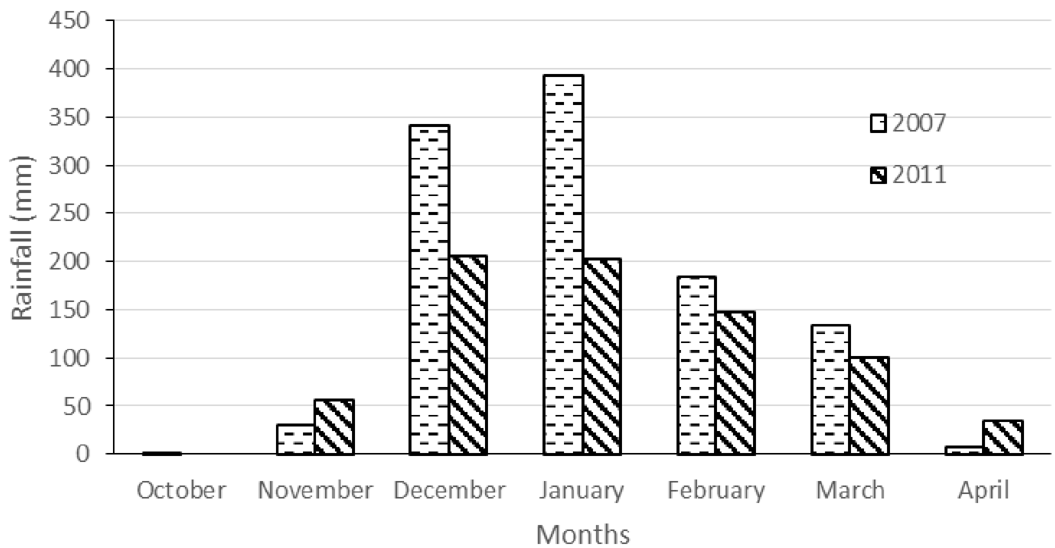

Figure 1. Rainfall distribution in the fist (2007) and fifth (2011) cropping seasons at Chitedze Research Station, Malawi.

Table 1. Treatment descriptions of long-term conservation agriculture trials at Chitedze Research Station, Malawi.

Treatment Number	Treatments Description
1	Control plot: traditional farmers practice using the hand hoe (ridge and furrow system), maize sole crop, no residues (Common practice)
2	CA sole cropping: Basin (0.15 m - length x 0.15 m - width x 0.15 m - depth), maize as a sole crop, residues retained
3	CA sole cropping: Direct seeding with dibble stick, maize as a sole crop, residues retained
4	CA crop rotation: direct seeding with dibble stick, maize-cowpea rotation, residues retained; (Cowpea – Maize – Cowpea)
5	CA crop rotation: direct seeding with dibble stick, maize-cowpea rotation, residues retained; (Maize-Cowpea – Maize)
6	CA intercropping: direct seeding with dibble stick, maize - pigeon pea intercropping, residues retained
7	CA intercropping: direct seeding with dibble stick, maize - cowpea intercropping, residues retained
8	CA intercropping: direct seeding with dibble stick, maize - velvet bean (*mucuna pruriens*) intercropping at 8 weeks after maize seeding, residues retained

20 min. The sieves were placed into a water vessel and a pulley allowing the sieve go up and down, ensuring an oscillation of 5 cm with 30 cycles per minute.

In the process of 10 min oscillation, unstable aggregates dissolved and passed through the sieves' meshes while stable ones stayed on top of the sieves. The sieves were then removed from the water and carefully separated from each other and soil fractions collected on the following sieves; >8, 4 - 8, 2 - 4, 1 - 2, 0.5 - 1 and <0.5 mm were collected into cups then dried for 48 h at 65°C. The dried soil samples were weighed and then percentage of each fraction was calculated.

Determination of earthworms

Earthworm counts were done when the soil moisture was estimated to be at field capacity in February 2012 (in the 5th year). Three sampling sites were selected at random per plot. Each soil sampling point had a dimension of 30 cm x 30 cm (width, length and depth). Soils were carefully collected using a spade at three depths (0 -10 cm, 10 - 20 cm and 20 - 30 cm), spread on a flat surface, and all the earthworms found in that particular soil depth of each sampling point were recorded.

Statistical data analysis

Data was statistically analyzed using GenStat 14th edition. Analysis of Variance, ANOVA, was used to determine treatment effects and their significances. The below statistical model was used:

$Y = u + t_i + b_j + e_{ij}$

Table 2. Soil pH values within the 0 - 10 cm depth of the soil profile in 2007 and 2011 at Chitedze Research Station, Malawi.

Treatment		**Year**	
		2007	**2011**
Common practice		5.19	4.68
CA Basin-sole maize		5.24	5.94
CA-Sole maize		5.28	5.89
CA-Cowpea after maize		5.25	5.89
CA-Maize after cowpea		5.18	5.98
CA-Maize + pigeon pea		5.20	5.91
CA-Maize + cowpea		5.13	5.90
CA-Maize + velvet beans		5.25	6.14
Mean		**5.05**	**5.82**
	P value	**LSD**	
Treatments (T)	<0.001	0.065	
Years (Y)	<0.001	0.032	
T x Y	<0.001	0.091	
CV (%)		**2.8**	

CV: Coefficient of variation, LSD: least significant difference.

Where Y = all variables under study
u = Overall mean
t_i= ith Treatment effect
b_j= jth Block effect
e_{ij}= Error term

Differences between and within treatments were separated using Least Significant Differences (LSD) tests at $p< 0.05$.

RESULTS

Soil pH

Table 2 represents results of soil pH in Year 1 (2007) and Year 5 (2011) of trial implementation. Lower pH values were observed in 2007 unlike in 2011 with an average of 5.04 and 5.82 respectively. The results revealed that by 5th year the control/common practice had decreased values of soil pH, while in the CA treatment plots there was an increase in soil pH values. Among the CA treatments, maize – velvet beans intercrop plot gave the highest pH value of 6.14 in the top soil.

Soil organic carbon (SOM)

SOM concentration steadily and gradually increased in the CA treatments from a mean value of 34.0 g kg^{-1} in the first year (2007) to 42.0 g kg^{-1} in the fifth year (2011) on the top soil of the CA treatments. Among conservation treatments, the cowpea - maize rotation had the largest SOM content of 45.0 g kg^{-1} % in the soil top layer, 0 - 10 cm, (Figure 2). Consequently, within a period of five years, common practice reduced SOM content from 35 g kg^{-1} in year 1 to 31 g kg^{-1} by the fifth year, giving a mean decrease in SOM of 4 g kg^{-1} (Figure 2). In both years, it was observed that the SOM content decreased with increase in soil depth. Results of SOM content also showed non-significant differences between soil depths, along the soil profile of study.

Correlation of soil organic matter and pH in the 5th year

Results on the relationship between soil organic matter and soil pH, (Figure 2), showed that there was a positive and strong correlation (74%) between soil organic matter and soil pH.

Soil aggregate stability

No significant differences were observed among treatment means of soil aggregates greater than 2 mm diameter, in the first year (2007) of trial implementation (Table 3). In contrary, significant differences (p=0.05) were observed in the fifth year (2011) for soil aggregates that were greater than 2 mm diameter among different treatments. In the fifth year, conservation agriculture treatments had larger percentage of soil aggregates that had a diameter of greater than 2 mm. The conservation agriculture soil aggregates, < 2 mm diameter, were in the range of 61.4 to 69.4% as compared to the conventional treatment that had 30.1% of its aggregates with diameter greater than 2 mm. Among the CA treatments, maize - cowpea rotation treatment recorded the highest percentage of soil aggregates (69.4%). greater than 2 mm diameter.

The results also revealed that practicing conservation agriculture for a period of five years contributed to the increase in the soil aggregates of >2 mm by 23.8 to 40.8% while in the control plot, aggregates >2 mm reduced by 0.3% on the top soil, 0 - 10 cm (Table 3).

Earthworms density

Earthworm counts per square meter of the soil in the fifth year (2011 – 2012) of the experiment showed significant differences among treatment means and at different soil depths (Table 4). There were more earthworms' populations in conservation agriculture than in the control treatments across the soil profiles under investigation. The highest population of earthworms was obtained in maize - cowpea rotation plots (Table 4).

Maize yield

Figure 4 represents results of maize grain yield in the

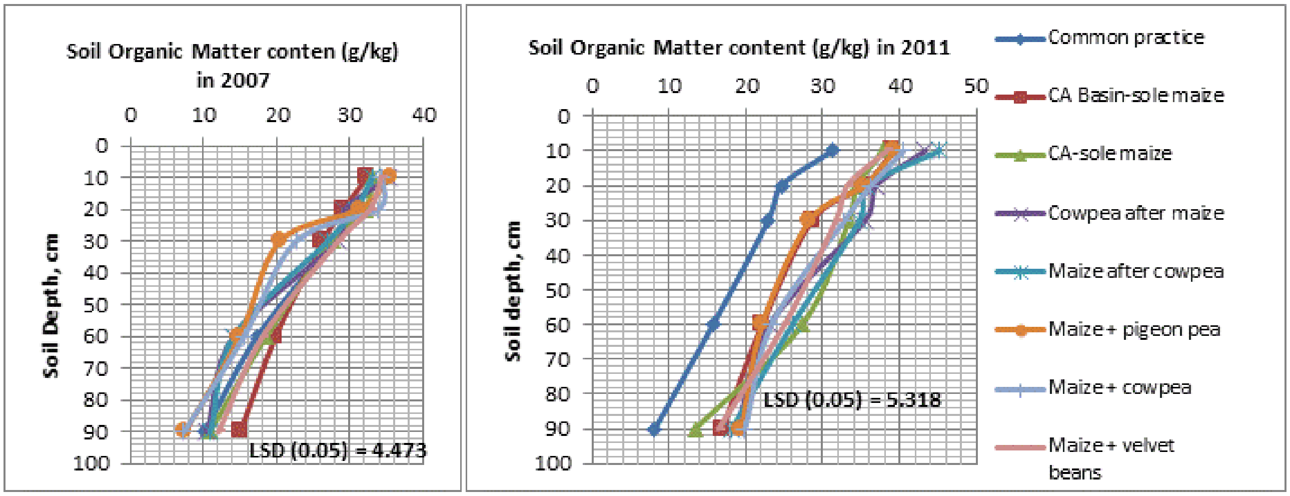

Figure 2. Soil organic matter content in Year 1 (2007) and 5 (2011) at five different soil depths at Chitedze Research Station, Malawi.

Table 3. Percentage of soil aggregates greater than 2 mm in the first year (2007) and fifth year (2011) at 0 - 10 cm soil depth at Chitedze Research Station, Malawi.

Treatment	% aggregates > 2 mm	
	2007	2011
Common practice	30.4	30.1
CA Basin-sole maize	21.5	61.8
CA-Sole maize	37.4	61.2
CA-Cowpea after maize	26.6	67.4
CA-Maize after cowpea	40.6	69.4
CA-Maize + pigeon pea	38.7	67.1
CA-Maize + cowpea	25.1	61.4
CA-Maize + velvet beans	26.5	63.6

	P value	LSD
Treatments (T)	0.004	11.6
Years (Y)	<0.001	5.8
T x Y	0.019	16.4
CV (%)		25.3

CV: Coefficient of variation, LSD: Least Significant Difference.

Year 1 (2007) and Year 5 (2011) of trial implementation. More grain yield in all treatments was observed in 2011 than in 2007. The rotation plot of maize after cowpea out yielded all treatments in both years.

DISCUSSION

Soil pH (H_2O)

The conservation agriculture treatments increased soil pH as compared with the one obtained from the control plot. This observation implies that, under common agricultural practices, there should be an increased solubility of the sesquioxides in form of aluminium (Al), Iron (Fe) and Manganese (Mn) due to depletion of the SOM as a result of yearly removal of crop residues (Bartoli et al., 1992). Accumulation of Al, Fe and Mn cause toxicity and impedes the availability of essential plant nutrients like phosphorus in the soil and to the growing plants. The high content of SOM in the CA plots influenced the increase in the pH resulting from a nutrient buffer effect (Duiker and Beegle, 2006). This is also evidenced by a positive correlation between the SOM and pH (Figure 3). The results from this study agrees with Ngwira et al. (2012) findings, who reported that soil pH was slightly higher under all conservation agriculture treatments than in the conventional after 4 years of practising CA. Sidiras and Pavan (1985) found less acidification and therefore higher pH values under zero tillage than conventional tillage at a depth of 60 cm in both oxisols and alfisols in Paraná, Brazil. Similarly, Govaerts et al. (2007) observed a significantly higher pH in the topsoil of the permanent raised beds with full residue retention compared to conventional raised beds with residue retention.

Soil organic matter

Increased content of soil organic matter, after the fifth year, in the CA treatments in the top soil, implies that the yearly residue retained in the field coupled with reduced tillage foster SOM build up through the slow decomposition rate taking place across the growing seasons (Karlen et al., 1994). This is as reported by (Bot and Benites, 2005) that the residues on the soil surface

Table 4. Earthworm counts per square meter of soil after five years of continuous cropping (2007 - 2011) at Chitedze Research Station, Malawi.

Treatment	Depth (cm)			Total
	0-10	10-20	20-30	
Common practice	9	7	1	17
CA Basin-sole maize	19	13	3	35
CA-sole maize	21	20	16	57
Cowpea after maize	43	27	11	80
Maize after cowpea	52	31	16	99
Maize + pigeon pea	30	13	7	50
Maize + cowpea	40	20	8	68
Maize + velvet beans	30	11	4	45

	P value	LSD
Treatments (T)	0.013	11.26
Depth (D)	<.001	6.9
T x D	NS	
CV (%)		39

CV: Coefficient of variation, LSD: Least Significant Difference, NS: Not significant.

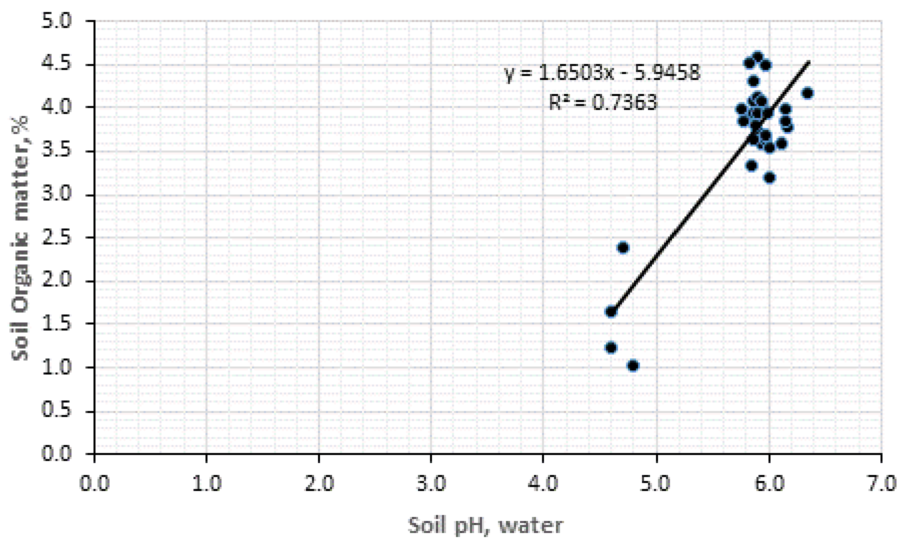

Figure 3. Correlation between soil organic matter and soil pH in the fifth year of practicing CA on the top soil, 0 – 10 cm soil depth.

slow the carbon cycle because they are exposed to fewer microorganisms and thus the decomposition is more slowly, resulting in the production of more stable humus. In the longer term, the slowly decomposing residue materials will lead to the accumulation of organic matter and availability of nutrients in the whole soil system under CA (Thierfelder and Wall, 2012). The low levels of SOM in the common practice plot are primarily due to crop residue removal and soil tillage that aerates the soil and speeds up the decomposition rate of the organic matter (Jackson, 1993). The level of organic matter present in the soil is a direct function of how much organic material is being produced or added to the soil versus the rate of decomposition (Flessa et al., 2000). Consequently, increased values of the SOM under conservation agriculture could create optimum conditions for plant growth as observed by Jackson (1993) who indicated that SOM maintains favourable conditions of moisture, temperature, nutrient status, pH and aeration for optimum plant growth.

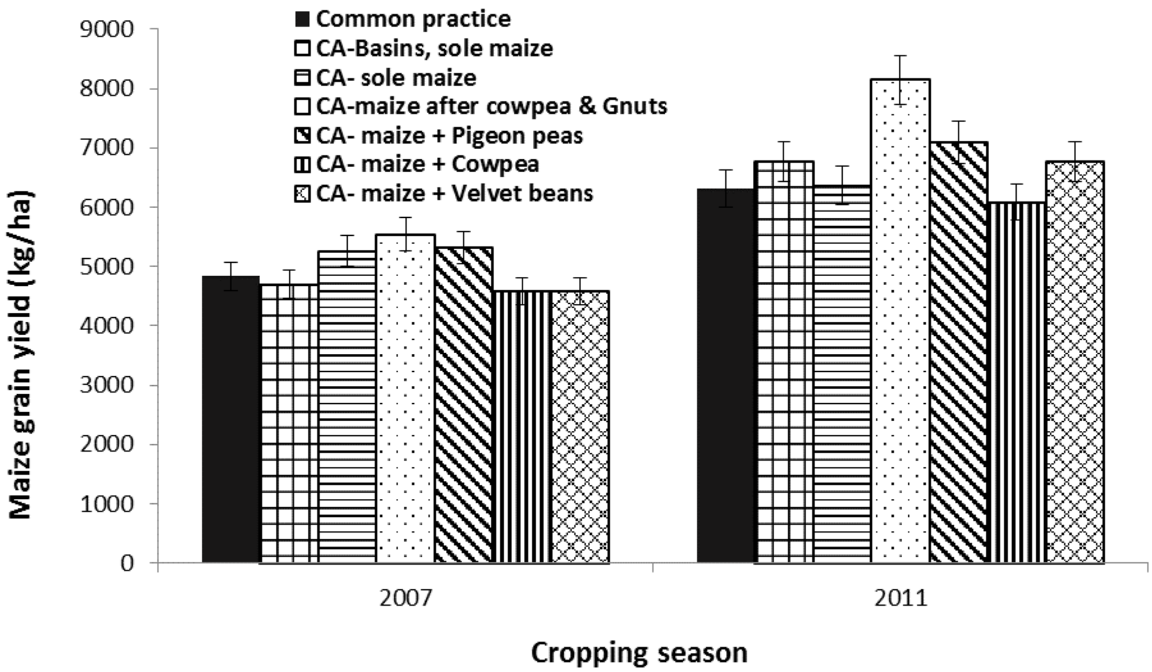

Figure 4. Maize grain yield (kg ha^{-1}) in year one, 2007 and year five, 2011 of trial implementation.

Correlation of soil organic matter and pH in the 5th year

A positive and strong correlation between soil organic matter and pH in the 5th year implies that the soil organic matter content has an influence on the acidity of the soil. When a soil has an increased SOM, the acidity decreases, because the carboxyl groups on the humus develop negative charge and suppress the positively charged H that reacts with the hydroxyl (OH^-) to form water (McCauley et al., 2017). Hence, with an increase in organic matter, the soil recovers its natural buffer capacity.

Soil aggregate stability

Larger percentage of soil aggregates greater than 2 mm diameter in the conservation agriculture treatments as compared to the control treatment was attributed to good soil structure brought in by minimum soil tillage and residue retention. Conservation agriculture practices would therefore promote increased water infiltration, increased aeration, and increased water-holding capacity (Boyle et al., 1989). The findings of this study are in agreement with Kladviko et al. (1986), Six et al. (2004) and Simpson et al. (2004) who noticed that reduced soil disturbance and higher soil organic matter contents contribute to the building up of a stable aggregated and porous structured soil matrix (Kladviko et al., 1986; Six et al., 2004; Simpson et al., 2004). Plant residues retention on the soil surface in conservation agriculture protect the soil from raindrop impact while no protection occurs when residues have been removed, causing further susceptible soil aggregate disruption (Six et al., 2000). The reduced aggregation in common tillage practice, again, is a result of direct and indirect effects of tillage on the soil aggregates (Beare et al., 1994). Physical disturbance of soil structure through tillage results in a direct breakdown of soil aggregates and an increased turnover of aggregates (Six et al., 2000). Tillage also increases fragmentation of roots and mycorrhizal hyphae, which are major binding agents for macro aggregates (Tisdall and Oades, 1982; Bronick and Lal, 2005).

Earthworm populations

The significant difference between earthworm’s densities in conservation agriculture and common agricultural practice is a good indicator of improved soil health under CA cropping systems. Earthworms occur in warmer places with high content of SOM and soil N (Mando and Stroosnijder, 1999). Although tillage is the main factor that affects earthworm populations, mulched crop residues are also important in maintaining a good water potential of the surrounding soil media for increased growth in numbers of earthworms (Edwards and Bohlen, 1996). The vertical movements of earthworm into the soil aids air circulation deeper into the soil, stimulating microbial nutrient cycling at those deeper levels (Edwards and Bohlen, 1996). Earthworm tunnelling can increase the rate of water percolation into the ground 4 to 10 times higher than fields that lack worm tunnels (Edwards and Shipitalo, 1998). The earthworm counts obtained in this study supports the findings reported by Thierfelder and Wall (2010), from similar experiment in Zambia where earthworm populations were, on average, 450% higher in the conservation agriculture treatments than in the conventionally tilled treatment. Consequently, annual soil tillage constantly disturbs the earthworm habitat, whereby food and moisture available for earthworms and other organisms are acutely reduced. Additionally, tillage promotes soil aeration, enhancing rapid oxidation of the limited SOM which in return leads to reduced earthworm numbers (Edwards and Shipitalo, 1998; Thierfelder and Wall, 2012) in the conventionally tilled plot. Earthworms need oxygen, tapped just under the near soil surface in order to carry out their metabolic processes, hence larger earthworm population in the top soil than in subsoil. Increased number of earthworms in CA plots is as a result of the enhanced soil surface roughness brought in by soil cover that increased aeration, soil moisture and SOM content on the soil surface (Ghabbour, 2010).

Maize yield

Other than higher rainfall in the 5th year (Figure 1), the higher maize yields might have been attributed to improved soil quality trend observed in the 5th year as compared to the first year of trial implementation. This might be a reflection of the improved soil quality as identified by all the soil quality indicators (chemical, physical and biological) by the 5th year. The results are in line with the findings of Govaerts et al. (2007) who observed a direct and significant relation between the soil quality status and the crop yield under zero tillage with crop residue retention.

Conservation agriculture fosters a gradual increase of soil pH, and SOM at medium term as compared to common tillage. Conservation agriculture cropping systems improves the physical structure of the soil (more soil aggregates >2 mm in diameter). Soil under conservation agriculture becomes more active biologically as compared to the soils under common tillage practice after a medium term period of five years and hence increased maize production.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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