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Original Research Article

On farm assessment of carbon stocks under sub optimal and optimal input management in Mpongwe and Chisamba districts of Zambia

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Soil management in agriculture can either contribute to further carbon emissions or carbon sequestration depending on the agricultural practices implemented. Conservation Agriculture (CA) is one of the promising practices being promoted for reducing the greenhouse gas effect in the face of climate change. This study sought to assess the amount of soil organic carbon (SOC) in CA and Conventional Tillage (CT) cropping systems under suboptimal and optimal input management in Mpongwe and Chisamba districts. Soil samples were randomly collected at a depth of 20 cm to assess the C-stock in fields which have been under CA/CT between 3 and 7 years under suboptimal and between 12 and 18 years under optimal input management. Changes on selected soil properties over time were determined using standard laboratory procedures. The amount of carbon sequestered was assessed using the adjusted Land Use Land-Use Change and Forestry (LULUCF) model. CA fields had sequestered 1,424 Kg SOC /ha,yr while the CT had 392kg SOC/ha,yr, representing a threefold difference. At GART SOC was 63,180kg/ha after 15 years of CA compared to 50,622kg/ha under CT over the same period. These findings suggest that CA can mitigate the effects of climate change by reducing the carbon emission resulting from the crop production practices. Further, there were significant differences between C-stocks under the 18 and 12 years CA fields under *Faidherbia albida* trees at GART. The results also showed increased pH values under the eucalyptus plantation compared to the other fields at GART suggesting that pH increases when land use is changed from agriculture to forestry.

Key words: Carbon, sequestration, emissions, conservation agriculture.

INTRODUCTION

Soil management in agriculture can either contribute to further carbon emissions or carbon sequestration depending on the agricultural practices implemented. Conservation Agriculture (CA) is one of the promising practices being promoted for reducing the greenhouse gas effect in the face of climate change. In 1996, the concerns about the role of the soil in the global carbon budget and its effects on soil organic carbon (SOC) were addressed by incorporating the decline in soil quality in international treaties through the Kyoto protocol. This protocol allows for taking into account sequestration of carbon into the soil as a carbon sink. Studies by Lal (Lal, 2004 and Lal, 2008) concluded that worldwide, the amount of C stored in soils is approximately four times greater than plant biomass carbon and three times greater than atmospheric carbon, and these amounts of carbon sequestered ranges from 0.4 – 0.8 Pg C per year 50 –100 years (IPCC 1996). Further, it has been documented that soil C accumulation is influenced by numerous factors, such as the climate, vegetation, organisms present, soil type, topography, parent material, soil texture and changes in land use (Stevenson, 1986). Using standards and rules developed in the IPCC protocol (2006) for the quantification of soil C and N stocks and GHG fluxes at the field scale, GHG inventories in different agricultural soil management systems can be prepared. As a management practice, conservation agriculture has been promoted in Zambia since the year 2000 by both the government through the ministry of Agriculture and Non-Governmental Organizations (NGO's) such as Conservation Farming Unit (Baudron et al., 2007). Studies by Moraes Sa' have shown that soils managed by plough based tillage systems (conventional agriculture) are a source of CO_2 and other GHGs because of increase in oxidation of soil organic matter (SOM) by microbiota, while, in contrast, the adoption of minimum-tillage production systems in which C inputs exceed C oxidation favours the gradual accumulation of soil C and thus helps mitigate the levels of some GHGs (carbon dioxide) (Moraes Sá et al., 2012). However, information on how much soil organic carbon is sequestered through CA practices is very limited. This study sought to do an on-farm assessment of soil organic carbon (SOC) from selected CA practices on farm lands in order to quantify the amount of SOC sequestered, and promote CA as a climate change mitigation technology. The objectives of this study were (i). To assess C-stock in soils under suboptimal input CA at small holder farmer level in Mpongwe district and (ii) under optimal input CA at Golden valley Agriculture Research Trust (GART) in Chisamba district.

MATERIALS AND METHODS

Description of the study sites

This study was conducted in Chisamba and Mpongwe districts of Zambia which are located at S 14° 57'50'' E28° 6'13" and S 13° 30' 30'', E 28° 10' 0''. Mpongwe district was selected because it had a higher CA adoption rate of 15% by 2015 compared to other districts in Zambia (Mwanza, 2016), while, Golden Valley Agriculture Research Trust in Chisamba district was selected because it has over the years carried out and promoted research in conservation agriculture technologies.

Mpongwe district is found in region III of Zambia's agro ecological regions, and receives above 1000 mm of rainfall annually. Its temperature ranges from as low as 5 to 35 °C, the region has a long plant growing season of 140-200 days. Soils in this region are predominantly *Acrisols, Alisols, Solonchaks, Leptosols* and some *Ferralsols* developed under conditions of high leaching intensity.

Chisamba district is in sub region IIa of agro-ecological region II which forms the medium rainfall region of Zambia, stretching in a central band across the country arching south-westwards from the Malawi border in the east to the Angolan border in the west. Rainfall ranges between 750-1000 mm in a growing season of 90-150 days. In the Sub-region IIa in the central and eastern parts of the country, soils are largely classified as *Lixisols, Luvisols, Alisols, Acrisols* and *Leptosols* with the respective associations and *Vertisols* in the Kafue floodplain.

Experimental fields

Fields were classified as suboptimal input CA and optimal input CA management levels. Suboptimal input CA farmers are small scale farmers that use the recommended fertilizer rates of four basal and four top dressing fertilizers in maize production per hectare, while optimal input CA farmers are farmers under commercial as well as researcher management. Following this classification, suboptimal input CA farmers were purposively selected from the list of farmers that have been involved in government and non-government programs in Mpongwe district on the copperbelt. The farmers selected were those who have adopted at least three technologies under CA (minimum tillage, crop rotation, adoption of *faidherbia albida* (Musangu trees) and crop residue retention). Golden Valley Agricultural Research Trust (GART) in Chisamba district was selected as optimal input CA farm under researcher management with CA/CT fields and eucalyptus plantation fields selected.

Under suboptimal input CA management, 30 paired soil samples from smallholder farmers under both government and non-governmental CA projects were collected from fields of between 3 and 7 years while under optimal input CA management, 80 soil samples from 0 to 20 cm depth were collected from five different fields. More soil samples under optimal management were collected because of the inclusion of the eucalyptus plantation field in the study. The five fields were 15 years CA field, CA fields with 12 and 18 years Musangu trees (*Faidhebia albida*), 15 years CT field and a 22 year old eucalyptus plantation field. These fields where selected in order to assess the difference in C-stocks as a result of land use change and management. Soil samples were randomly collected from 0 to 20 cm depth from CA and CT fields adjacent to each other for purposes of reducing soil variability between the paired samples.

Soil characterization

Soil samples were subjected to chemical and physical characterization after sieving through a 2 mm sieve at the Zambia Agriculture Research Institute (ZARI) laboratory. Three replicates were done per sample. The following are parameters that were characterized: Soil reaction (pH) (Mclean, 1982), soil organic carbon (Walkley and Black method), particle size distribution (Hydrometer method), exchangeable bases (K^+, Na^+ Ca^{2+}, Mg^{2+}) (Thomas, 1982), available phosphorus (bray 1), total nitrogen (Kjeldah method) and soil bulk density (core ring method). The analysis followed the standard procedures. Only soil reaction (pH_{CaCl2}), soil organic carbon and total nitrogen have been discussed in this paper.

The study was based on the IPCC's "Good Practice Guidance for land Use, Land-Use Change and Forestry"

Table 1. LSD All-Pairwise Comparisons Test of pH

Treatments	Mean	*p*-value
CA 3yrs	5.67[a]	0.0080
CT 3yrs	5.62[a]	0.0080
CA 7yrs	5.49[a]	0.0080
CT 7yrs	5.18[b]	0.0080

(LULUCF), Chapter 3, tier[3], published in 2006. The approach proposed in the IPCC Guidelines where carbon stocks are measured at two points in time to assess SOC changes was used. The C-stocks at 3 and 7 years for suboptimal and 12, 15 and 18 years under optimal input management were determined from laboratory analysis and calculations were then used in the general equation below.

- The equation below illustrates the generic approach for estimating carbon stock change in this way.

$C = ijk(Ct_2 - Ct_1) / (t_2 - t_1)\ ijk$

Where, Ct_1= C stock in pool at time 1, ton C/ha,

Ct_2= C stock in the pool at time 2, ton C/ha and

Ijk= Climate type (*i*), vegetation type (*j*), soil management practice (*k*)

At farm level the equation is simplified to:

$C\ kg/ha = ((Ct_2 - Ct_1) / (t_2 - t_1))\ 10kg\ \times$ mass of soil /ha

Statistical analysis

The statistical analysis was done using Genstat version 18. The results of soil tests were analyzed using Analysis of Variance with a randomized complete block design (RCBD) for the two levels of CA/CT under suboptimal input management and the blocking factor was soil texture. Under optimal input management completely randomized design (CRD) was used because there was no variation in the soil type or texture among the five fields at GART. The means were separated using the LSD test at 95% confidence level.

Correlation model was used to assess the type of relationship between variables whether it's positive or negative. In this study, a relationship between SOC accumulation and time under which a tillage system is used was assessed. The correlation coefficient (r^2) value in percentage of the results was used to ascertain the strength of the relationship.

RESULTS AND DISCUSSION

Effects of tillage practice (CA/CT), land use change and management on soil organic carbon (SOC) and total nitrogen (N)

Under suboptimal input management

The soil organic carbon was found to be significantly different in the CA compared to the CT fields at 3 years and 7 years. There were Significant differences observed among the SOC means at the two levels of CA and CT management (p = 0.0000) (Table 1). The mean values obtained were CA 7 years 1.58 % and CA 3 years 1.35 %, while CT 7 years was 0.89 % and CT 3 years was 0.84 % (Figure 1). Pair wise comparison of means indicated that there were no significant differences among the SOC means in the CT fields at the two levels sampled while there were significant differences among the SOC means under CA at the two levels.

The critical limit for SOC in soils is 1.5% (Fairhurst, 2012), the SOC obtained from the CA 7 years fields was more than the critical limit indicating that under this management type, SOC accumulation increased with time. The results also indicated that under suboptimal input CA management, there is a significant difference in SOC compared to CT management over time. These findings are in line with what Muchabi found when she assessed C-stocks under CA and CT at smallholder farmer level in fields of Kafue district of Zambia (Muchabi, 2014).

The results also showed that there were higher values of Total Nitrogen in CA compared to CT fields (p = 0.0000), there were significant differences between the two management types at both levels (Figure 2). Pair wise comparison of means showed that they were significant differences among the means of N in the CA 7 years, CA 3 years, CT 7 year and CT 3 years. The mean values obtained were CA 7 years 0.13, CA 3 years 0.11, CT 7 years 0.06 and CT 3 years 0.08. The results also indicated that there is loss of Total Nitrogen in the soil with prolonged practice of CT under suboptimal input management.

Under optimal input management

The results showed that SOC levels were above the 1.5% critical level across the two farming systems. They also showed that CA fields had higher values compared to CT fields. There were significant differences among the means (p = 0.0000). The mean values obtained were CA/Musangu field 18 years 3.21%, CA/Musangu field 12 years 2.05%, 15 years CA field 2.39%, whereas, 15 years CT field had 1.77% SOC (Figure 3) . Pair wise comparisons among the treatment means also showed significant differences at 95% CI across and within farming systems and time under such a farming system. The means were separated and CA/Musangu field 18 years (A) had higher values followed by the CA field 15 years (B), then CA/Musangu field 12 years (C) and Conventional field 15 years (D) had the least. It was observed that the CA field with 12 years old Musangu trees had lower 2.05% SOC compared to the CA field 15 years without Musangu trees 2.39%. Comparing the 18 and 12 years Musangu CA fields showed that the age of the trees have a significant influence on the amount of soil carbon accumulation. This conforms to what was found by Umar et al. (2012) who conducted a study to assess the effects of *Faidherbia albida* on the fertility of soil in smallholder conservation agriculture systems in eastern and southern

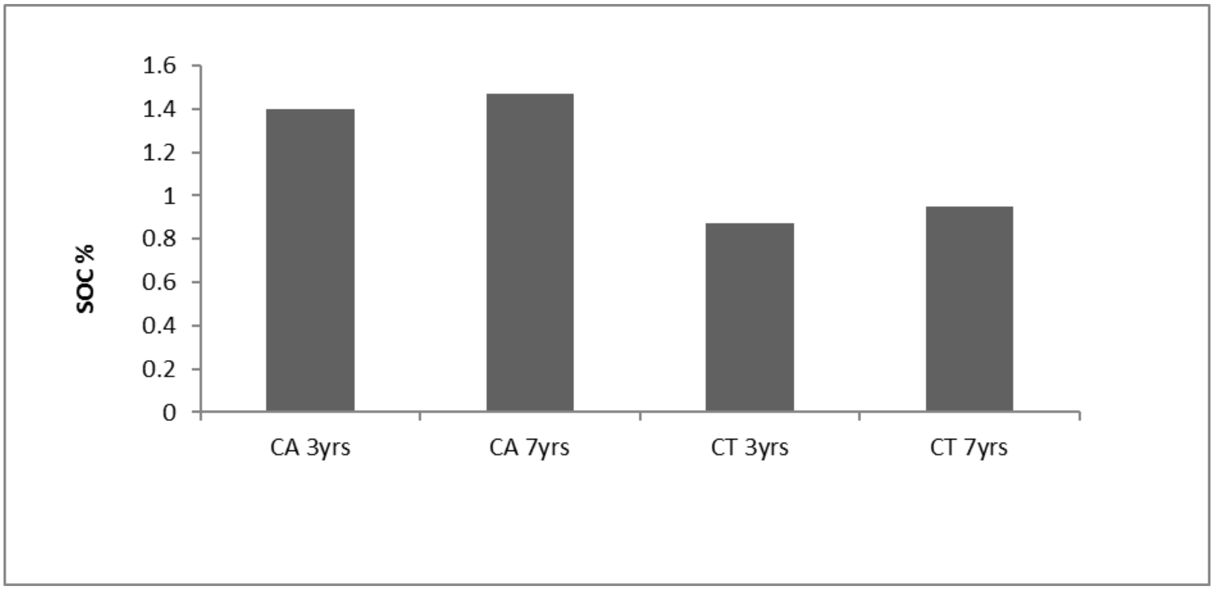

Figure 1: Soil organic carbon levels under suboptimal input CA management and CT

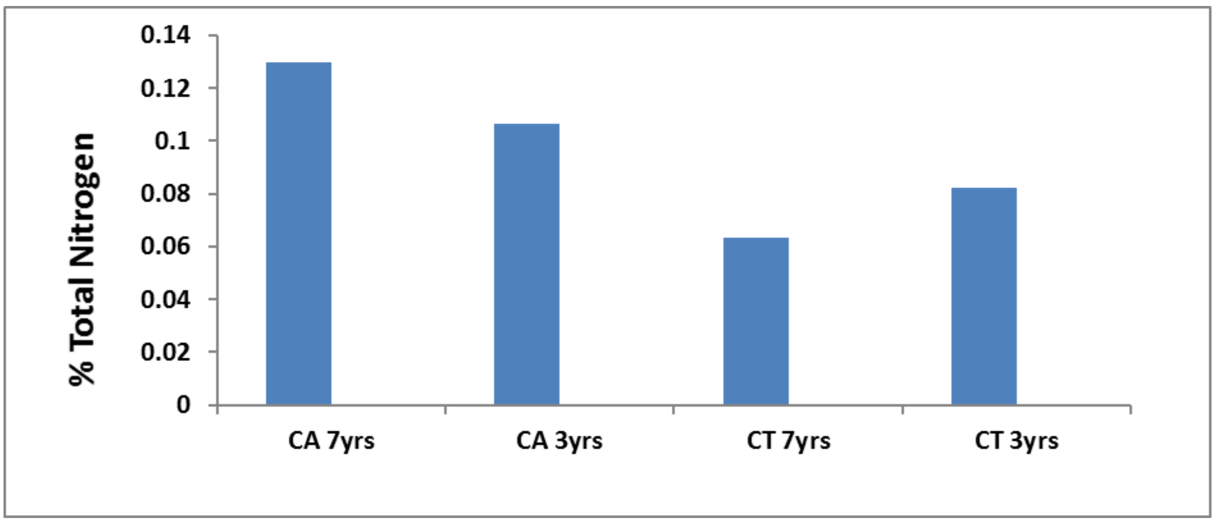

Figure 2: Distribution of Nitrogen in CA fields

Zambia. In this study, they found that the levels of SOC were increasing with the age and height of the trees.

With regards to Total Nitrogen, the results suggested that CA fields had higher values compared to CT fields (Figure 4). Significant differences were observed in the 18 years Musangu CA field, 12 years Musangu CA field, 15 years CA field (p = 0.0000). The values were 18 years Musangu CA field 0.43%, 12 years Musangu CA field 0.29%, 15 years CA-field 0.31% and 15 years CT fields 0.21%. From these results, it was observed that all the CA fields had higher total N values compared to the desired N value (0.25%) under which the soil is said to be low in Nitrogen (soil interpretation guide). The results also conform to the findings of other researchers who have indicated that *Faidherbia albida* (Musangu) trees add nitrogen to the soil (Umar et al., 2012).

Effects of tillage practice, land use change and management on Soil reaction (pH)

Under suboptimal input management

The pH of the Mpongwe soils under this study ranged from 5.18 to 5.67 pH units across the two tillage systems (Figure 5). The results indicated a significant difference in soil pH values at 95% CI (p = 0.0080). Upon mean separation using LSD at 95% CI, it was observed that there was a significant difference among the means of CT 7 years 5.18 compared to

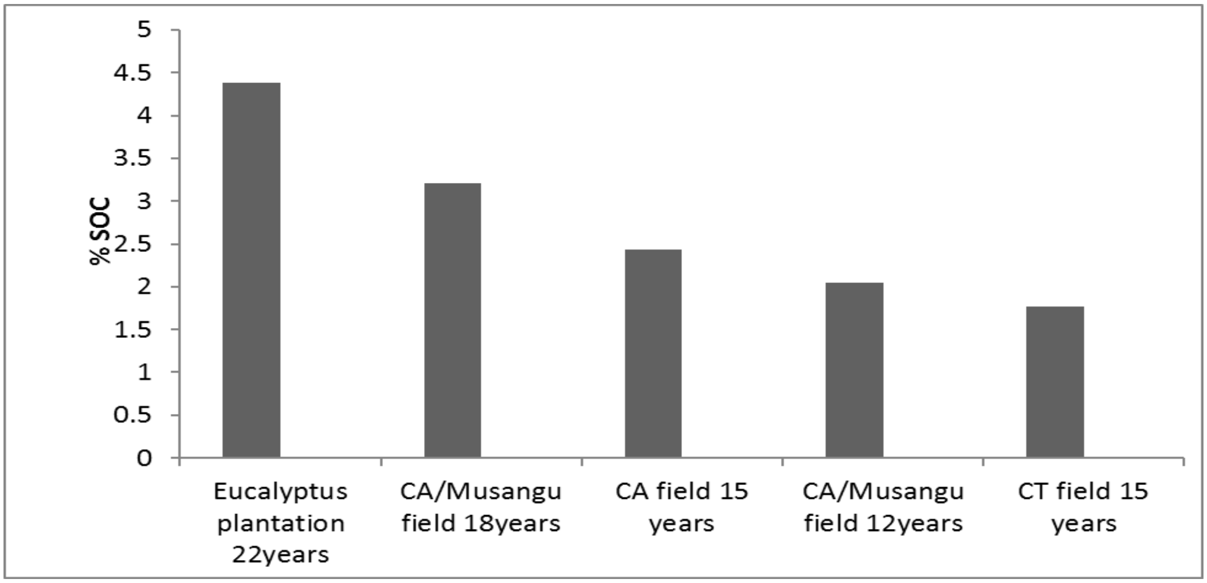

Figure 3: Percentage soil organic carbon at GART

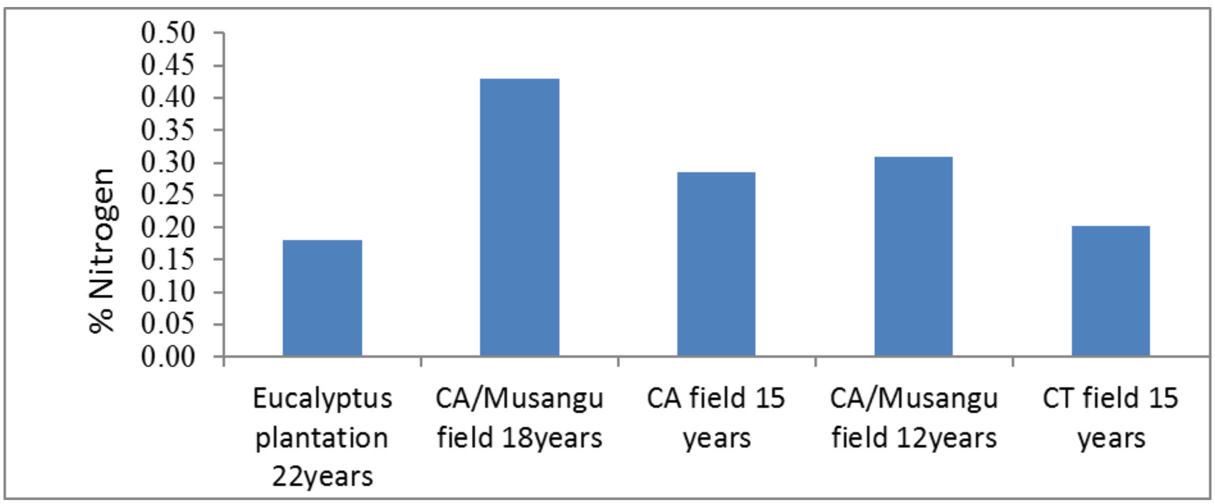

Figure 4: Percentage Total Nitrogen at GART

the CT 3 years 5.62 and CA 7 years 5.49 and CA 3 years 5.67. However, there were no significant differences among the means of CA 7 years, 3 years and CT 3 years as indicated the homogenous grouping letter A. These findings indicate that long term CT management tends to lower the soil pH compared to CA management.

Under optimal input management

The soil pH ranged from 4.60 in the CA/18 years Musangu field to 5.17 in the eucalyptus plantation field. Statistically there were significant differences (p = 0.0000) among the means across all fields (Figure 6). Pair wise comparison among means indicate that they were significant differences among the means, however, there were no significant differences between the eucalyptus field and 15 years CT field, and 15 years CT field and 15 years CA field. There were also no significant differences among means of 15 years CA field and CA/Musangu field 12 years, and CA/Musangu field 12 years and CA/Musangu field 18 years (Figure 6).

From these results, we observed that the soil pH under CA/Musangu fields is lower than the other fields at GART. This was attributed to the fact that Musangu trees add nitrogen into the soil as indicated in the analysis for Nitrogen above. The increased nitrogen level leads to more nitrification which adds hydrogen ions in the soil, the increased levels of hydrogen ions increases soil acidity hence the high acidity under CA/Musangu fields. The chemical equation $2NH_3 + 3O_2 \text{ -----> } 2NO_2 + 2H^+ + 2H_2O$

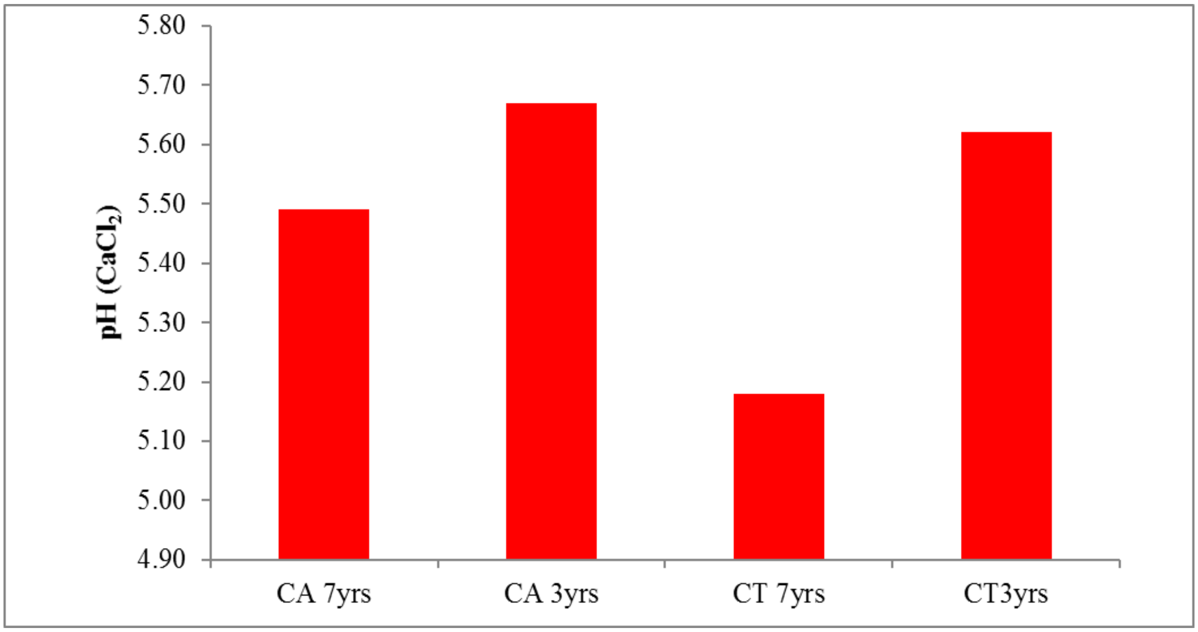

Figure 5: Soil pH under suboptimal input management

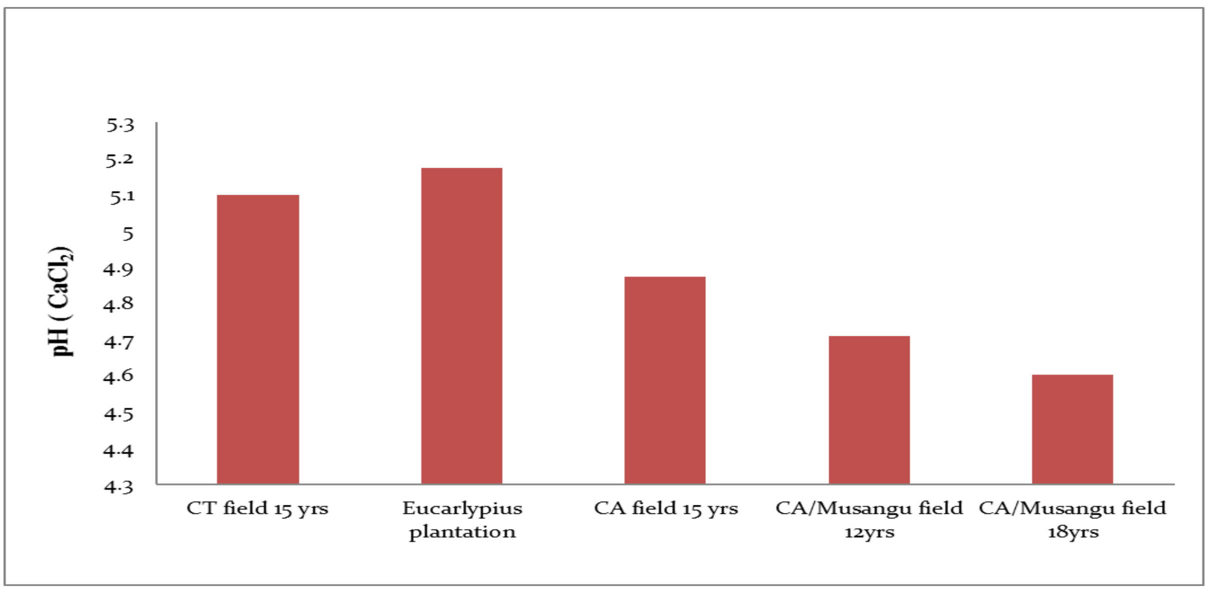

Figure 6: Soil pH under optimal input Management

summarizes the entire nitrification process which adds hydrogen ions to the soil solution that leads to soil acidity (Schmidt, 1982).

The levels of acidity under the 18 and 12 years *faidherbia albida* (Musangu) are not significantly different from each other but the trend seems to point to the fact that *faidherbia albida* (Musangu) trees tend to acidify the soil in the long run. During soil sampling, there was evidence of high levels of soil liming in the conventional tillage fields.

The high lime application accounts for the higher soil pH values in these fields compared to the 15 years CA field.

Comparing agroforestry and forestry, the results suggested that agroforestry using *Faidherbia albida* (Musangu trees) tend to acidify the soil compared to the eucalyptus trees which tend to neutralise the soil acidity as shown by the pH values obtained above. The high accumulation of organic matter under forestry plantation compared to the agroforestry with *faidherbia albida* (Musangu) trees conditions provides the soil with an increased number of exchange sites that bind the excess hydrogen ions in soil solution thereby neutralising the soil acidity.

Soil pH affects the relative binding of ions on exchange sites, it also influences the solubility of various compounds in the soil solution, affects plant crop growth and the diversity and activity of microorganisms. At both levels of CA management, the soil pH range was within the tolerant region for most crops grown in Zambia. The high organic matter levels in CA fields under high input CA management also provided more binding sites for H^+ ions in the soils thereby increasing the buffering capacity thereby reducing the negative effects that pH may have on the commonly grown crops (Umar et al., 2011). Similarly, Gupta (1998) reported that for most microbes, the thrive well in the pH range of 4.5 to 8.0, therefore, the microbes will survive in these fields both under suboptimal and optimal input CA management.

Comparing C-stock in CA fields under optimal and suboptimal input management

Under suboptimal input CA management the r^2 value obtained was 0.2327, this suggests that there is a significant relationship between the amount of SOC accumulated with the time under which CA is practiced in the field, however, this relationship can only be explained by 23.27% whereas other factors account for 76.73%. Under optimal input CA management the r^2 value obtained was 0.8281 suggesting a very significant relationship between CA management practices and soil organic matter accumulation over time (82.81%). These results conform to what Umar found in their study of soil organic matter content under fields of Musangu trees at various tree ages in eastern and southern provinces of Zambia (Umar et al., 2012). A comparison of the two r^2 values suggest that optimal input CA management is more efficient in soil carbon sequestration in conservation agriculture compared to suboptimal input management. However, these results many not paint the full picture because the management types under comparisons are at different durations. i.e. under optimal input management maximum average duration was 7 years with minimum being 3 years, but under optimal input CA, the longest duration was 18 years with 12 years being the minimum duration CA has been practiced. The planting of crops under *ferdhaibia albida* trees also contributed to the high levels of soil organic matter accumulation.

Levels of C-stocks using the adjusted LULUCF model at Model at Farm level

Under suboptimal input management level, it was determined that 1,423.75 Kg SOC /ha,yr was sequestered under CA fields with a bulk density of 1250kg/m^3, while 391.30kg SOC/ha, yr was found under the CT fields with a bulk density of 1400kg/m^3. This suggests that CA is able to sequester 1,032.45kg/ha more carbon annually compared to CT at smallholder farmer level.

Under optimal management, the results suggested that more soil organic carbon is lost when land use is changed from forest to CT (-26.073g/kg soil) compared to (-19.49g/kg soil) which results after land use is changed from forest to CA. However, it was observed that combing CA practices and agroforestry trees (Musangu) greatly reduces the loss of soil organic carbon (-11.684g/kg soil) compared to forestry conditions. Agroforestry cropping systems that produce and return biomass to the soil surface enhance SOC content. Relatively low biomass produced in monoculture grain crops may be greatly enhanced by mixed cropping systems or agroforestry. However, removal of biomass or intensive cultivation may reduce SOC contents even in these systems (Lal, 1989; 1995). Recommendations from studies done by Krishan et.al suggested that the amount of SOC determined using the Walkey and Black method is less than the actual amount contained in the soil. Their study suggested that a general correction factor of 1.42 and clay content specific correction factors of 1.35, 1.45 and 1.81 are used in order to up-scale the total carbon content in the soils into reliable estimates (Krishan et al., 2009). Taking into account the stated correction factors, the amount of SOC assessed in this study increases accordingly but the difference between the two treatments remains the same.

Conclusion

Based on the findings of this study, it can be concluded that Conservation agriculture under suboptimal and optimal input management levels leads to high carbon sequestration compared to conventional tillage system under both management levels. Combining CA and Agroforestry results in more soil carbon sequestration, improves soil chemical, physical and biological properties at farm level. At smallholder farm level, it was observed that benefits of CA after 3 years of practicing are evident, however, the benefits are more pronounced after 7 years of practice. Combining CA with *Ferdhaibia albida* (Musangu) trees increases soil nitrogen and organic matter, however, it also increases soil acidity over time due to nitrification processes that take place in the soil solution as a result of increased soil Nitrogen from the *Ferdhaibia albida* (Musangu) trees. Finally we conclude that conservation agriculture technologies can be used as a climate change mitigation technology which reduces the emission of the greenhouse gas (carbon dioxide) in the atmosphere as evidenced by the higher amounts of carbon sequestered in the CA practices studied.

Recommendations

It is recommended that more work is done on the biological properties of soils under CA/ *Faidherbia Albida* (Musangu trees) fields since soil acidity increases over time due to excess nitrification. There is need to establish the level at which the soil buffering capacity fails as a result of increased acidity.

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