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CARBON SEQUESTRATION IN AGROFORESTRY SYSTEMS BETWEEN CONSERVATION AGRICULTURE AND CONVENTIONAL PRACTICE IN THE ASAL AREA OF MACHAKOS COUNTY, KENYA

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Abstract. *Dryland ecosystems have always been prone to relatively high vegetation and general environmental degradation; translating to changes in soil physical and chemical properties and massive carbon losses. Despite their vast surface area, Carbon sequestration therein still remains low. However, this low carbon means they are less saturated and therefore a tremendous potential therein to sequester more Carbon. Conservation agriculture with trees (CAWT) presents an opportunity to reduce the degradation and enhance the carbon stocks. This study was set to compare the biomass productivity and carbon sequestration potential of agroforestry between conventional and conservation agriculture practice. The study was carried out as part of ongoing experimentation established in short rain (SR) season of 2012 by the World Agroforestry Centre in a trial site at the Agricultural Training Centre (ATC) in Machakos county, Kenya. The trials adopted a split plot arranged in a randomized complete block design with two farming systems (conventional and conservation agriculture) as the main blocks, 7 treatments and three replicates, summing to a total of 42 plots. In the fields, two shrub species (Calliandra calothyrsus Meissn. and Gliricidia sepium Jacq.) were planted in three different spacing (1.5x1 m, 3x1 m, 4.5x1 m) for maize-legume intercrops. Trees were harvested by coppicing, weighed and leaf/twig samples taken for determination of biomass, which was then converted to Carbon using a conversion factor 0.5. The data was statistically analyzed using ANOVA and means separated using LSD at $p < 0.05$. Results showed significant increase in carbon sequestration under conservation agriculture ($p < 0.001$), with a yearly sequestration potential of between 12.8 and 24 Mg C/ha/yr compared to 11.6-23 Mg C/ha/yr for conventional practice. Calliandra also sequestered more carbon than Gliricidia. CAWT is therefore concluded to be a feasible way of increasing carbon stocks in the drylands.*

Keywords: *agroforestry; carbon sequestration; conventional agriculture; conservation agriculture with trees; carbon*

1. Introduction

The large surface area of dry lands {about 6.15 billion hectares according to Lal, (2004) } gives them a more significant carbon sequestration potential (Lal et al., 2018) all over the globe although the plant biomass per unit area of dry lands is low (about 6 kilograms/m^2) compared with many terrestrial ecosystems (about 10–18 kilograms) (UNDP et al., 2009). However, dryland soils being degraded is an implication that they are currently far from saturated with carbon and their potential to sequester carbon may be very high (Farage et al., 2003; Akpa et al., 2016). Alluding from the IPCC Synthesis Report, land degradation, common in the dry lands, is one of the most

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important sources of greenhouse gas (GHG) emissions globally, causing carbon emissions through vegetation destruction and aggravated soil erosion (IPCC, 2007b). These reduce the primary productivity and suppress the potential of the soil to store carbon besides losing the stored organic matter (IPCC, 2007a; Lal, 2011). The world agro ecosystem soils (including semi-arid lands) have lost 25 to 75% (78±12 billion tons) of carbon through historic soil degradation and land use (Lal, 2011). There is need therefore to enhance carbon pool to improve soil quality and cope with climatic changes.

It is estimated that the dryland soils all over the globe contain about 40 times of carbon that is added to the atmosphere (241 pega grams of soil organic carbon in dryland soils (Eswaran et al., 2000) compared to 6.3 pega grams of carbon per year added to the atmosphere in the 1990s (Schimel et al., 2001). These areas therefore form a crucial part of the global carbon cycle and as such the proper management of this pool would aid in reduction in the emission of carbon dioxide to the atmosphere as Lal (2002) explains. It is however of deep concern that land degradation, desertification and environmental degradation have continued accentuating carbon loss (Hassan et al., 2016) in these regions, leading to further emissions (Lal, 2004).This is amidst the estimates of Lal (2001) that the dry lands have the potential to sequester 0.4-0.6 GtC annually upon restoration of their soils and prevention of more degradation. There is thus, in overall, a significant scope of sequestration that lies untapped and which can be done through improved land management practices.

Of importance to the improvement of soil organic pools is the enhancement of the efficiency of water use through prevention of losses due to evapotranspiration, surface run off and retention residue to decrease the soil temperatures (Batiano et al., 2000; Lal, 2004; Semenov et at., 2019). Moreover, there is need to improve soil quality, structure and moisture through conservation tillage (crop rotations, leguminous cover crops, minimum tillage) which will in turn lessen the risks of soil degradation and enhance soil organic pools in the dryland areas (Dalal, 1992; Ryan et al., 1997; Stewart and Robinson, 2000). That dryland carbon sequestration is also affected by biomass carbon sequestration warrants that biomass productivity in these areas is enhanced. Afforestation and agroforestry therefore come in handy in increasing the biomass productivity and thus enhance biomass carbon sequestration. The role of conservation agriculture with trees can therefore not be overlooked when it comes to dryland carbon sequestration.

Conservation agriculture with trees involves the intercropping of trees with crops (agroforestry) alongside practicing minimum tillage, soil cover and crops rotation (conservation agriculture) (Garrity, 2011) The two systems i.e. conservation agriculture and agroforestry have been practiced variedly. Conservation agriculture has been practiced for long especially in Zambia and Malawi where farmers practice minimum tillage and integrate nitrogen fixing trees (*Faidherbia albida* Delile A. Chev.) within the crop fields (Garrity et al., 2010). He continues to elaborate that this is because most small holder farmers farm without mineral fertilizers and as such they fail to produce enough to sell in the market and thus need affordable means of production. Combining conservation agriculture and agroforestry practices maximizes the benefits of both in one system-conservation agriculture with trees (CAWT); which has several benefits as maintaining vegetative cover all year round; improving soil structure and infiltration; production of fodder, food, fuel and fiber; enhancement of carbon storage above and below ground and enhancing greater organic matter in soil surface residues (Makumba et al., 2007). Garrity (2011) note that conservation agriculture with trees sequesters much more carbon than conservation agriculture alone both above and below ground (2.0-4.0 t C $ha^{-1}yr^{-1}$ and 0.2-0.4 t C $ha^{-1}yr^{-1}$, respectively). This is about ten times faster than conservation agriculture only, meaning that conservation agriculture with tree systems have considerable potential for attraction of carbon offset payments that stimulate more carbon sequestration in food crop systems; thus enhancing the environment and small holder livelihoods.

Since carbon losses in dry lands are mainly from soil erosion and vegetation loss, options that reverse these two would be most appropriate in enhancing the soil carbon and increasing the carbon stock (Lal, 2002, 2015). A number of such strategies have been presented in order to enhance the soil carbon of the dry land zones. These are afforestation and tree maintenance, no-till farming, nutrient management, fallow, agroforestry, mulching, organic matter input maximization and the use of legumes (FAO, 2004; Lal, 2004; Lal, 2002). The interest in knowing the carbon sequestration potential of such strategies has thus grown over the recent years and conservation agriculture with trees fits in well since it combines all these strategies.

The inclusion of trees in agricultural landscapes often improves productivity of the farming systems thereby providing relevant opportunities to create carbon sinks (Albrecht & Kandji, 2003; Garrity et al., 2010; Rahman et al., 2016) . In agroforestry systems, abundant litter from pruning biomass and root decay improves the soil physical properties and increase soil organic matter (SOM). Albrecht & Kandji (2003) further explain that establishment of agroforestry on land is currently one of the most promising strategies to raise carbon stocks on currently productive land without compromising food and fiber production. Agroforestry systems have higher potential to sequester carbon than crop fields and lead to a higher efficiency in biomass production and carbon sequestration vis-a-vis monoculture systems (Aertsens et al., 2013)

Conservation agriculture as the other component in conservation agriculture with trees operates on a principle of minimum soil disturbance and raises the SOC concentration both near the surface and in deeper layers compared to conventional tillage, which induces rapid mineralization of organic matter, leading to carbon and nitrogen losses from the soil (Chivenge et al., 2007). Aertsens et al., (2013) noted that reduced tillage has a potential effect on carbon sequestration. Conservation agriculture therefore is among the panaceas to the low carbon in the arid and semi-arid zones amongst other problems of soil fertility and moisture scarcity. Smith et al., (2005) suggest that other management strategies that can be combined with such no-tillage practices to increase the production of crops and contribute to carbon sequestration include increase in organic inputs through manure; mulching; cover crops; improved rotations and agroforestry.

In line with this background therefore, the study was set to 1) determine above and below ground biomass when trees are integrated into farms both conventionally and under conservation agriculture, 2) estimate and compare the quantity of carbon sequestered for conservation (CA) and conventional agriculture (CoA) both with and without trees and 3) determine the carbon sequestration potential for the two farming systems when trees are integrated with crops at different spatial patterns.

2. Materials and Methods

2.1. Study Area

The study was carried out at on-station demonstration plots earlier established by ICRAF at the Machakos Agricultural Training Centre at coordinates E037^{o}14.303ˈ and S 01^{o}32.738ˈin Machakos County (Figure 1). Machakos is an administrative County in Kenya and lies in the sub-humid and semi-arid eastern, Kenya covering an area of about 6,281.4km^2 located 64 km southeast of Nairobi city. It stretches from latitudes 0^0 4´ to 1^0 31' South and longitudes 36° 45' to 37° 45' east and is administratively divided into 12 divisions, 62 locations and 225 sub locations (Jaertzold et al., 2007). The region experiences annual mean temperature and rainfall range of 17.7 to 24.5^{o} C and 700 to 1300 mm respectively. The rainfall is bimodal with long rains (LR) from mid-March to June and short rains (SR) from late October to December hence potential of two annual cropping seasons. The average seasonal average rainfall range is 250mm and 400mm, but highly variable (coefficient of variation range of 45% to 58 %), characterized by prolonged dry-spells, frequent crop failure and high food insecurity (KARI, 1997) The soils are predominantly Luvisols, Ferralsols and Acrisols (FAO, 2009), which are characteristic of low water holding capacity, shallow and sandy, high deficiency in phosphorus and nitrogen and low organic carbon contents of between 0.5 – 1.0% (Gicheru and Ita, 1987; Jaertzold et al., 2007).

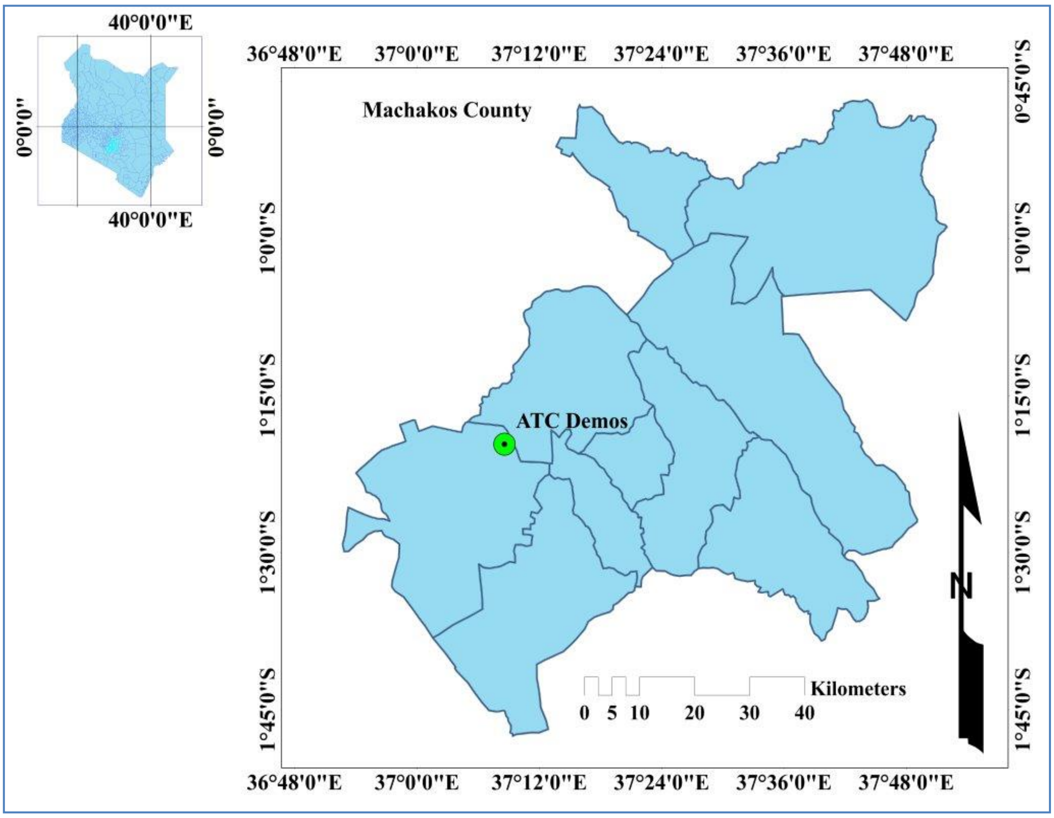

Figure 1: Map of study area-Machakos Agricultural Training Centre

2.2. Experimental Design

The experiment ran from Long Rains 2013 (LR 2013) to Long Rains 2014 (LR 2014). At the inception of the project, researcher managed trials on integration of selected leguminous shrubs (*Grilicidia sepium, Calliandra calothyrsus and Cajanas cajan* (Pigeon pea*))* into a maize-legume intercropping system under CA and Conventional agriculture (henceforth COA) were set-up at the Agricultural Training Centre (ATC) in Machakos. The trials utilized a split plot arranged in randomized block design with two main blocks -CA and COA, each with 7 treatments, replicated thrice. Thus, a total of 21 demonstration plots measuring 12 by 12 m in a randomized complete block design (RCBD) were established on each of the main block, summing up to 42 demonstration plots. *Gliricidia sepium and Calliandra calothyrsus* were integrated at different inter-row spacing of 4.5m, 3.0m or 1.5m; and an intra-row spacing of 1m between individual trees. Pure maize-legume plots without any trees acted as the control treatments in each block. Harvested stovers, haulms and tree biomass were totally removed from conventional plots and fully retained in the conservation agriculture plots.

2.3. Data Collection

Measurements of root collar diameter (RCD), heights and canopy width were taken and the short rotation trees were then harvested through coppicing (cutting the trees at 30 cm from the ground to allow regeneration) at the end of each season from which wood and leaf/twig samples from the harvested trees were taken (three trees per row-3 rows for 4.5m inter-row spacing, 9 rows for 1.5m inter-row spacing and 5 rows for 3.0m inter-row spacing) for the purposes of above ground biomass estimation. The harvesting of trees commenced after two seasons of establishment (in SR 2012) and was done just before planting the crops for each of the subsequent seasons LR 2013, SR 2013 and LR 2014.

The fresh weights of samples were recorded in the field and then oven dried at 70^0 Celsius for 48 hours to obtain the dry mass (Bi et al., 2015; Verwijst et al, 1999). Water content for the samples was calculated as:

$Water\ content = \frac{\text{Fresh weight} - \text{Oven dry weight}}{\text{Fresh weight}}$ and the dry wood mass was determined by multiplying wet mass by (1-Water content) as per the formula by Almulqu et al., (2019).

Total/Overall biomass (TB) was afterwards calculated as:

TB (Mg ha^{-1}) = above ground biomass (AGB) + below ground biomass (BGB) (Saint-André et al., 2005).

Where below ground biomass was estimated at 20% of the above ground biomass - which is widely accepted by researchers (Cairns et al.,1997; Mokany et al., 2006) - and the above ground biomass as the summation of twig biomass and wood biomass. The calculated total biomass was then converted to carbon concentration by multiplying with a carbon conversion factor default value of 0.46 (Hairiah et al., 2011) approximated as 0.5 based on the assumption that about 50% of tree biomass (Mokany et al., 2006) is carbon.

2.4. Statistical Analysis

Analysis of variance (ANOVA) was used to analyze variations in means of biomass produced and carbon sequestered, while Fisher’s least significant difference (LSD) was used to separate the means at $p <= 0.05$. The statistical tests were conducted with the aid of GENSTAT statistical software version 14. For post hoc analysis, multiple comparisons of means were done using both Fisher’s unprotected least significance test and Bonferroni test at 95% confidence interval.

3. Results and Discussion

3.1. Tree Biomass Yield

Above and below ground biomass (AGB and BGB) production was significant among treatments ($p < 0.001$) but not between the two tillage systems. Closely spaced trees produced the highest biomass (Table 1). *Calliandra* at 1.5m inter-row spacing for instance produced the highest leaf biomass of 6.37 Mg ha^{-1} under CA (Table 1) compared to *Gliricidia* at 1.5m under COA which only produced 4.06 Mg ha^{-1} of leaf biomass in LR 2013.In the first season, three treatments

(Calliandra at 3.3m, calliandra at 4.5m and Gliricidia at 1.5m) produced more wood biomass than twig biomass.

The lowest biomass production was realized on Gliricidia at 4.5m treatments under conventional agriculture for season LR 2013. Productivity however generally increased after each test season for most treatments (Table 1) and this can be attributed to the fact that the trees were coppiced at the end of every season, resulting to more shoot development and growth leading to increased biomass in both leaf and wood. The productivity of biomass was high under conservation practice in all the seasons, with the long rain seasons exhibiting the highest, an indication that rainfall and moisture content influenced the production of biomass of the trees.

3.2. Carbon Sequestration between Conservation Agriculture and Conventional Practice

The amount of carbon dioxide encapsulated and stored as structural carbon compound in biomass in trees differed significantly among seasons and among treatments ($p < 0.001$), ranging from 2.4 metric tons in the first season SR 13 to 10.32 metric tons per hectare in the third season LR14 . The season LR14 had the highest of carbon sequestered (mean = 3.882 compared to 2.64 in LR13 and 2.59 in SR13) both for conventional and conservation agriculture, with conservation agriculture recording a high of 8.18 Mg ha^{-1} compared to conventional agriculture's 7.34 Mg ha^{-1}. *Calliandra calothyrsus* was also found to have sequestered more carbon than *Gliricidia sepium* as evidenced in Table 2. Closely spaced trees at 1.5m inter-row spacing had the highest carbon storage. For instance, on average, carbon stored in calliandra at 1.5m > carbon stored in calliandra at 3m > carbon stored in calliandra at 4.5m (7.74 > 7.509 > 5.298).

From Table 2 conservation agriculture practice encapsulated more carbon both above and below ground than conventional farming in all the seasons. This indeed confirms that conservation agriculture serves as a panacea for raising carbon stocks in agricultural lands and this is even elevated when trees are integrated within the conservation agriculture practice. The season SR 2013 however recorded the lowest Carbon encapsulated compared to the immediate preceding LR 2013. This increased in the succeeding season of Long rains 2014.The explanations to the variations are discussed in the succeeding paragraphs of the section. Table 3 shows the mean seasonal carbon sequestration and the potential thereof of each treatment to store carbon per year per hectare.

Table 1. Overall biomass productivity among treatments under conservation and conventional agriculture in Machakos in the seasons LR13, SR13 and LR14

	Season														
	LR 13					SR 13					LR 14				
Treatment*Tillage	**TB**	**WB**	**AGB**	**BGB**	**OB**	**TB**	**WB**	**AGB**	**BGB**	**OB**	**TB**	**WB**	**AGB**	**BGB**	**OB**
Conventional_ Calliandra at 1.5m	9.31	5.09	14.40	2.88	17.28	5.24	5.24	10.48	2.10	12.58	7.50	7.50	15.00	3.00	18
Conservation_ Calliandra at 1.5 m	6.37	5.23	11.60	2.32	13.92	5.26	5.26	10.52	2.10	12.62	7.70	7.70	15.4	3.08	18.48
Conventional_ Calliandra at 3m	4.24	5.06	9.30	1.86	11.16	5.16	5.16	10.32	2.06	12.38	7.50	7.50	15.00	3.00	18
Conservation_ Calliandra at 3m	5.90	6.59	12.49	2.50	14.99	5.39	5.39	10.78	2.16	12.94	8.60	8.60	17.2	3.44	20.64
Conventional_ Calliandra at 4.5m	2.79	3.14	5.93	1.19	7.12	2.18	2.18	4.36	0.87	5.23	5.60	5.60	11.20	2.24	13.44
Conservation_ Calliandra at 4.5m	3.91	5.32	9.23	1.85	11.08	3.33	3.33	6.66	1.33	7.99	7.80	7.80	15.6	3.12	18.72
Conventional_ Gliricidia at 1.5m	4.06	4.03	8.09	1.62	9.71	4.17	4.17	8.34	1.67	10.01	6.50	6.50	13.00	2.60	15.6
Conservation_ Gliricidia at 1.5m	3.86	3.02	6.88	1.38	8.26	5.11	5.11	10.22	2.04	12.26	5.50	5.50	11	2.2	13.2
Conventional_ Gliricidia at 4.5m	2.99	1.07	4.06	0.81	4.87	4.18	4.18	8.36	1.67	10.03	3.50	3.50	7.00	1.40	8.4
Conservation_ Gliricidia at 4.5m	3.94	2.08	6.02	1.20	7.22	3.14	3.14	6.28	1.26	7.54	4.50	4.50	9	1.8	10.8
P	**<.001**	**<.001**	**0.39**	**0.39**	**<.001**	**<.001**	**<.001**	**0.39**	**0.39**	**<.001**	**<.001**	**<.001**	**0.39**	**0.39**	**<.001**
LSD	**1.81**	**1.82**	**03.44**	**0.68**	**4.13**	**1.81**	**1.82**	**3.44**	**0.68**	**4.13**	**1.81**	**1.82**	**3.44**	**0.68**	**4.13**
Treatments															
Calliandra at 1.5 m	7.84	5.16	13	2.6	15.6	5.25	5.25	10.5	2.1	12.6	7.6	7.6	15.2	3.04	18.24
Calliandra at 3 m	5.01	5.83	10.9	2.18	13.07	5.28	5.28	10.55	2.11	12.66	8.05	8.05	16.1	23.22	19.32
Calliandra at 4.5 m	3.35	4.23	7.58	1.56	9.1	2.76	2.76	5.51	1.1	6.61	6.7	6.7	13.4	2.68	16.08
Gliricidia at 1.5 m	3.96	3.53	7.49	1.5	8.98	4.64	4.64	9.28	1.86	11.14	6	6	12	2.4	14.4
Gliricidia at 4.5m	4.47	1.58	5.04	1.01	6.05	3.66	3.66	7.32	1.46	8.78	4	4	8	1.6	9.6
P	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**
LSD	**3.12**	**1.14**	**2.3**	**0.22**	**2.76**	**1.32**	**1.42**	**2.3**	**0.22**	**2.76**	**1.37**	**1.14**	**2.3**	**0.22**	**2.76**
Tillage system															
Conventional	2.34	1.84	4.18	0.84	5.01	2.09	2.09	4.19	0.84	5.02	3.06	3.06	6.12	1.22	7.34
Conservation	2.40	2.22	4.62	0.92	5.55	2.22	2.22	4.45	0.89	5.33	3.41	3.41	6.82	1.37	8.18
p	0.96	0.73	0.85	0.85	0.85	0.91	0.91	0.91	0.91	0.91	0.83	0.83	0.83	0.83	0.83
LSD	2.68	2.3	4.86	0.97	5.84	2.26	2.26	4.52	0.91	5.43	2.1	3.38	6.76	1.35	8.11

TB=Twig biomass; WB=Wood Biomass; AGB= Above ground biomass (TB+WB); BGB= Below ground biomass; OB= Overall biomass (BGB+AGB)

Table 2. Comparison of tree biomass carbon sequestration among treatments between conservation agriculture and conventional practice in Machakos for the seasons LR 2013, SR 2013 and LR 2014

	Carbon sequestered per season per farming system (Mg/ha)					
	LR 2013		SR 2013		LR 2014	
Treatment	CA	COA	CA	COA	CA	COA
Calliandra at 1.5 m	6.96	8.64 (0.67)	6.312	6.288 (0.99)	9.24	9.0 (0.96)
Calliandra at 3 m	7.494	5.58 (0.6)	6.468	6.192 (0.94)	10.32	9.0 (0.76)
Calliandra at 4.5 m	5.538	3.558 (0.51)	3.996	2.616 (0.59)	9.36	6.72 (0.51)
Gliricidia at 1.5 m	4.128	4.854 (0.8)	6.132	5.004 (0.74)	6.6	7.8 (0.75)
Gliricidia at 4.5 m	3.612	2.436 (0.63)	3.768	5.016 (0.67)	5.4	4.2 (0.7)
LSD	2.917	2.917	2.71	2.71	4.05	4.05
P	0.85	0.85	0.91	0.91	0.83	0.83
Mean C	2.77	2.51	2.67	2.51	4.01	3.67

In parenthesis are t-test p values comparing significance of carbon sequestered per treatment between conservation agriculture (CA) and conventional agriculture (COA) for each season

Table 3. Mean seasonal and predicted potential carbon sequestration between conservation and conventional practice potential per year in Machakos during LR 2013, SR 2013 and LR 2014

Treatment	Mean seasonal carbon sequestration		Predicted potential carbon sequestration per year (Mg/ha)	
	CA	COA	CA	COA
Calliandra at 1.5m	7.504 ^{ab}	7.976^{a}	22.512	23.928 (0.84)
Calliandra at 3m	8.094 ^{a}	6.924 ^{ab}	24.282	20.772 (0.6)
Calliandra at 4.5m	6.298^{abc}	4.298 ^{cd}	18.894	12.894 (0.29)
Gliricidia at 1.5m	5.62^{bcd}	5.886^{bcd}	16.86	17.658 (0.89)
Gliricidia at 4.5m	4.26 ^{cd}	3.884 ^{d}	12.78	11.652 (0.82)

Different superscripts show differences in means of treatments between farming systems.CA and COA denote conservation and conventional agriculture, respectively. In parenthesis are t-test p values comparing significance of predicted carbon sequestration for treatments between farming systems.

The encapsulation potential of carbon for conservation agriculture with trees in this study was found to be between 12.8 and 24 tons/Mg per hectare per year when trees are integrated into farming systems at the same time while practicing conservation agriculture. This is consistent with the projections of other researchers, who found the potential carbon sequestration for conservation agriculture to be between 24-40 Mg/ha/year (Lal, 2003) The amount of carbon sequestered is noted to be increasing in parallel to the amount of biomass in the trees as was also noted by Shively et al., (2004) who in their study highlighted that the carbon stored is an increasing function of above and below ground biomass.

According to Sanchez et al., (2006), less moisture leads to stunted plant growth (Mbah & Nwunuji, 2016) and ultimate consequences in lesser production of both fresh and dry matter.

This was evident in the short rain seasons from the study (LR 2013 had total rainfal of 321.1 mm compared to 269.7 mm and 266.2 mm in SR 2013 and LR 2014 respectively.

Nolte et al., (2003) corroborates the findings of this study which show that closely spaced trees yield more biomasss than widely spaced trees .In their study to compare the effects of spatial patterrns of *Calliandra* trees, they found out that those planted in closely spaced clusters of 0.4m × 0.4m yielded more biomass than equidistant pattern. This can be attributed to competition for below and above ground resources (Nair et al., 2009), meaning theat more crowded species will compete for nutrients, water and sunlight and as such don't get enough, rendering low productivity since the plants photosynthesize less and less photosynthesis means that the growth is minimal and less biomass is one of the ultimate outcomes (UNDP, 2009). This abundance of biomass under conservation farming involving no -till and minimum tillage practices has been proven to be greater compared to conventional tillage (Frey et al., 1999; Hackman, 2018) and the present study has shared in the same findings. The production of more wood biomass for three treatments in the first season is also found to be phenomenol with the study of Almulqu et al. (2019) who in their findings realized more stem biomass than leaf biomass and root component biomass.

Biomass production being affected adversely by planting density has also been confirmed by other researchers other than Nolte et al. (2003). In a study to evaluate the effects of different planting densities and cutting frequencies of *Moringa oleifera* plants, Sanchez et al., (2006) found that plant densities of 750,000 plants per hectare produced more biomass than density of 500,000 plants per hectare. This however reduced in the succeeding year where 500,000 plants/ha plant density produced higher biomass. The reduction was attributed to competition for resources which led to slow growth (Ball et al., 2000).This could also explain the cases from the study where inter-row spacing of 3.0m and 4.5 m led to higher biomass production (calliandra at 3.0 m for instance had 14.99 Mg/ha while calliandra at 1.5 m had 13.92 Mg/ha of biomass in LR 13 under conservation agriculture).

More biomass under conservation agriculture compared to traditional tillage practices has been proven both as sole and with the integration. Ngwira et al., (2012) for instance found more biomass production under conservation agriculture intercrop fields followed by sole conservation agriculture, with the least production realized in conventional practice. This has also been corroborated by this study where in all seasons, conventional tillage recorded low biomass production. The higher production of biomass under CA could be attributed to better plant water balance (Soutou et al., 2005) as was caused by improved moisture conditions, meaning better water utilization and more growth.

Conservation tillage practices involving no till, minimum till and ground cover have been found to increase biological diversity of soils both below and above ground (Jaipal et al., 2002; Riley et al., 2005; Roldan et al., 2003; Leskovar et al., 2016), implying that these biologically diverse flora and fauna ultimately contribute to the biomass of the soils (Hobbs, 2007). The general ecology of the soil has been known to improve under conservation agriculture and therefore better ecology, leading to more biomass especially microbial biomass which adds to the total biomass production of the soils therein (Madejón et al., 2007; Nolte et al., 2003). This could have led to increment of below ground biomass and could therefore explain the higher biomass productivity under conservation agriculture with trees in the study, corroborating the findings of previous research.

On the basis of the findings of Kabi & Bareeba (2008) that productivity of biomass is possible to the tune of 45.9 Mg $ha^{-1}yr^{-1}$ at a pruning frequency of four months (an equivalent of one season in this study), the biomass production potential of trees from this study would be threefold in a year (three prunnings of four months). This being the case, the biomass production potential for the treatments in the study per year per hectare are estimated as 45.02 and 47.29 in *Calliandra* at 1.5m; 48.56 and 41.54 in *Calliandra* at 3.0m; 37.79 and 25.79 in *Calliandra* at 4.5m; 33.72 and 35.32 in *Gliricidia* at 1.5 and 25.56 and 23.30 Mg/ha/year in *Gliricidia* at 4.5 m for Conservation and conventional agriculture respectively. The study of Kabi and Bareeba (2008) therefore corroborates the present study, and their estimated potential of 45.9Mg/ha/year is surpassed by *Calliandra* at 3.0m and at 1.5m inter-row spacing (48.56 and 47.28 Mg/ha/yr.).

The principles of conservation agriculture serve as best management practices (BMPs) and adopting such practices have always improved carbon sinks and encapsulation functions of agricultural systems (Rodríguez-Entrena et al., 2014; Hati et al., 2019; Yadav et al., 2019) as was also realized in the study. The two techniques – conservation agriculture and agroforestry have been recommended by other researchers as methods for increasing carbon stocks in woody vegetation of agricultural lands. Niles et al., (2002) enlists adoption of minimum/zero tillage, use of cover crops and green manure and increasing tree cover through agroforestry on arable lands as the ideal solutions through which more carbon can be achieved. These are the principles of conservation agriculture with trees and therefore more Carbon sequestered in tree treatments under conservation agriculture affirms the role of conservation agriculture with trees in raising carbon stocks, which is important in improving soil fertility and thus productivity in the drylands.

4. Conclusions

Carbon sequestration both above and below ground has been found to be highly significant under conservation agriculture and higher in all treatments except *Gliricidia* at 1.5 m where conventional agriculture practice sequestered more carbon than CA. *Calliandra* is seen to sequester more carbon than *Gliricidia*. The carbon encapsulation also increases in parallel with the biomass production of trees, with closely spaced trees at 1.5 m having more biomass, thus more carbon encapsulated. The practice of conservation agriculture with integration of tree component within farms therefore is a feasible way to increase the carbon stocks in the drylands and serve as a mitigation and adaptation strategy for climatic changes. It is worth noting however that extensive research over prolonged periods of time need to be carried out in the dry lands to further monitor the trends of carbon stocks in the dry lands upon injecting smart farming techniques.

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