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Full Length Research Paper

Soil fertility enhancement through conservation agriculture with trees (CAWT) in the arid and semi-arid lands of Eastern Kenya

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Arid and semi-arid lands (ASALs) are prone to relatively high vegetation and general environmental degradation including soils. Conservation agriculture with trees presents an opportunity to reduce such degradation and enhance soil characteristics-therefore redressing dryland challenges of low productivity- despite its low adoption. The study assessed the soil physical and chemical properties differences for conservation agriculture with trees (CAWT) and conventional tillage from a Kenyan dry land context. We used split plot design arranged in randomized complete block with two farming/tillage systems (conventional and conservation agriculture) as the main blocks, 10 treatments and three replicates. Three multipurpose leguminous shrub species (Calliandra calothyrsus, Cajanas cajan and Gliricidia sepium) were planted in three different spacing at project inception in 2012 (1.5x1 m, 3x1 m, 4.5x1 m) for maize-legume intercrops. Soil samples were taken from 0-30 cm depth and analyzed for selected physical and chemical characteristics. The data was statistically analyzed using ANOVA and means separated using LSD at p <0.05. We find significant moisture increment under conservation agriculture with trees with sole conservation agriculture retaining more moisture than sole conventional agriculture without trees (31.56 and 26.54% vol., respectively, p <0.001). Nitrogen, organic carbon, sodium and potassium are also found to be higher under conservation agriculture. Cation exchange capacity was significantly (p = 0.003) higher (14.372 cmolc/kg) in conventional agriculture than in conservation agriculture (12.718cmolc/kg), and strongly correlated with clay content (r=+0.869). High salinity is also depicted for conventional farming as a result of high Electrical conductivity (CA= 0.541 dS m-1 and COA= 0.063 dS m-1). The results show that conservation farming with integration of trees enhances soil properties in ASAL areas.

Key words: Conservation agriculture, multipurpose shrubs, soil fertility, conventional tillage, agroforestry, climate smart agriculture.

INTRODUCTION

Agroforestry systems as sustainable land use alternatives tend to imitate natural system characteristics especially those that are beneficial to soil and enhance the wellbeing thereof (Tornquist et al., 1999; Carsan et al.,

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2014; Coe et al., 2014). In fact, the potential of agroforestry systems as a means of achieving sustainable land use has been promoted since the 1980s (Kursten, 2000; Fischer and Vasseur, 2000) and has since been widely and progressively integrated into good farming practice. These systems either with or without conservation agriculture (CA) therefore have a considerable influence on soil properties. No tillage practices increases soil quality (Denardin et al., 2019), water quality and organic carbon thereby enhancing carbon sequestration to reduce emissions (Ketema and Yimer, 2014; Garland et al., 2011; Choudhury et al., 2014; Lal, 2015). Increased soil organic carbon has also been phenomenal with tree based systems in comparison to sole maize systems without trees (Makumba et al., 2007), emphasizing the importance of tree integration into farms.

High organic matter in agroforestry and conservation tillage systems (Palm et al., 2014; Rodrigues et al., 2015; Benbi et al., 2015; Blanco-Canqui and Ruis, 2018). No-tillage and soil physical environment is also known to improve soil porosity, aggregate and structure, contrary to conventional tillage that brings about discontinuity in pore space between cultivated layer and the sub layers of the soil (Yimer et al., 2008). Low bulk density has also been documented in agroforestry based conservation tillage compared to maize based conventional tillage (1.09 g cm^{-3} and 1.18 g cm^{-3}, respectively) (Ketema and Yimer, 2014). Higher bulk density in conventional farming (Bogunovic et al., 2018) has been contributed to by continuous tillage which causes structural deterioration; mineralization of soil organic matter and compaction due to lower infiltration rates (Yimer et al., 2008; Kalinda et al., 2015). Furthermore, agroforestry based conservation agriculture improves soil moisture content due to less exposure of soil to the direct impacts of sunlight thus a reduced evapotranspiration rate, meaning more of the moisture is able to be maintained within the soil (Ketema and Yimer, 2014; Pittelkow et al., 2015). Minimum tillage and maintenance of permanent soil cover, which are among the two principles of conservation agriculture have also been known to be moderators of the surface conditions of land, leading to improved yields, surface runoff control, increased net benefits as a result of the reduction in the costs of production, moderating soil temperatures as well as enhancing the rooting of crops (Gill et al., 1996; Govaerts et al., 2009; Lal, 2015). The retention of residue on the soil also lead to greater soil organic carbon in the soil surface as compared to removal of such residues which deteriorates the organic matter dynamics thus accentuating soil carbon loss and impacting low fertility (Guto et al., 2012).

MATERIALS AND METHODS

Study area

The study was carried out at on-station demonstration plots earlier established by ICRAF at the Machakos Agricultural Training Centre at coordinates E037º14.303ˈ and S 01º32.738ˈin Machakos County in 2012 (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 6,281.4 km^2 located 64 km southeast of Nairobi city. It stretches from latitudes 0°4´ to 1° 31' South and longitudes 36° 45' to 37° 45' east, administratively, divided into 12 divisions, 62 locations and 225 sub locations (HSK, 2005). The region experiences annual mean temperature and rainfall range of 17.7 to 24.5°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 250 to 400 mm, 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).

Experimental design

The experiment ran from Short rains 2013 (SR 2013) to Short rain 2014 (SR 2014)-encompassing three seasons of four months each (SR2013, LR2014 and SR 2014). At the inception of the project, researcher managed trials for both CA and Conventional agriculture (henceforth COA) where selected multipurpose leguminous shrubs (*Grilicidia sepium, Calliandra calothyrsus and Cajanas cajan* (Pigeon pea*))* were integrated into maize plantations to for a maize-legume intercropping system. The experiment and trials was set-up at the agricultural training centre (ATC) in Machakos. The trials adopted a split plot arranged in a randomized complete block design with two main blocks as CA and COA, each with 10 treatments, replicated three times. Thus, a total of 30 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 60 demonstration plots. *Gliricidia sepium, Calliandra calothyrsus and Cajanas cajan* were integrated at different inter-row spacing of 4.5, 3.0 or 1.5 m; and an intra-row spacing of 1 m between individual shrubs. The shrubs were selected because of their multipurpose usage abilities for the arid lands, the ability to enhance soils, and their ease of coppicing and blending with farm crops without competition. They were panted in 2012 at the inception of the project and were at 6 months when the study commenced. Moreover, the shrubs were coppiced at the beginning of every planting season to 30 cm height to pave way for the crops to grow. Pure maize-legume plots without any shrubs acted as the control treatments in each block. Harvested stovers and haulms were totally removed from conventional plots and fully retained in the conservation agriculture plots. Tillage practices also differed between the conventional and conservation plots in different ways. On the conventional plots, soil was fully disturbed by tractor cultivation and deep weeding. On the conservation agriculture plots however, minimum soil disturbance was observed as follows: Hard pan was broken by the use of a sub-soiler and then ripping was done only on the planting lines, weeds were removed by scrapping and uprooting and land clearance was done by using *Roundup* herbicide. The management on the conservation plots was strictly under the principles of conservation farming namely no till/minimum soil disturbance, crop rotations and soil cover.

Data collection

Two composite soil samples each from five sampling spots within a plot were taken for all the 60 plots at depths of 0-30 cm. Two soil profiles were also dug, one on each block in control treatments and soils sampled for 6 layers at depth intervals of 20 cm within the profiles, that is, 0-20, 20-40, 40-60, 60-80, 80-100 and 100-120 cm. Soil cores were also taken for each layer on the soil profile for

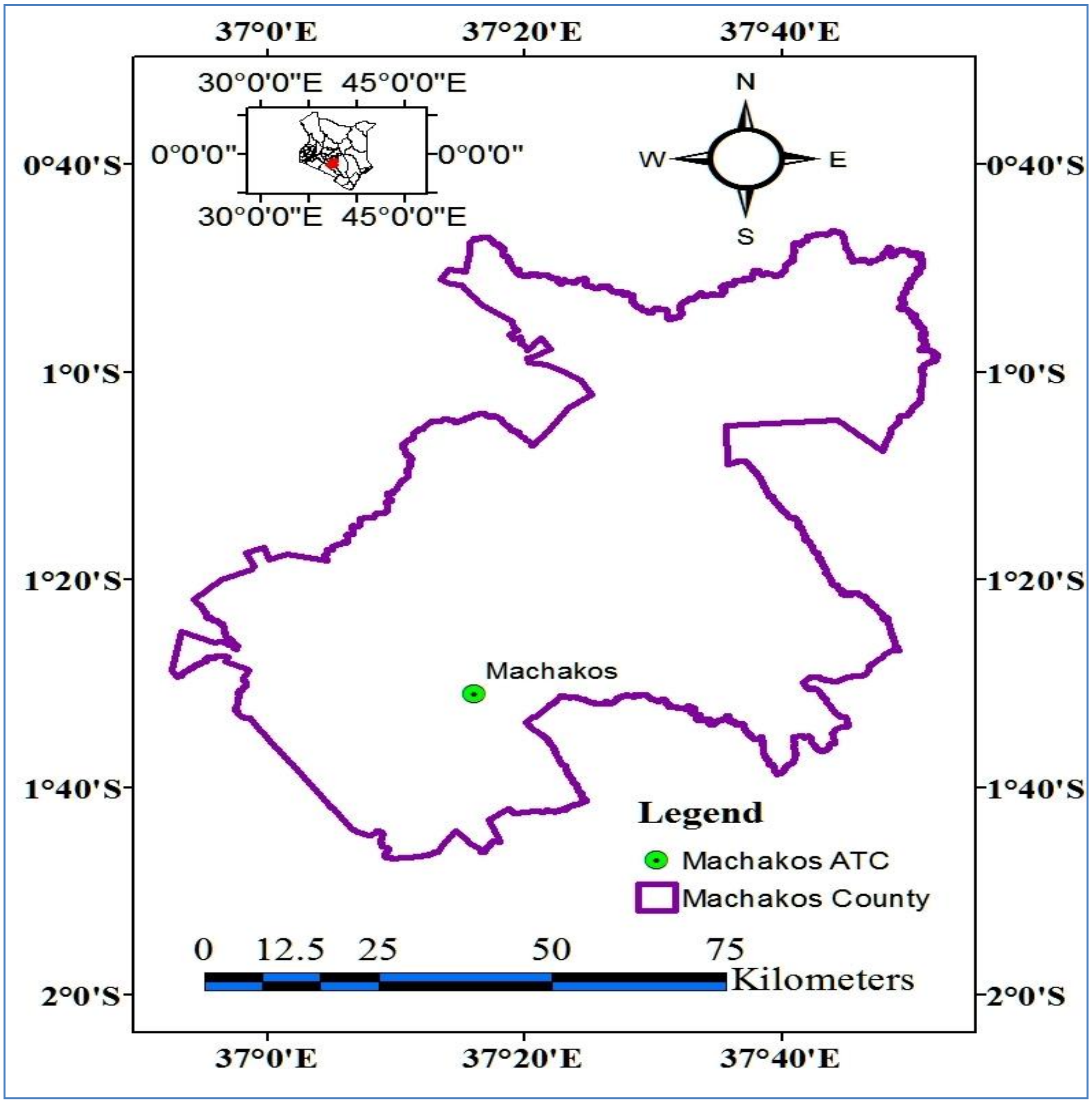

Figure 1. Study location.
Source: Authors 2023

determination of bulk density. The soil samples were taken in SR 2014 and ferried to the World Agroforestry Centre labs where they were processed (dried and sieved) and analysed for the different parameters. On-site calibrated capacitance probes (Delta T PR 2 profile) were installed in each plot and were used to measure soil moisture content. The readings from the probes were made every fortnight, commencing SR 2013 and ending at SR 2014.

Laboratory data analysis

The analyzed parameters included bulk density (BD), soil carbon and nitrogen (CN acidified/organic and total), soil moisture, electrical conductivity (Ecd), pH and cation exchange capacity (CEC). Available phosphorus (m^3.P), exchangeable calcium (ExCa), exchangeable potassium (ExK) exchangeable magnesium (ExMg) and exchangeable sodium (ExNa) were also determined by Mehlich 3 extraction (Mehlich, 1984) and the concentration of the least significance test and Bonferroni test at 95% confidence elements read from a spectrophotometer and flame photometer (for potassium). Soil moisture was determined from the data collected from the installed capacitance probes while analyses of all other soil parameters were done at World Agroforestry Centre (WAC) Plant-Soil spectral Diagnostics laboratories and Crop Nutrition Labs (CROPNUT) based on the standard methods and operation procedures, which have been described by Estefan et al. (2013) and Anderson and Ingram (1993).

Statistical analysis

Analysis of variance (ANOVA) was used to analyze variations in means of soil characteristics, 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. As a post hoc analysis, multiple comparisons of means were done using both Fisher's unprotected interval. Correlations were also done for relationships between various soil parameters including CEC and pH as presented in Table 6.

RESULTS

Soil chemical characteristics

Cation exchange capacity (CEC)

Table 1 shows variations in cation exchange capacity among the treatments for conservation and conventional farming practices. Multiple comparisons using ANOVA Bonferroni test however did not reveal any significant differences in CEC means among the treatments. The minimum CEC achieved was in *Calliandra* at 1.5 inter-row spacing (9.11 $cmol_c$/kg) under conservation agriculture and the maximum in Pigeon peas at 4.5 m inter-row spacing (15.35$cmol_c$/kg) under conventional agriculture. Even though there were no statistical significance in CEC among treatments (p = 0.641), such difference was found between the two tillage/farming systems: Conventional agriculture and conservation agriculture (14.39 and 12.75 $cmol_c$/kg, respectively, p = 0.003). There was no CEC below 5 $cmol_c$/kg (normally considered very low; Landon, 1991) and the soils therefore in both farming systems can be said to have been favorable for plant growth.

Soil pH (water)

The negative logarithm of hydrogen ions concentration among different treatments did not differ significantly in the study. The highest pH was recorded at *Calliandra* at 4.5 m under CA (10.25) while the lowest was at *Calliandra* at 1.5 m under COA (6.93). Conservation agriculture had higher pH than conventional system (7.65 and 7.05 respectively), though the difference was not significant (p= 0.39) (Table 1).

Electrical conductivity (Ecd)

The study showed higher electrical conductivity (meaning higher salinity) in conventional farming system than in conservation agriculture (CA = 0.541 dS m^{-1} and COA = 0.063 dS m^{-1}), but the difference was not significant (p = 0.326) (Table 1). Intervention with trees at different spacing moreover did not significantly affect salinity of the soils both under conservation and conventional farming (p value for treatment means = 0.503), although the electrical conductivity in *Calliandra* at 4.5 m under conservation agriculture was a high of 4.715 dS m^{-1}, an indication of more salts present in the system.

Carbon and nitrogen

Conservation agriculture recorded more nitrogen both total (TN) and organic (ON) compared to conventional practice (TN=0.171% for CA and 0.122% for conventional farming; ON = 0.158% for CA and 0.113% for conventional farming) but were not significant (p = 0.375 and p = 0.373 respectively) as shown in Table 2. Total carbon (TC) was however higher under conventional practice and also not significant (p= 0.07). However, the clay content was found to be strongly positively correlated to the cation exchange capacity (CEC) of the soil (correlation coefficient =0.869) (Table 6), an implication that clay content enhances CEC. This phenomenon of CEC increasing with the amount of clay was evident in the study where the treatment with the lowest (*Calliandra* at 4.5 m under CA) clay content of 57% (data not presented) recorded the lowest CEC of 9.11 $Cmol_c$/kg.

Exchangeable bases

The variations in exchangeable bases are presented in Table 3. Sodium (ExNa) and potassium (ExK) were more available under conservation farming practice compared to conventional farming but were not significantly higher (t (28.02) = 0.96, p = 0.339 and t (28.44) = 0.97, p = 0.337, respectively). On the other hand, exchangeable calcium (ExCa) and magnesium (ExMg) were significantly higher in conventional practice than in conservation practice (t (44.91) = -4.45, p < 0.001 and t (56) = -3.82, p=0.0003, respectively). Mehlich 3 phosphorus (m3.P) was moreover higher under conventional tillage, but was not significant (t (49.51) = -0.13, p = 0.896). Intervention with trees both in CA and conventional agriculture also led to more available nutrients as is exhibited by the generally low availability of nutrients experienced in control treatments. Comparison of means of individual treatments between the two farming system-conventional and conservation agriculture did not reveal any statistical difference except for *Calliandra* at 4.5 m which was significantly higher (p = 0.02) under conventional practice (26.653 mg/kg) than conservation practice (13.417 mg/kg) (Table 3).

Soil physical characteristics

Bulk density (BD)

Bulk density was found not to be different among the treatments nor was it different between farming systems. Mean BD for conservation agriculture was 0.971 g cm^{-3} while that for conventional agriculture was 0.92 g cm^{-3} (p = 0.186). *Calliandra* spaced at 4.5 registered the highest BD of 1.37g cm^{-3} under conservation agriculture and the lowest being 0.877 g cm^{-3} for pigeon peas at 1.5 m under conventional agriculture (Table 4). Comparison of BD down the soil horizons for both farming systems also did not reveal any statistical difference though the grand

Table 1. Comparison of soil chemical properties between farming systems, plant spacing and the interaction of spacing and tillage/farming systems over the study period SR 2013, LR 2014 and SR 2014.

	Soil chemical properties			
Treatment*Tillage/farming system	**pH**	**Ecd (dSm^{-1})**	**CEC ($cmol_c$/kg)**	**BD (g/cm^3)**
Conservation_ Calliandra at 1.5 m	6.957	0.057	12.85	0.956
Conventional_ Calliandra at 1.5 m	6.934	0.062	14.03	0.914
Conservation_ Calliandra at 3.0 m	7.080	0.054	13.97	0.902
Conventional_ Calliandra 3.0 m	7.188	0.047	14.84	0.943
Conservation_ Calliandra at 4.5 m	10.25	4.715	9.11	1.307
Conventional_ Calliandra at 4.5 m	7.130	0.056	14.38	0.917
Conservation_ Control	6.910	0.059	12.32	0.926
Conventional_ Control	7.147	0.056	13.87	0.943
Conservation_ Gliricidia at 1.5 m	6.936	0.062	13.59	0.927
Conventional_ Gliricidia at 1.5 m	7.111	0.114	14.62	0.903
Conservation_ Gliricidia at 3.0 m	6.957	0.076	13.28	0.895
Conventional_ Gliricidia at 3.0 m	7.015	0.056	14.35	0.944
Conservation_ Gliricidia at 4.5 m	7.006	0.052	13.98	0.940
Conventional_ Gliricidia at 4.5 m	7.005	0.060	13.61	0.961
Conservation_ Pigeon pea at 1.5 m	7.051	0.049	14.01	0.969
Conventional_ Pigeon pea at 1.5 m	7.124	0.058	13.76	0.877
Conservation_ Pigeon pea at 3 m	6.913	0.057	12.23	0.944
Conservation_ Pigeon pea at 3 m	6.994	0.054	15.04	0.921
Conservation_ Pigeon pea at 4.5 m	6.968	0.061	12.86	0.927
Conservation_ Pigeon pea at 4.5 m	6.973	0.061	15.35	0.882
LSD	5.323	3.754	2.45	0.243
P	0.518	0.499	0.641	0.340
Treatments				
Calliandra at 1.5 m	6.96	0.060	13.44	0.935
Calliandra at 3 m	7.134	0.051	14.41	0.923
Calliandra at 4.5 m	10.35	2.386	11.75	1.112
Control	7.029	0.574	13.10	0.935
Gliricidia at 1.5 m	7.023	0.088	14.10	0.915
Gliricidia at 3 m	6.896	0.066	13.81	0.920
Gliricidia at 4.5 m	7.005	0.056	13.79	0.950
Pigeon pea at 1.5 m	7.087	0.054	13.90	0.923
Pigeon pea at 3 m	6.953	0.055	13.63	0.933
Pigeon pea at 4.5 m	6.970	0.061	14.11	0.905
LSD	3.604	2.541	2.446	0.408
P	0.479	0.503	0.641	0.172
Tillage system				
Conservation Agriculture	7.65	0.541	12.718	0.971
Conventional Agriculture	7.05	0.063	14.372	0.92
LSD	1.371	0.966	1.045	0.077
P	0.39	0.326	***0.003**	0.186

*Significant at p<=0.05.
Source: Authors 2023

mean BD for conventional practice was slightly higher than conservation agriculture (0.945 and 0.88 g cm^{-3} respectively as shown in Table 4.

Soil moisture

Soil moisture content retention was found to be generally

Table 2. Total and organic carbon and nitrogen differences between conservation and conservation tillage, among plant spacing and the interactions of tillage and spacing in the period SR 2013 , LR 2014 and SR 2014.

Carbon and nitrogen (total and organic)				
Treatment*Tillage	**TN**	**TC**	**ON**	**OC**
Conservation_ Calliandra at 1.5 m	0.12	1.64	0.11	1.49
Conventional_ Calliandra at 1.5 m	0.12	1.77	0.11	1.62
Conservation_ Calliandra at 3.0 m	0.12	1.60	0.11	1.48
Conventional_ Calliandra 3.0 m	0.12	1.53	0.11	1.42
Conservation_ Calliandra at 4.5 m	0.64	1.07	0.58	25.81
Conventional_ Calliandra at 4.5 m	0.13	1.71	0.12	1.56
Conservation_ Control	0.12	1.65	0.11	1.50
Conventional_ Control	0.12	1.59	0.11	1.42
Conservation_ Gliricidia at 1.5 m	0.12	1.74	0.11	1.58
Conventional_ Gliricidia at 1.5 m	0.13	1.77	0.12	1.87
Conservation_ Gliricidia at 3.0 m	0.12	1.64	0.11	1.49
Conventional_ Gliricidia at 3.0 m	0.12	1.69	0.11	1.53
Conservation_ Gliricidia at 4.5 m	0.12	1.66	0.11	1.51
Conventional_ Gliricidia at 4.5 m	0.11	1.65	0.11	1.48
Conservation_ Pigeon pea at 1.5 m	0.11	1.59	0.11	1.46
Conventional_ Pigeon pea at 1.5 m	0.11	1.51	0.11	1.36
Conservation_ Pigeon pea at 3 m	0.11	1.60	0.11	1.45
Conservation_ Pigeon pea at 3 m	0.13	1.75	0.11	1.59
Conservation_ Pigeon pea at 4.5 m	0.11	1.48	0.10	1.31
Conservation_ Pigeon pea at 4.5 m	0.13	1.85	0.12	1.70
LSD	3.564	0.408	0.321	16.48
P	0.516	0.269	0.502	0.501
Treatments				
Calliandra at 1.5 m	0.12	1.70	0.11	1.55
Calliandra at 3m	0.02	1.57	0.11	1.45
Calliandra at 4.5m	0.38	1.39	0.35	13.67 [a]
Control	0.12	1.62	0.11	1.47
Gliricidia at 1.5 m	0.13	1.76	0.12	1.73
Gliricidia at 3 m	0.02	1.66	0.11	1.51
Gliricidia at 4.5 m	0.12	1.66	0.11	1.50
Pigeon pea at 1.5 m	0.11	1.55	0.11	1.41
Pigeon pea at 3 m	0.12	1.68	0.11	1.52
Pigeon pea at 4.5 m	0.12	1.67	0.11	1.50
LSD	0.252	0.29	0.23	11.66
P	0.492	0.393	0.489	0.501
Tillage system				
Conservation Agriculture	0.171	1.567	0.158	3.991
Conventional Agriculture	0.122	1.687	0.113	1.560
LSD	0.109	0.131	0.097	5.051
P	0.375	0.07	0.373	0.349

TN=Total Nitrogen, TC=Total Carbon, OC=Organic carbon, ON=Organic Nitrogen.
Source: Authors 2023

higher in conservation agriculture (CA) trials compared to conventional agriculture (COA) in all the three seasons as shown in Figure 2. The differences between the moisture contents for conservation and conventional agriculture were found to be statistically significant ($p < 0.001$) (Table 5). Conservation farming recorded grand

Table 3. Exchangeable bases availability among treatments, between tillage/ farming systems and among the interactions of tillage and plant spacing over the study period SR 2013, LR 2014 and SR 2014.

Treatment*Tillage	Exchangeable bases				
	m3.P (mg /kg)	**ExNa ($cmol_c$/kg)**	**ExCa ($cmol_c$/kg)**	**ExMg ($cmol_c$/kg)**	**ExK ($cmol_c$/kg)**
Conservation_ Calliandra at 1.5 m	26.811	0.115	7.094	2.501	1.904
Conventional_ Calliandra at 1.5 m	25.828	0.113	7.925	2.624	1.942
Conservation_ Calliandra at 3.0 m	22.842	0.150	7.817	2.633	1.977
Conventional_ Calliandra 3.0 m	20.840	0.171	9.093	2.912	1.772
Conservation_ Calliandra at 4.5 m	13.417	2.752	6.205	2.440	5.147
Conventional_ Calliandra at 4.5 m	26.653	0.142	8.310	2.564	2.088
Conservation_ Control	27.494	0.116	6.661	2.398	1.881
Conventional_ Control	23.307	0.130	8.473	2.957	1.720
Conservation_ Gliricidia at 1.5 m	25.315	0.121	7.441	2.550	2.019
Conventional_ Gliricidia at 1.5 m	26.157	0.154	8.466	2.731	2.129
Conservation_ Gliricidia at 3.0 m	28.816	0.144	6.858	2.356	2.247
Conventional_ Gliricidia at 3.0 m	23.228	0.134	8.201	2.766	1.897
Conservation_ Gliricidia at 4.5 m	25.636	0.141	7.946	2.532	1.897
Conventional_ Gliricidia at 4.5 m	27.017	0.118	7.869	2.685	1.894
Conservation_ Pigeon pea at 1.5 m	25.137	0.151	8.393	2.697	1.874
Conventional_ Pigeon pea at 1.5 m	22.810	0.147	7.931	2.541	1.957
Conservation_ Pigeon pea at 3 m	26.103	0.120	6.702	2.283	1.822
Conservation_ Pigeon pea at 3 m	24.333	0.142	8.639	2.793	1.992
Conservation_ Pigeon pea at 4.5 m	22.237	0.109	7.036	2.631	1.965
Conservation_ Pigeon pea at 4.5 m	25.062	0.138	8.803	2.983	2.028
LSD	8.701	1.77	1.863	0.466	2.281
P	0.062	0.497	0.571	0.572	0.629
Treatments					
Calliandra at 1.5 m	26.32	0.114	7.509	2.562	1.923
Calliandra at 3 m	21.84	0.161	8.455	2.773	1.875
Calliandra at 4.5 m	20.03	1.447	7.257	2.502	3.618
Control	25.40	0.123	7.567	2.677	1.801
Gliricidia at 1.5 m	25.74	1.138	7.953	2.640	2.074
Gliricidia at 3 m	26.02	0.139	7.529	2.561	2.072
Gliricidia at 4.5 m	26.33	0.129	7.907	2.609	1.895
Pigeon pea at 1.5 m	23.97	0.149	8.167	2.619	1.915
Pigeon pea at 3 m	25.22	0.131	7.670	2.538	1.907
Pigeon pea at 4.5 m	26.35	0.124	7.919	2.807	1.996
LSD	6.16	1.252	1.318	0.33	1.613
P	0.482	0.491	0.835	0.607	0.489
Tillage system					
Conservation Agriculture	24.467^a	0.399^a	$\mathbf{7.136^b}$	$\mathbf{2.483^b}$	2.282^a
Conventional Agriculture	24.651^a	0.138^a	$\mathbf{8.346^a}$	$\mathbf{2.75^a}$	1.948^a
LSD	2.804	0.543	0.545	0.134	0.691
P	0.896	0.339	***<0.001**	***0.0003**	0.337

Same superscript letters denote no significant differences in means.
Source: Authors 2023

mean moisture retention of 31.56% vol. while conventional agriculture had 26.24% vol. Reduction of inter-row tree spacing increased moisture retention, for instance interventions with *Calliandra* at 1.5 m showed high moisture rates under CA at an average of 40.25% vol. compared to the same treatment under conservation

Table 4. Bulk density (g cm^{-3}) down the soil profile between conservation agriculture (CA) and conventional agriculture (COA) over study period SR 2013, LR 2014 and SR 2014.

Profile depth	Farming system		t-test; p values
	CA	**COA**	
0-20 cm	0.937	0.985	0.97
20-40 cm	0.880	0.953	0.96
40-60 cm	0.836	0.955	0.93
60-80 cm	0.870	0.947	0.96
80-100 cm	0.857	0.982	0.93
100-120 cm	0.902	0.849	0.97
Mean BD	0.88^a	0.945^a	
p	**0.603**	**0.603**	
SED	**0.458**	**0.458**	

Values with same superscript letters are not statistically different. CA and COA denotes conservation agriculture and conventional agriculture respectively.
Source: Authors 2023

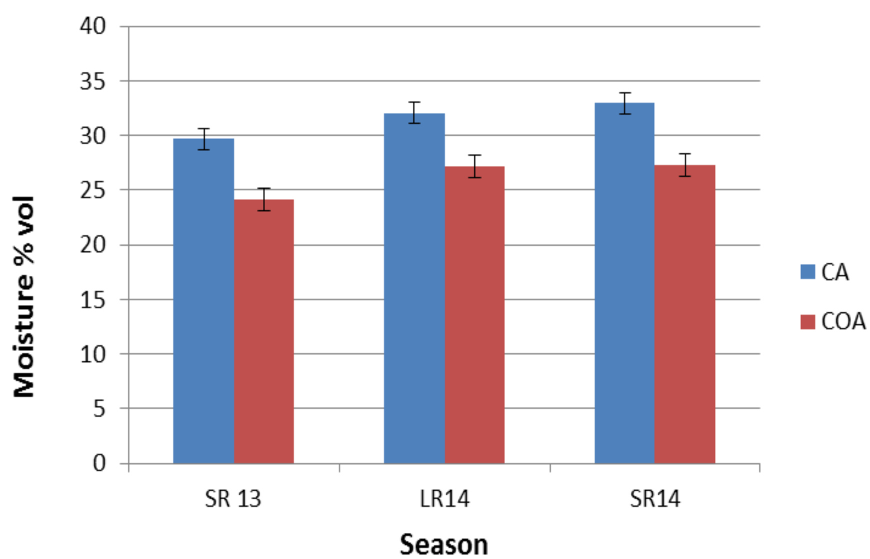

Figure 2. Comparison of soil moisture content between conservation agriculture and conventional agriculture for seasons SR 2013, LR 2014 and SR 2014.
Source: Authors 2023

farming (Table 5). Moisture by volume appeared to consistently increase after each season (Table 5) and was significant among seasons (p = 0.03) and treatments (p< 0.001).

Intervention with trees increased soil moisture content in both farming systems for all the test seasons with trees closely spaced maintaining more soil moisture than those widely spaced (*Calliandra* at 1.5 m had a grand mean moisture retention of 34.96% vol. compared to *Calliandra* at 4.5 m which had 31.99% vol.) over the three seasons as shown in the Table 5. Control treatments with no trees incorporated registered among the lowest soil moisture retention in both farming systems.

DISCUSSION

Cation exchange capacity being the total negative charge on soil is a good measure of the ability of a soil to retain and supply nutrients to a crop since the soil will be able to hold more positively charged ions for timely release of the exchangeable nutrients to crops. Landon (1991) considers CEC of below 5 centimoles of charge per kilogram to be very low and this would mean fewer nutrients available. This was however not the case in this study since most CEC levels surpassed the critical value of below 5 $Cmol_c$ /kg. Jones and Olson-Rutz (2016) highlighted that CEC of above 15 $Cmol_c$ /kg to be most appropriate generally. The

Table 5. Mean moisture content retention during the SR 2013, LR 2014 and SR 2014 seasons.

Treatment	Mean treatment moisture retention % vol.	Retention per season (% vol.)			Retention per farming system (% vol.)	
		SR 2013	LR 2014	SR 2014	CA	COA
Calliandra at 1.5 m	34.96[a]	32.73[abcd]	35.73[ab]	36.42[a]	40.25[a]	29.67[cd]
Calliandra at 3 m	28.52[bcd]	26.96[cdef]	28.96[abcdef]	29.64[abcdef]	31.21[c]	25.83[ef]
Calliandra at 4.5 m	31.99[ab]	28.6[abcdef]	34.6[abc]	32.78[abcd]	31.66[c]	32.63[c]
Gliricidia at 1.5 m	29.24[bcd]	27.68[cdef]	29.68[abcdef]	30.37[abcdef]	32.23[c]	26.65[ef]
Gliricidia at 3 m	32.67[ab]	30.17[abcdef]	33.57[abc]	34.26[abc]	37.64[ab]	27.7[def]
Gliricidia at 4.5 m	29.43[bc]	27.8[bcdef]	29.9[abcdef]	30.58[abcde]	36.96[b]	21.9[gh]
pigeon pea at 1.5 m	26.6[cd]	24.38[ef]	27.38[cdef]	28.06[bcdef]	27.91[de]	27.87[ef]
pigeon pea at 3 m	26.54[cd]	25.48[def]	26.72[cdef]	27.41[cdef]	29.45[ef]	27.62[def]
pigeon pea at 4.5 m	24.17[d]	22.61[f]	24.61[ef]	25.29[def]	27.87[def]	20.47[h]
control	24.87[cd]	22.97[ef]	24.97[def]	26.66[cdef]	24.75[fg]	24.99[efg]
Mean	**28.9**	**26.94**	**29.61**	**30.15**	**31.56**	**26.24**
p	**<0.001**	**0.031**	**0.031**	**0.031**	**<0.001**	**<0.001**
LSD	**5.188**	**2.513**	**2.513**	**2.513**	**0.995**	**0.995**

Values with same superscript letters are not different from each other. CA and COA denotes conservation agriculture and conventional agriculture respectively.
Source: Authors 2023

Table 6. Correlation coefficients of soil parameters.

C_E_C	1	-				
Clay	2	0.8687	-			
PH	3	-0.8258	-0.9590	-		
Total carbon	4	0.8286	0.7224	-0.8040	-	
Total nitrogen	5	-0.8216	-0.9679	0.9970	-0.7673	-
Organic carbon	6	-0.8348	-0.9683	0.9983	-0.7869	0.9993
		1	2	3	4	5

Source: Authors 2023

findings of this study are not far from this observation since most of the treatments recorded CEC of close to 15 $Cmol_c$/ kg with two treatments recording more than 15 under conventional farming.

Cation exchange capacity has been known to be affected by a number of factors. Schwab et al. (2015) found it to be affected by soil pH where low pH leads to high CEC. This has also been seen from the findings of this study where CEC was negatively correlated with pH (r = -0.826). Organic carbon has also been known to lead to an increase in the negative charge of soil with coarser textures leading to its reduction (Jones and Olson-Rutz, 2016) and indeed the treatment with the highest organic carbon (Pigeon peas at 4.5 m under conventional practice, with OC of 1.7%), which also was coarser with clay percentage of 76% (data not presented) was found to exhibit the highest CEC. There being no critical levels in the amounts of negative charge among the treatments from the study, it can be deduced therefore that most nutrients would be available to crops upon better management practices in the context of drylands.

Different researchers have found conflicting results on the effects of tillage on pH. Some like Rahman et al. (2008) found it to be lower in no-till systems (a form of CA) than in conventional tillage and attributed this to accumulation of organic matter and elevation in electrolyte concentration which in turn reduces pH while others like Lal (1997) on the other hand found it to be conversely high in no-till systems compared to conventional systems. The results from this study are therefore no different from those of other researchers due to noted variations on pH among the different treatments under conservation farming and conventional practice. Busari et al. (2015) concluded that tillage may not directly affect soil pH but rather the effects will be dependent on a number of factors as the management practices employed, soil types and climatic conditions eminent. This is also in line with the study of Rasmussen (1999) who showed that indeed tillage has no effect on the pH of soils. However, even if the pH was not affected by tillage, it was noted to be very crucial in effectuation of CEC, the correlation of which is negatively strong (coefficient = -0.8258), where higher pH translates to very low CEC and vice versa. This is also reinforced by the study of Schwab et al. (2015) in which they ascribed to low CEC in their samples to low pH.

Electrical conductivity being a measure of the salinity of soil is a vital indicator of soil health, affecting crop yields, crop suitability, plant nutrient availability, and activity of soil microorganisms which influence key soil processes including the emission of greenhouse gases such as methane, carbon dioxide and nitrogen oxides (Adviento-Borbe et al., 2006). The high EC under conventional agriculture as was found in this study could be due to low organic matter and low soil moisture in the conventional practice as compared to conservation practice, which is in agreement with Tejada et al. (2006) in their research that found amended treatments with organic matter to be low in salts compared to controls. Leaving residue on the surface therefore meant maintained soil moisture through limiting evaporation (Govaerts et al., 2006; Rockstrom et al., 2009), and therefore allowed more rainfall effectiveness in leaching the salts.

Minimum tillage and organic matter provision through continuous soil cover combined with soil architecture facilitates capture and infiltration of rainwater (Johnston et al., 2002; Liebig et al., 2004; Lichter et al., 2008) reducing amount of salts, explaining the low EC under conservation agriculture with trees, thus confirming the study of these researchers. In contrast, where conventional tillage is carried, the fields always exhibit compaction and resistance to penetration, which has an effect of hindering the water movement throughout the profile, causing a deficit of moisture and increase of salts (Porta et al., 1999; Fuentes et al., 2009). This can therefore substantiate the higher amount of salts which were realized under conventional agriculture in this study.

The bulk density results from this study tally with those of Mloza-Banda et al. (2016) who in a study to compare tillage effects of conservation agriculture and ridge tillage did not find any significance though conservation agriculture had lower bulk density than ridge tillage (1.49-1.58 and 1.53-1.59 Mg/m^3 respectively). Comparatively to the study of Mloza-Banda et al. (2016), the study found lower bulk density at the top most soil layer (0-20 cm) in conservation agriculture than in conventional practice (0.937 and 0.985 g cm^{-3}, respectively). This can be attributed to cultivation induced compaction in the conventional practice and also as a result of breaking of soil aggregates as was noted by Murty et al. (2002) when forest soils were converted to agriculture through cultivation.

Tillage has also been shown to largely influence the pore size distribution of soils, with soils under conventional tillage/agriculture generally exhibiting lower bulk density within the plough layer than under no tillage but this can vary due to soil type, antecedent soil properties, type of mulch, climate and land use (Lipiec et al., 2006). The use of mulch and crop residue under conservation agriculture has been found to lower bulk density by some researchers (Unger and Jones, 1998; Oliveira and Merwin, 2001) while others have concluded that it leads to increased bulk density in the soils (Bottenberg et al., 1999). The variations in bulk density between the two tested farming systems: conservation agriculture and conventional agriculture in this study are therefore substantiated by the different findings of previous researchers.

Sodium and potassium being high under conservation agriculture compared to the conventional farming can be attributed to the fact that the tillage layer of soil is less destroyed and also because there was residue (maize, legume and tree biomass) which was returned back to the soil during the experimentation period in conservation agriculture and totally removed in conventional practice (Tan et al., 2015). Taking back biomass to the soil therefore could have led to the enrichment of the nutrients and thus explains the higher levels of N, K and Na under conservation agriculture than conventional farming. The importance of agroforestry and conservation agriculture (thus CAWT) in building healthy fertile soils is therefore once again stressed in this study as it was in Garrity et al. (2010). The dynamics under which conventional tillage significantly enhanced levels of magnesium and calcium and causing higher extractable phosphorus amounts are however not well understood in this study. It is worth mentioning however that the three seasons may not have been sufficient for a more robust change in the soil properties between conventional and conservation agriculture with trees practices.

The high organic carbon and nitrogen in conservation farming over conventional practice can be attributed to minimum soil disturbance which lessens the destruction of soil structure and aggregate exposure. This in turn means that less of the inherent organic matter is decomposed and therefore the ultimate result is more organic carbon and total nitrogen maintained in the soil compared to conventional practice where the opposite is true (Xue et al., 2015; Małecka et al., 2012).

Control treatments exhibited among the lowest values of carbon and nitrogen both total and organic and this therefore shows that interventions with trees enhanced carbon and nitrogen availability, further stressing the importance of incorporation of trees into croplands in improvement of soil carbon and nitrogen among other soil physical and chemical properties (Nair et al., 2009). Owing to the fact that nitrogen is one of the major nutrient inhibiting plant growth in dryland ecosystems (Sainju et al., 2009), the high values obtained under conservation agriculture in this study is sufficient affirmation of the capability of the system to enhance nitrogen in the dryland context. The less carbon obtained under conventional agriculture can also be ascribed to soil disturbance through tillage which has been documented in literature to be the sole cause of persistent soil carbon losses (Baker et al., 2007; Reicosky, 2003). Lal (2004) narrates that the soils of drylands generally have organic carbon of less than 0.5% and that this may increase in proportion to the amounts of clay. This was corroborated by this study since there was no such value of less than 0.5 and the clay content was also noted to be higher than sand and silt.

The high moisture content experienced under conservation agriculture could be due to the adequate vegetative soil cover provided by the tree component integration into the farms and therefore evapotranspiration was reduced in these treatments, and more moisture retained within the soil. This was also noted by Ketema and Yimer (2014) who argued that agroforestry practices improved soil moisture. This also applies to conventional agriculture treatments with trees as compared to the control treatments. This moreover tallies with the research of Corbeels et al. (2014) who indeed reported that CA significantly increases soil water availability and thus higher moisture content. Thierfelder et al. (2013) also in their comparison on the effects of conservation agriculture on soils realized a higher moisture and infiltration in conservation agriculture treatments vis a vis the conventional treatments, and attributed this to the effects of mulch retention and no tillage which in turn increased the organic matter content of the soils therein besides reducing evaporation rates from the soil. Thierfelder and Wall (2009) also in a study in Zimbabwe recorded higher moisture retention in most conservation agriculture treatments throughout the experimentation season. Rockstrom et al. (2009) have also proved that minimum disturbance with increased soil cover prevents direct evaporation and thus the higher moisture contents under conservation agriculture. Govaerts et al. (2006) also concluded that the use of mulch in conservation agriculture leads to higher infiltration and favorable moisture dynamics which in turn improve farm productivity. This is reiterated by the findings of this study.

Conclusion

Greater improvement was found in measured soil physical and chemical properties under conservation agriculture compared to conventional farming practice. Conservation agriculture significantly increases soil moisture content conventional practice and this increased after every season. Incorporation of trees into farming systems has proved to significantly improve moisture retention in the soil with trees closely spaced at 1.5 m inter-row spacing having high moisture retention than distantly spaced at 3.0 and 4.5 m. Practicing sole conservation agriculture without trees also significantly enhances soil moisture compared to the conventional agriculture practice without trees. Convention farming leads to high bulk density down the profile and causes significantly high salinity as evidenced by the high electrical conductivity in this study. Potassium, sodium, nitrogen and organic carbon also become more available under conservation agriculture practice. The study adduce therefore, as has been evidenced by the results, that integration of multipurpose leguminous shrubs into farms in deed enhances soil fertility, concluding that the importance of conservation agriculture with trees in soil fertility enhancement is indubitable.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Adviento-Borbe MAA, Doran JW, Drijber A, Dobermann A (2006). Soil electrical conductivity and water content affect nitrous oxide and carbon dioxide emissions in intensively managed soils. Journal of Environmental Quality 35(6):1999-2010.

Anderson JM, Ingram JSI (Eds) (1993).Tropical soil biology and fertility: A handbook of Methods, Second Edition. Wallingford: C.A.B International Wallingford, Oxfordshire 221:62-65.

Baker JM, Ochsner ET, Venterea RT, Griffis TJ (2007).Tillage and soil carbon sequestration-What do we really know? Agriculture, Ecosystems and Environment 118(1-4):1-5.

Benbi DK, Brar K, Toor AS, Singh P (2015). Total and labile pools of soil organic carbon in cultivated and undisturbed soils in northern India. Geoderma 237:149-158.

Blanco-Canqui H, Ruis SJ (2018). No-tillage and soil physical environment. Geoderma 326:164-200.

Bottenberg H, Masiunas J, Eastman C (1999). Strip tillage reduces yield loss of snapbean planted in rye mulch. Hor Technology 9(2):235-240.

Bogunovic I, Pereira P, Kisic I, Sajko K, Sraka M (2018). Tillage management impacts on soil compaction, erosion and crop yield in Stagnosols (Croatia). Catena 160:376-384.

Busari MA, Kukal SS, Kaur A, Bhatt R, Dulazi AA (2015).Conservation tillage impacts on soil, crop and the environment. International Soil and Water Conservation Research 3(2):119-129.

Carsan S, Stroebel A, Dawson I, Kindt R, Mbow C, Mowo J, Jamnadass R (2014).Can agroforestry option values improve the functioning of drivers of agricultural intensification in Africa? Current Opinion in Environmental Sustainability 6:35-40.

Choudhury SG, Srivastava S, Singh R, Chaudhari SK, Sharma DK, Singh SK, Sarkar D (2014). Tillage and residue management effects on soil aggregation, organic carbon dynamics and yield attribute in rice–wheat cropping system under reclaimed sodic soil. Soil and Tillage Research 136:76-83.

Coe R, Sinclair F, Barrios E (2014). Scaling up agroforestry requires

research 'in'rather than 'for'development. Current Opinion in Environmental Sustainability 6:73-77.
Corbeels M, Jan de Graaff, Ndah TH, Penot E, Baudron F, Naudin K, Andrieu N, Chirat G, Schuler J, Nyagumbo I, Rusinamhodzi L, Traore K, Mzoba DH, Adolwa IS (2014).Understanding the impact and adoption of conservation agriculture in Africa: A multi-scale analysis. Agriculture, Ecosystems and Environment 187:155-170.
Denardin LG, Carmona FD, Veloso MG, Martins AP, de Freitas TF, Carlos FS, Marcolin É, Camargo FA, Anghinoni I (2019). No-tillage increases irrigated rice yield through soil quality improvement along time. Soil and Tillage Research 186:64-69.
Estefan G, Sommer R, Ryan J (2013). Methods of Soil, Plant, and Water Analysis: A manual for the West Asia and North Africa region (Third Edition). Lebanon: International Center for Agricultural Research in the Dry Areas.
Fischer A, Vasseur L (2000). The crisis in shifting cultivation practices and the promise of agroforestry: a review of the Panamanian experience. Biodiversity and conservation 9(6):739-756.
Fuentes M, Govaerts B, De León F, Hidalgo C, Dendooven L, Sayre KD, Etchevers J (2009). Fourteen years of applying zero and conventional tillage, crop rotation and residue management systems and its effect on physical and chemical soil quality. European Journal of Agronomy 30(3):228-237.
Garrity DP, Akinnifesi FK, Ajayi OC, Weldesemayat SG, Mowo JG, Kalinganire A, Larwanou M, Bayala J (2010). Evergreen Agriculture: a robust approach to sustainable food security in Africa. Springer, Food security 2:197-214.
Garland GM, Suddick E, Burger M, Horwath WR, Six J (2011). Direct N_2O emissions following transition from conventional till to no-till in a cover cropped Mediterranean vineyard (Vitis vinifera). Agriculture, Ecosystems and Environment 141(1):234-239.
Gill KS, PR Gajri, MR Chaudhary, Singh B (1996). Tillage, mulch and irrigation effects on corn (*Zea mays* L.) in relation to evaporative demand. Soil and Tillage Research 39(3-4):213-227.
Govaerts B, Mezzalama M, Sayre KD, Crossa J, Nicol JM, Deckers J (2006). Long-term consequences of tillage, residue management, and crop rotation on maize/wheat root rot and nematode populations in subtropical highlands. Applied Soil Ecology 32(3):305-315.
Govaerts B, Verhulst N, A Castellanos-Navarrete, KD Sayre, J Dixon, Dendooven L (2009). Conservation agriculture and soil carbon sequestration: Between myth and farmer reality. Critical Reviews in Plant Sciences 28:97-122.
Guto SN, Pypers P, Vanlauwe B, de Ridder N, Giller KE (2012). Socio-ecological Niches for Minimum Tillage and Crop-residue Retention in Continuous Maize Cropping Systems in Smallholder Farms of Central Kenya. Agronomy Journal 104(1):188-198.
HSK consulting limited (2005). Machakos District Strategic Plan. HSK.
Johnston AM, Clayton GW, Wall PC, Sayre KD (2002). Sustainable cropping systems for semiarid regions. Paper Presented at the International Conference on Environmentally Sustainable Agriculture for Dry Areas for the 2nd Millennium, September 15-19, 2002, Shijiazhuang, Hebei Province, P.R.C.
Jones C, Olson-Rrutz K (2016). Plant Nutrition and Soil Fertility. Nutrient Management Module 2: Montana State University.
Kalinda C, Mburu D, Ngamau K, Chisala LA, Zulu D, Kihoro J (2015). Short Term Leguminous Trees-Tillage Interactions and Their Effect on Soil-Water Content in a Semi-Arid Agroforestry Parkland. Open Journal of Forestry 5(7):668.
Kenya Agricultural Research Institute (KARI) (1997). Annual Report 1995. Agris 1:209.
Ketema H, Yimer F (2014). Soil property variation under agroforestry based conservation tillage and maize based conventional tillage in Southern Ethiopia. Soil and Tillage Research 141(2014):25-31.
Kursten E (2000). Fuelwood production in agroforestry systems for sustainable land use and CO_2-mitigation. Ecological Engineering 16:69-72.
Lal R (1997). Long-term tillage and maize monoculture effects on a tropical Alfisol in western Nigeria. II. Soil chemical properties. Soil and Tillage Research 42(3):161-174.
Lal R (2004). Carbon sequestration in dryland ecosystems. Environmental management 33(4):528-544.
Lal R (2015). Sequestering carbon and increasing productivity by conservation agriculture. Journal of Soil and Water Conservation 70(3):55A-62A.
Landon JR (1991). Booker Tropical Soil Manual. Longman Scientific and Technical Essex, UK. p. 474.
Lichter K, Govaerts B, Six J, Sayre KD, Deckers J, Dendooven L (2008). Aggregation and C and N contents of soil organic matter fractions in the permanent raised-bed planting system in the Highlands of Central Mexico. Plant and Soil 305:237-252.
Liebig MA, Tanaka DL, Wienhold BJ (2004). Tillage and cropping effects on soil quality indicators in the northern Great Plains. Soil and Tillage Research 78(2):131-141.
Lipiec J, Kus J, Słowin´ska-Jurkiewicz A, Nosalewicz A (2006). Soil porosity and water infiltration as influenced by tillage methods. Soil and Tillage Research 89(2):210-220.
Makumba W, Akinnifesi FK, Janssen B, Oenema O (2007). Long-term impact of a Gliricidia-maize intercropping system on carbon sequestration in southern Malawi. Agriculture, Ecosystems and Environment 118(1-4):237-243.
Małecka I, Blecharczyk A, Sawinska Z, Dobrzeniecki T (2012).The effect of various long-term tillage systems on soil propertiesand spring barley yield. Turkish Journal of Agriculture and Forestry 36(2):217-226. Doi: 10.3906/tar-1104-20.
Mehlich A (1984). Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Communications in Soil Science and Plant Analysis 15(12):1409-1416.
Mloza-Banda HR, Makwiza CN, Mloza-Banda ML (2016). Soil properties after conversion to conservation agriculture from ridge tillage in Southern Malawi. Journal of Arid Environments 127:7-16.
Murty D, Kirschbaum MUF, McMurtrie RE, McGilvray H (2002). Does conversion of forest to agricultural land change soil carbon and nitrogen? A review of the literature. Global change biology 8(2):105-123.
Nair RPK, Vimala DN, Kumar BM, Haile SG (2009).Soil carbon sequestration in tropical agroforestry systems: a feasibility appraisal. Environmental Science and Policy 12(2009):1099-1111.
Oliveira MT, Merwin IA (2001). Soil physical conditions in a New York orchard after eight years under different groundcover management systems. Plant Soil 234:233-237.
Palm C, Blanco-Canqui H, DeClerk F, Gatere L, Grace P (2014) .Conservation agriculture and ecosystem services: an overview. Agriculture, Ecosystems and Environment 187:87-105.
Pittelkow CM, Liang X, Linquist BA, Van Groenigen KJ, Lee J, Lundy ME, Van Gestel N, Six J, Venterea RT, Van Kessel C (2015). Productivity limits and potentials of the principles of conservation agriculture. Nature 517(7534):365-368.
Porta J, López-Acevado M, Roquero C (1999). Edafología para la agricultura y el medio ambiente. Mundi Prensa, Espana P 849.
Rahman MH, Okubo A, Sugiyama S, Mayland HF (2008).Physical, chemical and microbiological properties of an Andisol as related to land use and tillage practice. Soil and Tillage Research 101:10-19.
Rasmussen KJ (1999).Impact of ploughless soil tillage on yield and soil quality: A Scandinavian review. Soil and Tillage Research 53(1):3-14.
Reicosky DC (2003). Tillage-induced CO_2 emissions and carbon sequestration: effect of secondary tillage and compaction. In: Garcia-Torres, L, Benites J, Martinez-Vilela A, Holgado-Cabrera A (Eds.), Conservation Agriculture. Kluwer Acad. Pub., Dordrecht, The Netherlands pp. 291-300.
Rockstrom J, P Kaumbutho, J Mwalley, AW Nzabi, M Temesgen, L Mawenya, J Barron, J Mutua, S Damgaard-Larsen (2009). Conservation farming strategies in East and Southern Africa: Yields and rain water productivity from on-farm action research. Soil and Tillage Research 103(1):23-32.
Rodrigues RC, Araújo RA, Costa CS, Lima AJ, Oliveira ME, Cutrim Jr JA, Santos FN, Araújo JS, Santos VM, Araújo AS (2015). Soil microbial biomass in an agroforestry system of Northeast Brazil. Tropical Grasslands-Forrajes Tropicales 3(1):41-48.
Sainju UM, Caesar-Tonthat T, Lenssen AW, Evans RG, Kolberg R (2009). Tillage and cropping sequence impacts on nitrogen cycling in dryland farming in eastern Montana, USA. Soil and Tillage Research 103(2):332-341.
Schwab N, Schickhoff U, Fischer E (2015).Transition to agroforestry significantly improves soil quality: A case study in the central mid-hills

of Nepal. Agriculture, Ecosystems and Environment 205:57-69.

Tan C, Xue Cao, Shuai Yuan, Weiyu Wang, Yongzhong Feng, Bo Qiao (2015).Effects of Long-term Conservation Tillage on Soil Nutrients in Sloping Fields in Regions Characterized by Water and Wind Erosion. Science Reports 5:17592; doi: 10.1038/srep17592 (2015).

Tejada M, Garcia C, Gonzalez JL, Hernandez MT (2006). Use of organic amendment as a strategy for saline soil remediation: influence on the physical, chemical and biological properties of soil. Soil Biology and Biochemistry 38(6):1413-1421.

Thierfelder C, Wall PC (2009). Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil and Tillage Research 105(2):217-227.

Thierfelder C, Mwila M, Rusinamhodzi L (2013).Conservation agriculture in eastern and southern provinces of Zambia:Long term effects on soil quality and maize productivity. Soil and Tillage Research 126:246-258.

Tornquist GC, Hons FM, Feagley ES, Haggar J (1999). Agroforestry system effects on soil characteristics of the SarapiquõÂ region of Costa Rica. Agriculture, Ecosystems and Environment 73(1):19-28

Unger PW, Jones OR (1998). Long-term tillage and cropping systems affect bulk density and penetration resistance of soil cropped to dryland wheat and grain sorghum. Soil and Tillage Research 45(1-2):39-57.

Xue JF, Pu C, Liu SL, Chen ZD, Chen F, Xiao XP, Lal R, Zhang HL (2015). Effects of tillage systems on soil organic carbon and total nitrogen in a double paddy cropping system in Southern China. Soil and Tillage Research 153:161-168.

Yimer F, Messing I, Ledin S, Abdu A (2008). Effects of different land use types on infiltration capacity in a catchment in the highlands of Ethiopia. Soil Use Management 24(4):344-349.