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Agroforestry practices impacts on soil properties in the drylands of Eastern Kenya

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ABSTRACT

Agroforestry is one of the land use practices that is perceived to be sustainable and that has beneficial impacts on soil properties. However, as a universal statement, this may not be true as best documented successful agroforestry practices are located largely on good soils. Its impacts on dryland soils have rarely been quantified and studied in detail. This study determined the impacts of selected agroforestry practices on soil properties in Makueni, Eastern Kenya. A total of 252 soil samples were collected along transects located within mixed tree woodlots established in 2007, 2010 and 2013 and adjacent parklands and grazing lands at depths of 0–15 cm, 15–30 cm, 30–45 cm and 45–60 cm. Tree density per agroforestry practice was also determined using the quadrat technique. The soil samples were analyzed using laboratory soil physico-chemical properties techniques. The results showed that Soil Organic Carbon (SOC) and Total Nitrogen (TN) were significantly higher in the woodlots than in the parkland and grazing lands ($p \leq 0.05$). SOC was significantly higher in woodlots established in 2007 than those established in 2013 and strongly correlated with the tree density. Phosphorus was significantly higher in parkland as compared to woodlots and grazing lands. Phosphorus and Potassium were significantly higher at 0–15 cm depth compared to other soil depths. bulky density was significantly higher with a corresponding lower total porosity in grazing lands than in the woodlots and parklands. Mixed woodlots positively influenced soil property and could be considered as a strategy to restore degraded dryland soils as well act as important carbon dioxide and nitrogen sinks.

Introduction

Drylands are home to about 2 billion people (Reynolds et al., 2007). They face a myriad of problems, among them land degradation and water scarcity which are exacerbated by climate change and variability. Livelihoods options are limited, leading to rampant poverty and food insecurity in the drylands (Wekesa et al., 2012). Improving soil fertility is key to enhancing drylands livelihoods. However, drylands are characterized by degraded soils that support low agricultural outputs (Bishaw et al., 2013). According to Baimah (2001), soils in the drylands are limited in agricultural productivity due to severe soil erosion and low soil fertility. Soil infertility has contributed to a corresponding decline in crop and animal yields, an increase in food and nutrition insecurity and environmental degradation (Mafogoya et al., 2006). The price of synthetic fertilizers limits its use by smallholder farming households in the drylands (Buttoud et al., 2013). Chemical fertilizers use in the drylands is further considered ineffective due to unreliable supply of enough moisture to absorb it for plant growth. The long fallow periods traditionally practiced in the drylands to improve soil fertility is a limited option as the length has greatly reduced due to population increase (Leakey, 2010). The steady use of land without leaving it fallow for some time lowers the level of organic matter in the soil thus making it difficult to grow crops. It also accelerates the deterioration of the land resource thus threatening the livelihoods of many rural people (Otsuka and Place, 2001). As the population increases, the need to increase cultivated and grazing lands to provide food override vital environmental considerations. Rapid human population growth has put intense pressure on the drylands leading to increased conversion of grazing land to crop land for subsistence crop production. (Mganga et al., 2019). To address these challenges, sustainable land use and management practice is imperative in the drylands. Agroforestry which is an ecologically based traditional farming practice that integrates trees into the farming systems to ameliorate soil infertility and increase agricultural productivity (Bishaw et al., 2013) is a critical entry point for dryland sustainable productivity. Agroforestry enhances and maintains soil health which is vital for food security, livelihood enhancement, preserving the

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environmental services and their sustainability. It controls runoff and soil erosion thereby reducing loses of organic materials and nutrients. Litter fall and fine-root turnover increase soil organic matter concentration hence improving soil fertility and health (Ludeki et al., 2004; Jama and Zeila, 2005).

Agroforestry is generally perceived to be sustainable and enhances soil properties. However, as a universal statement, this may not be true. This is because the best documented successful agroforestry practices are largely located on good soils with examples such as stable coffee or cacao production under shade in volcanic soils (Russo and Budowski, 1986). However, agroforestry is considered especially applicable to marginal soils with severe physical and chemical constraints like in dryland soils. While evidence exists for beneficial impacts on soils of certain agroforestry practices especially on more fertile soils, there is tendency for over generalization and extrapolation of soil productivity and sustainability benefits of agroforestry to other more marginal sites. There is need therefore for a more vigorous analysis of agroforestry impacts, particularly on farmer-led agroforestry projects because most of the analyses on agroforestry techniques use field experiments led by researchers (Scherr and Frannzel, 2002). Farmer-led projects are show how agroforestry practices are used under normal circumstances. Nair et al. (2009), points out that most of the research work is performed on existing agroforestry practices in the humid and sub-humid tropics and not in the drylands. Unfortunately, studies of nutrient cycling and the monitoring of changes in soil chemical and physical properties are rarely considered in the experimental designs of agroforestry studies. The impact of agroforestry practices in soils have rarely been quantified and studied in detail (Schwab et al., 2015). According to Noble and Randall (1998), the identified research priorities in agroforestry practices are their influence on soil physical, chemical and biological properties.

Despite widespread promotion and adoption of agroforestry practices in Kenya's drylands, especially in Makueni County in Kenya, little has been documented on their impacts on soil physico-chemical properties. Drylands Natural Resources center (DNRC), a local non-governmental organization (NGO), has been promoting agroforestry practices among the small scale farmers of Makueni County since 2007. So far, more than 700 farmers are involved in the project and more than 800,000 dryland trees of diverse species planted in mixed tree woodlots at the farmers' individual farms. There has been no follow up research done to assess their impacts on soil physico-chemical properties by year of planting and in comparison with the dominant parkland (scattered trees in cropland) and grazing lands agroforestry practices. Identifying and monitoring changes in soil quality is important in counteracting ecological degradation in the fragile Arid and Semi-Arid Lands (ASALs). There is need to underpin the impacts of agroforestry practices on soil properties as a means of exploring the possibilities of expanding the same among dryland smallholder farmers so as to diversify their livelihoods and to contribute to sustainable land use and management. The objective of this study was to establish the contribution of selected dominant agroforestry practices to soil physico-chemical properties in Makueni County of Kenya. It was hypothesized that different agroforestry practices would improve soil physico-chemical properties differently.

Material and methods

Study area

The study was conducted in Makueni County of Kenya that lies between latitude 1° 35′ South and 3° 00′ longitude 37° 10′ and 38° 30′ East. The county and especially the location chosen was based on the recent high concentration of tree planting and agroforestry projects. The area receives a bi-modal rainfall pattern with long rains expected in April-May and short rains between November-December. The climate is typical semi-arid characterized by low and unreliable supply of enough moisture for plant growth (Mganga et al., 2019). The average annual rainfall is about 600 mm (Musimba et al., 2004), which is characterized by high rainfall variability often leading to crop failure. The annual mean temperatures are in the range of 21–24 °Celsius and an elevation of 800–1600 m.The natural vegetation is mostly grassland and dense shrub land or woodland. The dominant soils belong to Ferrosols and are either Rhodic (red color) or Xanthic (yellow color) and few are Aerosols. They are naturally low in Nitrogen, Phosphorus and Total Organic Carbon (Mbuvi 2000). The soils are generally low in organic matter, have unstable structure, high levels of salinity and sodicity, poor drainage, low soil fertility and are vulnerable to physical erosion, chemical and biological degradation (Biamah, 2005).

The county covers an area of 88,176.7 km^2 and has a population of 987,653 people with a population growth rate of 1.1% according to the 2019 Kenya Population and Housing Census. The largest community in the area is Kamba who practice mainly agro-pastoralism. There is no major economic activity apart from subsistence farming with the main crops being maize, sorghum, millet, beans and pigeon peas (Mganga et al., 2019). The livestock population is primarily goats and chicken with cattle whose number is limited because of insufficient supply of feeds during drought periods. The average land size is about 3 ha and over cultivation has left the land bare exposing it to soil erosion which has greatly reduced agricultural productivity in the area. The study area and household areas with various agroforestry practices are presented in Fig. 1.

Data collection and analysis

Study design

Pseudoreplication was used in this study where seven farms with mixed tree woodlots established in 2007, 2010 and 2013 and their corresponding parklands and grazing lands were randomly selected within the study area. The farms were located in close proximity with similar slope, topography and soil type. In each farm, woodlots of 2007, 2010 and 2013 and their adjacent parklands, and grazing lands were selected for tree density and soil sampling. Plots 10 × 10 m in size were established along line transects laid in woodlots established in 2007, 2010 and 2013 and their adjacent parkland and grazing land plots thus making a total of 9 sampling points per each of the 7 farms.

Determination of tree density under various agroforestry practices

To determine tree densities at the selected mixed tree woodlots established in 2007, 2010 and 2013 and their adjacent parkland and grazing lands, the quadrat technique was used. Density per individual tree species was determined by counting and recording all individual trees in the established 10 × 10 m plots both in the mixed tree woodlots and their adjacent parklands and grazing lands. Tree density was determined by estimating number of individual tree species over the area expressed as number of trees per hectare (No. of trees per 10 m x 10 m/ha). Relative density was also determined by number of individual tree species over the total tree density expressed in percentage (No. of individual tree Species /total density x 100%).

Soil sampling

Four soil samples were obtained using soil auger at 0–15 cm, 15–30 cm, 30–45 cm, 45–60 cm in a zigzag pattern at each of the 10 m x 10 m plots established along line transects laid in woodlots established in 2007, 2010 and 2013 and their adjacent parkland and grazing lands. A total of 252 soil samples were obtained (4 soil depths, 3 agroforestry practices, 3 age categories and 7 farms). About 0.5 kg of the sample was air-dried, sieved through a 2-mm mesh and stored at 4 °C in a refrigerator for physical and chemical analysis. Steel cylinders of 98.2cm^3 were used to obtain undisturbed soil samples from the marked plots for determination of bulk density. The soil samples collected were analyzed

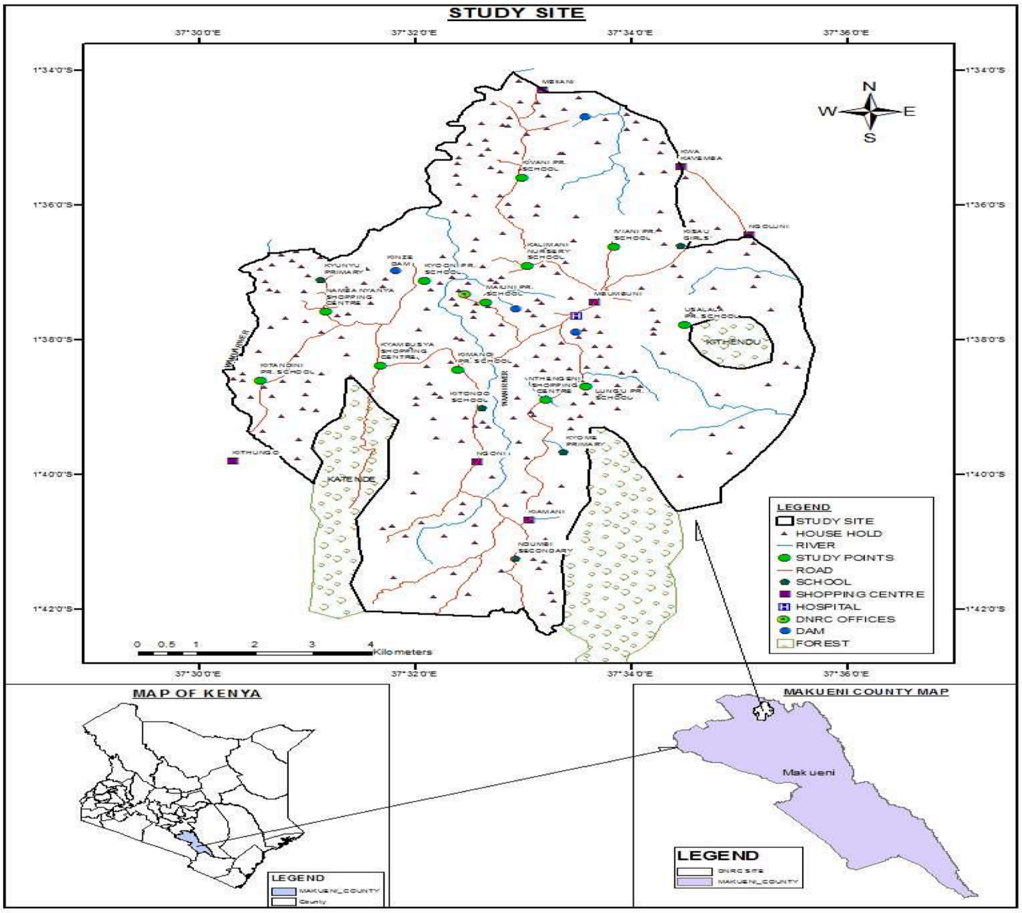

Fig. 1. Household Areas with various Agroforestry practices.

for pH, soil bulk density, total porosity, total nitrogen, soil organic carbon, and available phosphorus and potassium variables.

Soil analysis in the laboratory

Soil pH was measured using a glass electrode pH meter (model: HI 2211, Hanna instruments). Soil Bulk Density (BD) was determined using core ring method by oven-drying core samples at 105 °C for 48 h (McKenzie et al., 2004).Soil Organic Carbon (SOC) was determined using wet oxidation method using a mixture of sulphuric acid and aqueous potassium dichromate ($K_2Cr_2O_7$) (Nelson and Sommers, 1982). Total Nitrogen (TN) was determined by distillation and titration of acid digested soil sub-sample following the procedures by Kjedahl method (Bremmer and Malvany, 1982). Available Phosphorous was determined calorimetrically using double acid (0.05 NHCl in 0.025 N H_2SO_4) extraction method (Mehlich, 1984). Potassium was determined using a flame photometer after extraction soil sub-sample with excess of 1 M ammonium acetate (NH_4OAc) solution (Osborne, 1973). These tests were done to establish and compare nutrient contents, bulk density and porosity of the sampled soils under the three different agroforestry practices and age categories.

Data analysis

R software (version 3.5.2) was used to conduct Principal Component Analyses (PCA) to examine relationships between the following variables: total organic carbon, total nitrogen, land use, total tree density, woodlots year of establishment, extractable K, available P and soil bulk density. Kaiser criterion was followed to select the principal components with eigenvalues that are greater than 1. GenStat 14th edition was used to conduct a two-way analysis of variance (ANOVA) of the impacts of different agroforestry practices and their soil depths on pH, total organic carbon, total nitrogen, total phosphorus, potassium, bulk density and total porosity. Means were separated using Fischer's protected least significant difference (LSD) test, with differences considered significant at $P \leq 0.05$.

Results

Tree densities at different agroforestry practices

The results show that across agroforestry practices, tree density was high in woodlots, followed by grazing area and then parklands (Table 1). More trees were planted in woodlots by the farmers at earlier stages of woodlot introduction in the study area as shown in Table 1.

Dominant tree species and their densities at different agroforestry practices

Table 2 presents the dominant trees species and their individual tree densities. The results show that the agroforestry practices were dominated by different tree species of different densities. Mixed woodlot was dominated mostly by exotic trees species while grazing land was dominated by local tree species. In parkland, there were more fruit trees

Table 1
Tree densities at different agroforestry practices.

Agroforestry practice	Mean tree density /Ha		
	2007	2010	2013
Mixed tree woodlot	3530	2815	2359
Grazing land	302	341	170
Parkland	50	90	120

Table 2
Dominant tree species and their densities at different agroforestry practices.

Agroforestry Practice	Tree Species	Mean	Density (Trees/Ha)	Relative density (%)
Mixed tree woodlot	*Senna spectabilis*	7.0	700	19.8
	Grevillea robusta	5.2	520	14.7
	Senna siamea	3.0	300	8.5
	Eucalyptus camadulensis	3.0	300	8.5
	Acacia tortilis	2.4	240	6.7
Grazing land	*Combretum collinum*	0.8	80	26.5
	Acacia tortilis	0.5	50	16.5
	Terminalia brownii	0.4	40	13.2
	Grevillea robusta	0.3	30	10
	Croton megalocarpus	0.3	30	10
Parkland	*Mangifera indica*	0.1	10	20
	Senna siamea	0.1	10	20
	Citrus auratica	0.1	10	20
	Erythrina abyssinica	0.1	10	20
	Azanza garckeana	0.1	10	20

Table 3
Eigen analysis of the correlation matrix.

	Eigenvalue	Percentage of Variance	Cumulative Percentage of Variance
comp 1	6.11	61.12	61.12
comp 2	1.23	12.31	72.44
comp 3	1.00	10.01	83.45
comp 4	0.55	5.52	88.96
comp 5	0.38	3.81	92.78
comp 6	0.29	2.92	95.70
comp 7	0.20	2.04	97.75
comp 8	0.13	1.26	99.00
comp 9	0.09	0.89	99.89
comp 10	0.01	0.11	100.00

Table 4
Correlation matrix of the first five components.

	comp 1	comp 2	comp 3	comp 4	comp 5
Soil depth	−0.92	−0.01	0.01	0.23	0.05
Tree density	0.63	0.57	0.01	0.30	−0.42
Total N	0.84	−0.32	−0.29	0.11	−0.02
Land use	0.51	0.70	−0.22	0.17	0.38
Available P	0.86	−0.20	−0.02	0.18	0.15
Year of establishment	−0.61	0.25	0.69	0.03	0.10
Bulk density	−0.82	−0.11	−0.44	0.21	0.07
Extractable K	0.90	0.06	0.20	−0.18	0.13
Soil pH	0.62	−0.44	0.40	0.44	0.06
Total SOC	0.96	−0.01	0.02	−0.02	−0.03

than in the woodlots and grazing land. The most dominant tree species were *Senna spectabilis* and *Combretum collinum* accounting for 19.8% and 26.5% in the woodlots and grazing land respectively (Table 2). In parklands, the trees were evenly distributed as shown in Table 2.

From Principal Component Analysis, the first two components explained 73% of the variability in the first component accounting for 61% of the variance (Table 3). The first component exhibited a strong positive ($r = 0.96$) and negative ($r = -0.92$) correlation with total SOC and soil depth respectively ($p = 0.000$) (Table 4). This implies that SOC responds to changes in land use. Therefore, the total SOC content increased with land use change from cropland to woodlots ($r = 0.51$), soil pH ($r = 0.62$), tree density ($r = 0.63$), and total N ($r = 0.84$), but reduced with increasing soil bulk density ($r = 0.82$) and soil depth ($r = 0.92$). The second component was a reflection of agroforestry practice ($r = 0.70$) which related strongly to tree density ($r = 0.57$) but weakly with age of woodlot ($r = 0.25$), total N ($r = 0.32$) and soil pH ($r = 0.44$) as shown in Fig. 2.

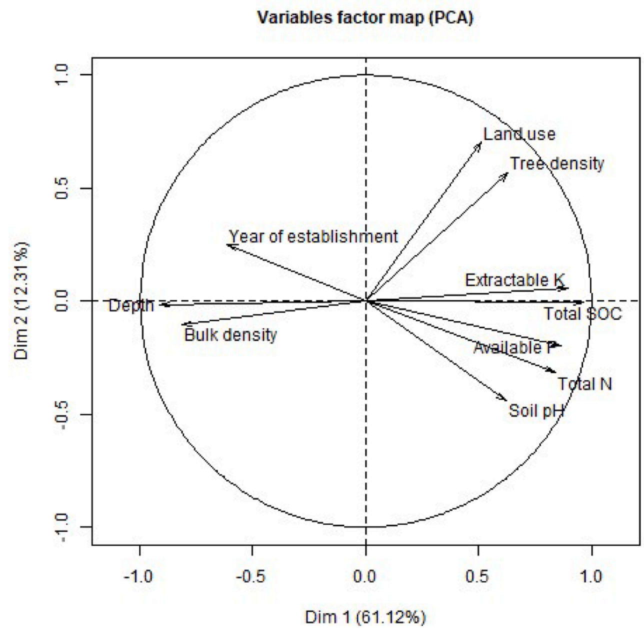

Fig. 2. Loading plot showing the factor map for the first two principal components affected by the choice of agroforestry practice. Vectors indicate the degree of correlation between each factor and the axes.

Impacts of different agroforestry practices on soil chemical and physical properties

The two-way Analysis of Variance (ANOVA) revealed that there was no significant difference on soil pH ($P>0.05$) across the three agroforestry practices and their respective soil depths. Soil Organic Carbon (SOC) was significantly higher ($P < 0.001$) in mixed tree woodlots compared to parkland and grazing lands. Total Nitrogen (TN) was significantly higher ($P < 0.01$) in mixed tree woodlots compared to parkland and grazing lands. Phosphorus content was significantly higher ($P < 0.01$) in parkland compared to mixed tree woodlots and grazing land. Potassium content had no significance difference across the three agroforestry practices as shown in Fig. 3.

Impacts of different agroforestry practices on soil chemical properties by soil depth

The results show that different agroforestry practices did not significantly influence the soil pH values ($P>0.05$) by depth and it ranged between 5.8 and 6.3. Soil organic carbon was significantly influenced by soil depth and generally decreased with increase in soil depth. It was significantly higher at 0–15 cm and 15–30 cm depths as compared to 30–45 cm and 45–60 cm depths. Phosphorus was significantly influenced by depth and generally decreased with increase in soil depth. At 0–15 cm, phosphorus was significantly higher compared to 45–60 cm soil depth. Potassium was significantly higher at 0–15 cm soil depth ($P = 0.01$) as compared to the other soil depths as shown in table 5. No significant difference was detected among the agroforestry practices.

Soil organic carbon under different age categories of mixed tree woodlots

Soil Organic Carbon content was significantly higher ($P < 0.001$) under mixed woodlots established in 2007 as compared to those established in 2010 and 2013. The SOC was 1.2%, 1.0% and 0.8% in the woodlots established in the year 2007, 2010 and 2013 respectively as shown in Fig. 4.

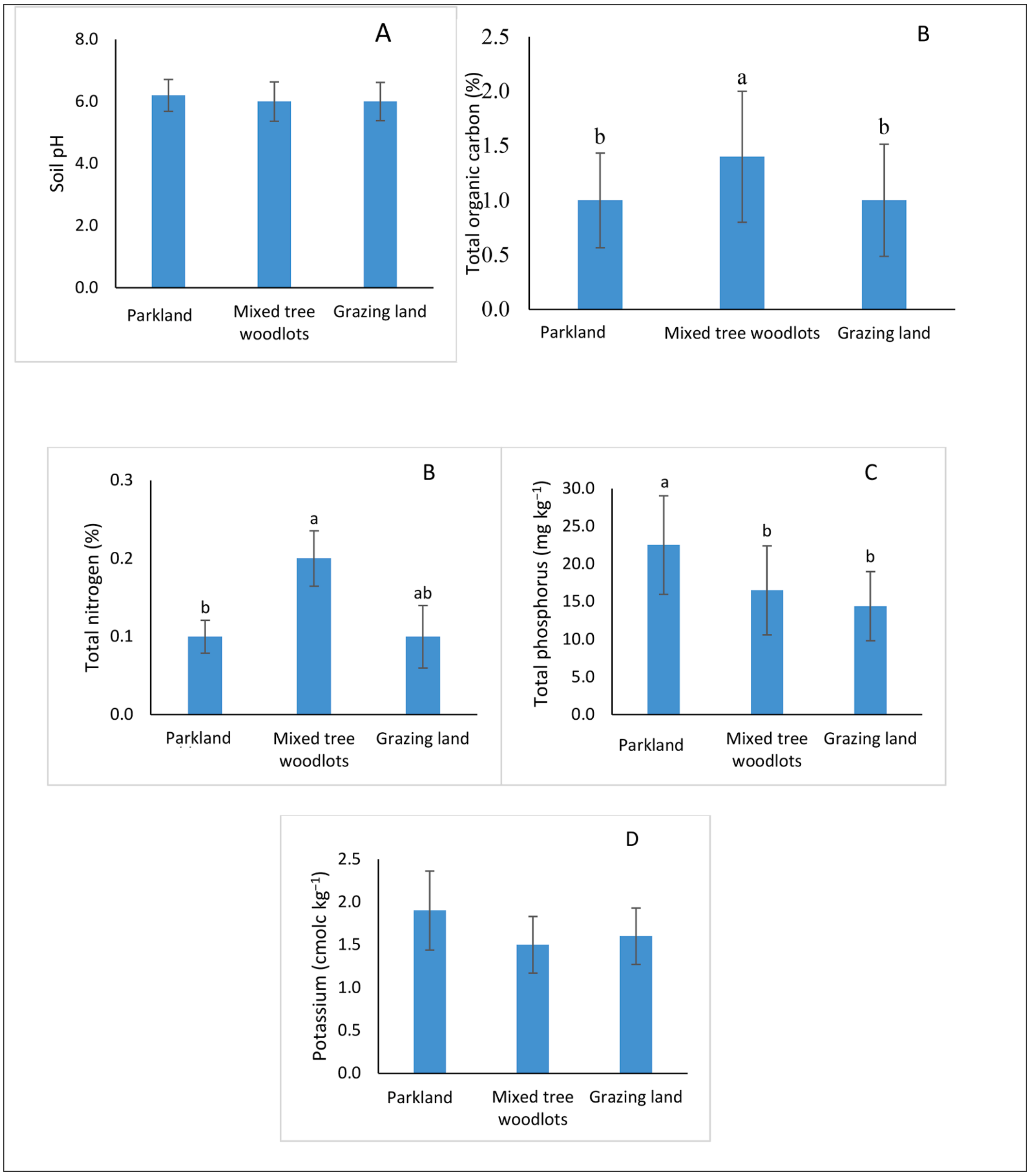

Fig. 3. Impacts of different agroforestry practices on soil physico-chemical properties. Vertical lines represent standard deviation (SD) of the mean. Different lowercase letters represent significant difference between agroforestry practices.

Soil bulk density and total soil porosity of the three agroforestry practices

Results show that soil bulk density and the corresponding total porosity exhibited significant interaction between different agroforestry practices and soil depths. ($P < 0.001$). Total porosity was significantly lower at depths 0–15 cm and 15–30 cm in grazing land as compared to parkland and woodlots. Total porosity decreased with increase in depth across the three agroforestry practices. Bulk density was significantly higher at depths 0–15 cm and 15–30 cm under grazing land as compared to parkland and woodlots. The bulk density increased with depth under parkland and woodlot and reduced with depth in grazing land. Total porosity was higher where bulky density was lower and vice-versa as shown in Fig. 5.

Discussion

The results on tree density indicate that woodlots had higher tree density than parkland and grazing land. The low level of trees in parkland is partly because of farmers reducing wood cover to protect the crops from tree shading and to enable easier ox-ploughing of their parkland. This is in agreement with the results of Takimoto (2007) in his research on carbon sequestration potential of agroforestry systems in West Africa that showed that farmers kept low levels of tree density of about 20 to 30 trees/ha to reduce shading and to facilitate easy animal ploughing. Common trees in the woodlots are *Senna spectabilis* and *Grevillea robusta* which is an indication of the most preferred trees by the farmers and which are commonly promoted by agroforestry projects in the study area. *Acacia tortillis* and *Terminalia brownii* are the common tree species in the grazing land indicating they are the common natural trees in the study area. In the parkland, the common trees were citrus and mangoes which are common fruit trees in the county and highly promoted for income generation (Makueni County Integrated Development Plan 2013–2017).

There was no significant difference in soil pH across the three agroforestry practices and soil depths though it was higher in parkland as compared to woodlots and grazing land. The results are similar to

Table 5
Effects of different agroforestry practices on soil chemical properties by soil depth.

Parameter	Agroforestry practice	Soil Depths (cm) 0–15	15–30	30–45	45–60
pH	Parkland	6.1 ± 0.6	6.2 ± 0.4	6.2 ± 0.5	6.2 ± 0.4
	Woodlot	6.1 ± 0.6	6.1 ± 0.6	6.0 ± 0.6	6.0 ± 0.7
	Grazing land	6.1 ± 0.3	6.0 ± 0.5	6.0 ± 0.4	5.8 ± 0.9
	Pooled mean	**6.1 ± 0.6**	**6.1 ± 0.5**	**6.1 ± 0.5**	**6.0 ± 0.6**
Organic Carbon (%)	Parkland	1.3 ± 0.4	1.2 ± 0.4	0.9 ± 0.3	0.6 ± 0.3
	Woodlot	1.9 ± 0.6	1.7 ± 0.7	1.1 ± 0.4	0.9 ± 0.3
	Grazing land	1.4 ± 0.6	1.1 ± 0.4	0.9 ± 0.4	0.7 ± 0.4
	Pooled mean	**1.4 ± 0.5a**	**1.2 ± 0.5a**	**0.9 ± 0.4b**	**0.7 ± 0.3b**
Total Nitrogen (%)	Parkland	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.1
	Woodlot	0.2 ± 0.3	0.2 ± 0.2	0.1 ± 0.2	0.1 ± 0.1
	Grazing land	0.1 ± 0.1	0.2 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
	Pooled mean	**0.2 ± 0.2**	**0.1 ± 0.1**	**0.1 ± 0.1**	**0.1 ± 01**
Phosphorous (mg kg−1)	Parkland	27.7 ± 7.5	25.6 ± 6.1	20.3 ± 4.4	16.6 ± 5.8
	Woodlot	18.9 ± 6.2	16.6 ± 8.2	15.5 ± 4.5	14.8 ± 4.8
	Grazing land	18.1 ± 5.6	16.1 ± 5.1	12.8 ± 3.7	10.7 ± 3.1
	Pooled mean	**22.6 ± 6.7a**	**20.4 ± 7.4ab**	**17.2 ± 4.7bc**	**15.0 ± 6.1c**
Potassium ($cmol_c$ kg^{-1})	Parkland	2.2 ± 0.6	2.0 ± 0.6	1.7 ± 0.4	1.7 ± 0.2
	Woodlot	2.1 ± 0.4	1.6 ± 0.3	1.2 ± 0.2	1.2.0.3
	Grazing land	2.0 ± 3	2.0 ± 0.2	1.4 ± 0.3	1.0 ± 0.1
	Pooled mean	**2.1 ± 0.4a**	**1.8 ± 0.4ab**	**1.5 ± 0.3b**	**1.4 ± 0.2b**

Values are means ± standard deviation (SD) of the mean. Lowercase letters within rows represent significant differences between soil depths at $P < 0.05$.

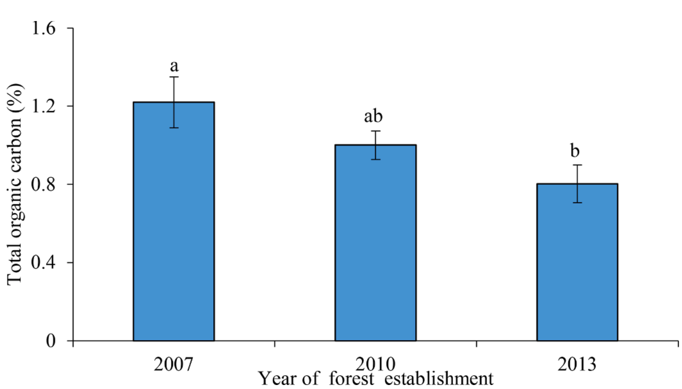

Fig. 4. Soil Organic Carbon under different age categories of mixed tree woodlots. Vertical lines represent standard deviation (SD) of the mean. Different lowercase letters represent significant differences between age categories.

those found by Madalcho et al. (2016) in his research on the effects of agroforestry practices in Gununo Watershed in Ethiopia which showed no significant difference in soil pH across home gardens, parkland and woodlots. The lower pH in Woodlots and grazing land could be due to higher levels of trees as deep tree roots produce acid this is, release of $H+$ during absorption of positively charged basic cautions (Keefer, 2000).

The results revealed that total soil carbon was positively influenced by the trees. The soil organic carbon in the study area was significantly higher in woodlots than in parkland and grazing lands. This could be partly because of the higher leaf litter fall and tree roots from higher density of trees in the woodlots. Tree roots and litter fall make a large contribution of soil organic carbon (Schmidt et al., 2011). Lower soil carbon stock in parkland in the study area could be due to increased cultivation and semi-annual removal of crop residue like maize stocks every season. According to Nair et al. (2010), decrease in cultivation intensity may result in an increase in soil organic carbon. Agro ecosystems that are cropped and have intensive site preparation tend to have lower soil organic carbon (Sherrod et al., 2005). Overgrazing in the grazing land characterized by low tree density could have affected the low soil organic carbon. This is in agreement with the results by Guibin et al. (2015) in his study investigating enhanced soil carbon storage under agroforestry and afforestation in subtropical China which indicated that a critical influence of soil organic carbon balance is the influence and intensity of live biomass removal and/or its conversion to dead organic matter. Soil organic carbon was also significantly influenced by soil depth and generally decreased with increase in soil depth. This could be due to accumulation of tree residues and root fragments at the surface top layers of the soil profile. This corroborates results of a study by Causarana *et al.*, (2006) who found that soil organic carbon decreased with soil depth in pasture land and crop land while investigating soil organic carbon fractions and aggregation in the Southern Piedmont and Coastal Plains in the USA. Soil organic carbon and Nitrogen contents are directly related to amount of plant residue in the soil (Ortega et al., 2002).

The results show that total nitrogen was significantly higher in the woodlots compared to parkland and grazing land. Higher value of total nitrogen in woodlot could be associated with higher organic matter from leaf litter fall and dead tree roots. The results are consistent with the results by Misana et al. (2003) who found out that total nitrogen decreased at lower elevation due to reduction of organic matter in their research on the linkages between changes in land use biodiversity and land degradation on the slopes of Mount Kilimanjaro, Tanzania. Nitrogen contents are directly related to amount of plant residue in the soil (Ortega et al., 2002). According to Misana et al. (2003), soil organic matter is a major source of Nitrogen. Presence of Nitrogen fixing trees such as *Acacia tortilis* in the woodlots could have resulted to higher nitrogen value than in cropland and grazing land. Nitrogen fixing trees convert atmospheric Nitrogen into organic form in plant tissues through symbiotic association of roots and special types of bacteria hence improving soil Nitrogen (De leeuw et al., 2014).

From the results, Phosphorus content was significantly higher in parkland compared to mixed tree woodlots and grazing land. This could be due to addition of animal manure by the farmers which has readily available phosphorus compared to decomposing forage in woodlot and grazing land. This is in agreement with the results by Kihanda *et al.*, (2007) in their study on the effects of manure application on crop yield and soil chemical properties in long term field trial in semi-arid, Kenya which showed an increase in phosphorus after continued application of goat manure. Animal manure contains significant amounts of phosphorus in organic form (Kihanda *et al.*, 2007). Phosphorus was significantly higher at 0–15 cm as compared to 45–60 cm soil depth. This could be associated with phosphorus uptake from greater soil depths by trees followed by return to soil surface through litter fall which concentrate nutrients near the soil surface (Fisher, 1995).

SOC increased significantly in mixed woodlots established in 2007 as compared to woodlots established in 2013. This corroborates results of the study by Gupta et al. (2009) who found that soil organic carbon increased over successive years in their research on soil organic carbon and aggregation under poplar based agroforestry systems in relation to age and soil type in India. According to Derpsch et al. (2015), clear

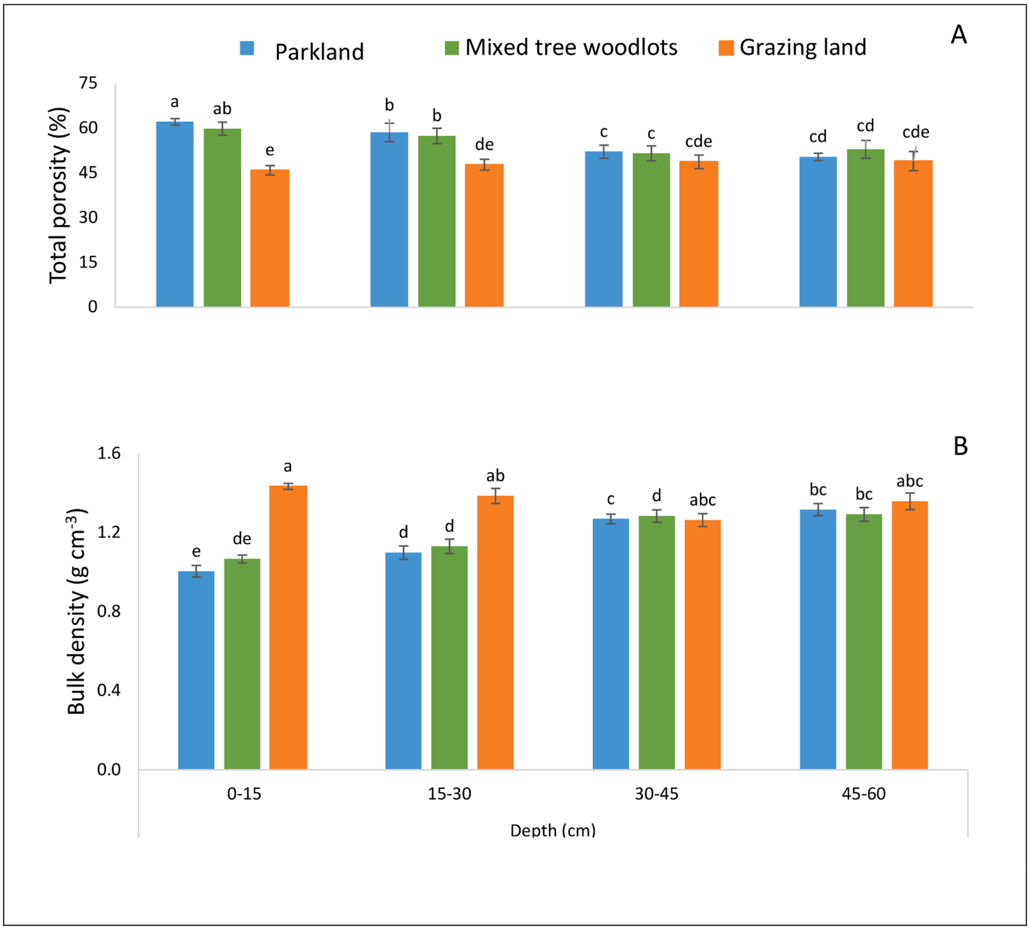

Fig. 5. soil bulk density (A) and total soil porosity (B) of the three agroforestry practices and soil depth. Different lowercase letters represent significant difference between agroforestry practices and soil depth. Vertical lines represent standard deviation (SD) of the mean.

increases in soil organic matter only appear 5–10 years after the adoption of continuous no-till agriculture.

The results show that bulk density was significantly higher in the grazing land as compared to woodlot and parkland. This could be partly attributed to long term soil compaction caused by grazing animals. This corroborates results of a study by Mganga *et al.*, (2011) who found higher bulk densities in grazing land compared to cultivated and fallow lands while investigating different land use types in the rangelands in Kibwezi, Makueni County.

Total porosity was significantly lower in grazing land as compared to woodlots and parkland. This could be due to livestock trampling. The results are similar to those found by Nyangito et al. (2009) who found higher bulk density and corresponding lower total porosity in grazed land as compared to un grazed land while investigating hydrologic properties of grazed perennial swards in Semi-Arid Southeastern Kenya.

Conclusions and recommendations

The productivity of soils in the drylands which are known to have low fertility and are susceptible to degradation could be improved significantly through agroforestry. As it can be seen from the results, mixed tree woodlots contributed significantly to soil properties over time and could be considered as a strategy to restore degraded and infertile soils in the drylands. Woodlots also contributed positively to Soil Organic Carbon and Nitrogen which are central components that could alter the capacity of the soil to act as Carbon and Nitrogen sinks for climate change mitigation. Therefore, adoption of appropriate drylands agroforestry practices should be part of the National and County government policy interventions and should be factored in as a strategy for enhanced soil fertility, carbon credit payments to the farmers and for a green economy. To achieve this, there is need for retrospective studies on accurate evaluation of impacts of different agroforestry practices on soil carbon and Nitrogen at different soil types.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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