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Abstract

Drylands, which are home to about 2 billion people face a myriad of problems among them low land productivity. Agroforestry is one of the land use practices that is perceived to be sustainable with beneficial effects on soil properties. However, the effects of agroforestry practices on soils especially in the drylands have rarely been quantified and studied in details. The study determined the effects of selected agroforestry practices on soil properties in Makueni County of Kenya where agroforestry has been promoted by various organizations. Four soil samples were collected at 0-15cm, 15-30cm, 30-45cm and 45-60cm depths in a zigzag pattern at each 10 x 10m plots established along line transects laid in woodlots established in 2007, 2010 and 2013 and their adjacent parkland and grazing land. Seven randomly selected farms were sampled. The samples were analyzed using laboratory methods for soil nutrients and physical properties. Density of tree species in these established plots were also determined using quadrat technique. Tree density was higher in woodlots followed by grazing area and parkland .Soil samples showed that Soil Organic Carbon and Total Nitrogen were significantly higher in the woodlots than in the parkland and grazing lands (($p \leq 0.05$). Soil Organic Carbon was significantly higher in woodlots established in 2007 than those established in 2013. Phosphorus was significantly higher in cropland compared to woodlots and grazing land. 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. The results suggest that different agroforestry practices contribute differently to soil properties. Mixed tree woodlots contributed significantly to improving soil properties and could be considered as a strategy to sustainably restore degraded and infertile soils in the drylands.

Key words: Dryland agroforestry, soil fertility, soil organic carbon, physico-chemical properties,

INTRODUCTION

Drylands which are home to about 2 billion people (Reynolds et al. 2007) face a myriad of problems among them environmental degradation and declining land productivity which are exacerbated by climate variability. Drylands are characterized by degraded soils and low agricultural outputs (Bishaw *et al*., 2013). As the population increases, the need to increase cultivated and grazing land to provide food override major environmental considerations. Rapid human population growth has put intense pressure on the drylands leading to the increased conversion of grazing land to crop land for subsistence crop production. (Kevin *et al.,* 2011). In order to sustainably address these challenges, sustainable land use and management is imperative in the drylands. Agroforestry which is an ecologically based traditional farming practice, integrates trees into the farming systems to ameliorate soil fertility and increase agricultural productivity, control soil erosion, conserve biodiversity and diversify income for households and communities (Bishaw *et al.,* 2013) presents a critical entry point for dryland productivity and sustainability. Agroforestry enhances and maintains soil fertility which is vital for food security, reducing poverty, preserving the environmental services and for sustainability. However, as a Universal statement, this may be not true. This is because the best documented successful agroforestry practices are located largely on good soils with examples such as stable coffee or caocao production under shade in volcanic soils (Fernandez *et al.,* 1984, Russo and Budowski 1986). However, agroforestry is considered especially applicable to marginal soils with severe physical, chemical constraints like in drylands. While evidence exists for beneficial effects 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 for more vigorous analysis of agroforestry impacts, particularly on farmer-led agroforestry projects because most of analyses on agroforestry techniques use field experiments led by researchers

(Follis, 1993, Scherr and Frannzel, 2002). The effects of agroforestry practices in soils have rarely been quantified and studied in details (Schwab N. *et al.,* 2015).

Despite widespread promotion and adoption of agroforestry practices in Kenya's drylands, especially in Makueni County, little has been documented on their effects on soil properties. Drylands Natural Resources Centre (DNRC) which is a local NGO has been promoting agroforestry practices among small scale farmers of Makueni Country since 2007. There has been no follow up research done to assess their effects on soil physico-chemical properties by year of planting and comparison with other dominant agroforestry practices like multipurpose trees on crop land and grazing land. Identifying and monitoring changes in soil quality is important in counteracting ecological degradation in the fragile semi-arid areas. The objective of this study was to establish the contribution of selected agroforestry practices to soil physico-chemical properties in Makueni County of Kenya.

METHODS AND STUDY SITE

Study site

The study was conducted in Makueni County of Kenya that lies between latitude 1º 35' South and longitude 37º 10' East and 38 º 30'. 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 a typical semi-arid characterized by low and unreliable supply of enough moisture for plant growth (Mganga *et al*., 2010). The annual mean temperatures is in the range of 21-24^0 Celsius and an elevation is 800-1600m.The natural vegetation is mostly grassland and dense shrub land or woodland. The dominant soils belong to ferrolsols and are either Rhodic (red colour) or xanthic (yellow colour) and few are Aerosols and are naturally low in Nitrogen, Phosphorus and Total Organic Carbon (Mbuvi 2000).

Study design

Seven farms with mixed tree woodlots established in 2007, 2010 and 2013, parkland and grazing land were selected in Kisau Location in Makueni County for the study. In each farm, woodlots of 2007, 2010 and 2013 and adjacent parkland and grazing land were selected for tree and soil sampling. 10m x 10m plots were established along line transects laid in woodlots established in 2007, 2010 and 2013 and their adjacent plots established within parkland and grazing land thus making a total of 9 sampling points per each of the 7 farms.

Soil sampling

Four soil samples were obtained using soil auger at 0-15 cm, 15-30cm, 30-45cm, 45-60cm in a zigzag pattern at each of 10m x 10m plots established along line transect 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 sub-sample was air-dried, sieved through a 2-mm mesh and stored at 4 ºC in a refrigerator for physical and chemical analyses. 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 for PH, Soil bulky 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 ºC for 48 hours (McKenzie *et* al., Blake 1965).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, 1996). Total Nitrogen 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 N HCl 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, bulky density and porosity of the sampled soils under the three different agroforestry practices and age categories.

Data Analysis

GenStat 14th edition was used to conduct a two-way analysis of variance (ANOVA) of the effects 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 unprotected least significant difference (LSD) test, with differences considered significant at $P \leq 0.05$.

RESULTS

Tree Densities at different agroforestry practices

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

Effects of different agroforestry practices on soil chemical and physical properties

The results show that there was no significant difference on soil PH (P>0.05) across the three agroforestry practices. Soil Organic carbon (SOC) was significantly higher ((P < 0.001) in mixed tree woodlots compared to parkland and grazing lands and was 40% more compared to that in the parkland and grazing land. Total Nitrogen 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

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

Table 3 shows results of the two way ANOVA on how different agroforestry practices affected soil chemical properties by depth. The results show that different Agroforestry practices did not significantly influence the soil pH values (P>0.05) and ranged between 5.8 and 6.3 in all soil depths. Soil organic carbon significantly influenced by soil depth and generally decreased with increase in soil depth. It was significantly higher at 0-15cm and 15-30cm depths as compared to 30-45cm 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 45-60cm soil depth. Potassium was significantly higher at 0-15cm soil depth (P = 0.01) as compared to the other soil depths.

Soil Organic Carbon under different age categories of mixed tree woodlots

Soil Organic Carbon content was significantly higher (P = 0.01) under mixed woodlots established in 2007 as compared to those established in 2010 and 2013.It was 1.2%, 1.0% and 0.8% in the woodlots established in the year 2007, 2010 and 2013 respectively as shown in figure 2.

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

Results in Figure 3 shows 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 0-15cm and 15-30cm in grazing land as compared to parkland and woodlots. Total porosity decreased with increase in depth across the three agroforestry practices. Bulky density was significantly higher at depths 0-15cm and 15-30cm under grazing land as compared to cropland and woodlots. The bulky 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.

DISCUSSION

The results on tree density indicate that woodlots had higher tree density than parkland and grazing land. This is in agreement by the results of Takimoto (2007) in his research on carbon sequestration potential of

agroforestry systems in the West Africa that shown farmers kept low levels of tree density of about 20 to 30 trees/Ha to reduce shading and to facilitate easy animal ploughing. The soil organic carbon in the study area was significantly higher in woodlots than in parkland grazing land. According to Nair et al., (2010), decrease in cultivation intensity may result in an increase in 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. The results shown that Total Nitrogen was significantly higher in the woodlot compared to parkland and grazing land. The results is 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 his research on the linkages between changes in land use biodiversity and land degradation on the slopes of Mount Kilimanjaro, Tanzania.
From the results, Phosphorus content was significantly higher in parkland compared to mixed tree woodlots and grazing land. This is in agreement with the results by Kihanda et al., (2007) in his study on the effects of manure application on crop yield and soil chemical properties in long term field trial in Semi-arid, Kenya which shown an increase in phosphorus after continued application of goat manure. Phosphorus was significantly higher at 0-15cm as compared to 45-60cm soil depth. According to Fisher (1995), when litter fall, they concentrate nutrients near the soil surface.
Soil Organic Carbon increased significantly in mixed woodlots established in 2007 as compared to woodlots established in 20103. This corroborates results of study by Gupta et al. (2009) who found that soil organic carbon increased over successive years in his research on soil organic carbon and aggregation under poplar based agroforestry systems in relation to age and soil type in India.
The results show that bulk density was significantly higher in the grazing land as compared to woodlot and parkland. 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 Semi-Arid 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 bulky density and corresponding lower total porosity in grazed land as compared unglazed land while investigating hydrologic properties of grazed perennial Semi-Arid Southeastern Kenya.

CONCLUSIONS AND RECOMMENDATIONS

The productivity of soils in the drylands which are known to have low fertility and susceptible to degradation could be improved significantly through agroforestry. As it can be seen from these results and others, mixed tree woodlots contributed significantly to soil properties 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 key variables that cause climate change. Therefore is should be part of National and County government policy to promote dryland agroforestry as a strategy for carbon credit payments to the farmers and as a green economy approach. To achieve this though, there is need for retrospective studies on accurate evaluation of effects of different agroforestry practices on soil organic carbon sequestration at different soil profiles.

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