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Differences in carbon forms under two land use types in Abia State, South-east Nigeria

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Abstract. The storage of carbon in the soil helps to sustain the ecosystem of our environment. However, this study was to determine the differences in carbon forms (total carbon, organic carbon and inorganic carbon) under selected forest and pasture land use types in Abia State, Nigeria. Two profile pits were sunk on each of the land use types using free survey technique. The profile pits were sampled based on horizon differentiation for routine and special laboratory analyses. The data obtained were statistically analyzed for coefficient of variation and correlation. Total carbon had mean of 2.07% and 2.12% for profiles 1 and 2 under pasture land use and 2.46% and 2.45% for profiles 3 and 4 under forested land use. Organic carbon as indicated by the mean was higher in forest land (profile 3=1.85%, profile 4=2.09%) than in pasture land (profile 1=1.37%, profile 2=1.40%) while inorganic carbon was higher in pasture land (profile 1=0.70%, profile 2=0.72%) over forest land (profile 3= 0.39 %, profile 4= 0.36 %). Organic carbon had high variation (≥45.97% ≤ 49.38%) in profiles of the pastured land use while it had low - moderate variation (≥12.55% ≤ 27.03%) in profiles of forested land use. Also, inorganic carbon recorded moderate variation (≥16.12% ≤ 25.95%) in profiles of pasture and forest land use types. The forest land use type was determined to contain more forms of carbon when compared with the pasture land use type.

Keywords: forest and pasture land, carbon storage, climate change, horizon

Introduction

Carbon forms determine the redistribution of carbon within the soils ecosystem. Carbon enters the soil as roots, litter, harvest residues and animal manure. It is stored primarily as soil organic matter (SOM). Elliot and Bethany (1995) reported that the ability of a soil to trap and store carbon is a function of texture and structure while Potter et al. (1997) and Lal (2004) attributed soil carbon storage to texture, farming system and management and nitrogen inputs to soil. However, diverse anthropogenic activities on most land use types have altered the natural balance in the soil carbon cycle, contributing to an increase in carbon release.

The abundance of organic and inorganic carbon forms in the soil affects and is affected by climate and vegetation cover (Wang et al., 2010) and the role of organic carbon as a key factor of soil fertility and vegetation production has been documented by Halvorson et al. (2002), Yoo et al. (2006) and Ahukaemere et al. (2012). He et al. (2008) reported that human activities have adversely affected global carbon cycles and contributed to climate change that has generated visible feedbacks to terrestrial ecosystems. Most researches were focused on the surface horizons for soil organic carbon storages (Fang et al., 2002; Singh et al., 2007) with little or no studies on the soil inorganic carbon forms pool.

Forest and pasture land use types have variable impact on soil organic carbon pool and dynamics. Lal et al. (1997) stated that forested and pastured lands make up the most land area and have a potential to absorb large amounts of carbon. Understanding the impacts of forest and pasture on soil carbon pools and fluxes will allow for a better understanding of the potential of soil to absorb and release carbon (Lantz et al., 1999). The studies by Neill et al. (1997) and Yakimenko (1997) have shown that due to large amounts of biomass and high rate of biomass turnover, pasture land use absorbs more soil organic and inorganic carbon than forest land use. In contrast, Guggenberger et al. (1994) found that pasture absorbs carbon only at a slightly faster rate than forest.

Soil carbon forms studies have not comprehensively analyzed the relevant eco-regional factors, which are essential to understanding the effects of land use on soil carbon forms pools and dynamic. However, there are needs to measure and compare rate of carbon storage across land uses as these will aid to predict soil carbon forms stored and global climate change consequences. The era of climate change has facilitated research on how best to manage the situation and also determine other natural factors that will help to mitigate the effect of climate change. Researchers (Lal, 2004; Pathak et al., 2008) have shown that carbon emission is a key factor that has contributed immensely to climate change formation. There is essential need to carry out research in other to evaluate the rate of carbon storage under different land use types. Information on soil carbon forms of an area suggests best management practices to enhance and sustain carbon in the soils ecosystem. However, several studies have been conducted on effect of land use changes but not much has been done to compare the rate of different carbon forms stores with increase in soil depth under pasture and forest land use types. Hence, this study was to ascertain the differences in forms of carbon stored under profiles of forest and pasture land use types in Abia state, Nigeria.

Materials and methods

Study area

The study was conducted on the forested land at Osah,
Umuhia and the pastured land at Michael Okpara University of Agriculture, Umudike. The land uses are situated in Abia State, South-Eastern Nigeria. The study area lies between latitude 5°29' S and 5°42' N and longitudes 7°24' E and 7°29' E. The lithology of the study area is Falsebedded Sandstone (Orajaka, 1975). The area is humid tropics with annual mean rainfall range of 1800-2300mm and average temperature of 28°C (NIMET, 2015). The dominant vegetal community remains the tropical rain forest where some forest region has been altered by human activity. The forested land is a secondary forest that contains different plant species such as oil palm (Elaeis guineensis), oil bean tree (Pentaclethra macrophylla Benth.), bush mango (Ivvingia gabonensis, Aubry-Lecomte Baille.), siam weed (Chromolaena odorata L.), Velvet tamerind (Dialium quinense Willd). The pasture land consists of plant species such as southern gamba grass (Andropogon tectorum Schugi.), guinea grass (Panicum maximum Jacq.), elephant grass (Pennisetum purpureum Schumach.), spear grass (Imperata cylindrica Linn., Raeuschel.) Pigeon pea (Cajanus cajan L., Huth.), centro (Centrosema pubescens Benth.), Muccuna (Muccuna utilis Wight. Sizolobium aterrim Piper and Tracy), broom weed (Sida acuta Burm.f.), goat weed (Ageratum conyzoids Linn.). Farming is primarily the major socio-economic activity of the area.

Field study
Free survey technique was used in citing two profile pits on each of the selected sites (forest land use type and pasture land use type) of the study area. A total of four profile pits were dug for the study. Samples were collected based on horizons differentiation following the guidelines of FAO (2006). Core samples were also collected for bulk density determination. The collected soil samples were air dried, sieved using 2mm sieve in preparation for routine and special laboratory analysis.

Laboratory analysis
Particle size distribution was determined by hydrometer method (Gee and Or, 2002). Soil pH was determined using 1:2.5 soil – liquid (water) ratio (Thomas, 1996). Bulk density was determined by core method (Grossman and Reinsch, 2002). Moisture content was determined by gravimetric method (Obi, 2009). Organic carbon was determined by wet digestion method (Nelson and Sommers, 1996). Total carbon was determined by loss of ignition method (Obi, 2009). Available phosphorus was determined using Bray II method (Olsen and Sommers, 1982). Soil exchangeable bases were determined by the neutral ammonium acetate procedure (Thomas, 1982). Exchangeable acidity was determined titrimetrically after extraction of exchangeable H+ and Al3+ with 1N KCl (McLean, 1982). Effective cation exchange capacity was determined by summation of exchangeable cations.

Statistical analysis
Coefficient of variation as used by Wilding et al. (1994) was used to estimate the degree of variability existing among horizons of each profile pits. Correlation was also applied to compare relationship between different carbon forms and selected soil properties. All analyses were conducted using Genstat Statistical Package version 8.1.

Results and discussion
The result as indicated in Table 1 showed that sand particles dominated over other particles and had low variation (24.60% ±7.80%) in all profiles of pasture and forest land use types. Silt content was more predominant in forest land than pasture land. Clay content had means of 380.8 g/kg and 382.8 g/kg for profiles 1 and 2 under pasture land use while it had means of 304.0 g/kg and 320.8 g/kg for profiles 3 and 4 under forest land use. Clay increased with soil depth in all the profiles which is attributable to clay migration as a result of eluviation and illuviation process. This was in conformity to the findings of Eshett (1989) for soils underlain by Falsebedded Sandstone. Clay content had low variation across the profiles of the land use types. The variation could be associated to homogeneity in parent material and climatic condition. Bulk densities were higher in pasture land-use type (profile 1= 1.49 g/cm³, profile 2= 1.49 g/cm³) when compared to the forest land use type (profile 3= 1.35 g/cm³, profile 4= 1.36 g/cm³). However, mean values confirm that pasture land had high clay and bulk density over the forest land. This agrees with the work of Michel et al. (2010) and Yihenew and Getachew (2013) on soils under forest and non-forest land uses. Bulk density had low variation across the studied profiles. The bulk density in natural soil is used as an indicator of soil strength and/or mechanical resistance to plant growth (Gregorich et al., 1997) and can thus have an impact on distribution of soil carbon forms content. The result of the bulk density was less than the critical limits for root restriction (1.75–1.85 g/cm³) (Soil survey staff, 1996). However, soil bulk density is inversely proportional to its porosity. The moisture content of pasture land use type (profile 1= 13.70%, profile 2= 13.21%) was lower when compared to that of forest land use type (profile 3= 15.42%, profile 4= 15.38%). This could be as a result of availability of organic matter and clay content. The moisture content had low variation (≥3.39% ≤10.02%) in all profiles of pasture and forest land use types. The variation could be as a result of similarity in climatic conditions. According to Hayney et al. (2004), soil moisture retention influences the level of CO₂ influxes in the soil which may alter soil microbial biomass and potential mineralization of carbon.

Soil pH(H₂O) as stated in Table 2 were strongly acidic in all the profiles of the studied land use types according to the ratings of Chude et al. (2011). The profiles of the pasture land use was more acidic (profile 1= 5.11, profile 2= 5.11) compared to that of forest land use (profile 3= 5.19, profile 4= 5.17). Soil pH(H₂O) had low variation (≥1.14% ≤2.08%) in profiles of pasture and forest land uses. Available phosphorus as recorded in all the profiles of the land use types was below critical value (15 mg/kg) according to the ratings of Chude et al. (2011). However, available phosphorus had higher mean in profiles of forest land (profile 3= 7.98 mg/kg, profile 4= 7.89 mg/kg) when compared to the profiles of pasture land (profile 1= 7.46 mg/kg, profile 2= 7.65 mg/kg). This is in conformity to the findings of Davis (1994) and Giddens et al. (1997) that concentration of phosphorus was higher in forest than pasture land. Available phosphorus had low variation in all the profiles. Effective cation exchange capacity (ECEC) had mean of 3.71 cmol/kg and 3.40 cmol/kg in profiles 1 and 2 of pasture land use types while it had mean of 3.72 cmol/kg in profiles 3 and 4 of forest land use type. The ECEC had low variation (≥1.58% ≤13.26%) in all the profiles except for profile 1 of the pasture land where it had a moderate variation (25.49%). The ECEC was low when compared to the rating of Enwezor (1990), hence ECEC is at critical limit. According to Raji (2011) ECEC determines the soil capacity to hold and exchange natural and artificial sources of cationic plant nutrients.

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Table 1. Physical properties of the soil of the land use types

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Sand (g/kg)</th>
<th>Silt (g/kg)</th>
<th>Clay (g/kg)</th>
<th>TC</th>
<th>BD (g/cm³)</th>
<th>MC (%)</th>
<th>TP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture land</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Profile 1)</td>
<td>A</td>
<td>0 – 10</td>
<td>559.6</td>
<td>75.6</td>
<td>364.8</td>
<td>SCL</td>
<td>1.42</td>
<td>14.79</td>
</tr>
<tr>
<td></td>
<td>AB</td>
<td>10 – 35</td>
<td>539.6</td>
<td>85.6</td>
<td>374.8</td>
<td>SCL</td>
<td>1.45</td>
<td>14.76</td>
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<tr>
<td></td>
<td>Bt1</td>
<td>35 – 70</td>
<td>519.6</td>
<td>95.6</td>
<td>384.8</td>
<td>SCL</td>
<td>1.51</td>
<td>14.10</td>
</tr>
<tr>
<td></td>
<td>Bt2</td>
<td>70 – 110</td>
<td>509.6</td>
<td>105.6</td>
<td>384.8</td>
<td>SCL</td>
<td>1.53</td>
<td>12.57</td>
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<tr>
<td></td>
<td>Bt3</td>
<td>110 – 160</td>
<td>499.6</td>
<td>105.6</td>
<td>394.6</td>
<td>SCL</td>
<td>1.54</td>
<td>12.27</td>
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<tr>
<td></td>
<td>Mean</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>525.6</td>
<td>93.6</td>
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<tr>
<td></td>
<td>CV</td>
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<td></td>
<td></td>
<td></td>
<td>4.60</td>
<td>13.93</td>
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<td>Pasture land</td>
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<td></td>
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<tr>
<td>(Profile 2)</td>
<td>A</td>
<td>0 – 13</td>
<td>569.6</td>
<td>65.6</td>
<td>364.8</td>
<td>SCL</td>
<td>1.40</td>
<td>14.63</td>
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<td>13 – 45</td>
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<td>75.6</td>
<td>364.8</td>
<td>SCL</td>
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<td>14.40</td>
</tr>
<tr>
<td></td>
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<td>105.6</td>
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<td>SCL</td>
<td>1.49</td>
<td>13.25</td>
</tr>
<tr>
<td></td>
<td>Bt2</td>
<td>90 – 130</td>
<td>489.6</td>
<td>115.6</td>
<td>394.8</td>
<td>SCL</td>
<td>1.54</td>
<td>12.00</td>
</tr>
<tr>
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<td>Bt3</td>
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<td>479.6</td>
<td>115.6</td>
<td>404.8</td>
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<td>1.54</td>
<td>11.76</td>
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<tr>
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<td>Mean</td>
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<td>24.50</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Profile 3)</td>
<td>A</td>
<td>0 – 15</td>
<td>619.6</td>
<td>95.6</td>
<td>284.8</td>
<td>SCL</td>
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<td>16.03</td>
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<td>AB</td>
<td>15 – 45</td>
<td>619.6</td>
<td>95.6</td>
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<td>SCL</td>
<td>1.32</td>
<td>15.93</td>
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<tr>
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<td>Bt1</td>
<td>45 – 60</td>
<td>599.6</td>
<td>95.6</td>
<td>304.8</td>
<td>SCL</td>
<td>1.35</td>
<td>15.25</td>
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<tr>
<td></td>
<td>Bt2</td>
<td>60 – 120</td>
<td>579.6</td>
<td>105.6</td>
<td>314.8</td>
<td>SCL</td>
<td>1.39</td>
<td>15.01</td>
</tr>
<tr>
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<td>120 – 180</td>
<td>549.6</td>
<td>115.6</td>
<td>334.8</td>
<td>SCL</td>
<td>1.39</td>
<td>14.90</td>
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<tr>
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<td>Mean</td>
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<td>(Profile 4)</td>
<td>A</td>
<td>0 – 11</td>
<td>609.6</td>
<td>95.6</td>
<td>294.8</td>
<td>SCL</td>
<td>1.31</td>
<td>15.97</td>
</tr>
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<td>AB</td>
<td>11 – 35</td>
<td>599.6</td>
<td>105.6</td>
<td>314.8</td>
<td>SCL</td>
<td>1.34</td>
<td>15.90</td>
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<tr>
<td></td>
<td>Bt1</td>
<td>35 – 60</td>
<td>589.6</td>
<td>105.6</td>
<td>324.8</td>
<td>SCL</td>
<td>1.35</td>
<td>15.33</td>
</tr>
<tr>
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<td>60 – 120</td>
<td>549.6</td>
<td>115.6</td>
<td>334.8</td>
<td>SCL</td>
<td>1.39</td>
<td>14.99</td>
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<tr>
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<td>Bt3</td>
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<td>539.6</td>
<td>125.6</td>
<td>334.8</td>
<td>SCL</td>
<td>1.41</td>
<td>14.72</td>
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<td>CV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.40</td>
<td>10.40</td>
</tr>
</tbody>
</table>

*TC = textural class, BD = bulk density, MC = moisture content, TP = total porosity, SCL = sandy clay loam, CV = coefficient of variation, <15 = low variability, >/= 15<35 = moderate variability, >35 = high variability.
Table 2. Chemical properties of the soil of the land use types

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>pH ((\mathrm{H_2O}))</th>
<th>TEB (cmol/kg)</th>
<th>TEA (cmol/kg)</th>
<th>ECEC (cmol/kg)</th>
<th>OC (%)</th>
<th>IC (%)</th>
<th>TC (%)</th>
<th>OC:IC</th>
<th>Av.P (mg/kg)</th>
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</thead>
<tbody>
<tr>
<td>Pasture land (Profile 1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0 – 10</td>
<td>5.28</td>
<td>2.76</td>
<td>1.44</td>
<td>4.20</td>
<td>2.12</td>
<td>0.54</td>
<td>2.66</td>
<td>3.93</td>
<td>8.13</td>
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<tr>
<td>AB</td>
<td>10 – 35</td>
<td>5.12</td>
<td>3.06</td>
<td>1.79</td>
<td>4.85</td>
<td>1.69</td>
<td>0.59</td>
<td>2.28</td>
<td>2.86</td>
<td>7.96</td>
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<tr>
<td>Bt1</td>
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<td>5.09</td>
<td>2.31</td>
<td>1.73</td>
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<td>0.65</td>
<td>2.15</td>
<td>2.31</td>
<td>7.48</td>
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*TEB = total exchangeable base, TEA = total exchangeable acid, ECEC = effective cation exchange capacity, OC = organic carbon, IN = inorganic carbon, TC = total carbon, Av.P = available phosphorus, CV = coefficient of variation, <15 = low variability, >/= 15<35 = moderate variability, >35 = high variability.*
Total carbon (Table 2) had means of 2.07 g/kg and 2.12 g/kg in profiles 1 and 2 of pastured land and 2.45 g/kg and 2.46 g/kg in profiles 3 and 4 of forested land. Total carbon had moderate variation (≥23.48% ≤24.73%) in pastured land use and low variation (≥28.25% ≤11.54%) in forested land. The variability could be due to amount and rate of decomposition of organic matter. Total carbon decreased down the profiles with increasing soil depth and had the highest value at the A-horizon. The higher values recorded in the forested land may be due to vegetal cover and amount of organic matter deposit. The high total carbon content in the surface horizons is contrary to the findings of Bačes (1996) and Abebayehu (2013) who reported high total carbon content in the subsurface horizons. The organic carbon (OC) of the soils was higher in the forested land (profile 3 = 1.85%, profile 4 = 2.09%) when compared to that of the pastured land (profile 1 = 1.37%, profile 2 = 1.40%), which agrees with the findings of Wang et al. (2010). Organic carbon had high variation (≥45.97% ≤49.38%) in profiles of pastured land while it had low to moderate variation (≥12.55% ≤27.03%) in profiles of the forested land. The variation could be attributed to amount of organic matter deposit, rate of mineralization, and plant uptake. Organic carbon decreased down with increasing soil depth and recorded the highest value in A-horizon in all the profiles. But the A-horizons forested land has more OC compared to that of pastured land. The high concentration of OC in the surface horizon is not connected with the deposition of more organic matter on the soil surface. However, Bulluck et al. (2002) and Schröth et al. (2002) stated that the amount of organic carbon in the soil represents a balance between primary productivity as influenced by environmental conditions and biologically-mediated decomposition processes.

Inorganic carbon was higher in the profiles of the pastured land (profile 1 = 0.70%; profile 2 = 0.72%) when compared to those of the forested land (profile 3 = 0.39%; profile 4 = 0.36%). This result conforms to the findings of Wang et al. (2010) that inorganic carbon is high in pastured land when compared to forested land. Inorganic carbon had moderate variability (≥16.12% ≤25.95%) in both the pastured and forested land use types. The variation could be as a result of translocation process within the profiles. Soil inorganic carbon increased down the soil depth in all the studied profiles. This could be attributable to high presence of inorganic carbon that usually accompanies clay content of the soil, high concentrations of CO₂ as depth increases because of the anaerobic conditions that exist at greater depths (Donahue and Miller, 1990). The Bt horizons possess more (>60%) inorganic carbon when compared with other horizons across the profiles. This could be attributed to nutrient migration from the surface horizon down to the subsurface horizons.

The ratio of organic and inorganic carbon (OC:IC) was high for soil under forest land (profile 3 = 4.95, profile 4 = 6.08) compared to the soil under pasture land (profile 1 = 2.19, profile 2 = 2.27). The OC:IC had high variation (CV=42.86%-89.20%) in all the profiles except for profile 4 where it had moderate variation (CV=31.27%). However, the OC:IC decreased down the profile in a specific trend except for profile 3 under forest land that had no specific trend of decrease down the profile. The ratio indicated the ability of the forest land over the pasture land in increasing the carbon content of soils, which is essential for fertility sustainability. According to Shi et al. (2012), inorganic carbon was mainly affected by climate, soil physical and chemical properties, while organic carbon was predominantly affected by biotic and climatic factors.

Relationship between forms of carbon and selected soil properties are presented in Table 3. Clay particle correlated negatively and significantly (r = -0.70, p = 0.05) with total carbon, while it had positive significant correlation (r = 0.91, p = 0.05) with inorganic carbon. Furthermore, Clay had negative and highly significant correlation (r = -0.65, p = 0.01) with organic carbon. Bulk density correlated negatively and significantly (r = -0.81, p = 0.05) with total carbon and organic carbon but had a positive significant correlation (r = 0.96, p = 0.05) with inorganic carbon. Soil pH(H₂O) correlated significantly positively (r = 0.98, p = 0.05) with total carbon and organic carbon, while it had a negative significant relationship (r = -0.81, p = 0.05) with inorganic carbon. Available phosphorus had a positive significant relationship with total carbon and organic carbon (r = 0.87, r = 0.74, p = 0.05) and negative significant relationship with inorganic carbon (r = -0.75, p = 0.05). Effective cation exchange capacity had a highly significant positive correlation (r = 0.52, r = 0.54, p = 0.01) with total carbon and organic carbon while it correlated negatively and highly significantly (r = -0.53, p = 0.01) with inorganic carbon. However, the positive correlation implies that increase in one soil property increases the other, while negative correlation implies that increase in one soil property decreases the other and vice versa.

Table 3. Relationship between forms of carbon and selected soil properties

<table>
<thead>
<tr>
<th>Soil property</th>
<th>Total carbon</th>
<th>Organic carbon</th>
<th>Inorganic carbon</th>
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<td>Av.P</td>
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<td>0.74**</td>
<td>-0.75**</td>
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<td>Bulk density</td>
<td>-0.81**</td>
<td>-0.77**</td>
<td>0.96**</td>
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<td>Clay</td>
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<td>-0.65*</td>
<td>0.91**</td>
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<td>ECEC</td>
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<td>0.54**</td>
<td>-0.53**</td>
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<tr>
<td>Moisture content</td>
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<td>0.83**</td>
<td>-0.97**</td>
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<tr>
<td>pH(H₂O)</td>
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<td>-0.81**</td>
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<td>0.85**</td>
<td>-0.81**</td>
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<td>Silt</td>
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<td>-0.37ns</td>
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<tr>
<td>Total porosity</td>
<td>0.81**</td>
<td>0.77**</td>
<td>-0.96**</td>
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</table>

*Av.P = available phosphorus, ECEC= effective cation exchange capacity, *= significant at correlation level (p<0.05), **= significant at correlation level (p<0.01), ns= non-significant.
Conclusion

The result of the studied land use types as determined showed that forested land stores more carbon forms compared with that of the pastured land. Studies revealed that the surface horizon stores more carbon forms compared with the subsurface horizons. Achieving more carbon storage in soils of pastured land involves increasing plant productivity, which can be achieved through improved water and nutrient management, as well as through restricted grazing practices. However, improved management practices that protect pastured land and forested land soils from erosion and improve plant productivity through organic matter addition, avoidance of bush burning can restore lost soil carbon over vast areas.

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