INTRODUCTION

Temperate and deciduous forest covers major portion of terrestrial ecosystem in India. The two forest types with different dominant tree species differ in litter quality and root exudates, thereby exerting species specific impact on soil properties and microbial activity. Natural forests that occur all over the world are formed through natural regeneration following stand-replacing disturbances by anthropogenic activities or by extreme natural events (Yang et al., 2010; Wang and Yang 2007). Approximately 30% of total land area is covered by forest (boreal, temperate and tropical forest) (Holden and Treseder 2013). These forests are the source of global terrestrial carbon in which temperate forest ecosystem plays a major role in carbon sequestration from increasing atmospheric carbon dioxide, as it covers the major portion of terrestrial land (Myneni et al., 2001). Forest ecosystem has a high carbon density and is considered to have a considerable potential as carbon sinks (Halliday et al., 2003; Perruchoud et al., 1999) containing about 80% of terrestrial above ground carbon on one hand and more than 70% of all soil organic carbon on the other (Batjes, 1996; Jobba`gy and Jackson, 2000). To sustain the quality and productivity of soils, knowledge of Soil Organic Carbon (SOC) in terms of quality and quantity is essential. Soil organic matter (SOM) and SOC constitute usually a small portion of soil, but they are one of the most important components of ecosystems. Decline in soil organic carbon has major implications for the maintenance of soil health (Bhattacharyya et al., 2007). Global warming and its effect on soils in terms of SOC management have led to several quantitative estimates for carbon content in the soils (Eswaran et al., 1993; Velayutham and Bhattacharyya, 2000; Kimble et al., 1990). Recent global concerns over increased atmospheric CO₂, which can potentially alter the earth’s climate systems, have resulted in rising interest in studying SOC changes and carbon sequestration capacity in various ecosystems. The concern about increasing atmospheric CO₂ and its role in future global climate change has lead soil

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scientists to quantify soil organic carbon content (also referred as stocks or storage) and residence time in specific locations to better constrain global carbon budget. The common method of quantifying soil organic carbon is to use the total soil organic carbon data for specific sites and scale up to regional or global estimates using soil maps (Lacelle et al., 2001). The soil fertility refers to the level of mineral nutrients essential for plant growth and development, and the chemical characteristics that effect nutrient availability to the plant. The fertile soil has the capacity of soil to provide nutrients on adequate quantity and in proper balance to produces abundant crops under suitable environmental conditions such as light, moisture, temperature and the other physical conditions of the soil, soil has different types of properties: physical, chemical and biological properties. Physical properties of soil include: soil texture (gravel, silt, and clay), soil structure (oblique cube, granular, plate shaped, prism-like, columnar, and oblique cube with flat edges), soil specific weight, lime and gypsum contents of soil, soil aeration, soil atmosphere, soil temperature, soil color, and soil and water interaction.

Microbial community composition plays a crucial role in determining the diversity of carbon mineralization processes and their stability in response to stress (Ramsey et al., 2005; Schimel et al., 2007; Nottingham et al., 2009). Soil microbes, bacteria, archea , and fungi play a diverse and often critical role in these ecosystem services. The vast metabolic diversity of a soil microbes means their activities drive or contributes to the cycling of all major elements contribute to the cycling of all major elements (C, N, P) and this cycling affects the structure and the functions of soil ecosystems as well as the ability of soils to provide services to people (Aislabie and Deslippe, 2013) Therefore, the present study was designed with the following objectives: firstly to examine the variation in SOC stocks in different forest types and secondly to examine the relationship of SOC stock with microbial population.

**METHODOLOGY**

The study has been undertaken in two different natural forest types of India. The two forest types are classified into deciduous and temperate forest. Study sites were selected at different altitudes viz. < 500m, 1000 m and > 1500 m in different locations in Uttarakhand. Soil samples were collected from Dalbergia sissoo, Tectona grandis, Shorea robusta, Mix forest, Pinus Roxburghii, Cedrus deodara, Quercus leucoc-trichophora forest. Stratified sampling design was followed for soil sample collection. At each altitude, three sites were selected to cover the variations at sampling site at the selected altitude. Three replicates were collected from each study site Soil samples were collected from predetermined depths i.e. 0-30 cm, samples were transferred to a polythene bag and the bag was tightly closed with proper labeling. In the laboratory, samples were divided into two parts one for microbiological parameters which were stored in deep fridge at 4°C temperature and one for physic-chemical parameters the sample for physico-chemical parameters were air dried, grinded and sieves through 2 mm mesh sieve. Soil pH was determined by using calomel electrode by 1:2.5 soil water ratios. Soil organic carbon (SOC) was determined by (Walkley and Black Method, 1934). Soil texture analysed by

Hydrometer method (Bouyoucous, 1962). Bulk density of every sample was estimated by standard core method (Wilde et al., 1964). Soil available nitrogen was analysed Subbiah and Asija (1956). Potassium by (Hanway and Heidel, 1952), Determination of available phosphorus is by the Olsen method (Olsen, et al., 1954).

**Bacteriological analysis:** For the isolation of bacteria, serial dilution method given by Johnson and Curl 1972, was followed using Nutrient Agar medium. Nutrient agar was poured in each sterilized petridishes. For each dilution two petridishes were used. 1mL of the aliquot was spread on the medium of petridish. Then the petridishes were incubated at 37°C for 48 hours in inverted position. After 48 hours the different colonies were counted with the help of colony counter. The number of bacteria per gram soil was calculated by using the following formula- Three replicates were maintained for each sample. Inoculated Petri plates were then incubated upside down at 30 ± 1°C for 24 hours in a BOD incubator. The number of bacterial colonies was counted and the Colony Forming Unit (CFU) was calculated based on dry weight basis.

CFU of bacteria g⁻¹ dry weight= Number of colonies x dilution factor x inoculums

Dry weight of Soil (g)

**SOC Pool Estimation**

Amount of coarse fragments was estimated and deducted from the soil weight to get an accurate soil weight per ha basis for soil organic carbon pool estimation. The data for SOC pool was calculated by using the following equation as suggested by IPCC Good Practice Guidance for LULUCF (IPCC, 2003):

**Equation for SOC**

\[
SOC = \sum_{\text{Horizon}=n} \left( \frac{([SOC] \times \text{Bulk density} \times \text{depth} \times (1 - \text{C frag}) \times 10)}{\text{Horizon} \times 1} \right)
\]

Where,

SOC = Representative soil organic carbon content for the forest type and soil of interest, tons C ha⁻¹

SOC_{horizon} = Soil organic carbon content for a constituent soil horizon, tons C ha⁻¹

[SOC] = Concentration of SOC in a given soil mass obtained from analysis, g C (kg soil)⁻¹

Bulk density = Soil mass per sample volume, tons soil m⁻³ (equivalent to Mg m⁻³)

Depth = Horizon depth or thickness of soil layer, m

C Frag = % volume of coarse fragments / 100, dimensionless

**Statistical Analysis**

Data were summarized as mean ± SD (standard deviation).Pearson correlation analysis was done to assess associations between the variables. A two tailed values less than 0.005(p<0.05) was considered statistically significant.
RESULT AND DISCUSSION

Comparisons between chemical properties and microbiological properties of soils under different forest species found at different altitudes and under different forest tree species of Uttarakhand are presented in (Table:-1). In the forest, the different tree species have a different outcome along the carbon storage of ecosystem, for example superficial rooting coniferous species tend to accumulate Soil Organic Matter (SOM) in the forest floor, but are low in the mineral soil, compared with deciduous trees (Jandl et al., 2007). The soil C concentration varies across the landscape but more soil C variability is found at varying elevations (Powers and Schlessinger 2002). In the present study SOC ranged between 0.9 (Dalbergia sissoo) to 5.9% (Quercus leucotrichophora), SOM ranged from 1.6 (Dalbergia sissoo) to 10.1% (Quercus leucotrichophora). SOM in the form of surface residues can also influence water retention directly by reducing evaporation rates and increasing the infiltration of water. Its impact on soil biology is even more enormous. Most soil organisms are heterotrophic and gain their energy from the decomposing of the organic matter. In the present study Carbon stock ranged from 21.8 (Dalbergia sissoo) to 91.2 (Quercus leucotrichophora). Soil pH in the present study ranged from 5.6 under Pinus Roxburghii to 6.9 under mixed forest. The values of available N varied significantly under different forest Species. Values of available N in the study area ranged between 0.01 % (Dalbergia sissoo) to 0.04% (Quercus leucotrichophora, Shorea Robusta, Mixed forest). The availability of N depends to a large extent on the amount and properties of organic matter (de Hann 1977). The amount of P indicates the character of soil to allow specific plants to grow at a particular site, which is also useful to identify the vegetation type of the area. It has been reported that a large proportion of P is stored in the forms that are unavailable to plants (Murphy 1958). Available P ranged from 0.001% (Dalbergia sissoo) to 0.006% (Cedrus deodara) in the present study.

Potassium performs very vital processes like regulating transpiration and respiration, influencing enzyme action, and synthesis of carbohydrates and proteins, etc. (Brady 1996). The decrease of K is caused by leaching and drainage, which results in the destruction of vegetation (Basmumtary and Bordonlo 1992). Available K ranged from 0.009% (Pinus Roxburghii) to 0.01% (Tectona grandis and Mixed forest).

Among different forest vegetation we found highest colony forming units (CFU) in the soil samples collected from Mixed forest (119 CFU) and lowest was observed under Dalbergia sissoo forest (22.67) at 10^5 dilution.

From the particle size distribution, significant differences of soil texture were detected. Soils classified according to its texture as: Loam, Loamy sand, Sandy loam, Silty loam clay loam (Table:-2).

Table 2 Soil texture under different forest species of Uttarakhand

<table>
<thead>
<tr>
<th>Species</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Soil texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quercus leucotrichophora</td>
<td>68.43</td>
<td>13.66</td>
<td>17.90</td>
<td>Loam</td>
</tr>
<tr>
<td>Pinus Roxburghii</td>
<td>57.60</td>
<td>28.33</td>
<td>14.06</td>
<td>Silty loam</td>
</tr>
<tr>
<td>Cedrus deodara</td>
<td>66.23</td>
<td>15.83</td>
<td>17.93</td>
<td>Loam</td>
</tr>
<tr>
<td>Shorea robusta</td>
<td>69.28</td>
<td>12.66</td>
<td>18.05</td>
<td>Loam</td>
</tr>
<tr>
<td>Dalbergia sissoo</td>
<td>84.38</td>
<td>7.33</td>
<td>8.28</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>Mixed forest</td>
<td>53.30</td>
<td>21.33</td>
<td>25.36</td>
<td>Clay loam</td>
</tr>
<tr>
<td>Tectona grandis</td>
<td>55.48</td>
<td>18.85</td>
<td>25.66</td>
<td>Clay loam</td>
</tr>
</tbody>
</table>

Table 3 Correlation studies under different forest species

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Carbon stock</th>
<th>Sand</th>
<th>silt</th>
<th>clay</th>
<th>pH</th>
<th>OC</th>
<th>OM</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Bact CFU</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature forest</td>
<td>91.2±4.8</td>
<td>5.8±0.2</td>
<td>5.9±0.4</td>
<td>10.1±0.7</td>
<td>0.04±0.006</td>
<td>0.0222</td>
<td>±0.0002</td>
<td>0.001</td>
<td>±6.11</td>
<td>72.33</td>
<td>±0.0008</td>
</tr>
<tr>
<td>Pinus Roxburghii</td>
<td>44.9±3.9</td>
<td>5.6±0.2</td>
<td>2.7±0.4</td>
<td>4.6±0.7</td>
<td>0.03±0.003</td>
<td>0.0016</td>
<td>±0.0009</td>
<td>±0.0006</td>
<td>72.33</td>
<td>±0.0005</td>
<td>±0.001</td>
</tr>
<tr>
<td>Cedrus deodara</td>
<td>46.7±3.9</td>
<td>6.2±0.1</td>
<td>2.2±0.8</td>
<td>3.8±1.3</td>
<td>0.02±0.002</td>
<td>0.006</td>
<td>±0.009</td>
<td>0.080</td>
<td>±0.0008</td>
<td>±0.001</td>
<td>±2.0</td>
</tr>
<tr>
<td>Dry deciduous forest</td>
<td>21.8±1.8</td>
<td>6.4±0.05</td>
<td>0.9±0.07</td>
<td>1.6±0.1</td>
<td>0.01±0.002</td>
<td>0.001</td>
<td>±0.0002</td>
<td>±0.0001</td>
<td>±1.5</td>
<td>106.7</td>
<td>±0.0001</td>
</tr>
<tr>
<td>Dalbergia sissoo</td>
<td>83.0±4.6</td>
<td>6.0±0.1</td>
<td>5.0±0.6</td>
<td>8.6±1.0</td>
<td>0.04±0.40</td>
<td>0.002</td>
<td>±0.009</td>
<td>±0.0001</td>
<td>±4.9</td>
<td>119.0</td>
<td>±0.0002</td>
</tr>
<tr>
<td>Shorea robusta</td>
<td>73.6±3.8</td>
<td>6.9±0.25</td>
<td>3.3±0.4</td>
<td>5.7±0.8</td>
<td>0.04±0.005</td>
<td>0.002</td>
<td>±0.01</td>
<td>52.00</td>
<td>±0.0005</td>
<td>±0.001</td>
<td>±3.6</td>
</tr>
<tr>
<td>Mixed forest</td>
<td>41.1±1.1</td>
<td>6.8±0.0</td>
<td>1.3±0.2</td>
<td>3.1±0.7</td>
<td>0.02±0.004</td>
<td>0.002</td>
<td>±0.01</td>
<td>22.67</td>
<td>±0.0005</td>
<td>±0.001</td>
<td>±3.6</td>
</tr>
</tbody>
</table>

As C and N are intimately linked and primary source of C and N is found in the soil as an organic matter, in the form of plants and animal’s debris (Aber and Melillo 1991). Available N showed a significantly positive relationship with organic C (r=0.797) Available P was positively correlated with organic C (r=0.733). Gupta and Sharma (2008) also showed that organic C and P were positively correlated chiefly because all these attributes were intimately linked with soil humus. Gupta and Sharma (2008) also showed that N and K were positively correlated (0.83) chiefly because all these attributes are intimately linked with soil humus.

Table 1 Soil chemical and microbiological properties under different forest species of Uttarakhand (Mean values and SD)

<table>
<thead>
<tr>
<th>Species</th>
<th>carbon stock</th>
<th>pH</th>
<th>OC%</th>
<th>OM%</th>
<th>N%</th>
<th>P%</th>
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<td>0.04±0.006</td>
<td>0.0222</td>
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<td>44.9±3.9</td>
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<td>4.6±0.7</td>
<td>0.03±0.003</td>
<td>0.0016</td>
<td>±0.0009</td>
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</tbody>
</table>
Soil physico-chemical factors, ambient temperature and/or substrate availability were found to influence soil bacterial growth and population density at various level of significance (p<0.05).

The negative correlation between the pH and SOC was found in the present study (r=-0.189) and is also confirmed in the studies (McIntosh and Allen, 1993; Shi et al., 2012), concluding that acidified soil inhibits the decomposition of SOC, thus avoids loss of carbon from the soil to the atmosphere (Shi et al., 2012). In present study, our results noticeably demonstrated that soil textural differences significantly affected bacterial population, and that smaller size fractions (silt and clay) host higher bacterial community than larger size particles (sand). There were strong correlations between percentages of clay contents and bacterial population. The roots of trees and grasses are additional major sources of organic matter to the soil, as well as sites of plant and soil microorganism interactions. Root exudates affect the soil bacterial community structure (Benizri and Guckert 2003) and their quality and quantity may differ in different vegetation ecosystems. A positive correlation has been found between soil bacterial colonies and carbon and nutrient contents, consistent with the findings obtained by Chan et al. 2006. Soil bacteria have a negative correlation with sand (r = -0.457) and soil pH (r = -0.0110)

CONCLUSION

In this study, the carbon and nitrogen levels of the forest ecosystem soils were high and could provide enough nutrients for the growth of soil bacteria. From the study, it may be conclude that the biochemical as well as microbial properties of soil is significantly affected by forest type. The edaphic properties and vegetation types are driving bacterial population in the deciduous and temperate forest of Uttarakhand.

Acknowledgments

we thankfully acknowledge the financial support provided by the Department of Science and Technology, Government of India, New Delhi, vide its Project No. DST No. No. Sr/FTP/ES-73/2014dt/07/10/2015

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How to cite this article:

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