Carbon Sequestration: Estimation of Soil Organic Carbon Pool in Agroforestry Land Use in Uttarakhand State

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Introduction

Increase of CO$_2$ in atmosphere is attracting global concern. Concentration of atmospheric CO$_2$ can be lowered either by reducing emissions or by taking CO$_2$ out from the atmosphere and storing it in the terrestrial, oceanic or aquatic ecosystems. Agroforestry defined as sustainable management system for land use (Bene et al., 1977) but, some time, criticized for using the land of producing crops for growing trees (Matta and Jordan, 1995) and below ground competition between agriculture and forestry crops for nutrients, moisture, etc. Trees being perennial remain on the site for many years and shed their litter on soil surface. Most of the carbon enters the ecosystem via photosynthesis in the leaves. More than half of the assimilated carbon eventually transported to below ground via root growth, root exudates (of organic substances) and litter decomposition. Therefore, soil contains the major stock of C in the ecosystem. Soil organic carbon levels in agricultural sites are getting depleted; therefore, agroforestry practice would not only improve soil quality but also increase the amount of carbon sequestered. Jha and Gupta (2002) have observed about one and half times more organic carbon under poplar plus wheat agroforestry than wheat farming alone.

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Soil plays an important role in carbon sequestration by increasing soil organic carbon. Carbon pool in the soil is higher than the vegetation carbon pool. Though, forest is the most important land use for mitigation of GHGs, agroforestry intervention in the farming sector, appears to be the most suitable land use strategy for carbon sequestration. Agroforestry not only helps in conserving soil nutrients but also in enhancing the soil fertility and carbon sequestration (Montagini and Nair, 2004). Agroforestry has been recognized to be of special importance as a carbon sequestration strategy because of its applicability in agriculture lands as well as in reforestation programmes (Cairns and Meganck, 1994). The potential of agroforestry as a strategy for carbon sequestration has not yet been fully recognized so far. Average carbon storage by agroforestry practices has been estimated as 9, 21, 50, 63 Mg C/ha in semiarid, sub-humid, humid and temperate regions. For small holder agroforestry system in tropics, potential C sequestration rate range from 1.5 to 3.5 Mg C/ha/yr. Agroforestry can also have an indirect effect on C sequestration when it helps decrease pressure on natural forests (Schroeder, 1994).
Within tropical region, it has been estimated that 1 ha of sustainable agroforestry could potentially offset 5 to 20 ha of deforestation (Dixon, 1995).

Accurate quantification of soil organic carbon is necessary for detection and prediction of changes over a period of time. No systematic study has been undertaken to estimate the soil organic carbon pool in agroforestry land uses in Uttarakhand. Therefore, a study was conducted to estimate SOC pool in the soils under this land uses. Information generated from this study can be used as a benchmark for future work to estimate the changes in SOC pool in this land uses in future.

**Materials and Methods**

The input of organic matter is largely from aboveground litter, forest soil organic matter tends to concentrate in the upper soil horizons, with roughly half of the soil organic carbon of the top 100 cm of mineral soil being held in the upper 30 cm layer. The carbon held in the upper profile is often the most chemically decomposable, and the most directly exposed to natural and anthropogenic disturbances (IPCC, 2003). Therefore, soil organic carbon pool was estimated up to the depth of 30 cm in this study.

This study was conducted in whole of Uttarakhand which is located between 28° 43’ – 31° 27’ N latitudes and 77° 34’ – 81° 02’ E longitudes. The average annual rainfall of the state, as recorded is 1,547 mm. In agroforestry, SOC pool was estimated in wheat – poplar and sugar cane – poplar agroforestry model which were available in Uttarakhand. In most of the area, wheat – poplar model is in use while in few places sugarcane – poplar model is in practice. Agroforestry land uses were mainly available in Hardwar and U.S. Nagar districts.

Sampling sites were selected randomly in different districts of Uttarakhand as per the availability of particular agroforestry model. At each sampling site, an area of about ½ km were covered and five soil samples from this area for soil organic carbon estimation and two separate samples for bulk density and coarse fragment estimation were collected. It was ensured that sampling points typically represent the study area. Variation in the number of samples was due to difference in area available under particular forest stand. Details of the sites from where soil samples were collected in different plantations and numbers of sample collected are presented in Table 1.

Latitude, longitude and altitude of each sampling site were recorded by GPS. Forest floor litter of an area of 0.5 m x 0.5 m, at each sampling point was removed and a pit of 30 cm wide, 30 cm deep and 50 cm in length was dug out. Soil from 0 to 30 cm depth, from three sides of the pit, scraped with the help of Kurpee. This soil mixed thoroughly and removed gravels. Kept in a polythene bag and tightly closed with thread with proper labeling. In the laboratory, samples were air dried and after drying the samples were, grind it and sieve it through 100 mesh sieve (2 mm sieve). This sieved sample used for soil organic carbon estimation. Soil organic carbon was estimated by standard Walkley and Black (1934) method. Amount of coarse fragments were estimated in each sample collected from different plantations and deducted from the soil weight to get an accurate soil weight per ha basis and soil organic carbon estimation. Bulk density of every site was estimated by standard core method (Wilde et al., 1964). All the methods used in this study are in accordance to Ravindranath and Ostwald (2008). The data for SOC pool was calculated by using the equation as suggested by IPCC Good Practice Guidance for LULUCF (IPCC, 2003).

**Results and Discussions**

SOC pool in the soils under sugarcane – poplar model was 33.48 t ha⁻¹ (CI 22.21 – 27.40) was higher in comparison to wheat – poplar which contain 24.81 t ha⁻¹ (CI 24.34 – 42.63). Sugarcane – poplar has 34.95 per cent higher SOC pool as

<p>| Table 1. Area covered under agroforestry land use in Uttarakhand for SOC pool estimation |
|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>S. no.</th>
<th>Altitude range (m)</th>
<th>Location</th>
<th>District</th>
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<tbody>
<tr>
<td>Poplar - Wheat</td>
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<td></td>
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<td></td>
<td>U S Nagar</td>
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<tr>
<td>Poplar - Sugarcane</td>
<td></td>
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<tr>
<td>2.</td>
<td>248 - 283</td>
<td>Majra, Tanda Kushalpur, Chanakpur Kishanpur</td>
<td>U S Nagar</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hardwar</td>
</tr>
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compared to wheat–poplar. Mitigation potential was worked out and observed that sugarcane–poplar model can hold 1.35 times more SOC in the soils as compared to wheat–poplar model (Table 2). Standard error in both the cases was less than 5 per cent which indicates lesser variation in the data. There is higher carbon sequestration in agroforestry as compared to agriculture as crops cannot hold the carbon for a longer duration while in agroforestry trees can hold the carbon for a longer duration. Secondly, for agriculture, fields are completely ploughed and carbon had great opportunity to escape (as CO₂) due to opening up of the field. In agroforestry models, trees normally planted at 4 x 4 or 4 x 5 m spacing and during the ploughing of field, some area has to leave unploughed near the trunks of the trees. This area helps to keep carbon intact in the soil and not allow it to escape. Simultaneously, standing trees will produce litter and after decomposition it will enhance the SOC pool in these soils. Jha et al. (1997) reported that the carbon store in forestland is the highest followed by agroforestry, agricultural lands and barren lands and agroforestry has 37.28 per cent higher soil organic carbon store in comparison to agriculture and 121 per cent higher than in barren land.

Agroforestry not only helps in conserving soil nutrients but also in enhancing the soil fertility and carbon sequestration (Workman et al., 2003; Montagini and Nair, 2004. Trees in agriculture can increase the amount of carbon stored in the soil (Kursten, 2001). Singh et al. (1997) compared soil organic carbon content of open land to agriculture crops, agroforestry with Eucalyptus, with Acacia, with poplar and reported an increase in soil organic carbon contents in agroforestry system. Duguma et al. (2001) reported that carbon in total biomass in Cacao agroforestry was much greater (304 Mg C/ha) than food crop field (85 Mg C/ha). These reports indicate that agroforestry accumulate considerably more carbon than agriculture crops, of course less than natural forests.

Lack of reliable estimates on the extent of area under agroforestry system in the different ecological zones is a serious problem in projecting the extent to which agroforestry practices could encounter carbon emission from deforestation. Nevertheless, the IPCC Report (2000) estimated the area currently under agroforestry worldwide 400 million ha with an estimated carbon gain of 0.72 Mg C/ha/yr, with potential for sequestration 26 Tg C/yr by 2010 and 45 Tg C/yr by 2040 (1 Tg = 10¹² g or 1 million tons). That Report also estimates that 630 million ha of unproductive cropland and grassland could be converted to agroforestry worldwide, with the potential to sequester 391 Tg C/yr by 2010 and 586 Tg C/yr by 2040. These studies recognized that agroforestry improvement practices generally have lower carbon uptake potential than land conversion to agroforestry because existing agroforestry system have much higher carbon stock than degraded croplands and grasslands that can be converted to agroforestry. At a global scale, it has been estimated that agroforestry systems could be implemented on 585 to 1,275 x 10⁶ ha of technically suitable land and this system could store 12 to 228 Mg C/ha under the prevalent climatic and edaphic conditions (Dixon, 1995).

In temperate region, potential carbon storage with agroforestry ranges from 15 to 198 Mg C/ha with a model value of 34 Mg C/ha. Planting windbreaks around 300,000 unprotected farms in USA would result in 120 million trees (@ 400 trees/farm) storing 3.5 Tg C in 20 years or 0.175 Tg C/yr (NAC, 2000). In fact, dynamics of the amount of carbon sequestration in agroforestry is based on the crop rotation, tree species planted, age of trees, amount of litter fall and its decomposition, etc. Research on these aspects needs to be carried-out.

Results of one–way ANOVA indicates that SOC pool between the two models were significantly different at 0.05 level (Variance ratio, F = 5.308; p < 0.05). SOC pool under sugarcane–poplar was significantly higher from the SOC pool under wheat–poplar.

International Conference on Soil and the Greenhouse Effect, the Wageningen, 1989 (1990) recommended that

<table>
<thead>
<tr>
<th>S. no.</th>
<th>Vegetation cover</th>
<th>SOC pool (t/ha)</th>
<th>Mitigation potential</th>
<th>SE</th>
<th>Confidence interval (t ha⁻¹)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Land use wise)</td>
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<td>Confidence interval (t ha⁻¹)</td>
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<td></td>
<td></td>
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<td>(α = 0.05)</td>
</tr>
<tr>
<td>1</td>
<td>Wheat - Poplar</td>
<td>24.81 ± 12.74</td>
<td>1.00</td>
<td>1.30</td>
<td>22.21 - 27.40</td>
</tr>
<tr>
<td>2</td>
<td>Sugarcane - Poplar</td>
<td>33.48 ± 15.84</td>
<td>1.35</td>
<td>4.23</td>
<td>24.34 - 42.63</td>
</tr>
<tr>
<td></td>
<td>Over all agroforestry</td>
<td>25.92 ± 13.4144</td>
<td>-</td>
<td>-</td>
<td>23.37 - 28.47</td>
</tr>
</tbody>
</table>

Same alphabets represent statistically at par group.
Deforestation and shifting cultivation is lowering soil carbon store beside the land use is replaced by unproductive grassland, wastelands or unsustainable system. In order to reduce emission level and improve sink potential, vast area of forest plantation are needed to produce a significant reduction of CO₂. Sustainable land use such as agroforestry provide alternative to shifting cultivation. There is need to study closely the wetland ecosystem, rice cultivation system, land use systems, forest ecosystem, role of different farming and cropping systems and soil properties change.

Under Kyoto Protocol, the developed countries have agreed to limit and reduce their green house gases between 2008 to 2012. This protocol makes provision to take in to account afforestation, reforestation in land use land use change in forestry activities in meeting their commitments (IPCC, 2000). Many observers believe that the clean development mechanism (CDM) offered by Kyoto Protocol could reduce rural poverty by extending payments to low income farmers who will provide carbon storage through land use system such as agroforestry (Smith and Scherr, 2002).

References


