Abstract: Agroforestry has been recognized as a means to reduce CO$_2$ emissions as well as enhancing carbon sinks although the rice-wheat cropping system increases the green house gases level. Agroforestry is a large sink of carbon and its role in carbon cycles is well recognized. The article reviews the impact of different land use systems on properties such as EC, pH and the carbon sequestration potential of soils. Agroforestry provides a unique opportunity to combine the twin objectives for capturing atmospheric CO$_2$ to ameliorate environment and, improving the soil nutrient status as well. Soil organic carbon has been recorded abundantly in agroforestry systems than other land use systems. The emphasis of land use systems that led to higher carbon content than other cropping systems can help to achieve net gains in carbon in soils specifically and, significant increases in carbon storage can be achieved by moving from lower biomass land uses.

Keywords: Land-use systems, Agroforestry, Soil properties, Carbon sequestration potential

INTRODUCTION

Studies carried out in the plains and hills indicate declining soil fertility due to soil erosion. Farmlands have reportedly been losing soils at the rate of 8-12 t ha$^{-1}$ y$^{-1}$ (Carson, 1992). As a result, yields of staple crops, like rice, maize, wheat and millet have followed a decreased trend (Vaidya et al., 1995). Constant loss of soil fertility has been a serious land management constraint for sustaining agricultural production in the plains and hills (Schreier et al., 1995) which is likely to be aggravated further. Improvements in vegetative cover through better agronomic practices and contour hedgerows were found desirable (Angus et al., 1998).

At a global level, reviewing the fertilizer impacts on the environment based on data from Bockman et al. (1990) and Ayoub (1999) showed that in 1970, 48% of the nutrients used by crops were derived from the soil, 13% from manure, and 39% from inorganic fertilizers. By 1990, the percentages had changed to 30% from soil, 10% from manure and 60% from inorganic fertilizer. The projection for 2020 is 21% from the soil, 9% from an organic source, and 70% from an inorganic fertilizer source. Considering that only about half of the applied fertilizer is taken up by the crop in a given season (Bockman et al., 1990), the negative impact of fertilizer use on environmental quality is likely to increase with time on a global scale.

The cropping system occupies around 13.5 Mha in the Indo-Gangetic Plains (IGP) of Bangladesh, India, Nepal and Pakistan. The cropping system is of utmost importance for ensuring regional food security. There are reports of stagnating or declining rice and wheat yields in the IGP (Ladha et al., 2003), which have presumably been related to declining soil organic matter (SOM) content and decreased soil fertility (Bhandari et al. 2002; Regmi et al., 2002).

However, temporal analysis of 25-years data on organic C content of the regional soils showed that the stagnating productivity was not related to SOC (Benbi and Brar, 2009). So far there is no information available on the quality of SOM under rice-wheat system in comparison to other agroecosystems. Maize-wheat is another important cropping system in the region. Rice and maize result in alternating soil aeration status viz., anaerobic conditions during rice season and aerobic conditions in maize fields that can significantly influence decomposition and accumulation of SOM.

According to Nair and Graetz (2004), U.S. Natural Resources Conservation Service (NRCS) has the responsibility to provide planning assistance to land-use decision-makers that will protect the five major resource concerns of Soil, Water, Air, Plants, and Animals (SWAPA). According to a study by the World Agroforestry Centre (ICRAF), 43% of the planet’s agricultural land has more than 10% tree cover (Zomer et al., 2009), 160 million hectares land area has more than 50% tree cover. Within the array of benefits brought by trees, an important element is the positive effect of trees on soil properties and consequently benefits for crops.

Maintenance of soil fertility requires preservation of its organic matter, physical properties and nutrient levels. Soils do not support intensive annual plant cultivation without fertilizer applications (Sanchez et al., 1983; Alfaia et al., 1988), and even these may not maintain sustainability. Due to the fragility of soils, all agricultural projects must consider soil fertility and its maintenance as a priority. Thus, the use of diverse tree species and other practices
employed in agroforestry systems can represent alternative forms of increasing soil fertility and maintaining agricultural production, with important practical applications for the sustainability of tropical agriculture. Agroforestry offers not only a sustained productivity, but also an increase in productivity per unit area. Considering all above aspects, we tried to review the impacts of different landuse systems on soil properties.

**Land uses v/s soil properties**

The basic properties of the surface soils under different cropping systems viz. rice-wheat, maize-wheat and cotton-wheat and a poplar based agroforestry system are presented in Table 1. The soils under all the land-uses were non-saline and near-neutral to alkaline in reaction. However, the soils under agroforestry had significantly lower pH than the other land-uses that did not differ significantly (Prakash, 2016). Soils under all the land-uses were sandy loam in texture with sand content ranging between 60 and 64.6% and silt content between 21.8 and 25.1%. Soils under all the land-uses were medium to high (9.8 to 16.0 mg P kg\(^{-1}\)) in available P and high in available K (83 to 100 mg K kg\(^{-1}\)). However, available P concentration was significantly lower in soils under agroforestry, compared to the other land-uses. The relatively greater P concentration under sole cropping systems may be attributed to regular use of organic manure (FYM) and fertilizer P during crop production. Contrarily, available P concentration was significantly lower in soils under agroforestry, compared to the other land-uses (Prakash, 2016). Lower concentration of available P in soils under agroforestry may be due to wide C: P ratio. Wide C: P ratio reduces P mineralization leading to decrease in available P concentration in soil (Broder et al., 2012). Available K concentration was significantly higher in soils under agroforestry compared with other land-uses. The CaCO\(_3\) concentration in soils under different land-uses did not differ significantly and ranged between 0 and 19.5 g kg\(^{-1}\) soil (Prakash, 2016).

In an evaluation of more than 20,000 globally distributed soil profiles, the greater part in temperate climates, Jobbagy and Jackson (2001) found that cycling mediated by plants exerts a marked influence on the vertical distribution of nutrients in the soil, especially in the case of more limiting nutrients such as P and K. Studies of forests in temperate climates indicate variations in soil that can be related to individual tree species. Besides the expected correlations, such as greater levels of N under legumes (Uleroy et al., 1995) or lower pH under species that produce acidifying litter, such as *Pinus* spp. (Uleroy et al., 1995; Reich et al., 2005), other interesting interactions show that different species can alter soil in distinct ways, with variations in the increment of soil carbon (C) (Uleroy et al., 1995) exchangeable Ca and Mg and per cent base saturation (Finzi et al., 1998; Reich et al., 2005). In a study of 14 tree species in Poland, Reich et al., (2005) found varied effects on soil characteristics; however, these effects were significantly related to the level of Ca in litter, independent of the species. Trees producing litter rich in Ca were associated with soils with greater pH, exchangeable Ca, and per cent base saturation, as well as greater rates of forest floor turnover and greater diversity and abundance of earthworms. Dijkstra (2003) emphasized that the rate of mineralization of organic Ca is a fundamental factor in this process, since it determines the immediate availability of this nutrient in the soil and can vary between species. In the areas where the biophysical condition is suitable for tree and shrub species, agroforestry can contribute to enhance soil fertility. Subsequent studies also demonstrated patterns in the variation of soil characteristics as influenced by trees, such as in tropical savannas (Belsky et al., 1989; Burke et al., 1998), deserts (Schlesinger et al., 1996), and areas of temperate forests (Ulery et al., 1995; Finzi et al., 1998; Dijkstra, 2003; Reich et al., 2005). In analyzing soil characteristics under individual tree crowns in Kenyan savannas, Belsky et al., (1989) found greater levels of mineralizable N, microbial biomass, P, K, and Ca underneath the crowns when compared to open savanna.

In the arid region of India, the effect of *Prosopis cineraria*, *Tecomella undulata*, *Acacia albida* and *Azadirachta indica* on the productivity of *Hordeum vulgare* (barley) was found to be positive. *P. cineraria* enhanced grain yield by 86.0%, *T. undulata* by 48.8%, *A. albida* by 57.9% and *A. indica* by 16.8% over the control. Biological yield was also higher under trees than that in the open area. Soils under different tree canopies were rich in organic carbon content, moisture availability and nutrient status (Kumar et al., 1998). There is robust evidence that agroforestry systems have the potential for improving water use efficiency by reducing the unproductive components of the water balance (runoff, soil evaporation and drainage) (Turner and Ward, 2002). That is why such systems are more beneficial as compared to agricultural cropping systems. Increases in soil nutrients especially soil available nutrient, soil microbial biomass carbon, microbial quotient, soil basal respiration, microbe numbers and enzyme activities were reported high in tree-crop combinations. The greater soil microbial biomass carbon (SMBC) reflects the response of more input of organic matter to the soils under tree-crop combinations (Wang et al., 2005). Ocic and Brookes (1990) have also reported that SMBC influenced much more quickly by organic inputs in comparison to the agricultural management induced changes in soil organic matter.
Land uses v/s soil carbon pools

Soil carbon pool in an ecosystem is controlled by the balance between the C inputs derived from litter fall, root biomass and root exudates and the outputs through heterotrophic respiration. Soils in agroforestry and maize-wheat systems had approximately 28% higher concentration of total carbon than those in rice-wheat system but these differences were statistically insignificant. Total organic carbon (TOC) differed significantly with respect to land-use practices. In contrast, soils in the rice-wheat system exhibited significantly lower SOC concentrations than those in the other two agro-ecosystems (Table 2). Compared to the rice-wheat system, agroforestry and maize-wheat systems were 88% and 65% higher in SOC, respectively (Figure 1). The higher SOC concentration under agroforestry may be attributed to input of C through litter fall that occurs at the beginning of winter season and greater root biomass compared to sole annual crops. Poplar trees, grown in the region, add 2.9-3.3 t ha⁻¹ of litter fall every year (Rahlan et al., 1996; Tandon et al., 1991) and supply 2.3 t C ha⁻¹ y⁻¹ through roots and leaves (Chauhan et al., 2011). Soils in the maize-wheat system also exhibited higher SOC stocks than those in the rice-wheat system, probably because of C input through farmyard manure application to maize. Positive effect of manure application on SOC build-up under maize-wheat system in semi-arid India has earlier been reported by Benbi et al., (1998).

The effect of different land-use systems on SOC concentration and its labile pools viz. hot water soluble carbon (HWSC) and KMnO₄-C are given in Table 3. Averaged across sites, SOC concentration was the highest under agroforestry and the lowest under cotton-wheat cropping system, while maize-wheat and cotton-wheat systems exhibited similar SOC concentration. The rice-wheat system had significant higher SOC concentration than two cropping systems but significantly lower than agroforestry systems. Significantly higher concentration of SOC in soils under agroforestry compared to sole cropping systems could be attributed to the effect of large return of plant biomass C through leaf litter and reduced tillage practices under agroforestry. Bene et al (2011) has reported that soil organic matter is closely related to the amount of above and below ground organic matter inputs. Lobato et al (2014) has reported that reduced tillage and its duration tends to build-up SOC under agroforestry than the sole cropping systems. In many long-term experiments, researchers have shown a significant relationship between C input through plant biomass and organic manures with SOC sequestration (Benbi et al., 2012; Huang et al., 2014). The results of the present investigation corroborates the findings of Benbi et al (2012), who also reported higher SOC concentration under agroforestry than in soils under rice-wheat cropping system. The comparison of three cropping systems revealed significantly higher SOC concentration in the soils under rice-wheat than the maize-wheat and cotton-wheat cropping systems. This could be attributed to retarded rate of soil organic matter decomposition due to prevailing anaerobic conditions during rice cultivation (Manlay et al., 2002). Since rice-wheat cropping involves cultivation of wetland and upland crops in sequence, it experiences alternate wetting and drying and thus differential stabilization of soil organic matter, compared to the other two cropping systems which are grown under upland conditions.

The concentration of HWSC was significantly higher in soils under agroforestry and rice-wheat than the maize-wheat and cotton-wheat cropping systems (Table 3). Lower HWSC under sole cropping systems than agroforestry could be possibly due to intensive cultivation which includes several times tillage practices per year leads to greater breakdown of SOM or decomposition of native SOC (Wardle 1992; Haynes 2000; Ghani et al 2003; Shi et al 2015). Greater rhizo-deposition of root mass and exudates in soils under agroforestry also influences turnover rate of C (Kuzyakov et al., 2001). The concentration of KMnO₄-C was significantly higher in soils under agroforestry than the other land-uses. The soils under maize-wheat and cotton-wheat cropping systems did not differ significantly for their effect on KMnO₄-C. Higher concentration of HWSC and KMnO₄-C in soils under agroforestry indicates the quantitative as well as qualitative differences in soil organic matter compared to other land-uses.

Sharma et al (2009) studied the soil fertility and quality assessment under tree, crop and pasture-based land-use systems in a rain-fed environment, observed that among the land-use systems, agroforestry system resulted in the highest SOC content (9.6 g kg⁻¹) compared to arable land (3.66 g kg⁻¹). Thienkoua and Zech (2004) observed that SOC significantly (P=0.05) higher in soils under Eucalyptus grandis plantations (73.3 g kg⁻¹) followed by Camellia sinensis plantations (69.1 g kg⁻¹) compared with semi-permanent, maize (Zea mays L.)-based, mixed food crop fields (39.4 g kg⁻¹). Under Eucalyptus treatment, greater litters with high C: N ratio (64) was a major factor of high SOC build up, lower OC in Camellia sinensis system was associated with reduced litter input due to harvest of young shoots as well as its rapid turnover rate as indicated by the low C: N ratio (26) for tea leaves.

Microbial activity plays a major role in nutrient turnover in general and in P transformation and redistribution into different inorganic and organic forms in particular (Stewart and Tiessen, 1987). Cardoso et al (2003) observed that organic P/total P was lower in the conventional systems than in the agroforestry systems, suggested that agroforestry systems influence the dynamics of P through the conversion of part of the inorganic P into organic P.
Agroforestry systems are expected to have more microbial activity than the conventional systems. Availability of soil P increased by intercropping with potential of some non-crop plants in agroforestry systems to release P from recalcitrant pools, thus making it available to crops (Palm, 1995). Bene et al., (2011) has reported that soil organic matter is closely related to the amount of above and below ground organic matter inputs. Lobato et al., (2014) has reported that reduced tillage and its duration tend to build-up SOC under agroforestry than the sole cropping systems.

In many long-term experiments, researchers have shown a significant relationship between C input through plant biomass and organic manures with SOC sequestration (Benbi et al., 2012, Huang et al., 2014). The results of the present investigation corroborates the findings of Benbi et al., (2012), who also reported higher SOC concentration under agroforestry than in soils under rice-wheat cropping system. The comparison of three cropping systems revealed significantly higher SOC concentration in the soils under rice-wheat than the maize-wheat and cotton-wheat cropping systems. This could be attributed to retarded rate of soil organic matter decomposition due to prevailing anaerobic conditions during rice cultivation (Manlay et al., 2002). Since rice-wheat cropping involves cultivation of wetland and upland crops in sequence, it experiences alternate wetting and drying and thus differential stabilization of soil organic matter, compared to the other two cropping systems which are grown under upland conditions.

**Agroforestry as carbon sink**

Trees add organic matter to the soil system in various manners, whether in the form of roots or litter or as root exudates in the rhizosphere as rhizodeposition (Bertin et al., 2003). Fast growing trees including *Populus, Eucalyptus, Melia, Leucaena, Paulonia* etc. have an important role for capturing atmospheric carbon dioxide to ameliorate environment. Although carbon (C) constitutes almost 50% of the dry weight of branches, 30% of foliage, the greater part of C sequestration (around 2/3) occurs belowground, involving living biomass such as roots and other belowground plant parts, soil organisms, and C stored in various soil horizons (Nair et al., 2010). Therefore, agroforestry systems are known to maintain soil organic matter and promote nutrient cycling (Chander et al., 1998).

In homegardens in India, Saha et al., (2010) found levels of SOC to be 30% and 114% greater than in coconut plantations and rice paddies, respectively. In the Northeast of Spain, Howlett et al., (2011) studied the levels of SOC in silvopastoral systems composed of different species, and found that systems with birch (*Betula pendula*) presented greater levels of soil C than systems with pine (*Pinus radiata*).

Several studies have shown that the inclusion of trees in the agricultural landscapes often improves the productivity of systems while providing opportunities to create carbon sinks (Schoreder, 1994; Montagnini and Nair, 2004; Chauhan et al., 2007a; Jose, 2009; Schoeneberger, 2009; Nair et al., 2010; Sharma and Sharma, 2011). The amount of carbon sequestered largely depends on the agroforestry put in places, the structure and function, which to a great extent are determined by environmental and socio-economic factors. The carbon sequestration potential for agroforestry practices is more variable, depending on the planting density, production objective, components in system, productivity, etc. Actually, the carbon storage in plant biomass is better feasible in the perennial agroforestry systems (perennial-crop combinations, agroforestry, windbreaks, hedgerow inter-cropping, horti-silvicultural system, etc.), which allow full time tree growth where the wood component represents an important part of the total biomass. However, the cost of carbon sequestered through agroforestry appears to be much lower than other CO₂ mitigation options.

Organic carbon varied according to soil type, with higher concentrations in the Oxisol than in the Inceptsol (Alfaia et al., 2004). In the Oxisol, C was significantly higher in areas with forest and agroforestry systems (AFS) than in pastures, while no significant differences among land use systems were observed in the Inceptsol. Changes in SOC after conversion of primary forest to agricultural systems in Amazonia are after contrasted (Desjardins et al., 2000). With the change of forest to pasture, a gradual increase in C in the soil after burning has been observed (Koutika et al., 1977), while others report relative stability (Eden et al., 1991) or a pronounced decrease (Falesi and Veiga, 1986). Isotopic tracer studies revealed that the amount of forest-derived C remaining in the soil decreases quickly in the first years after pasture establishment, and slows as the supply of pasture-derived organic matter decomposition increases (Desjardins et al., 1994). The effect of AFS on changes in soil C in comparison with pasture or primary forest is not as well known. McGrath et al., (2001) did not find significant differences in C concentration between AFS and primary forest. Recco et al., (2000) observed that older AFS showed a trend of recovery and maintenance of organic C similar to that in primary forest in western Amazonia.

The area under the poplar based agroforestry system is increasing every year because of huge demand from industry. Singh and Lodhiyal (2009); Rizvi et al., (2010); Benbi et al., (2012) also suggested great potential of poplar based intercropping systems in reducing the atmospheric CO₂ concentration compared to sole cropping systems. However, data is insufficient, and an understanding of plant/climate relationships is essentially required to guide the future policies. Some studies have been conducted to explore carbon sequestration potential in poplar-
wheat based system. Total CO₂ assimilation by the biomass in the poplar-wheat based agroforestry system and mono-cropping of poplar and wheat was estimated at 28.6, 17.2 and 17.8 t ha⁻¹ yr⁻¹, respectively as shown in Figure 2 (Chauhan and Chauhan, 2009). Therefore, even when only the accumulation of biomass carbon is considered, an agri-silvicultural system is very efficient in terms of carbon sequestration (Chauhan and Chauhan, 2009). However, these figures hold true if harvested products are transformed into durable products. Litter (leaves, branches and bark) and roots are added and allowed to decompose in the soil to sequester carbon. Gera et al. (2011) reported 66 and 37 t ha⁻¹ carbon sequestration potential (2.20 and 1.37 t C ha⁻¹ yr⁻¹, respectively) under poplar block and poplar boundary plantations, respectively. Chauhan et al., (2010a) after seven years, estimated timber carbon content of 23.57 t ha⁻¹, whereas, carbon content of the roots, leaves, and bark was 23.9 t ha⁻¹ and branches 15.01t/ha. Hence, total biomass carbon storage after seven years was equivalent to 62.48 t ha⁻¹ (8.92 t ha⁻¹ yr⁻¹). The combined contribution of poplar and wheat was substantially high within the intercropping system. This may be due to the additional carbon pool in the trees and the increased soil carbon pool resulting from litter fall and fine root turnover. The high carbon storage may also be due to the increased growth and assimilation rates of intercropped components as compared to monocropping systems. Moreover, poplar timber locks up carbon in its wood products for longer periods, thereby making it the major carbon assimilator of this type of agroforestry system. Poplar-wheat based agroforestry system, thus fare better than traditional agricultural systems, providing the best land use option for increased carbon sequestration. Clonal variation in carbon sequestration has been recorded in poplar clones by Pal et al., (2009). The carbon content in different components estimated by Chauhan and Chauhan (2009) were found to ranged from 44.08 to 47.82 (stem, branches, root, leaves and bark values were 45.67, 46.56, 47.82, 44.08 and 46.93 per cent, respectively). Rizvi et al., (2011) estimated 27-32 t ha⁻¹ and 66-83 t ha⁻¹ carbon storage in boundary and block poplar plantations, respectively at a rotation of seven years. Dhiman (2009) estimated that only 1.04 mt C out of 2.5 mt C is locked in poplar based products for different durations and the remaining is released back in the form of fuel and only a marginal fraction of 0.3 mt C is added to soil through leaf litter every year. Gupta et al., (2009) found that the average soil organic carbon increased from 0.36 in sole crop to 0.66 per cent in P. deltoides based agroforestry soils. The soil organic carbon increased with increase in tree age. The soils under agroforestry had 2.9-4.8 t ha⁻¹ higher soil organic carbon than in sole crop. The poplar trees could sequester higher soil organic carbon in 0-30 cm profile during the first year of their plantation (6.07 t ha⁻¹ yr⁻¹) than the subsequent years (1.95-2.63 t ha⁻¹ yr⁻¹) (Gupta et al., 2006). However, it is important to mention that less than 50% of the total timber is locked for longer period and remaining biomass is used as fuel to meet the energy requirements and replaces fossil fuel. Therefore, an estimate of carbon sequestration for wood used for energy as well was calculated (Table 4) and it was found that poplar block and boundary plantation sequester substantial amount of carbon in long lived biomass and replace fossil fuel (3.38 and 1.03 t ha⁻¹ yr⁻¹) in poplar based system with block and boundary plantations, respectively.

**CONCLUSION**

Land use management and soil depth influence contents of total, particulate and mineral associated soil organic carbon fractions. Crop cultivation led to a decrease in total soil organic carbon, but the value was higher than the contents obtained in the fallow land. There are agricultural management practices that show promise for restoring soils and sequestering a very significant portion of atmospheric carbon. Therefore, it is important to take into account the importance of agroforestry to sequester the C and improving the soil properties.

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**Table 1. Physical and chemical properties of the surface (0-15 cm) soils under different land-use in Indian Punjab. Numbers in parenthesis indicate standard error.**

<table>
<thead>
<tr>
<th>Soil properties</th>
<th>Land use</th>
<th>Range¹</th>
<th>Mean²</th>
<th>Range</th>
<th>Mean</th>
<th>Range</th>
<th>Mean</th>
<th>Range</th>
<th>Mean</th>
<th>Range</th>
<th>Mean</th>
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<tbody>
<tr>
<td></td>
<td>Rice-wheat</td>
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<td></td>
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<tr>
<td>pH</td>
<td></td>
<td>7.26-</td>
<td>7.76</td>
<td>7.24-</td>
<td>7.73</td>
<td>7.24-</td>
<td>7.72</td>
<td>7.13-</td>
<td>7.29</td>
<td></td>
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<tr>
<td></td>
<td>8.24</td>
<td>(0.05)</td>
<td></td>
<td>8.23</td>
<td>(0.06)</td>
<td>8.23</td>
<td>(0.06)</td>
<td>7.63</td>
<td>(0.03)</td>
<td></td>
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<tr>
<td>E.C. (dS m⁻¹)</td>
<td>0.23-</td>
<td>0.31</td>
<td>0.25</td>
<td>0.34</td>
<td>0.21</td>
<td>0.28</td>
<td>0.25</td>
<td>0.33</td>
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<tr>
<td></td>
<td>0.43</td>
<td>(0.01)</td>
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<td>(0.01)</td>
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<tr>
<td>Sand (%)</td>
<td>47.8-</td>
<td>60.0</td>
<td>53.4</td>
<td>63.0</td>
<td>56.1</td>
<td>63.3</td>
<td>53.4</td>
<td>64.6</td>
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<tr>
<td></td>
<td>71.5</td>
<td>(1.4)</td>
<td>(1.1)</td>
<td>(1.1)</td>
<td>(1.2)</td>
<td>(1.2)</td>
<td>(1.2)</td>
<td></td>
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<tr>
<td>Silt (%)</td>
<td>18.4-</td>
<td>25.1</td>
<td>17.1</td>
<td>23.1</td>
<td>16.4</td>
<td>23.3</td>
<td>17.7</td>
<td>21.8</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>30.5</td>
<td>(0.72)</td>
<td>(0.62)</td>
<td>(0.62)</td>
<td>(0.70)</td>
<td>(0.70)</td>
<td>(0.63)</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Clay (%)</td>
<td>8.2-</td>
<td>14.1</td>
<td>9.5</td>
<td>13.1</td>
<td>8.1</td>
<td>13.5</td>
<td>8.2</td>
<td>13.6</td>
<td></td>
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<tr>
<td></td>
<td>21.7</td>
<td>(0.79)</td>
<td>(0.58)</td>
<td>(0.64)</td>
<td>(0.64)</td>
<td>(0.69)</td>
<td></td>
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1. Range
2. Mean

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*Note: The above table provides a summary of physical and chemical properties of surface soils under different land-use in Indian Punjab.*
Table 2: Total C, inorganic C (SIC), total organic C (TOC), soil organic C (SOC) and total N concentration in soils of agroforestry, rice-wheat, and maize-wheat systems in the Rupnagar district of Indian Punjab (Benbi et al., 2012)

<table>
<thead>
<tr>
<th>Soil carbon pool</th>
<th>Land-use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rice-wheat</td>
</tr>
<tr>
<td>Total C (g kg⁻¹ soil)</td>
<td>6.90 (1.32)</td>
</tr>
<tr>
<td>Total organic C (g kg⁻¹ soil)</td>
<td>6.50 (1.41)</td>
</tr>
<tr>
<td>Soil organic C (g kg⁻¹ soil)</td>
<td>3.88 (0.89)</td>
</tr>
</tbody>
</table>

Mean values in a column followed by the same letter are not significantly different at P<0.05. NS = non-significant. Values in parenthesis indicate standard error of mean.

Table 3. Soil organic carbon (SOC), hot water soluble carbon (HWSC) and potassium permanganate oxidizable carbon (KMnO₄-C) in the surface (0-15 cm) soils under different land-uses (Prakash, 2016)

<table>
<thead>
<tr>
<th>Soil carbon pool</th>
<th>Land-use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rice-wheat</td>
</tr>
<tr>
<td>Range</td>
<td>Range</td>
</tr>
<tr>
<td>SOC (g C kg⁻¹)</td>
<td>2.83</td>
</tr>
<tr>
<td></td>
<td>(0.02)</td>
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<tr>
<td>HWSC (mg C kg⁻¹)</td>
<td>6.35</td>
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<tr>
<td></td>
<td>(0.02)</td>
</tr>
<tr>
<td>KMnO₄-C (mg C kg⁻¹)</td>
<td>168</td>
</tr>
<tr>
<td></td>
<td>(10.4)</td>
</tr>
</tbody>
</table>

Mean values in a column followed by different letters differ significantly (p<0.05) by Duncan’s multiple range test (DMRT). Values in parenthesis indicate standard error of mean.

Table 4. Carbon sequestration in poplar based agroforestry models

<table>
<thead>
<tr>
<th>Treatments*</th>
<th>Total biomass* t (ha⁻¹)</th>
<th>Long lived timber C Storage (ton C ha⁻¹)</th>
<th>Heat from biomass combustion (ton C ha⁻¹)</th>
<th>Carbon storage from coal substitute (ton C ha⁻¹)</th>
<th>Total C Sequestratio n** (ton C ha⁻¹)</th>
<th>Total C sequestration (ton C ha⁻¹ yr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block</td>
<td>Trees + wheat straw</td>
<td>77.14</td>
<td>9.23</td>
<td>1022.04</td>
<td>17.17</td>
<td>28.96</td>
</tr>
<tr>
<td></td>
<td>Trees without wheat straw</td>
<td>48.49</td>
<td>9.23</td>
<td>506.34</td>
<td>8.50</td>
<td>20.27</td>
</tr>
<tr>
<td>Boundary</td>
<td>Trees + wheat + Rice straw</td>
<td>86.47</td>
<td>3.18</td>
<td>1444.32</td>
<td>24.26</td>
<td>27.86</td>
</tr>
<tr>
<td></td>
<td>Trees + rice straw</td>
<td>57.49</td>
<td>3.18</td>
<td>922.68</td>
<td>15.50</td>
<td>19.10</td>
</tr>
<tr>
<td></td>
<td>Trees without Rice and wheat straw</td>
<td>14.83</td>
<td>3.18</td>
<td>154.80</td>
<td>2.60</td>
<td>6.20</td>
</tr>
</tbody>
</table>

* Calculations made with the presumption that wheat straw is used as fodder, whereas rice straw is used as fuel
** Tree and crop (grain + straw) biomass
*** Includes soil as well as long lived carbon storage in timber
Fig 1. Soil organic carbon (SOC) stocks in agroforestry, maize-wheat, and rice-wheat systems in the Rupnagar district of Indian Punjab. Bars labeled with the same letter are not significantly different at P=0.05 (LSD 4.2). Line bars indicate standard error of mean.

Fig 2. Total CO₂ assimilation (t ha⁻¹) by poplar-wheat (above- and below-ground biomass) in agroforestry system and sole wheat crop (Chauhan and Chauhan, 2009).

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