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Effect of different agricultural land use systems on distribution of carbon fractions in soils of sub-montaneous Districts of Punjab, India

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Abstract

Land-use controls the carbon footprint in terrestrial systems. Different land uses have different potentials for carbon sequestration due to differential SOC and aggregation dynamics. The study was conducted to investigate the impact of different agricultural land-use systems on soil carbon pools with the specific objective to study carbon sequestration and its distribution in soil organic carbon pools in soils of sub-montaneous districts of Punjab. Two sites were selected in '*lower Shiwaliks foothills of Punjab locally known as Kandi area'* i.e Village Takarla, Tehsil Takarla, District Shaheed Bhagat Singh Nagar and Villages Rajwaal, Shri Pandyan and Chak Pandyan, Tehsil Mukerian, District Hoshiarpur. The results showed that Soil organic carbon (SOC) was more in forestry (5.00 g kg^{-1}) in Takarla and at Mukerian, grassland possessed higher amount (15.88 g kg^{-1}). Among the SOC fractions, the POC was most dominant but LC and HWC showed vulnerability to land use change. At Takarla, HWC (490 mg kg^{-1}), LC (1626 mg kg^{-1}), IC (7.00 mg kg^{-1}) and total POC (3389 mg kg^{-1}) were more in agro-forestry. At Mukerian, HWC (1370 mg kg^{-1}), LC (1963 mg kg^{-1}), IC (5.75 mg kg^{-1}) and total POC (7991.6 mg kg^{-1}) were more in grassland. Soil properties and physical, biological as well as functional pools of SOM are strongly influenced by different agricultural land-use. Soil C sequestration has numerous ancillary benefits. Carbon sequestration seems to be more in agro-forestry at Takarla and in grassland at Mukerian. Climatic conditions / temperature also influenced carbon fractions at both sites. At Mukerian, values for carbon fractions were high as compared to Takarla, due to comparatively low temperature which decreases the rate of decomposition of soil organic matter in Mukerian.

Keywords: agricultural land use, soil organic c, labile c, particulate organic c, hot water soluble c and inorganic c

Introduction

Soil organic carbon (SOC) represents major component in the global carbon cycle and it is estimated that about 1100 to 1600 Pg carbon is sequestrated in soils (Izaurralde *et al.* 2000) [18]. This represents more than twice the amount of carbon in vegetation (560 Pg) and in the troposphere (750 Pg). SOC is divided into three pools: active, slow and recalcitrant based on the decomposition turnover time. Several carbon fractions have been used as indicators of changes in SOC (De Gryze *et al.* 2004). The SOC fractions viz. labile, hot water soluble and aggregate-associated carbon have been proposed as sensitive indicators of change in land use and management practices (Cambardella and Elliott 1992) [6]. The SOC fractions like hot water soluble carbon (HWC), dissolved organic carbon (DOC) and particulate organic matter C (POM-C) are considered as more sensitive indicators of management induced changes than total SOC(Yang *et al.* 2005; Tan *et al.* 2007) [40, 37]. These fractions exhibit different rates of biochemical and microbial degradation (Stevenson 1994) [36] as well as different accessibility and interactions (Sollins *et al.* 1996) [34]. Labile fraction of SOC can respond rapidly to changes in C supply and such components have, therefore, been suggested as early indicators of the land use effect on soil quality (Jinbo *et al.* 2006). Depending on land use system, soils can be a net sink or source for CO_2. It is estimated that about 40-80 Pg of carbon can be sequestred in soils over next 50-100 years through sustainable land management (Houghton *et al.* 1996) [17]. Restoring soil carbon pools by reducing land use intensity is a potentially high impact and rapidly deployable strategy for partially offsetting atmospheric CO_2 increases (Grandy and Robertson 2007). SOC is considered as the largest global terrestrial carbon pool (Schlesinger 2000) which can stock about 1500-2000 Pg of carbon in various organic forms to a depth of 1 m (Neider and Benbi 2008). This amount is roughly twice the carbon present in the atmosphere (Schlesinger 2000).

The soil C pool has two principal components: soil organic C (SOC) and soil inorganic C (SIC). Soils capture and store both organic and inorganic forms of C thus acting both as sink and source for atmospheric CO_2 (Bhattacharyya *et al.* 2008) [4]. In arid and semiarid regions that cover as much as one-third of the surface of the planet, SIC pool is approximately two to ten times larger than SOC storage (Batjes 2004) while the SIC rate of accumulation is generally higher than of SOC (Landi *et al.* 2003) [23].

The SOC pool, estimated at 2500 million tons to 2 m depth (Batjes, 1999) [2], has been considerably depleted by the conversion of natural to agricultural ecosystems and by several soil degradation processes such as erosion, salinization and nutrient depletion/imbalance (Lal 2011) [22]. The SOC pool in soils of most agroecosystems is below its capacity as determined by climatic, pedological and terrain characteristics (Lal 2004) [20]. Processes which lead to depletion of the SOC pool are deforestation, biomass burning and the attendant soil erosion which create a large C debt (Fargione *et al.* 2008) [9].

Soil organic matter fractions with turnover times of years to decades such as particulate organic matter (POM) or light fraction (LF), often respond more rapidly to management-induced changes in the SOC pool than more stabilized, mineral associated fractions with longer turnover times (Cambardella and Elliott 1992) [6]. It has been suggested that enhanced protection of SOM by aggregates in undisturbed soils results in an accumulation of more labile C within aggregates (Six *et al.* 2002) [32].

Material and methods

Study site

To achieve the objective of the "Effect of different agricultural land uses on carbon sequestration in soils of sub-montaneous districts of Punjab", two sites were selected in '*lower Shiwaliks foothills of Punjab locally known as Kandi area'* i.e Takarla from District Shaheed Bhagat Singh Nagar and Mukerian from District Hoshiarpur. At takarla site four land use sytems were located at 31º06'45.2"N and 76º22'39.7"E with height of 339 meter above mean sea level and at mukerian site four land use sytems were located at 31º56'29.50"N and 75º51'39.76"E with height of 365 meter above mean sea level.

Land use systems

Four land use systems were identified for each selected site in the lower Shiwalik foothills of Punjab:

- Cropland
- Forestry
- Agro-forestry
- Grassland

Cropland systems are characterized by addition of chemical fertilizer and farm yard manure. Soil samples were collected under Maize-Wheat system. Forest land use systems are characterized by regular addition of organic matter in the form of falling leaves including those of tree species (Beri, Neem, Bamboo, Sharinh, Kikar, Tahli, Lantana and Subabul) in both sites whereas, Agro-forestry are characterized by Poplar-fodder (Bajra, Baru) / Wheat and Sagwaan / Toon, Bahera, Sarihn – Wheat / Barseem. On the other hand, Grassland are characterized by grass stands, at Takarla, grassland is 25 years and Chak Pandian is >50 years old.

Soil sampling and Soil analysis

Three spots were randomly selected from selected sites under each land use system. Soil samples were taken with the help of spade from 0-15, 15-30, 30-60 and 60-90 cm depths, with replication, in each land use system. All the samples were brought to the laboratory and air-dried. Soil samples were passed through a set of 5 and 8 mm sieves and the soil fraction retained on the 5 mm sieve was used for analysis of aggregate size distribution. The soil fraction that passed through 2 mm size sieve was used for determining soil texture, pH and Carbon fractions.

Soil organic carbon

Soil organic carbon was determined by Walkey and Black's (1934) rapid titration method.

Hot water soluble C (HWC)

The HWC was determined as per the method given by Schulz *et al.* (2003) [30]. Twenty gram of soil sample was weighed in 250 ml round bottomed flask and 100 ml distilled water added to it. After heating up to moderate boiling for one hour under reflux condenser, the samples were cooled down to room temperature immediately using a water bath and 5 drops of magnesium sulphate were added to support the sedimentation. The supernatant solution was centrifuged at 3000 rpm for 10 minutes. After centrifugation, 10 ml aliquot and 10 ml chromosulfuric acid were taken into Erlenmeyer flask and the reaction was heated up for 20 minutes in an oven at 125º C. After cooling, the mixture was titrated against 0.2 M ammonium iron (II) sulfate hexahydrate standard solution using 5 drops of indicator (0.2 g N-phenylicanthranilic acid + 0.2 g sodium carbonate) solution. It follows the reaction:

$$K_2Cr_2O_7 + 4H_2SO_4 + C = Cr_2\,(SO_4)_3 + K_2SO_4 + CO_2 + 4H_2O + O_2$$

Where, V_b and V_a represent the volume of ammonium iron (II) sulfate hexahydrate standard solution used for titrating blank and samples, respectively; FR is the reduction factor of the ammonium iron (II) sulfate hexahydrate standard solution as equivalent of the reduction of potassium dichromate by carbon mmol ml^{-1}, W_g is the soil sample weight in gram and W_{dm} is the dry matter of the air dried soil sample (percent).

Labile C

Labile carbon (LC) was determined by $KMnO_4$ oxidation method (Blair *et al.* 1995).

Determination of labile carbon in the soil samples

Three gram soil sample was treated with 25 ml of 33 *mM*$KMnO_4$ and was shaken for 24 hours on a reciprocal shaker. After centrifuging at 2000 revolutions per minute for 5 minutes, the samples were filtered through a Whatman No. 1 filter paper. A corresponding blank without soil was also prepared in the same manner. The 2 ml aliquot of $KMnO_4$ from each samples and blank were transferred using a Pipetman into 50 ml volumetric flask and diluted to volume. The absorbance of filtrate from samples and blank was measured at 565 nm.on a spectrophotometer. The concentration of $KMnO_4$ from samples and blank was determined using standared calibration curve. It follows the reaction:

$$4Mn^{+7} \xrightarrow{reduction} 4Mn^{+4}$$

$$3C^{o} \xrightarrow{oxidation} 3C^{+4}$$

Where 50/2 is the dilution factor, V is the volume of $KMnO_4$ added to samples and 9 is the factor used to convert *mM*$KMnO_4$ to mg C.

Particulate organic C (POC)

Particulate organic carbon (POC) was determined by the method as described by Camberdella and Elliott (1992) [6] and Hassink (1995) [16]. Fifty-gram soil samples was dispersed in

150 ml of 0.5percent sodium hexametaphosphate solution by shaking for 15 h on a reciprocal shaker. The dispersed soil sample was passed through 250 and 53 µm sieves. After rinsing several times with water, the material that was retained on the sieves was collected and very fine fraction which is collected in beakers were dried at 50º C over night. The POC fraction of >250 µm size (coarse fraction) was separated from sand by sieving. The coarse fraction (>250 µm), fine fraction (53-250 µm) and very fine fraction (<53 µm). POC were ground and analysed for total carbon by Walkey and Black's (1934) rapid titration method.

Statistical analysis

All the data were analyzed statistically using analysis of variance for Completely Randomized Design (CRD).

Results and discussion

Soil organic carbon

At Takarla, soil organic carbon (SOC) concentration ranged from 2.95 to 5.00 g kg^{-1} soil in the 0-15 cm soil depth. The highest concentration of SOC was in the forestry (5.00 g kg^{-1}) followed by agro-forestry (4.32 g kg^{-1}), grassland (3.14 g kg^{-1}) and cropland (2.95 g kg^{-1}). Irrespective of the land-use, SOC concentration decreased with depth and ranged from 1.05 to 2.91 g kg^{-1} in 15-30 cm, 0.33 to 2.06 g kg^{-1} in 30-60 cm and 0.36 to 2.00 g kg^{-1} in 60-90 cm depth. The SOC content in grassland soils sharply decreased as compared to other land-use systems. 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 (Ralhan *et al.* 1996) [27] and supply 2.3 t C ha^{-1} y^{-1} through roots and leaves (Chauhan *et al.* 2011) [7]. The lowest soil organic carbon in cultivated fields could be due to low organic matter inputs coupled by reduced physical protection of SOC as a result of tillage and oxidation of soil organic matter. This was in agreement with John *et al.* (2005) [19] who reported an increasing SOC concentration in the A horizons in the order arable soils < grassland soils < forest soils. The results of the present study are also in confirmity with the findings of Gebeyaw (2007) [11].

The SOC of virgin forestlands were higher than the virgin grasslands most probably because of differences in management practices between the two-land use systems. Soils of the forest sites were well protected, with little disturbance but that of the virgin grassland were heavily overgrazed, and mostly they were susceptible to surface erosion and poor texture. In addition to this, cow dung is largely used as fuel sources rather than enriching SOC of grassland sites (Abera and Belachew 2011) [1]. In Mukerian, Soil organic carbon (SOC) concentration ranged from 8.97 to 15.88 g kg^{-1} soil in the 0-15 cm soil depth. The highest concentration of SOC was in the grassland (15.88 g kg^{-1}) followed by forestry (14.50 g kg^{-1}), cropland (11.76 g kg^{-1}) and agro-forestry (8.97 g kg^{-1}). Irrespective of the land-use, SOC concentration decreased with depth and ranged from 5.04 to 7.57 g kg^{-1} in 15-30 cm, 3.54 to 6.16 g kg^{-1} in 30-60 cm and 2.85 to 5.83 g kg^{-1} in 60-90 cm depth. At both sites, SOC content in grassland soils sharply decreased as compared to other land-use systems. Smith and Paul (1990) [33], comparing three different systems, reported that biomass increased in the order: cultivated soils < forest soils < grassland soils. The higher SOC concentration in grassland soils is attributed to the chemical stabilization of organic C in the soil matrix (Percival *et al.* 2000) [26]. Schnurer *et al.* (1985) [19] observed a close relationship between contents of biomass and soil organic carbon, usually considered the most important substrate for soil microrganisms.

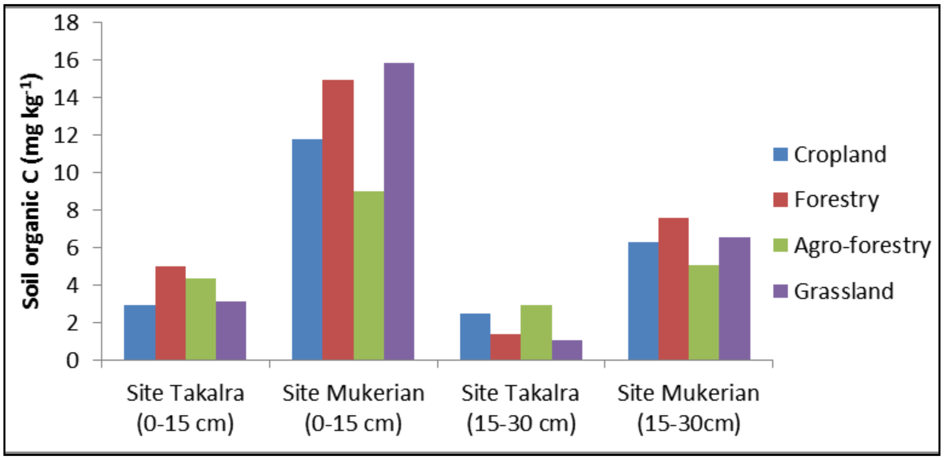

Fig 1: Effect of different land-use systems on Soil organic C (g kg^{-1}) at 0-15 and 15-30 cm soil depth at Takarla and Mukerian.

Hot water soluble C (HWC)

In Takarla, HWC was highest (490 mg kg^{-1}) in agro-forestry, followed by grassland (240 mg kg^{-1}), forestry (150 mg kg^{-1}) and cropland (130.0 mg kg^{-1}). Among all land uses, only agro-forestry possessed significantly higher value than others. The loss of organic carbon with cultivation could be attributed to the repeated exposure and subsequent aeration and oxidation of light fraction of organic carbon associated with macro-aggregates and macro-pores (Shephered *et al.* 2001). Lower water soluble carbon in cultivated soils is known to degree of aggregation (Sollins *et al.* 1996) [34]. In Mukerian, HWC was highest (1370 mg kg^{-1}) significantly in grassland, followed by forestry (900 mg kg^{-1}), cropland (860 mg kg^{-1}) and agro-forestry (460 mg kg^{-1}). The HWC is a subset of SOC pool, relatively labile in nature (Sparling *et al.* 1998 and Ghani *et al.* 1999) [35, 14]. It is one of the most sensitive measurements to grazing intensities within the grassland soils. Ghani *et al.* (2002) [14] reported that native bush and grassland soils had significantly greater amount of HWC than cultivated sites. Hot water soluble C represents the easily degradable fraction of SOM; it also includes soil microbial biomass and has a low proportion of aromatic compound (Schulz 2004). It may be used as stability indicator of SOM, higher value of HWC indicates lower stability and lower value indicates higher stability of SOM.

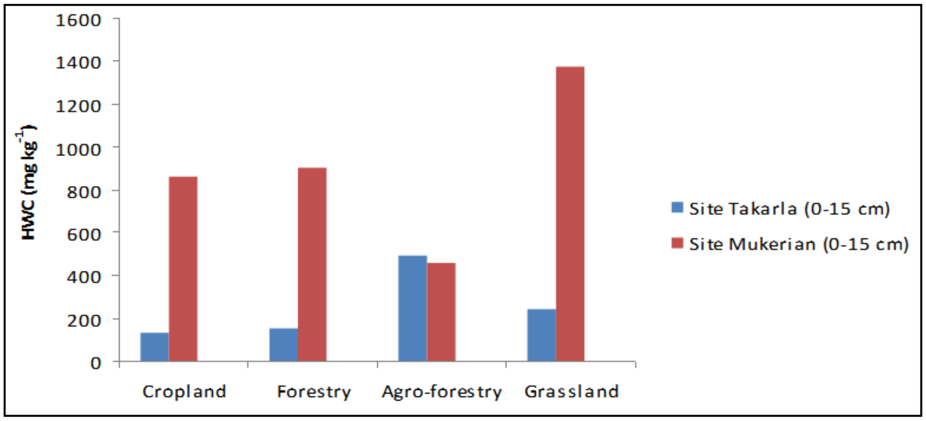

Fig 2: Effect of different land-use systems on hot water soluble C (g kg^{-1}) at 0-15 cm soil depth at Takarla and Mukerian.

Labile carbon

The range for Labile C (LC) concentration in the 0-5 cm soil depth was 418 to 1626 mg C kg^{-1} at Takarla and 807 to 1963 mg C kg^{-1} at Mukerian site. In Takarla, its concentration was higher in agro-forestry (1626 mg C kg^{-1}), followed by forestry (755 mg C kg^{-1}), grassland (705 mg C kg^{-1}) and cropland (418 mg C kg^{-1}). At Mukerian, grassland possessed significantly higher value (1963 mg C kg^{-1}) followed by forestry (1540 mg C kg^{-1}), cropland (1420 mg C kg^{-1}) and agro-forestry (806.66 mg C kg^{-1}). Labile C represents an easily decomposable fraction of soil organic matter that decomposes within a few weeks or months. Higher level of LC indicates greater turnover rate of organic matter and higher availability of other nutrients also. Changes in carbon stocks following land use change can be more pronounced in light fractions (Schwendenman and Pendall 2006). The LC is characterized by rapid mineralization due to labile nature of its constituents and lack of protection by soil colloids (Turchenek and Oades 1979) [38]. The labile fractions of SOC might have significant effect on soil quality and are, therefore, more sensitive indicators of the effects of land-use compared with SOC (He *et al.* 2008). Labile fractions generally represents only a small proportion of total SOC in biologically active soils (Gregorich *et at.* 2006) [15]. It has been suggested that enhanced protection of SOM by aggregates in undisturbed soils results in an accumulation of more labile C within aggregates, or, in other words, in differences among the chemical composition of unprotected or free SOM and protected or occluded SOM (Six *et al.* 2002) [32].

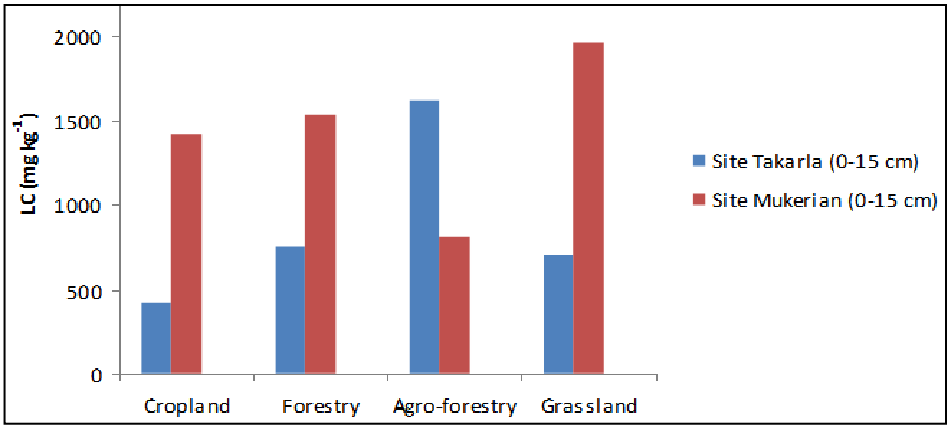

Fig 3: Effect of different land-use systems on labile C (g kg^{-1}) at 0-15 cm soil depth at Takarla and Mukerian.

Particulate organic C (POC)

At Takarla, particulate organic carbon (POC) in the 0-5 cm soil layer ranged from 2415.97 to 3389 mg C kg^{-1} soil. Its concentration was highest (3389 mg C kg^{-1}) in agro-forestry. The concentration of POC was minimum (2415.97 mg C kg^{-1}) in grassland. Particulate organic carbon was further fractioned into (i) very fine (<53 µm), fine (53-250 µm) and coarse (>250 µm) fractions. Among the land-uses, forestry influenced very fine fraction at the surface significantly with highest value followed by cropland. In fine fraction, agro-forestry and, in coarse fraction, grassland possessed highest value. The SOC distribution among the intra-aggregate fractions indicates the importance of micro-aggregates of the less disturbed system (afforested and forest). Previous studies have demonstrated that stable micro-aggregates can stabilize and sequester C in the long term (Skjemstad *et al.*, 2006) [15]. Six *et al.* (2002) [31] found that high enrichment of micro-aggregate POM C (53) in forest ecosystem illustrated this high stabilization of SOC by micro-aggregates. In addition, the fine iPOM (250f), a fraction stabilized by mM (Six *et al.*, 2000) [32], was the most important fraction on a whole soil basis and was stabilized under the forest. At Mukerian, particulate organic carbon (POC) in the 0-5 cm soil layer ranged from 7991.6 to 4084.5 mg C kg^{-1} soil. Grassland possessed significantly higher value of very fine fraction as compared other land-uses but no significant difference was found in forestry, agro-forestry and cropland. In fine fraction, grassland attained higher value followed by forestry and lowest in cropland. Forestry significantly possessed higher value in coarse fraction. Cropland possessed higher POC as percent of SOC in size fraction < 53 µm followed by forestry. Agro-forestry contain high POC as percent of SOC in 53-250 µm size fraction and grassland possessed higher value in > 250 µm size faction (Table 6). On the other hand at Mukerian, grassland contain higher POC as percent of SOC both in 53-250 µm and < 53 mm size fraction followed by agro-forestry and forestry. In course size fraction high POC was observed in forestry followed by agroforestry. Pastures represent an option to increase C sequestration, mainly due to aggressive root system, where rhizodeposition occurs and roots are constantly renewed (Lal 2006) [21], working as a system of soil C accumulation and recovery. The main source of POC in soil is difficultly decomposable organic residues having high lignocellulose index as is found in rood biomass (Rudrappa *et al.* 2006) [28]. It was observed that recycling of particulate organic matter from pasture was slower than from wheat residues (Cambardella and Elliot, 1992) [6]. This fact, coupled with the large amount of roots produced by grasslands, may explain the high POC levels in this system. The use of suitably managed pastures, without grazing, led to increases in the levels of particulate organic matter and to association with larger aggregates (2-8 mm) (Figueiredo *et al.* 2010) [10]. Salvo *et al.* (2010) also found that greater humification under the mixed crop-pasture systems has a benefitial effect if we consider the stabilization of the captured C. In crop-pasture systems, the contribution of N from legumes may have favored humification processes in lightest SOC fractions (POM-C). In addition, medium to heavy textures of this soil, favor the retention mechanisms of most transformed C. In order to increase stabilized SOM, it is necessary to incorporate material with high lignin and/or polyphenol contents and high N contents (Palm *et al.* 2001) [25], a condition similar to that of the crop-pasture rotations, where residues of different composition are mixed. Particulate organic matter represents uncomplexed organic matter, which mainly consists of partially decomposed plant.

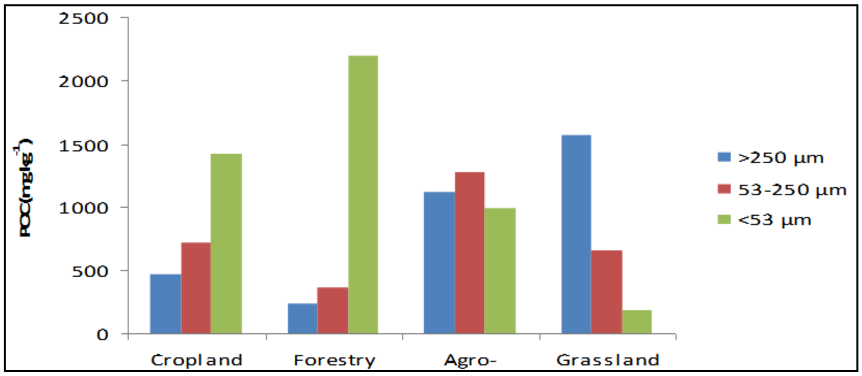

Fig 4: Effect of different land-use systems on particulate organic C (mg kg^{-1}) in different size fractions at 0-15 cm soil depth at Takarla.

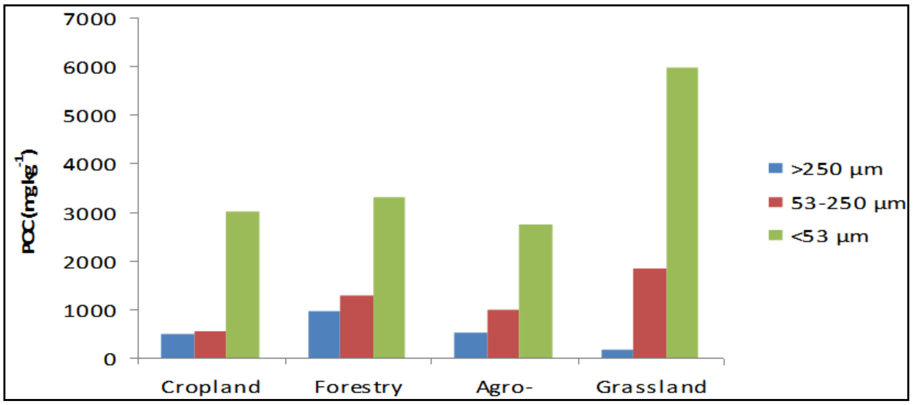

Fig 5: Effect of different land-use systems on particulate organic C (mg kg^{-1}) in different size fractions at 0-15 cm soil depth at Mukerian.

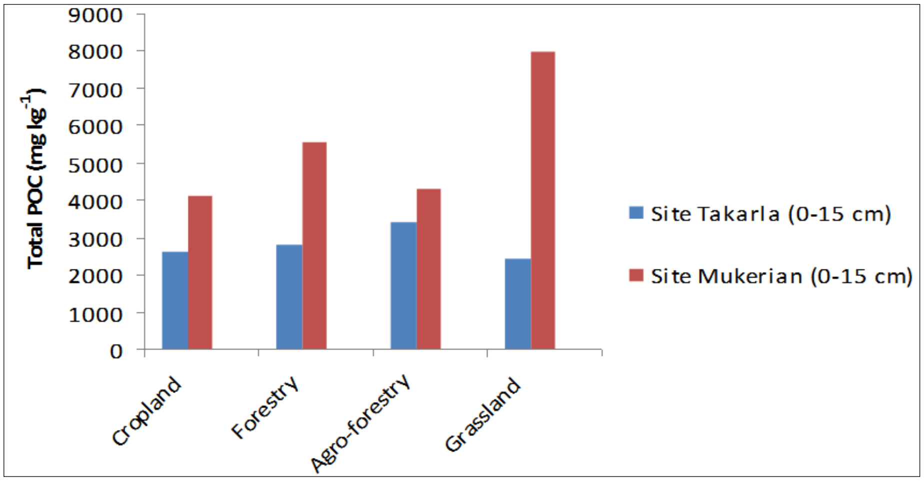

Fig 6: Effect of different land-use systems on total particulate organic C (mg kg^{-1}) at 0-15cm soil depth at Takarla and Mukerian.

and animal residue, root fragments, fungal hyphae, spores, seed, faunal skeletons and charcoal. It is the more active pool of soil organic carbon (SOC) and is a sensitive indicator of soil management effects on SOC (Elliott *et al.* 1994) [8]. The coarse fraction represents the unprotected pool of SOM as it is not associated with soil minerals. The unprotected POM represents the labile fraction of SOM and it consists of plant residues in various stage of decomposition along with microbial biomass and microbial debris. Positive effect of organic sources on POC has been reported in a number of studies (Hassink 1995, Rudrappa *et al.* 2006) [16, 28]. The results show that POC can be used as a sensitive indicator of management effect on organic carbon in soil. Since POC is considered as an effective measure of active SOM pool (Gerzabek *et al.* 2001). Grassland had higher value of particulate organic matter C as compared to cropland. Cropland was more disturbed due to tillage effect as compared to native sod (Cambardella and Elliott 1992) [6]. Tisdall and Oades (1982) proposed that microaggregates were formed free within the soil and subsequently became the building blocks for macroaggregate formation. Carbon is first incorporated into macroaggregates and then forms the core of new microaggregates (Oades 1984) [24]. For the surface layer, the largest differences in iPOM concentration were observed for the microaggregate associated iPOM C, with much higher concentrations apparent for soils from native vegetation than in either of the tillage treatments.

Conclusion

The accelerated greenhouse effect is an important issue. The net emission of greenhouse gases by anthropogenic activities can be reduced by bio-sequestration in soils and vegetation. While soil carbon is rapidly lost by erosion and/or plowing, enhancing soil carbon pool is a slow process. Gross rate of C sequestration may be greater in cool and humid regions than in warm and dry climates. Management of SOC is crucial to high soil quality and attainment of agricultural sustainability.

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