Research Article

The Effect of Land Use Type and Climatic Conditions on Carbon Dynamics and Physico-Chemical Properties of Inceptisols and Mollisols

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Abstract | Carbon has an important role in soil fertility; its sequestration is essential for sustainable agriculture. Soil organic carbon of three land uses viz. forest land, grassland, and cultivated land were quantified. These land uses belonged to two soil groups having different soil type and climate. Selected soil groups were Inceptisols (site 1) and Mollisols (site 2). Soil samples were analyzed for bulk density (BD), soil organic carbon (SOC), total nitrogen (TN), available phosphorus (AP), extractable potassium (K) and pH. Statistically ($p \leq 0.05$) higher SOC contents of Inceptisols and Mollisols were 14.18 g kg^{-1} and 23.42 g kg^{-1}, respectively under forest land use. At both sites forest soils had higher SOC and AP while K was higher in grassland use. Forest soils had slightly acidic pH and lower BD than cultivated land uses. Data combined over locations illustrated that Mollisols contained higher SOC and K, whereas, TN, AP, and BD were statistically similar at both sites. The SOC was positively correlated with TN, AP and K of soil, whereas, SOC was negatively correlated with BD and pH of the soil. There is a large difference in SOC storage and physico-chemical properties mainly in relation to climate, soil type and vegetation.

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Introduction

Soil organic carbon is an indicator of soil quality that play role in the cycling of important nutrient elements such as nitrogen, phosphorus and sulfur in terrestrial ecosystems. Carbon sequestration is the process of storing carbon in soil. The storge of SOC will lower the amount of carbon in the atmosphere, and therefore help to reduce the problem of global warming and climate change.

The main factors which determine organic carbon levels in soil are rainfall, temperature, vegetation and soil type. Soil organic carbon levels of agricultural soils are lower than equivalent soils under natural vegetation. The quantity of soil carbon that can be stored is dependent on the farming system (management practices), soil type and climatic conditions. Portion of the active SOC pool is largely influenced by climate (Franzluebbers et al., 2001). The result of climate change may be different in tropical, temperate and Boreal regions. Thus, Feller et al. (1992) reported that independent of climatic variations such as precipitation, temperature, and duration of the dry season, SOC increased with the clay and silt contents but there was a poor relationship with the amount of rainfall. Clay and silt play an important role in the stabilization of organic compounds and small variations

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in topsoil texture could have large effects on SOC (Bationo and Buerkert, 2001). Moraes et al. (1998) has shown combinations between soil type and vegetation for carbon storage. The soil, by affecting water availability influences vegetation, elemental cycling and soil temperature regime (Cheddadi et al., 2001).

Species composition in the ecosystem can be affected by changes in soil temperature and moisture regime. These changes may also affect the SOC pool and soil physical properties because of the changes in biomass (detritus material, above ground and below ground biomass) returned to the soil. In China, the carbon storage for forest and woodland is 8.72 GtC and tropical and sub-tropical evergreen broad leaf forests have the highest carbon density just because of favourable temperature and water conditions (Kerang et al., 2004). All the way cropping strength increases by SOC through greatest return of crop residues and microbial activities (Sherrod et al., 2003; Stromberger et al., 2007). The land use change from natural to agricultural environments diminishes the SOC pool over time (Lal, 2003). Moreover, mineralization rates may increase under tillage systems while soil structure deteriorates and organic matter contents get reduce under cultivation (Govaerts et al., 2007).

The mountainous regions of the state of Azad Jammu and Kashmir Pakistan due to gently-steep slopes, high intensity erratic rainfalls, higher demand for firewood, shelter and clearance of forests for construction trends are vulnerable to land degradation and ultimately less SOC storage and poorer soil quality. The cultivated land has low fertility status and poor soil structure due to less trend of addition of inputs i.e both organic and inorganic. To highlight the importance of SOC sequestration and its variation under different agro-climatic conditions, the statistics on SOC determination is pre-requisite. In this study, the concentrations of SOC and its correlation with physico-chemical properties was compared under different agro-climatic conditions.

The specific objectives of the study were:

1. Determination of carbon storage of three different land uses *i.e.* forest, grassland and cultivated of soil groups Mollisols and Inceptisols.
2. Construction of correlation between soil carbon and soil properties (pH, bulk density, Total N, P and K) to monitor changes in soil carbon storage stimulated by these properties.

Materials and Methods

Study site

Two soil groups were selected having different climate, vegetation and soil type. Description of soil groups according to soil survey of Pakistan 2004 is:

1. Inceptisols (site 1) mostly comprised of Dupata soil series [Loamy skeletal, mixed, thermic Humic Lithic Eutrudepts] Humid, sub-tropical/temperate with a mean annual rainfall of 1481 mm, 46% of which is received in summer (May to Aug), 33% in winter (Dec to March) and the remaining in spring and autumn seasons.
2. Mollisols (site 2) mostly comprised of Chinasi soil series [coarse silty Loamy skeletal, mixed, thermic Typic Hapludolls] Humid/subtropical, with a mean annual rainfall of 1690 mm, 40% of which is received during the winter season (Dec to March) 41% is received in summer (May to August) and the remainders in spring and autumn season. Mean annual, mean maximum and mean minimum temperature are 16.5°C, 21.2°C and 11.5°C, respectively.

Collection of Soil Samples

Soil samples were collected from three different lands uses of forest land, grass land and cultivated land from each site. Three replications were taken for each site at the soil depth of 0-15 and 15-30 cm. The forest land indicated an undisturbed soil while grass land was covered with rough meadow grass, and maize was grown in cultivated land. At both sites cultivated fields were not properly managed and organic/inorganic inputs were not being added according to fertility status of soil or according to crop requirement.

Soil Analysis

Soil analyses were carried out for SOC by using method of Nelson and Sommers (1982), $pH_{1:2}$ (Mclean, 1982), TN by Kjeldahl method of Bremner and Mulvaney (1982), AP, and extractable K were determined by ABDTPA extraction (Soltanpour and Workman, 1979). Bulk density was determined by core method (Blake and Hartage, 1986).

Statistical Analysis

Statistical analysis was carried out by using procedure adopted by Steel et al. (1997) and correlation of SOC with soil physico-chemical properties were constructed.

Table 1: *Physico-chemical characteristics of soil under different land uses of Inceptisols*

Land uses	Parameters					
	Soil organic Carbon (g kg^{-1})	pH	Total Nitrogen (g kg^{-1})	Phosphorus (mg kg^{-1})	Potassium (mg kg^{-1})	Bulk density (g cm^{-3})
Forest	14.18 a	6.73	2	3.77	170 b	1.03 b
Grassland	10.13 b	7.10	1.6	3.41	190 a	1.13 ab
Cultivated	7.73 b	6.69	1.4	3.59	143 c	1.23 a
Depth (cm)						
0-15	14.03 a	6.54 b	2	3.98 a	174	1.10
15-30	7.33 b	7.14 a	1.3	3.19 b	162	1.16
LSD						
Land uses (L)	3.09	NS	NS	NS	13.78	0.12
Depth (D)	2.52	0.04	NS	0.51	NS	NS
L×D	4.37	NS	NS	NS	NS	NS

Means in columns sharing same letters are statistically non-significant at $p \leq 0.05$

Table 2: *Physico-chemical characteristics of soil under different land uses of Mollisols*

Land uses	Parameters					
	Soil organic Carbon (g kg^{-1})	pH	Total Nitrogen (g kg^{-1})	Phosphorus (mg kg^{-1})	Potassium (mg kg^{-1})	Bulk density (g cm^{-3})
Forest	23.42 a	6.70	3.6 a	3.75	134 b	1.01 b
Grassland	13.18 b	7.22	3 a	3.51	186 a	1.09 b
Cultivated	8.98 b	7.07	0.9 b	3.60	95 c	1.25 a
Depth (cm)						
0-15	22.30 a	6.83	0.30 a	3.88 a	144	1.06 b
15-30	8.09 b	7.17	0.20 b	3.35 b	133	1.17 a
LSD						
Land uses (L)	7.17	NS	0.9	NS	15.73	0.12
Depth (D)	5.86	NS	0.8	0.36	NS	0.10
L×D	10.15	NS	NS	NS	NS	NS

Means in columns sharing same letters are statistically non-significant at $p \leq 0.05$

Results and Discussion

Soil Organic Carbon

The data on SOC under different land uses of Inceptisols are presented in Table 1. The order of SOC contents in different land uses was forest > grassland > cultivated. Forest land had 83 % more SOC than the soils under grassland and 40 % higher than cultivated land. Similarly, soil from the grassland had 31 % more SOC than cultivated land. Surface soil (0-15) had more SOC than the subsurface 15-30 cm. The data presented in Table 2, revealed the effect of different land uses on SOC of Mollisols. Statistically ($p \leq 0.05$) significant difference among different land uses was observed. SOC content in different land uses was ranging from the highest 23.42 g kg^{-1} in forest soils to the lowest 8.98 g kg^{-1} in cultivated soils. Grassland soils contained 13.18 g kg^{-1} SOC and it was statistically at par with cultivated land. Soil from forest land had 78 % and 161 % higher SOC than the soils under grassland and cultivated land, respectively. Likewise, soil from the grassland had 47 % higher SOC than cultivated land. These results showed the highest percentage of SOC in forest soils. The means of both depths showed significantly higher amount of SOC content at 0-15 cm as compare to 15-30 cm depth. Table 3 shows soil organic carbon of soil under different land uses of Inceptisols and Mollisols (Data is combined over locations).

The means of sites showed that Mollisols had statistically higher SOC of 15.19 g kg^{-1} as compare to the SOC of Inceptisols i.e. 10.68 g kg^{-1}. Mollisols had 42 % higher SOC than Inceptisols.

Table 3: *Physico-chemical characteristics of soil under different land uses of Inceptisols and Mollisols (data is combined over locations)*

Land uses	Parameters					
	Soil organic Carbon (g kg^{-1})	pH	Total Nitrogen (g kg^{-1})	Phosphorus (mg kg^{-1})	Potassium (mg kg^{-1})	Bulk density (g cm^{-3})
Forest	18.80 a	7.05 b	0.28 a	3.61	152 b	1.02 b
Grassland	11.66 b	7.25 a	0.23 a	3.52	188 a	1.11 b
Cultivated	8.36 c	7.21 a	0.15 b	3.66	119 c	1.24 a
Locations						
Site 1	15.19 a	6.99	0.25	3.62	138 a	1.12
Site 2	10.68 b	7.34	0.17	3.58	168 b	1.12
LSD						
Land uses (L)	2.80	0.0113	0.07	NS	5.28	0.09
L×S	3.97	NS	0.10	NS	NS	NS

Site 1: *Mollisols;* **Site 2:** *Inceptisols; Means in columns sharing same letters are statistically non-significant at $p \leq 0.05$*

At both Inceptisols and Mollisols forest soils had more carbon and this is might be due to return of more litter, OM and ability of trees in forests to conserve more SOC as compare to other land uses. The SOC pool is greatly reactive and responsive to natural and anthropogenic perturbations. Therefore, land use change diminishes the SOC pool over time, generally in the order cropland > grazing land > forest (Lal, 2003). The annual additions of OM are decreased when the natural vegetation is cleared for cultivation (Follett et al., 2005). Removal of upper fertile soil by wind or water erosion is another reason for decrease in SOC content in arable lands (Jacinthe et al., 2001; Martinea-mena et al., 2002). Zhi et al. (2015) found the highest SOC density under grassland and the lowest under unutilized land.

The higher content of SOC in Mollisols compare to Inceptisols could be due to the variation in climatic conditions of both sites. As the temperature of Mollisols ranges from mean minimum 11.5 °C to mean maximum 21.2 °C, this is favourable for the accumulation of SOC. Wang et al. (2001) who from their research found that in the eastern and northern parts of Northeast China, the highest SOC content was recorded because of the dense litter layer in the native forests and temperatures are lower, hence slows down the decomposition of SOC which increases the density of SOC. The SOC variation at both sites could also be attributed to variation in natural vegetation at both sites. Mollisols has natural vegetation of grasses and shrubs consist of *Acer casesium, Cynodon dactylon, Palum, Pinus wallichina* and Inceptisols has natural vegetation of forest and scrub consist of *Jungians, Dalbargia sisoo, Mourous alba, Poplar, Pinuroxbughii, Acacia nilothica* and *Pyrus pashia*.

Soil Physico-Chemical Properties

Bulk density: The data regarding soil BD under different land uses of Inceptisols is given in Table 1. The data showed the highest soil BD (1.23 g cm^{-3}) in cultivated soils followed by grass (1.13 g cm^{-3}) and cultivated (1.03 g cm^{-3}) land use. The cultivated land had 19 % higher BD than the soils under forest and 9 % higher than grass land. Similarly, soil from the grass land had 10 % higher soil BD than forest land. The means of depths indicated statistically lower soil BD of 1.10 g cm^{-3} at 0-15 cm than 1.16 g cm^{-3} at 15-30 cm. The effect of land uses on soil BD of Mollisols is presented in Table 2. From the results it was analyzed that cultivated land had the maximum 1.25 g cm^{-3} and forest land had the minimum 1.01 g cm^{-3} while cultivated land had moderate 1.09 g cm^{-3} BD. Soil from cultivated land had 24 % and 15 % more BD than the soils under forest and grassland, respectively. Similarly, soil from the grass land had 8% more BD than forest land. The upper soil depth (0-15 cm) had lower soil BD than the lower depth (15-30 cm).

Soil BD under different land uses of Inceptisols and Mollisols (Data is combined over locations) is given in Table 3. Combined data of land uses of both sites illustrated statistically ($p \leq 0.05$) similar soil BD of 1.12 g cm^{-3} for Inceptisols and Mollisols.

The highest BD in the cultivated land is attributed to conventional tillage and deprivation of organic matter as a result of continuous and intensive cultivation with heavy farm machinery or even manually (Girma, 1998). Puget and Lal (2005) also showed in their results that lower BD was observed in forest soils compared to cultivated plots and the pasture up to 30 cm depth.

pH: Data presented in Table 1 shows the effect of different land uses on pH of Inceptisols site. Results showed that forest and cultivated soils had acidic pH (6.73, 6.69, respectively), however, grassland soils had alkaline pH (7.10). Upper 0-15 cm depth had acidic (6.54) while lower depth had alkaline (7.14) pH. The effect of different land uses on pH of Mollisols is indicated in Table 2. Inceptisols forest soils had acidic pH (6.70) while cultivated and grassland soils had alkaline pH (7.07, 7.22 respectively). Upper 0-15 cm depth had acidic (6.83) while lower 15-30 cm depth had alkaline (7.17) pH. Data given in Table 3 illustrated that Mollisols had slightly acidic while Inceptisols had alkaline pH.

At both sites forest soils were acidic that may be due to the presence of higher OM which release acids (humic acid, fulvic acid *etc.*) and lowers the pH of forest soils. These results are also in agreement with the study of Schjonning et al. (1994) who reported that pH will decrease due to the accumulation of SOC, which upon decomposition releases different acids.

Total Nitrogen: The effect of different land uses on TN content of Inceptisols is presented in Table 1. The forest land had maximum (2 g kg^{-1}) TN and minimum TN (1.4 g kg^{-1}) was in cultivated soils. It was calculated that forest land had 25 % and 43% more TN than the soils under grassland and cultivated land, respectively. Soil from the grassland had 25% more TN than cultivated land. Results shows that TN of 0-15 cm soil depth was statistically at par with TN of 15-30 cm. However, non-significant higher TN of 2 g kg^{-1} was in 0-15 cm than 1 g kg^{-1} TN of 15-30 cm. The effect of different land uses on TN content of Mollisols is presented in Table 2. Data indicated that the forest soils had higher TN content (3.6 g kg $^{-1}$) as compare to cultivated (0.9 g kg^{-1}) and grassland (3 g kg^{-1}). The soil from forest land had 300 % and 20% more TN than the soils under grass and cultivated land use, respectively. Similarly, soil from the grassland had 28 % higher TN than cultivated land. The means of depths showed statistically higher TN at 0-15 cm than 15-30 cm. Table 3 shows TN of soil under different land uses of Inceptisols and Mollisols (Data is combined over locations). The Mollisols had higher TN (0.25 g kg^{-1}) than TN (0.17 g kg^{-1}) of Inceptisols. Mollisols had 47 % more TN than Inceptisols.

Soil nutrients can be lost from upper layer of the soil through the surface runoff and leaching where less or no vegetation is present (Lal, 1976, 1992). The more TN in forest soils was may be due to more accumulation of OM in forest soils. These results are in harmony with Abbasi et al. (2007); their results showed that there is linear relationship between nitrogen and OM so lower OM content in arable lands may be a reason for decrease of TN content from upper layer of soil. Comparatively higher TN in Mollisols is may be due to more OM content and higher microbial activities in Mollisols which enhanced mineralization process and increased nitrogen content.

Potassium: The data of soil K under different land uses of Inceptisols are presented in Table 1. Soil K contents varied from the lowest 143 mg kg^{-1} in cultivated soils to the highest 190 mg kg^{-1} in grass land soils. The order of K contents in different land uses was grassland > forest > cultivated. Grass land had 12 % and 33% more K than the soils under forest and cultivated land, respectively. Similarly, soil from the forest had 12% more K than cultivated land. Surface soil (0-15) had more K than the subsurface 15-30 cm. The data presented in Table 1 revealed the effect of different land uses on K of Mollisols. Potassium content in different land uses was ranging from the highest 186 mg kg^{-1} in grass land soils to the lowest 95 mg kg^{-1} in cultivated soils. Forest soils contained 134 mg kg^{-1} soil K and it was statistically at par with cultivated land. Soil from grass land had 39 % and 96 % higher K than the soils under forest and cultivated land, respectively. Likewise, soil from the forest had 41 % higher soil K than cultivated land. These results showed the highest percentage of soil K in grass land soils. The means of both depths showed significantly higher amount of soil K content at 0-15 cm as compare to 15-30 cm depth.

Data in Table 3 shows soil K under different land uses of Inceptisols and Mollisols (Data is combined over locations). Soil K of combined sites ranged from the highest value of 188 mg kg^{-1} of grass land soil to the lowest value 119 mg kg^{-1} of cultivated soil. However, the means of sites showed that Inceptisols had statistically higher soil K of 168 mg kg^{-1} as compare to the soil K of Mollisols *i.e.* 138 mg kg^{-1}, and Inceptisols had 22 % more potassium than Mollisols.

Low soil K in top-soils of cultivated and forest soils may be due to plentiful growth of herbaceous species and tree seedlings that leads to more uptakes of K and reduced mineralization and/or increased nutrient loss from top-soil through leaching and run off .

Phosphorus: The data regarding to soil AP under different land uses of Inceptisols is given in Table 1. The data shows the highest soil AP (3.77 mg kg^{-1}) in forest soils followed by cultivated (3.59 mg kg^{-1}) and grass (3.41 mg kg^{-1}) land use. The forest land had 11 % and 5 % more AP than the soils under grassland and cultivated land, respectively. Similarly, soil from the cultivated land had 5 % more soil AP than cultivated land. The means of depths indicated statistically higher soil AP of 3.98 mg kg^{-1} at 0-15 cm and 3.19 mg kg^{-1} at 15-30 cm.

The effect of land uses on soil AP of Mollisols is presented in Table 2. From the results it was analyzed that forest soil had the maximum 3.75 mg kg^{-1} P and grass land had the minimum 3.51 mg kg^{-1} while cultivated land had moderate 3.60 mg kg^{-1}. Soil from forest land had 7 % and 4 % more AP than the soils under grassland and cultivated land, respectively. Similarly, soil from the cultivated land had 3% more AP than grass land. The upper soil depth (0-15 cm) had higher ($p \leq 0.05$) soil AP than lower depth of 15-30 cm. Soil AP under different land uses of Inceptisols and Mollisols (Data is combined over locations) is given in Table 3. Combined data of land uses of both sites showed higher ($p \leq 0.05$) soil AP of 3.62 mg kg^{-1} of Mollisols followed by 3.58 mg kg^{-1} of AP of Inceptisols, similarly, Mollisols had 21 % more AP than Inceptisols.

These results are in agreement with the findings of Liu et al. (2002) who observed that cultivated and grass lands had significantly less amount of AP as compare to the soils under forests and this variation may be due to the organic matter. From combined study of both Inceptisols and Mollisols it was observed that Mollisols contained more AP than Inceptisols. Mollisols were rich in organic matter so more AP released.

Correlation of Soil Organic Carbon with Physico-Chemical Properties

Correlation between soil organic carbon and bulk density: The negative correlation (-0.590; $p < 0.05$) between SOC and BD confirmed the dependence of BD on SOC (Table 4). When organic matter in soil increases, BD decreases due to increase in porosity which is required for the proper growth of the plant. Leifeld et al. (2005) found a strong negative correlation between OM and BD of soils. A reverse correlation between OM and BD was also declared by Pravin et al. (2013).

Table 4: *Correlation of soil organic carbon with physico-chemical properties of soil*

	Soil organic Carbon (g kg^{-1})	***p* value**
pH	-0.487	0.04
Total nitrogen (g kg^{-1})	0.639	0.004
Phosphorus (mg kg^{-1})	0.086	0.73
Potassium (mg kg^{-1})	0.012	0.96
Bulk Density (g cm^{-3})	-0.590	0.01

Correlation between soil organic carbon and pH: In Table 4 negative correlation (r = -0.487; $p < 0.05$) coefficient between SOC and soil pH was observed. When OM content of the soil will be high, pH of the soil will be acidic due to release of certain organic acids but if the OM content of the soil will be low then pH of the soil will be alkaline. Correlation between SOC and pH of the soil was also given by the findings of Schjonning et al. (1994) who had analyzed from their study that due to accumulation of SOC, pH of the soil had changed. Abbasi et al. (2007) also indicated a significant correlation between (r = -0.61) organic matter and pH showing that OM contribute significantly towards the change in pH of the soil.

Correlation between soil organic carbon and total nitrogen: Table 4 shows a significantly positive correlation (r = 0.639; $p < 0.01$) between SOC and total nitrogen. This is because OM in soil contained different nutrients including nitrogen and if SOC increases, the total N also increases (Li et al., 2007). The dynamics of N in mineral soil is closely linked to SOC, because most N exists in organic compounds (Kara et al., 2008).

Correlation between soil organic carbon and soil potassium: There was no significant or strong correlation (r = 0.012; $P < 0.05$) between SOC and soil K, (Table 4). Our results are in contrast with the findings of Abbasi et al. (2007) who from their research concluded that correlation between OM and soil K was high.

Correlation between soil organic carbon and avail-

able phosphorus: Correlation between SOC and AP was r = 0.086 and statistically non-significant at $p < 0.05$. Lower content of OM will release fewer amounts of organic acids which solubilize the phosphates and phosphate bearing minerals. Havlin et al. (1999) also confirmed that in the alkaline soil where the OM content is low, the available P reacts with calcium to form calcium phosphate and make the availability of P low.

Conclusions

The SOC sequestration was found in increasing order of forest > grassland > cultivated land use. Soil TN, AP, K was higher under natural vegetation than cultivated land while soil BD was higher under cultivated lands. Positive correlation of SOC with TN, AP, K and negative correlation with pH and BD showed that SOC is important indicator of soil fertility and soil quality. To increase SOC sequestration under cultivated land uses, there is a need to adopt practices that add SOC to the system either directly or indirectly.

Authors' Contribution

This research is part of research project of first author Aqila Shaheen. The co-author (Mehwish Matien) worked for her M.Sc (Hons.) research in the same project.

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