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Soil organic carbon stock variation with climate and land use in shale derived soils

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Abstract: Anthropogenic activities, urbanization and industrialization cause an increase in the atmospheric carbon dioxide. Current focus of the soil scientists and the environmentalists is to quantify the carbon stocks and its flow in the agroecological system which is one of the main causes of global warming and climate change. The information on the distribution of soil organic carbon (SOC) stocks in the soil profiles in relation with changing climate is barely sufficient. Objective of this study was to quantify the effect of climate and land on the equilibrium of SOC stocks in soil profiles with development. Murree soil series (Typic Hapludolls) in humid climate and under coniferous forest, and Tirnul soil series (Typic Haplustepts) in semiarid climate under cultivation, were selected. Triplicate soil profiles were selected for each of the soils and sampled at genetic horizons level. Cumulative SOC stocks in Typic Hapludolls soil profiles (95 Mg ha^{-1}) were significantly greater than Typic Haplustepts (30 Mg ha^{-1}). The Typic Hapludolls had significantly greater SOC stock at each horizon level under humid climate. This research concludes that soils under forest and humid climate had higher SOC stocks as compared to the soils under semiarid climate and cultivation.

Keywords: soil genesis; cultivation; climate; land use; carbon stocks.

INTRODUCTION

The global emission of soil carbon dioxide is well recognized as one of the largest contributor to worldwide carbon fluxes. Atmospheric carbon dioxide concentration is significantly affected by the slight change in the rate of the soil

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respiration.[1] Atmospheric carbon dioxide is one of the largest anthropogenic sources which enhance the greenhouse effect.[2] The reliable estimates of C stocks are required under the Kyoto Protocol by the United Nations Framework Convention on Climate Change thought to be the major factor in global warming.[3] Balance between biomass debris and decomposition driven by various parameters of natural and human origin controls the quantity of organic matter and soil carbon stock.[4–6] The organic matter reduction in top soils severely affects the water holding capacity, the structure stability, the nutrient storage and the supply as well as the soil microbes, *i.e.*, mycorrhizas and the nitrogen-fixing bacteria.[7]

The estimated soil carbon contents in the 100 cm soil profile depth are about 1500 Pg. Soil carbon is an important component of the global carbon cycle, the exchange with the atmosphere through soil respiration is approximately 80 Pg C yr^{-1}.[8] It is well known that the SOC pools have distinct residence times. Most of the soil carbon occurs as the resistant material that cannot be altered by the recent land uses and thus it is a low cycling carbon.[9–11] Whereas less resistant material has rapid response to the recent land use changes and considered as much faster carbon cycling pool.[9–13] Consequently, it is important for humans to store carbon managing the soils or controlling high losses of it with tillage practices.[14] Stratification of SOC act as quality indicator to reduce the greenhouse gas emissions. The additional research is needed to identify the stratification ratio in the soil horizon with the change in climosequences in the future.[15]

The rainfall intensity has a positive effect, the while rising temperature has the inverse effect on the soil organic carbon levels.[16] Soil carbon stocks may vary with change in the climatic conditions and the land use practices. The land use and the climosequence frequently influence the dynamics of organic carbon stocks. However, changes in total SOC stocks in response to the land use and to the climosequence may be difficult to quantify because of the natural soil inconsistency. However, the dissolved organic carbon (DOC), is much more sensitive than SOC stocks.[17] In current study, two soils from shale parent material were selected, varying in development from the different rainfall zones and the different land use. The triplicate soil profiles in each soil were selected and sampled at the genetic horizon level. Objective of the study was to quantify the effect of climate on the cumulative SOC stocks as well as on the carbon stock of each layer in soil profiles with the climate change and the land use.

EXPERIMENTAL

Soil description and sampling

Typic Hapludolls (Murree soil series) is developed in Murree's shale of Miocene Epoch in humid climate and under coniferous forest. The soil is noncalcareous due to the high rainfall (1440 mm per annum and annual temperature 12.7 °C). Typic Haplustepts (Tirnul soil series) is developed in Murree's shale in the semiarid climate (< 500 mm per annum and annual temperature 21.7 °C) and was under cultivation. The dominant coniferous tree is Pinus

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in Murree while main crops grown in Tirnul soil are maize, wheat and groundnut. The Murree soil series occurs on the mountain tops, the Tirnul at the bottom of troughs within the mountain ridges. Three replicate profiles for each soil were dug at separate locations. Soil samples were taken at genetic horizon level after profile description. Soil samples from each genetic horizon for both soils were taken.

Soil characterization

Soil texture was determined by the dispersion of soil in 1 % sodium hexametaphosphate followed by the sonication and density of the suspension was recorded at s the pecific time intervals by hydrometer[18] and soil pH was measured using a pH meter after preparing saturated soil paste.[19] Dithionite extractable iron and aluminum from soil were extracted in 0.3 M $C_6H_5Na_3O_4\cdot 2H_2O$ solution, 1 M $NaHCO_3$ solution adding 1 g $Na_2S_2O_4$ and heating at 80 °C.[17] Iron and aluminum were analyzed using atomic absorption spectrometer (AAS) in the extract. Amorphous iron was extracted by the 0.2 M acidified $(NH_4)_2C_2O_4\cdot H_2O$ solution. The Fe concentration in the extract was determined by AAS.[20] Calcium carbonate was determined by the CH_3COOH consumption method.[21] Soil organic carbon was measured by the wet digestion.[22] Soil bulk density (ρb) was measured taking 5 cm high core with 5 cm inner diameter from the centre of each horizon. The soil sample taken with fixed volume of core was oven dried until the constant weight at 105 °C.[23]

Soil carbon stock and stratification ratio calculation

Total SOC stock of each genetic horizon was quantified by the following formula

$$\text{C stock} = SOC\times\rho\times H\times 10$$

where *SOC* is the quantity of the soil organic carbon (g kg^{-1}), ρ is the bulk density (g cm^{-3}) and H is the depth of respective soil layers. The stratification ratio (*SR*) of the organic carbon (OC) stocks and the *DOC* were calculated dividing the concentration of OC stocks and *DOC* with other layers.[15]

The variance in the soil organic carbon content and stock at the horizon level was analyzed using the multivariate analysis of variance (MANOVA) in GLM procedure of SAS version 9.0.[24] Class variable was "soil" and the measurements at various depths were multiple dependent variables.

RESULTS AND DISCUSSION

The basic soil characteristics important for estimating the degree of soil development namely the soil pH, texture, and dithionite and oxalate extractable iron are presented, first followed by the distribution of the total organic carbon (TOC), the cumulative carbon stock and the carbon stock of each soil horizon.

Soil characteristics

The selected soil Typic Haplustepts is at the early stage of development with weak to moderate horizon differentiation and the Typic Hapludolls is relatively at the weathered stage of development compared to Typic Haplustepts.[25] The basic properties of the soils are given in Fig. 1. The Typic Haplustepts were calcareous with no distinct zone of lime accumulation, while the Typic Hapludolls were decalcified to a variable depth, and had a distinct zone of lime accumulation. Similarly, the Typic Hapludolls had greater dithionite extractable iron and clay

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content, than the Typic Haplustepts. The dithionite extractable iron and the clay content are increased with the soil depth in Typic Hapludolls due to weathering processes, while the Typic Haplustepts has the uniform distribution indicating greater development in the Typic Hapludolls than Typic Haplustepts.

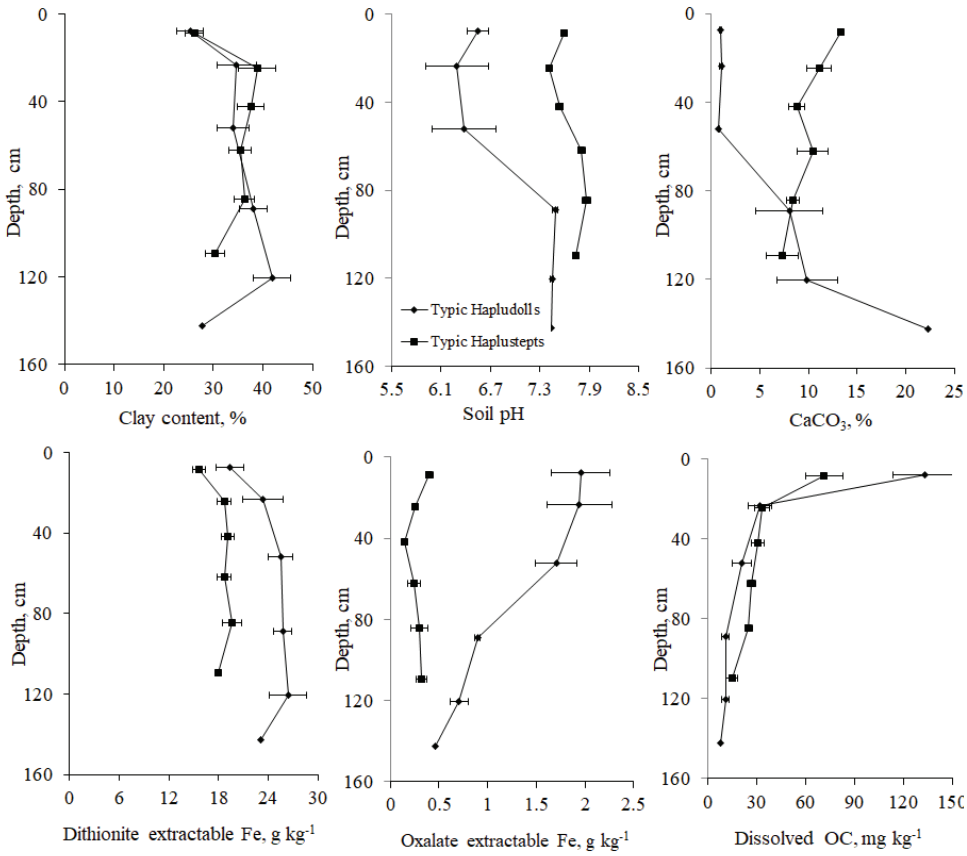

Fig. 1. Basic characteristics (clay, pH, $CaCO_3$, dithionite extractable Fe, oxalate extractable Fe and *DOC* content) of Typic Hapludolls and Typic Haplustepts. Each number is mean of 3 and error bars show standard errors.

Soil organic carbon distribution

The accumulation of SOC in agricultural fields depends on time, parent material, climate, organisms and relief.[26] The parent material variation causes differences in soil texture or clay content. The soil organic carbon ranged between 0.35 to 24 g kg^{-1} in the data set. The soil organic carbon content was high at Ap/A and Bw/BA horizons. The extent of SOC and the plant biomass production changes with the degree of soil development.[27] The soil organic carbon significantly correlated with DOC (r = 0.89, $p \leq 0.001$). The soil organic

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carbon decreased with the soil depth in both soils. The Typic Hapludolls had greater SOC content than Typic Haplustepts at all soil depths (Fig. 2). Owing to humid climatic conditions, the Typic Hapludolls had high organic carbon content. High SOC content also relates with Mollisols.[28] The soil organic carbon decreased with the increase in bulk density ($r = –0.77$, $p \leq 0.001$). The reduction in bulk density, the increase in aggregate stability, porosity and water holding capacity are the important long-term functions of the applied organic matter.[29] The concentration of SOC correlated significantly with the dithionite extractable aluminum ($r = 0.51$, $p \leq 0.01$) as aluminum is associated with the organic matter's exposed edges in calcareous system.[30] In some studies, SOC is better correlated with the factors other than clay such as extractable aluminum, allophane content or specific surface area.[31]

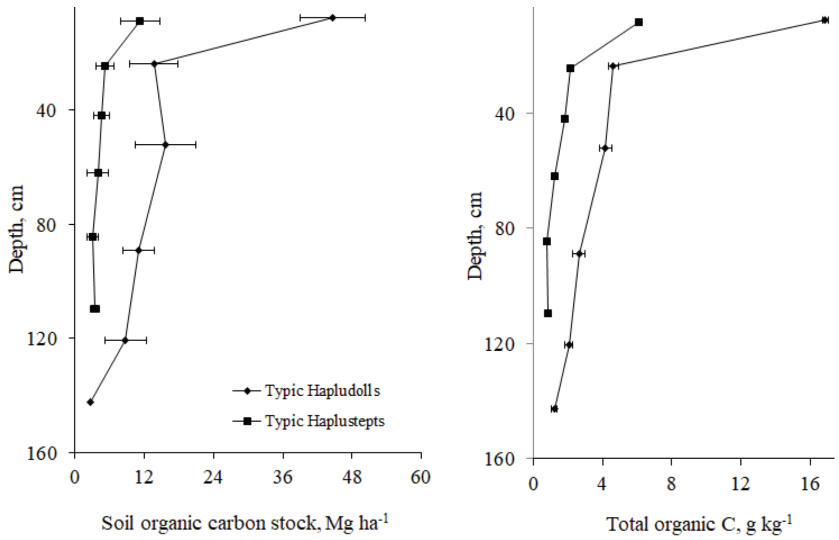

Fig. 2. Distribution of soil carbon stock and soil organic carbon in soil profiles. Each number is mean of 3 and error bars show standard errors.

Soil organic carbon stock distribution

The soil organic carbon stock was calculated using TOC, the soil bulk density and the depth of each soil horizon. The soil organic carbon stock ranged between 1.5 to 46.3 Mg ha^{-1} in the data set. The soil carbon stock had the similar trend, as the *SOC* increased towards the surface in both soils. Typic Hapludolls had greater carbon stocks as compared to Typic Haplustepts at all horizon levels (Fig. 2). The soil organic carbon stock negatively correlated with the soil pH ($r = –0.38$ $p \leq 0.05$) and the calcium carbonates ($r = –0.45$, $p \leq 0.01$). The relationship of SOC stock with the soil properties is given in Fig. 3. The soil organic carbon stock positively correlated with DOC, the oxalate extractable iron and the

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dithionite extractable aluminum as the organic carbon contents are associated with the amorphous iron and the crystalline aluminium oxides. The soil organic carbon stock negatively correlated with the soil bulk density and the clay content. The cumulative organic carbon stock was estimated by the addition of all horizons of soil profiles. The cumulative organic carbon stock for Typic Hapludolls was 95 Mg ha^{-1}, while it was 30 Mg ha^{-1} for Typic Haplustepts.

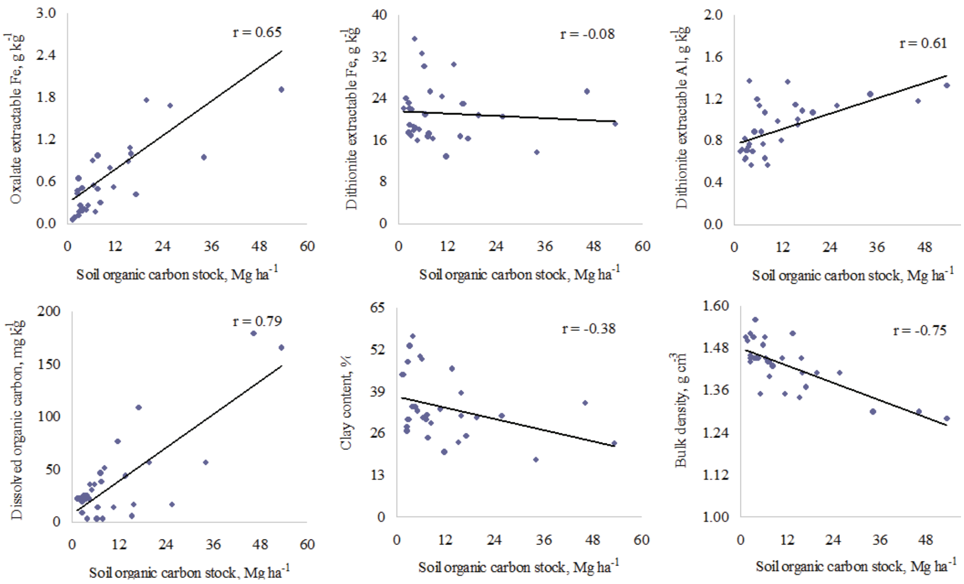

Fig. 3. Relationship of soil organic carbon stock with selected soil properties.

Typic Hapludolls is located in high rainfall areas, under coniferous forest, which result in the accumulation of high organic carbon whereas Typic Haplustepts is located in semiarid areas, under continuous cultivation, which result in a consumption of carbon from soil. The land use and the management practices influence the distribution of the organic carbon content.[32] The accumulation potential of the organic carbon in arid and semi-arid climate is more than in humid regions.[33] As a result of high temperatures and the atmospheric carbon dioxide concentration the calcium carbonate concentration and the soil pH increase, which reduces the organic carbon quantity in soil by the increase in the rate of mineralization. As the rate of mineralization increase, the plants use carbon more effectively for the biomass production. The negative correlation between OC and the clay content and the bulk density are due to the reduced contact with the surface layer. With the depth the micro porosity increases and the bulk density also causes lower carbon stocks. However, the macro-porosity increases with the increase in carbon stocks and provides the positive correlations.[34]

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Stratification ratio of total and dissolved organic carbon

Overall SR of TOC and DOC in Typic Haplustepts is more relative to Typic Hapludolls (Table I). The stratification ratio of TOC in first three layers in Typic Hapludolls D1: D2, D1: D3 and D1:D4 were 0.25, 0.22 and 0.014, respectively. However, in Typic Haplustepts the pronounced effect observed in the first two layer D1: D2 and D1: D3 SR were 0.46 and 0.38. The stratification ratio of DOC in Typic Hapludolls and Typic Haplustepts were greater in D1:D2 (0.21 and 0.57, respectively) than other depths of both soil profiles (Table I). Although the soils under arid or semiarid climate are vulnerable to degradation, the work in favor of carbon stratification in soil profile as the residence time of carbon in dry lands soils is longer than in humid soils.[35]

TABLE I. Stratification ratio of total and dissolved organic carbon in selected soils

Soil	Depth	Total organic carbon	Dissolved organic carbon
Typic Hapludolls	D1:D2	0.25 a	0.21 a
	D1:D3	0.22 ab	0.13 ab
	D1:D4	0.14 bc	0.08 b
	D1:D5	0.10 c	0.08 b
Typic Haplustepts	D1:D2	0.46 a	0.57 a
	D1:D3	0.38 a	0.52 ab
	D1:D4	0.28 b	0.48 bc
	D1:D5	0.18 c	0.43 c

CONCLUSION

From the current study it can be concluded that the soil organic carbon content and SOC stock varies with the climate, the land use and the soil development. The soil developed in humid climate under forest had higher cumulative soil carbon stock, as compared to the soil developed in semiarid climate and under cultivation. The soil organic carbon stock decreased with the soil depth in the profiles of both soils and was greater at all soil depths in the soil under forest, than in the soil under cultivation. The stratification ratio of TOC and DOC was greater on the surface layer and on the Typic Haplustepts. The soil organic carbon content, as well as SOC stock was controlled by the dithionite extractable aluminium, the oxalate extractable iron, the bulk density and DOC, rather than on the clay content and the dithionite extractable iron.

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ИЗВОД

ВАРИРАЊЕ ЗАЛИХА ОРГАНСКОГ УГЉЕНИКА У ЗЕМЉИШТУ СА ПРОМЕНОМ КЛИМЕ И КОРИШЋЕЊЕ ЗЕМЉИШТА НАСТАЛОГ НА ШКРИЉЦУ

AYAZ MEHMOOD[1], MOHAMMAD S. AKHTAR[2], SHAH RUKH[2], MUHAMMAD IMRAN[2], ASMA HASSAN[2], KASHIF S. ABBASI[3], ABDUL QAYYUM[1], TALAT MAHMOOD[1], WASEEM AHMED[1], KHURAM SHAHAZAD[1], AYUB KHAN[1] и ZAHOOR AHMAD[1]

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Антропогене активности, урбанизација и индустријализација изазивају повећање садржаја атмосферског угљен-диоксида. Тренутни фокус интересовања науке о земљишту и животној средини је на квантификовању залиха угљеника у земљишту и на његовом току у агроеколошком систему, што је један од главних криваца за глобално загревање и промену климе. Премало је доступних података о расподели залиха органског угљеника у земљишту (SOC) по профилима земљишта у корелацији са променом климе. Циљ овог испитивања је био да се квантификује утицај климе и коришћења земљишта на равнотежу залиха SOC, према профилима земљишта у току развоја. Изабране су серија Murree земљишта (Typic Hapludolls) у влажној клими под четинарском шумом, и серија Tirnul земљишта (Typic Haplustepts) у полусушној клими под култивацијом. Узети су профили земљишта у трипликату за свако земљиште и узорковани на нивоу генетичких хоризоната. Кумулативне SOC залихе у профилима Typic Hapludolls (95 Mg ha^{-1}) биле су значајно веће него Typic Haplustepts (30 Mg ha^{-1}). Typic Hapludolls су имале значајно већу SOC залиху на сваком нивоу хоризонта у влажој клими. Ова истраживања показују да земљишта под шумом у влажној клими имају већу залиху органског угљеника него она култивисана, у полусушној клими.

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