International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2018; 6(3): 2296-2301

Received: 01-03-2018
Accepted: 03-04-2018

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# Land use effects on soil organic carbon stocks in the submontane areas of north-western Himalayas, India

**Vijay Kumar, KR Sharma, Vikas Sharma and Vivak M Arya**

**Abstract**
A study was conducted to assess the impact of soil organic carbon stock under different land use systems in submontane areas of north-western Himalayas India. Soil samples were collected from the five landuse systems viz: forest, horticulture, agriculture, pasture and degraded land to a depth of 1 m. Soil physical-chemical properties reveal that the soil bulk density in the surface soil (0-15 cm) was maximum in degraded (1.54 g $cm^{-3}$) and the least in pasture (1.32 g $cm^{-3}$) and forest (1.33 g $cm^{-3}$), landuse systems, respectively. The bulk density recorded at the surface soil layer (0-15 cm) was found to be significantly lower than the subsurface soil layer 15-30 cm, 30-60 cm and 60-100 cm). Soil bulk density increased with soil depth. In the surface soil the maximum organic carbon concentration was found in the pasture (7.57 g $kg^{-1}$) and the least (5.01 g $kg^{-1}$) in degraded landuse systems. The soil organic carbon concentration was decreased with increasing soil depth. Forest and degraded landuse systems displayed the maximum value of soil organic carbon stock (15.40 and 14.59 Mg $ha^{-1}$) in 0-15 cm layer and the least (12.97 Mg $ha^{-1}$) in pasture. Soil of soil organic carbon stock in surface soil is 1.32 times higher in subsurface soils. Soil organic carbon stock in 0-15 cm layer was found to be significantly higher than that of 15-30 cm layer. The highest soil organic carbon stock (0-100 cm) layer was observed in forest land (53.38 Mg $ha^{-1}$), and was least in agriculture (42.09 Mg $ha^{-1}$) landuse systems. The present study indicates that forest system is a better option to enhance the SOC stocks in the submontane areas.

**Keywords:** Soil organic carbon, SOC stocks, land use, submontane areas

## Introduction

Soil carbon is an important indicator to soil quality and its crop productivity. Agricultural soils are among the earth’s largest terrestrial reservoirs of carbon (C) and hold potential for expended C sequestration. Thus, they provide a potential way to reduce atmospheric concentration of carbon dioxide (Bhattacharyya *et al*. 2008) [1]. Agri practices greatly contributed to global net flux of $CH_4$, $N_2O$ and $CO_2$ from the terrestrial biosphere into the atmosphere. Increase in the flux from the change and intensification of land use systems in order to feed needs of the rapidly growing human population, increased biomass burning, soil cultivation, increased number of livestock, increased acreage of paddy fields and increased use of fertilizer have been considered as the most important factor for the increased flux. In response to Kyoto protocol in 1977 policy makers or the Ministry of Agriculture of many countries have involved in discussion about policy measures to decrease greenhouse gases emission from agriculture.

Soil organic carbon is not just an inert C store, as it also influences the physical, chemical and biological properties of the soil, which have significant impact on sustainability of agriculture (Dexter *et al*. 2008) [2]. Consequently, modeling and quantification of the spatial distribution of SOC stocks is necessary to find the SOC sink capacity of soils (Mishra *et al.* 2009) [3] for enhancing C sequestration. Concentration of atmospheric $CO_2$ can be lowered either by reducing emissions or by taking $CO_2$ out from the atmosphere and stored in the terrestrial, oceanic or aquatic ecosystems. Most of the carbon enters the ecosystem through the process of photosynthesis in the leaves. After the litter fall, the detritus is decomposed and forms soil organic matter by microbial process. Intergovernmental Panel on Climate Change has recognized soil organic carbon pool as one of the five major carbon pools for the Land Use Land Use Change in Forestry sector. It is mandatory for all nations to provide soil organic carbon pool and changes from (LULUCF) sector under national communications to the United Nation's Framework Convention on Climate Change. Especially in the forest soil is one of the main sinks of carbon on earth because these soils normally contain higher soil organic matter. However, the soil organic carbon (SOC) has been ignored since long because it was treated as a dead biomass. Soil contains an important pool of active carbon that plays a major role in the global carbon cycle (Prentice *et al*. 2003) [4]. Soil organic matter is a key component of terrestrial ecosystem. Enhanced sequestration of atmospheric $CO_2$ in the soil, ultimately as stable soil organic matter, provides a more lasting solution than sequestering $CO_2$ in the standing biomass.

Soils in the submontane region are low in soil SOC particularly those under the influence of subtropical climate and this is the major factor to poor soil fertility and poor productivity. Therefore, proper management of SOC is important for sustaining soil productivity and ensuring the food security as well as protection from degradation. Maintaining or improving soil organic carbon levels in subtropical soils is more difficult because of its rapid oxidation under prevailing high temperature. Lack of moisture stress does no support higher cropping intensity in this region, contribution of root biomass towards organic C is dismally low. Soils store 2.5 to 3.0 times as much that stored in plants and two to three times more than the atmospheric as $CO_2$ (Davidson *et al*. 2000) [5]. Conversion of natural to vegetation to various landuse systems results in rapid decline in soil organic matter (Post *et al*. 2000) [6].

Many investigations have been carried out and data generated on the soil organic carbon pool in the forests, but it was on the basis of desk review by using some indirect methods or using some assumptions. While the spatial variability of SOC concentration, bulk density and depth should be considered when estimated the SOC stocks for a given area, many previous estimates of SOC stocks at global (Eswaran *et al*. 1993) [7] and regional (Yu *et al*. 2007) [8] scales, were estimated by multiplying the mean C concentration, bulk density, depth and area. The bulk density, which is the key factor for soil organic carbon estimation has been calculated by indirectly in their method. Therefore, a study was conducted to compute SOC stocks under different landuse systems in the submontane areas.

## Materials and methods

### General characteristics of the study areas

The study area is located between $36^0$ 58'-$37^0$ 17'N latitude and $73^0$ 26'-$80^0$ 30'E longitude forming a part of Hill and Mountain ecosystem of India. Rainfall of 1100 mm occurs annually from about 70 to 80 per cent from July to September and with a very high intensity of the South-West monsoon. The rainfall distribution patterns are especially erratic in time and space leading to moisture stress condition during the major part of the year. The submontane is situated at a low altitude zone with the state the range of above 320 and less than 1200 meters above the mean sea level having hot and sub-tropical climate (Fig. 1.). In May to June and October to November are the driest months. Most of the rainstorms received in summer season are of short duration and high intensity whereas those received in winter season are of low intensity and inconsistent. The submontane or foothills of Shiwaliks comprise of hilly portion having small dry hillocks, with rugged and undulating topography. The entire lower Shiwaliks are drained by a number of major and minor rivers.

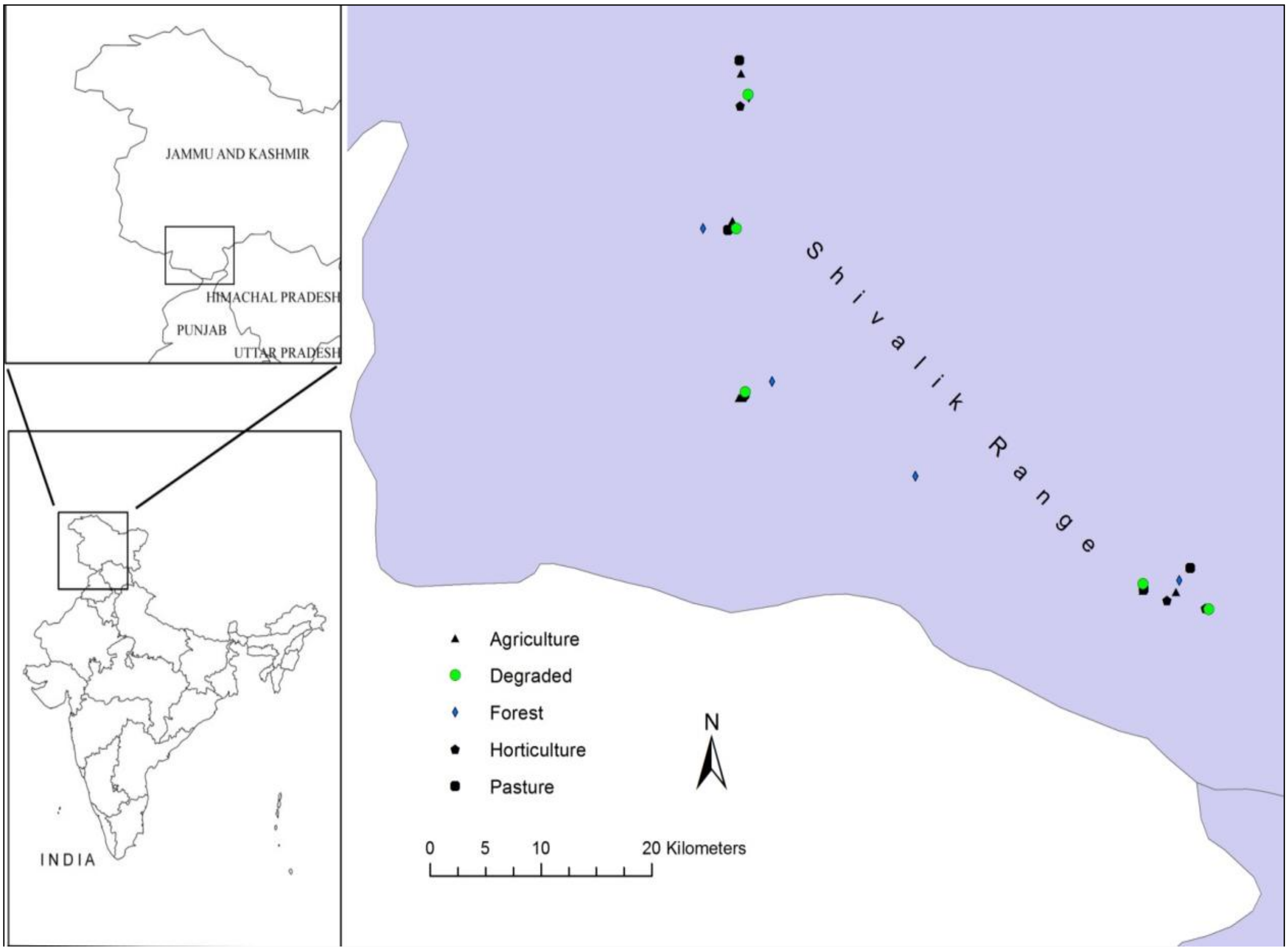


**Fig 1:** Location map of the soil sampling sites in the submontane areas of Shiwaliks

### 2.2 Soil sampling and preparation
Soil samples were collected from five landuse systems viz agriculture, horticulture, forest, pasture and degraded lands. In each landuse for five sities were selected at different locations in the submontane region of Jammu. Further, at each of these sities, five samples were collected. The soils were collected from up to a depth of 0-15cm, 15-30 cm, 30-60 cm and 60-100 cm. A portion of each of the soil sample was air dried, ground in a wooden pestle with mortar and passed through a 2 mm stainless steel sieve for determining various soil properties.

### 2.3 Soil analysis and carbon stock
The physical and chemical analysis of the air-dried soil is briefly described as follows. Soil organic carbon (SOC) content was determined by the Walkley-Black method with dichromate extraction and titrimetric quantization (Walkley and Black, 1934) [9]. Soil reaction was determined in 1:2.5 soil: water ratio (w/v) with the help of glass electrode pH meter (Jackson, 1973) [10]. Bulk density was determined by using the method outlined by Chopra and Kanwar (Chopra and Kanwar, 1986) [11]. Soil textural class was predominantly in sandy loam followed by sandy clay loam.

### Soil Organic Carbon stock
Oxidizable organic carbon, referred to as soil organic carbon (SOC) in text, was estimated according to the wet oxidation method (Walkley and Black, 1934) [9].

For an individual profile with k layers, the total organic carbon by volume is:

$$T_d = \sum_{i=1}^{k} \text{piPiDi}\,(1 - \text{Si})$$

where Td is the total amount of organic carbon (in Mg $m^{-2}$) over depth, d, pi is the bulk density (Mg $m^{-3}$) of layer i, Pi is the proportion of organic carbon (g C $g^{-l}$) in layer i, Di is the thickness of this layer (m), and Si is the volume of the fraction of fragments > 2 mm. In the absence of measured data, Si was approximated by using the median concentration of fragments > 2 mm of the particular (Batjes, 1996) [12].

Further, the soil organic carbon stock (Mg $ha^{-1}$) for an individual soil profile was calculated as follows:

$$\text{SOC stocks (Mg ha}^{-1}\text{)} = \sum_{i=1}^{k} \text{piPi Di}\,(1 - \text{Si}) \times 10{,}000$$

Where; the value of 10,000 indicates the stock for 1 ha of land.

### Statistical analysis
The data obtained were subjected to statistical analysis using completely randomized design (CRD) and factorial completely randomized design (FCRD) at all soil depth. Wherever, the effects exhibited significance at 5 per cent level of probability, the critical difference (CD) was calculated. The analyses of above data have done with help of SPSS 16.0.

## Results and discussion
### Soil organic carbon concentration
It is evidently clear from the data presented in the (Fig.2.) that soil organic carbon content was significantly influenced due to land use system. In the surface soil layers was maximum soil organic carbon (7.57 g $kg^{-1}$) was found in the pasture land use system, which was followed by forest (7.30 g $kg^{-1}$), horticulture (6.68 g $kg^{-1}$), agriculture (5.89 g $kg^{-1}$), and degraded (5.01 g $kg^{-1}$), respectively in the descending order. The decrease in organic carbon content was increasing soil depth. The high soil organic carbon content under tree based system can be ascribed to more leaf litter deposition and root turnover from trees based land use systems. These results are also in line with the findings of (Pal *et al*. 2013) [13]. The carbon fixed by the plant is the primary source of organic matter input into the soil, which provides substrate for microbial process and accumulation of soil organic matter. The below ground allocation of photosynthates is also an important factor for improving soil organic carbon content. The greater accumulation of soil organic carbon on the surface soil is due to the incorporation of leaf litter. Similar findings i.e. decrease in organic carbon content with increase in soil depth have also been reported by (Sharma *et al*. 2014) [14]. Pasture soils are the shallow roots of the grasses are limited only to the surface layer thus accounting for the higher surface SOC. Similar results were also reported by (Debasish-Saha *et al*. 2011) [15]. The variation in organic carbon in different landuse systems could be attributed to variation in leaf litter and root biomass incorporation due to specific landuse systems. The lowest soil organic carbon content in degraded land may be due to poor growth and scanty vegetation, negligible forest litter, vis-à-vis overgrazing and highly eroded nature of these soils (Sollins *et al*. 1996) [16] ascribed poor formation of organic carbon in sandy textured soils. The deeper root biomass of trees in forest land might have increased the SOC accumulation in the subsurface layers. On the contrary, forest and other landuse systems have better growth and vegetation, better SOC status and are slightly degraded (Gupta *et al*. 2010) [17]. The pasture soil had higher SOC concentration than cropland soils because of continuous plant carbon inputs from above ground and below ground biomass and reduced rate of mineralization from decreased soil disturbance (Six *et al*. 2000) [18]. (Percival *et al*. 2000) [19] Are also reported that the higher SOC concentration in pastures soils is attributed to the chemical stabilization of organic C in the soil matrix.

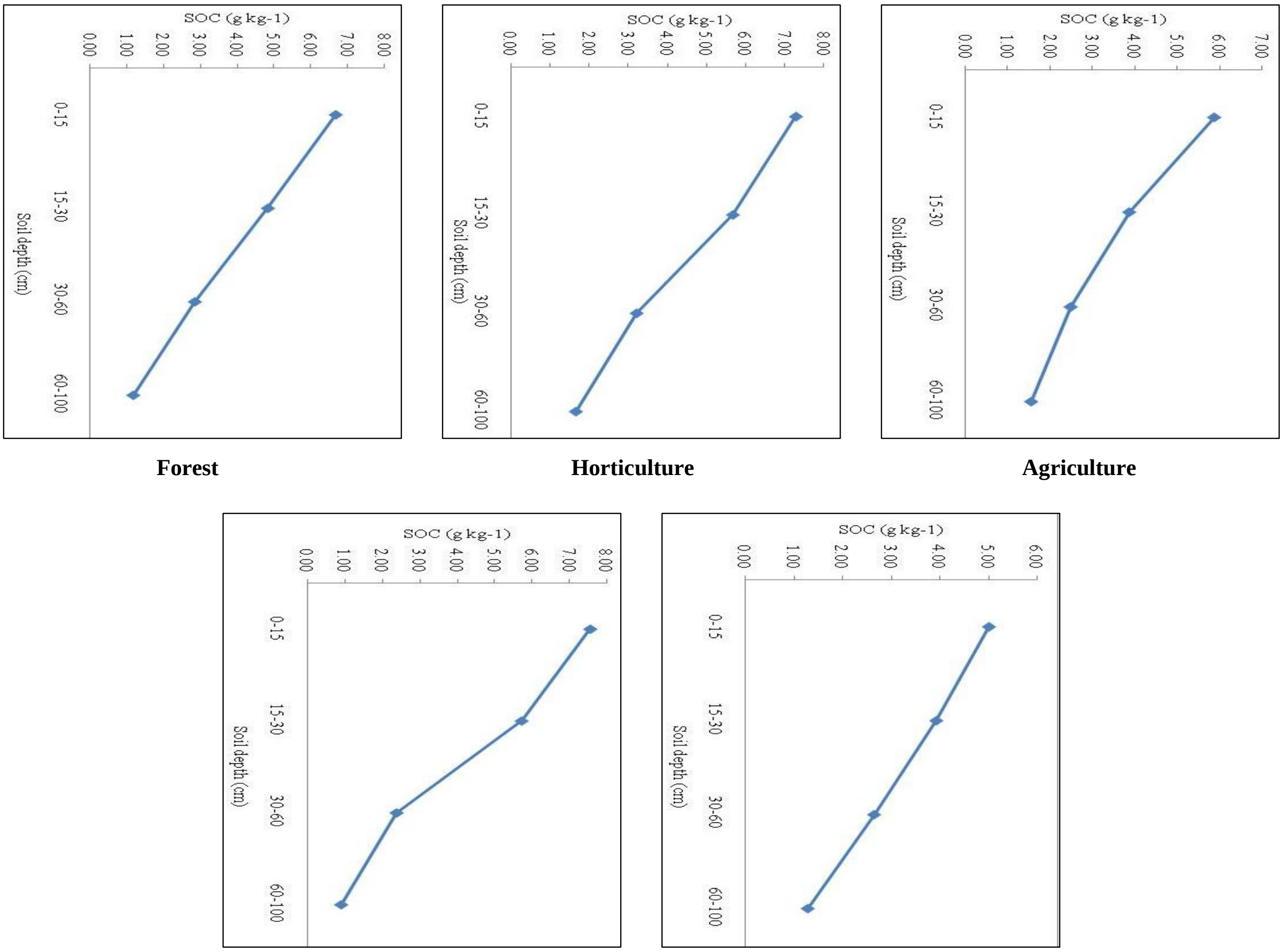


**Fig 2:** Profile distribution of soil organic carbon (g $kg^{-1}$) in the 0-15 cm, 15-30 cm, 30-60 cm and 60-100 cm of soil depth for various landuse systems in the submontane areas

## Soil organic carbon stocks

It is evident from the data presented in Table 1 that soil organic carbon stock was significantly influenced by land use system in the soil layer effect. The higher amount of soil organic carbon stock on the surface layer i.e. 0-15 cm may be explained in the sense that there is continuous accumulation of leaf litter on the surface which keeps on decomposing and thus enriches the upper layer (0-15 cm) continuously. Similar results are reported with the findings of (Joao *et al*. 2001) [20].

**Table 1:** Soil organic carbon stock (SOCS) in Mg $ha^{-1}$ and bulk density (BD) in Mg $m^{-3}$ in soil layers under different landuse systems in the submontane

| Soil depth | Landuse | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Forest | | Horticulture | | Agriculture | | Pasture | | Degraded | |
| | SOCS | BD | SOCS | BD | SOCS | BD | SOCS | BD | SOCS | BD |
| 0-15 cm | 14.59 | 1.33 | 13.22 | 1.49 | 13.37 | 1.52 | 12.97 | 1.32 | 15.40 | 1.54 |
| 15-30 cm | 11.70 | 1.35 | 9.76 | 1.51 | 9.39 | 1.54 | 9.57 | 1.34 | 11.86 | 1.57 |
| 30-60 cm | 16.23 | 1.40 | 13.86 | 1.53 | 11.38 | 1.56 | 12.47 | 1.38 | 13.95 | 1.61 |
| 60-100 cm | 10.86 | 1.42 | 9.46 | 1.55 | 7.95 | 1.59 | 8.39 | 1.41 | 10.39 | 1.63 |
| SOCS = | | | | | | BD = | | | | |
| LSD (P =0.05) | | | | | | LSD (P =0.05) | | | | |
| Landuse = 1.45 | | | | | | Landuse = 0.042 | | | | |
| Depth = 1.30 | | | | | | Depth = 0.037 | | | | |
| Landuse x Depth = N.S. | | | | | | Landuse x Depth = N.S. | | | | |

The maximum soil organic carbon stock (SOC stock) was recorded in 0-100 cm in forest landuse systems (53.38 Mg $ha^{-1}$) which was followed by degraded land (51.60 Mg $ha^{-1}$), horticulture (46.30 Mg $ha^{-1}$), pasture (43.40 Mg $ha^{-1}$) and agriculture (42.09 Mg $ha^{-1}$), respectively in the descending order (fig. 3). This may have happened because of enhanced accumulation of leaf litter in the tree and fruit based land use systems. The abundant litter and/or pruned biomass returns to soil, combined with the decay of roots contribute to the improvement of organic matter under complex land use systems (Kumar *et al*. 2001) [21]. (Gupta *et al*. 2009) [22] Reported that the higher litter addition in the forest and horticulture soils could have resulted in higher SOC stock at the upper layers, whereas in the lower layers of agricultural soils, the dead crop roots being added after every crop season could be a major source of higher SOC stock. Low amounts of soil organic carbons stocks under the agriculture land use system can be ascribed to intensive cropping as also reported by (Lal *et al*. 1998) [23]. The increase or decrease in the soil organic carbon stocks was associated with the bulk density and organic carbon content of the soil of a particular depth. The higher SOC stock in degraded land than agriculture and grasslands could be due to the previously existing trees in the degraded lands, which vanished due to deforestation, but the root biomass of these trees could have added to the SOC stock in the lower layers (Brown, 2002) [24]. The type of landuse is important factor controlling organic matter storage in soils because it affects the amount and quality of the litter input, the litter decomposition rate and processes of organic matter stabilization in soils (Schwendenmann *et al*. 2006) [25]. Higher soil organic carbon stock in the forest land use system can be ascribed to greater incorporation of leaf litter and addition of decayed roots to the soil layers than in the other land use systems. Moreover, the soil of the submontane areas site is sandy loam, which is known for lower soil organic carbon content.

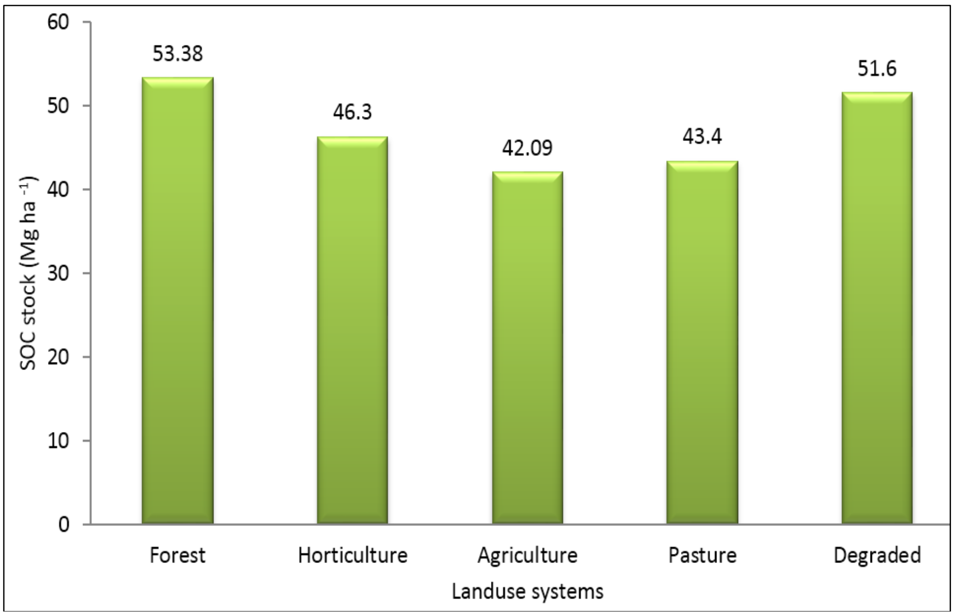


**Fig 3:** Soil organic carbon Stock (Mg $ha^{-1}$) of 0-100 cm soil under different landuse systems

**Conclusions**

Soil physico-chemical property reveals that maximum bulk density in degraded soil followed by agriculture, horticulture, forest and pasture landuse systems. Maximum soil organic was pasture soil and lowest was in degraded. Bulk density of all the landuse systems increased with soil depth and opposite in soil organic carbon was decrease in increasing soil depth. The total soil organic carbon stocks observed was highest in forest landuse systems was found to be 1.03, 1.15, 1.22 and 1.27 times higher under degraded, horticulture, pasture and agriculture land in 0-100 cm soil depth. These finding further evinced that forest conserve the major pool of the carbon stocks in the submontane areas of the north western Himalaya, which need to be conserved, but conversion of degraded and agriculture field into subtropical fruit based systems. Degraded lands need to be replaced by effective resources systems to prevent their further degradation. Such lands need to put areas under vegetation and to adopt the sustainability of soil and water resources conservation systems like horticulture, agri-horticultutre, agroforestry and natural regeneration. Hence, the management practices are to improve C sequestration, then the increase of soil C stabilization on a long-term scale. In the pasture lands are converted to agricultural land without using proper practices of securing organic matter and soil stability.

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