

QUANTIFICATION OF SOIL ORGANIC CARBON STOCK OF FORESTS IN SOLAN DISTRICT OF HIMACHAL PRADESH

Thesis

by

ANU THAKUR

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This is to certify that the thesis entitled, **“Quantification of soil organic carbon stock of forests in Solan district of Himachal Pradesh”** submitted in partial fulfillment of the requirements for the award of degree of **MASTER OF SCIENCE in ENVIRONMENTAL SCIENCE** to Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) is a record of bonafide research work carried out by **Mr Anu Thakur (F-2009-11-M)** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigations has been fully acknowledged.

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This is to certify that the thesis entitled, **“Quantification of soil organic carbon stock of forests in Solan district of Himachal Pradesh”** submitted by **Mr Anu Thakur (F-2009-11-M)** to Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) in partial fulfillment of the requirements for the award of degree of **MASTER OF SCIENCE in ENVIRONMENTAL SCIENCE** has been approved by the Student’s Advisory Committee after an oral examination of the same in collaboration with the external examiner.

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This is to certify that all the mistakes and errors pointed out by the external examiner have been incorporated in the thesis entitled, **“Quantification of soil organic carbon stock of forests in Solan district of Himachal Pradesh”** submitted to Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) by **Mr Anu Thakur (F-2009-11-M)** in partial fulfillment of the requirements for the award of degree of **MASTER OF SCIENCE** in **ENVIRONMENTAL SCIENCE**.

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Place: Nauni, Solan

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ABBREVIATIONS USED

BD	Bulk density
C ha ⁻¹	Carbon per hectare
C ha ⁻¹ yr ⁻¹	Carbon per hectare per year
°C	Degree celsius
CD	Critical difference
CH ₄	Methane
cm	Centimeter
CO ₂	Carbon dioxide
CIFOR	Centre for International Forestry Research
EC	Electrical conductivity
g	Gram
g cm ⁻³	Gram per centimeter cube
GHGs	Green house gasses
Gt	Giga tonne
g Kg ⁻¹	Gram per kilogram
ha	Hectare (10,000 m ²)
IPCC	Intergovernmental Panel on Climate Change
Km	Kilometer
Kg C m ⁻²	Kilogram carbon per meter square
LULUCF	Land Use, Land Use Change and Forestry
m	Meter
m sl	Meter sea level
M ha	Million hectare
Mg ha ⁻¹	Mega gram per hectare
Mg C ha ⁻¹	Mega gram carbon per hectare
Mg C ha ⁻¹ yr ⁻¹	Mega gram carbon per hectare per year
NFTs	Nitrogen fixing trees
N ₂ O	Nitrous oxide
NOC	Net organic carbon
OC	Organic carbon
Pg	Peta gram
Pg C	Peta gram carbon
Pg c yr ⁻¹	Peta gram carbon per year

SOC	Soil organic carbon
SOCD	Soil organic carbon density
t c ha ⁻¹	Tonne carbon per hectare
t c ha ⁻¹ yr ⁻¹	Tonne carbon per hectare per year
Tg	Tera gram
%	Per cent
UNFCCC	United Nations Framework Convention on Climate Change



INTRODUCTION



Chapter-1

INTRODUCTION

Carbon dioxide is one of the major greenhouse gases (GHGs) which has increased in the atmosphere during the past few decades due to combustion of fossil fuel, deforestation and anthropogenic activities. Increasing level of CO₂ in the atmosphere has drawn the attention of the scientific community towards the process of carbon sequestration and soil organic carbon store. The terrestrial environment is the most important living space for human beings, and soils are at the core of the terrestrial ecosystem. Soil Organic Carbon (SOC) is a part of the global carbon cycle and the global SOC pool (1580 Gt) is nearly three times as large as stock in the vegetation of terrestrial ecosystems (Post *et al.*, 1990) and twice as large as stock in the atmosphere (Eswaran *et al.*, 1993). Changes in SOC will affect the density of greenhouse gases in the atmosphere, possibly leading to global climate change (Lal *et al.*, 1998).

Soil organic carbon sequestration refers to the storage of carbon in soil and is being considered as a strategy for mitigating climate change. Accurately quantifying SOC stored in soils is considered fundamental to global climate change modeling (Tan and Shibasaki, 2003 and Janzen, 2004). The forest ecosystems have great capacity in carbon cycle and are proposed as a means to reduce net GHGs emissions, by either reducing sources or enhancing sinks. They have the ability to lock carbon for long term in addition to other environmental benefits they bestow upon us. Forests with an approximate area of 4 billion ha support the diverse plant ecosystem which is better able to absorb CO₂. More the number of species, better job they do at absorbing the green house gases (CIFOR, 2005). As components of the global climate system, forests play a major role in the present and projected future carbon budget, since they store about 80 per cent of all above ground and 40 per cent of all below ground terrestrial organic carbon (Houghton, 1995).

Soil organic matter is in a state of dynamic balance between inputs and outputs of organic carbon. Inputs are largely determined by the forest

productivity, the decomposition of litter and its incorporation into the mineral soil, whereas, rates of organic matter decay and the return of carbon to the atmosphere through respiration control outputs (Pregitzer, 2003). Other losses of soil organic carbon occur through erosion or the dissolution of organic carbon, but these processes may not result in immediate carbon emissions. In general, human activities and other disturbances alter the carbon dynamics of forest soils. Soil organic carbon can also increase or decrease depending on numerous factors, including land use, management practice, vegetation type, landscape, disturbance and climate. Physical soil properties such as structure, particle size and composition have profound impact on soil organic carbon. The release of nutrients from litter decomposition is a fundamental process in the initial biogeochemical cycle of an ecosystem and decomposers recycle large amount of carbon that is sequestered in the plant or tree. Deforestation can contribute a large volume of carbon to the atmosphere either by reducing the amount stored in above ground biomass or increasing the oxidation of SOC. Currently, annual global deforestation is of the 15×10^6 ha, releasing 1.6×10^{15} g C to the atmosphere (Dixon *et al.*, 1994). Soil organic carbon is sensitive to impact of anthropogenic activities. The conversion of natural vegetation to various land uses results in rapid decline in soil organic matter (Post and Kwon, 2000).

Change in the atmosphere has the potential to affect forest soil through a variety of pathways. Various impacts upon forest soils, in turn, may affect forest nutrient cycling and ultimately productivity. Global warming, atmospheric deposition and increase in atmospheric CO₂ concentration are the primary atmospheric factors which may have impact on forest soils (Josline and Johnson, 1997).

Intergovernmental Panel on Climate Change has recognized SOC pool as one of the five major carbon pools for the LULUCF (Land Use, Land Use Change and Forestry) sector. Since soil organic carbon pool plays an important role in organic matter dynamics and nutrient cycling, it is very important to know the pool size and its turnover with time scale in an ecosystem. Precise determination of change in SOC stocks is prerequisite to understand the role of

soils in the global cycling of carbon and to verify the changes in stocks due to management. In the recent past the green house effect has created a great concern that led to several studies on qualities, kinds, distribution and behaviour of SOC (Bhattacharyya *et al.*, 2008). It has been made mandatory for all nations to provide soil organic carbon pool and changes from LULUCF sector of the forests under National Communications to the UNFCCC (United Nations Framework Convention on Climate Change). Accurate quantification of soil organic carbon is therefore necessary for detection and prediction of changes in response to changing global climate.

In order to know the total soil carbon sink in forest soils and to formulate future strategies not only to conserve this sink but also to increase it by bringing more and more wasteland, degraded land and other unusable land under afforestation programme, the information on SOC stock quantification seems essential. However, so far no systematic study has been undertaken to estimate the soil organic carbon pool of different forest types of Himachal Pradesh. In most of the cases, researchers have estimated soil organic carbon as one of the soil attributes depending upon the objectives of the study. The depth of soil sampling and method of analysis varied from study to study as per the objective of the study. Although both organic and inorganic forms of carbon are found in soil, land use and management practices have profound impact on organic form of carbon. Therefore, present study accordingly focuses on organic form of carbon with the following objectives:

Objectives:

- To study the effect of forest types and aspects on soil organic carbon status.
- Prepare the soil organic carbon pool of forests in Solan district of Himachal Pradesh.



REVIEW
OF
LITERATURE



Chapter-2

REVIEW OF LITERATURE

There is growing international concern over the increase of carbon in the atmosphere over the past few decades. Removing atmospheric carbon and storing it in the terrestrial biosphere is one of the options, which have been proposed to compensate GHGs emission. Carbon sinks can play an important role in meeting the challenges of climate change. Forests are the reservoir of terrestrial above ground carbon whereas soils are the other reservoir of atmospheric carbon. Therefore, to offset carbon release into the atmosphere, mitigation through forestry activities and land management appear to be the most practical, potential, natural and manageable option. Soil organic carbon is of local importance as it determines ecosystem and agro-ecosystem function, influences soil fertility, water holding capacity and many other functions. The available literature from the sources available has been reviewed under the following heads:

Soil physico-chemical properties under different forest types

Soil organic carbon under different forest types

Distribution of soil organic carbon with depth and aspect

Soil organic carbon stock of different forest types

Soil physico-chemical properties under different forest types

Alexender (1989) explored the potential of *Acacia albida* in ameliorating the soil. The study revealed that soil mounds, organic carbon, total N, pH, percentage base saturation and exchangeable Ca, Mg and Na were all significantly higher in soils from beneath the canopy than those from outside.

Murthy *et al.*, (1985) reported pH values in the range of 5.4 to 6.1 for the soil of Garhwal Himalayas under Pine forest and was noticed to increase with soil depth. pH is the most commonly used method for expressing soil acidity or alkalinity. Most often forest soils have a pH range varying from 3.5 to 6.5 (Prithcett, 1979). Chakraborty and Chakraborty (1989) studied the physio-

chemical properties of soil under four year old *Acacia auriculiformis* plantation and reported an increased organic carbon, nitrogen, potassium, electrical conductivity over control plots.

Sharma (1991) and Malik (1992) found soil pH values ranging from 5.0 to 8.4 and 5.1 to 7.9 respectively under chir-pine forest of Solan division and noticed progressive increase in pH down the profile. Garg and Jain (1992) observed, after eight years of establishment of *Acacia auriculiformis* plantation, enrichment of soils through leaf litter and noticed increase in soil pH from 4.98 to 5.37. They also investigated the influence of *Acacia nilotica* on sodic soils and revealed that the percentage of exchangeable Na and soil pH decreased under tree cover.

Bhola (1995) investigated the soil enrichment potential of seven nitrogen fixing trees (NFTs) including *Acacia auriculiformis* and found considerable improvement in soil chemical properties under all species. The overall enrichment was 15.52 to 39.52 per cent in organic-C, 8.8-17.98 per cent in available nitrogen, 15.36 to 98.91 per cent in available P, 4.88 to 17.92 per cent in available K, 2.09 to 14 per cent in exchangeable Ca and 1.93 to 9.54 per cent in exchangeable Mg. He further reported significantly lower pH under NFT's.

Mongia *et al.* (1998) studied the ameliorating effect of forest trees on highly sodic soils in Haryana. They found that by growing *Acacia nilotica* for more than three years the pH, electrical conductivity and CaCO₃ content of the soil were lowered while organic matter, Fe and Mn content increased. Phogat *et al.* (1999) studied soil properties under *Acacia tortilis* in arid region of Haryana. *Acacia* plantation was found to considerably increase the organic matter but decreased soil pH in 10 to 15 cm soil depth.

Soil organic carbon under different forest types

Total organic matter accumulated in soils constitutes a major portion of the world's fixed carbon reserves. Bohn (1976) estimated that the soil contains approximately 30×10^{14} kg organic carbon. Distribution of this organic matter among soil types is highly variable and generally not easily predictable from above ground vegetation types. The quantity of organic material retained with in

the soil matrix is the difference between total biomass production and decomposition.

Soil is the largest pool of terrestrial carbon, estimated as 2200 Pg; tropical top soils contain about 13 per cent of world's soil carbon (Young, 1977). Estimation of biomass and sequestered carbon on farm forest plantations in northern New South Wales, Australia (Specht and West, 2003) revealed that organic carbon content of soil below plantations and adjacent pasture paddocks decline with time following establishment.

Ruecker *et al.* (1980) while studying the effect of trees on the amelioration of degraded soils observed that in eastern Spain natural tree establishment on degraded soils significantly increased soil organic carbon content in the 0-10 cm layer after 30 years of growth. In north-eastern Sudan, Alstad and Vetas (1994) observed improvement in soil quality due to increased SOC content under the stand of *Acacia tortilis*.

Trees improve soil productivity through ecological and physico-chemical changes that depend upon the quantity and quality of litter reaching soil surface and rate of litter decomposition and nutrient release (Meentemeyer and Berg, 1986).

Houghton *et al.* (1987) reported that deforestation in the tropics is responsible for an annual net release of carbon to the atmosphere. Growing trees can improve soil quality, however at a slow rate and sequester carbon in soil and biomass. Grass covered soil released more CO₂ than did forest vegetation (Dorr and Munnich, 1987).

Harmon *et al.* (1990) reported that a 450 year old Douglas fir (*Pseudotsuga menziesii*) and Western hemlock (*Tsuga heterophylla*) forests in the Pacific Northwest contains at least twice as much biomass carbon as a 60 yr old Douglas fir plantation.

Post *et al.* (1990) reported that the ratio between SOC and biomass carbon is 2.5 to 3 times in the terrestrial ecosystem. According to Adger *et al.* (1991) the

high forests in Britain contained 30.4 million t C in coniferous stands and 50.5 million t C in broad leaved wood lands

Gracia *et al.* (1990) studied the effect of slash and burn management on soil aggregates, organic carbon and nitrogen in a tropical deciduous forest soils and reported that approximately 80 per cent of the total carbon and nitrogen content in the soil was due to slash and burn in these forests. They also stated that slash and burn activities did not destroy micro aggregates but the soil organic carbon associated with micro aggregates decreased by 32 per cent due to combustion during burning. Knowalenko and Lwarson, 1978 observed that CO₂ evolution was greater from clay loam soil (6.2 Kg CO₂ ha⁻¹ day⁻¹) than sandy soil (3.3 CO₂ Kg ha⁻¹ day⁻¹).

Global warming and its effect on soils in terms of SOC management have led to several quantitative estimates for global C content in the soils (Eswaran *et al.*, 1999; Batjes, 1996 and Kimble *et al.*, 1990).

Dewar and Cannell (1992) observed that the equilibrium carbon storage in plantations in Britain is quite low. They noticed that some forest types were capable of very rapid storage rates over the first rotation of poplars grown on agricultural land which achieved both high equilibrium and rates of carbon storage. Oak and beech woodland plantations have similar equilibrium carbon storage to conifer plantations but have much lower rates of storage during the first rotation. Successive oak plantations contained much less carbon in the trees, forest litter and soil than poplar plantation. Therefore, they suggested that different forest types should be selected depending on the carbon storage objectives.

According to Lugo and Brown (1992) changes in land-use and rates of carbon accumulation by land-use including mature, logged and fallow tropical forests and degraded lands can be used to estimate the role that the tropical landscape serves as a sink of atmospheric carbon.

Schroeder *et al.* (1992) while studying carbon storage potential of short rotation tropical tree plantation has found mean carbon storage of 59 t ha⁻¹ and

72 t ha⁻¹ in *Pinus canbeae* and *Pinus patula*, respectively. However, mean carbon storage for *Cupressus lusitanica*, *Acacia meamsii*, *Cassia siamea* and *Azadirachta indica* was 57, 78, 28 and 81 t ha⁻¹, respectively. They also recorded vast variations in total carbon storage under different land types i.e. logged forests, forest fallows, deforested watersheds and dry lands as 2.87, 4.26, 4.95 and 2.65 t C ha⁻¹, respectively.

Katagiri *et al.* (1992) reported that dry weight of dead organic matter including dead standing trees was 4.1 and 16.8 per cent of total above ground biomass in Sanbe forest, Shimane Japan. *Quercus semicarpifolia* and *Castanea cernato* comprised the principal broad leaved species.

The greenhouse effect has been of great concern during the past one decade which has led to several studies on the quality, kind, distribution and behaviour of SOC (Eswaran *et al.*, 1993; Batjes, 1996 and Velayutham *et al.*, 2000). Deforestation, changes in land use and predicted climate change has been reported to alter the amount of organic carbon held in the superficial soil layer (Batjes, 1996).

Farm forestry plantations raised on farmer's fields on marginal and sub marginal lands with low levels of soil carbon had been reported to attain high SOC and the soil carbon in such area rises normal forest soil status in a period of 15-20 years (Sampson and Sedja, 1997).

Conversion of natural forests to agriculture in the humid tropics had been reported to reduce ecosystem carbon storage due to removal of above ground biomass and a gradual subsequent reduction in soil carbon. Whereas, forest conversion to well managed grasslands was found to increase soil carbon storage, after an initial decline (Van *et al.*, 1997).

Physical soil properties, such as soil structure, particle size, and composition, have profound impact on soil carbon. Soil particle size has an influence on the rate of decomposition of soil organic carbon (Jobbagy and Jackson, 2002). Soil organic matter can also increase or decrease depending on

numerous factors, including climate, vegetation type, nutrient availability, disturbance, land use and management practices (Six and Jastro, 2002 and Baker, 2007).

The release of nutrients from litter decomposition is a fundamental process in the initial biogeochemical cycle of an ecosystem, and decomposers recycle a large amount of carbon that is bounded in the plants or trees (Sevgi and Tecimcn, 2008).

To sustain the quality and productivity of soils, knowledge of SOC in terms of its amount and quality is essential. The first comprehensive study of organic carbon status in Indian soils was conducted by collecting 500 soil samples from different cultivated fields and forests with variable rainfall and temperature patterns. However, the study did not make any estimate of the total carbon reserves in the soils (Jenny and Raychaudhary, 1960). The first estimate of the organic carbon stock in Indian soils was 24.3 Pg (1 Pg = 10^{15} g) based on 48 soil samples (Gupta and Rao, 1984).

Sharma (1991) and Malik (1992) conducted a study on soils under chir-pine in Solan forest division of Himachal Pradesh and found organic carbon in the range of 0.17 to 3.37 and 0.33 to 3.27 per cent, respectively.

Singh *et al.* (1995) compared the bamboo forest soil with the soils of natural forest and jhum fallow in Jorhat district of Assam and found that total NPK and organic carbon were highest in natural forest followed by bamboo forest and lowest content were observed in jhum fallow. They further observed that in bamboo soil the concentration of all the nutrients including SOC was fairly high in the upper soil layers which followed a gradual decrease with increase in soil depth.

In western Nigeria, Lal (1996) observed that the soil organic carbon (SOC) of the surface 10 cm layer declined by about 50 per cent within 10 years after deforestation and cultivation.

Trees are known to maintain soil organic matter and nutrient cycling through the addition of litter and root residues into the soil. There is a large potential of sequestering carbon in soil and vegetation by adopting suitable agroforestry systems on salt affected soils (Singh and Singh, 1997). In Haryana, a large increase in soil organic carbon content by reclamation of sodic soils through growing *Prosopis juliflora* was recorded by (Bhojvaid *et al.*, 1998)

Lal (2002) reported that most soils in mid Western USA have lost 30 to 50 per cent of their original pool or 25 to 40 Mg C ha⁻¹ upon conversion from natural to agricultural ecosystems. About 60 to 70 per cent of the carbon thus depleted can be resequenced through adoption of recommended soil and crop management practices. The gross rate of soil organic carbon sequestration ranges from 500-800 Kg ha⁻¹ yr⁻¹ in cold and humid regions and 100- 300 Kg ha⁻¹ yr⁻¹ in dry and warm regions. And there is also a large potential to sequester soil inorganic carbon in arid and semi arid regions.

Indian soils are largely carbon depleted but can be brought back to their native carbon carrying capacity by reforestation. Moreover, wastelands in India cover more than 100 million ha of which 70 per cent is low in carbon. These soils have been reported to have relatively high potential for accumulating organic carbon in vegetation and soil by growing suitable trees along with proper soil conservation measures (Rai and Sharma, 2003).

Forests show the best mitigation potential followed by agroforestry, plantation and agriculture. Degradation of soil has its adverse effect on soil carbon which in the Asian region is caused by deforestation, industrialization, agricultural activities, overgrazing and over exploitation (Jha and Gupta, 2003).

Soil can act as a sink or source for carbon in the atmosphere depending on the changes happening to soil organic matter. Equilibrium between the rate of decomposition and rate of supply of organic matter is disturbed when forests are cleared and land use is changed (Lal 2004 and Buringh 1984). Forest soils are one of the major carbon sinks on earth, because of their higher organic matter content (Dev, 2005).

Total organic matter accumulated in the soil constitutes a major portion of the world's fixed carbon reserves. The distribution of organic matter among soil types is highly variable and generally not easily predictable from above ground vegetation type. Decreased soil carbon content with time in agricultural plots in arid regions with a loss of SOC by 56 per cent during 5 years period was studied by Singh *et al.* (2005). He further reported that integration of trees reduced SOC loss which was 3.2 per cent under *Emblia officinalis*, 22 per cent under *Hardwickia binnata* and 35.5 per cent under *Colophospermum mopan* based agroforestry system as compared to 56 per cent under agricultural plots. Ramchandran *et al.* (2007) estimated 3.48 Tg soil carbon in the natural forests in Eastern Ghats of Tamil Nadu, India.

The Himalayan zones, with dense forest vegetation, cover nearly 19 per cent of India and contain 33 per cent of SOC reserves of the country (Bhattacharyya *et al.*, 2008). The forests are recognized for their unique conservation value and richness of economically important biodiversity. Managing these forests may be a useful technique to increase soil carbon status because the presence of trees affects carbon dynamics directly or indirectly.

Kumar (2010) while studying the distribution, growth and biological yield potential of bamboos in Himachal Pradesh found organic carbon in the range of 2.43-3.0 per cent which decreased with increasing soil depth.

Mbah and Idike (2011) examined the carbon storage at two soil depths (0-5 and 5-20 cm) in four agricultural practices namely: natural undisturbed forests, *Gmelina arborea* forests, alley crop farming and sewage sludge dump sites in south-eastern Nigeria. At both depths the soil pH, bulk density, total porosity, water holding capacity and sand fraction showed low variation while silt + clay fraction was observed to vary moderately. Total carbon stored in soil was recorded highest in natural uncultivated forest. The increase in SOC status under natural uncultivated forests was 37, 62 and 27 per cent over alley cropping, sewage sludge dump and *Gmelina arborea* forest, respectively. The study further

revealed that forests and alley cropping can store large quantities of C in soils as compared to other agricultural practices.

Singh *et al.* (2011) studied two forest types: *Quercus leucotrichophora* (oak) and *Pinus roxburghii* (chir-pine) in Garhwal Himalaya, for vegetation analysis and soil carbon stock along altitudinal gradient and soil depth. The soil carbon was assessed in each forest type by collecting soil samples from three different altitudes and depths. In both the forest types, soil carbon has positive relation with leaf litter production, density and basal cover of the forests which decreased significantly with increasing altitude and soil depth. The results indicated that a change in vegetation type and a shift of vegetation belts as expected in most climate change scenario might have a profound impact on SOC in the Himalayas. Between the forests; oak forest soil had more capacity to sequester carbon compared to pine forest. The study further suggested that to enhance carbon sequestration potential, the forests should be managed by promoting more regeneration for high density and basal cover to mitigate future carbon level.

Distribution of soil organic carbon with depth and aspect

Batjes and Dijkshoorn (1999) reported the mean carbon densities to a depth of 1m range from 4 kg m⁻² for coarse textured Arenosols to 72.4 kg m⁻² for the poorly drained Histosols of the Latin America. Mean carbon density for the mineral soils excluding Arenosols and Andosols (30.5 kg c m⁻²) was 9.8 kg m⁻². In total the top one m holds 66.9 Pg C and 6.9 Pg N. Approximately 52 per cent of the carbon pool was held in the top 30 cm of the soil layer which was most prone to changes upon land use conversion and deforestation.

Bai *et al.* (2011) while studying the soil organic carbon content and their vertical distributions in two natural saline-alkalined wetlands in Xianghai National Nature Reserve of Northeast China in 2011 found that soil organic carbon generally decreased with depth in soil profiles and was mainly stored in

the upper 30 cm (11.82 in), accounting for more than 50 per cent of the total SOC content

According to Yadav (1967) Himachal Pradesh soils on an average contained 1.17 per cent organic carbon. The Saproon valey of Solan district of Himachal Pradesh contained 0.719 to 0.988 per cent organic carbon in the surface soils (Sankhyan, 1972), which is found to decrease with an increase in the soil profile depth.

Rajamanner *et al.* (1979) reported that in vertisols of Andhra Pradesh, the SOC content increased from 0.39 per cent in 0-15 cm layer to 0.78 per cent in 122 to 137 cm layer, but decreased to 0.16 per cent below 137 cm. The organic carbon content in soil was also found to decrease with depth (Sharma and Aggarwal, 1980; Bhoumik and Totey, 1990).

Bhandari and Randhawa (1985) revealed that the SOC contents decreased with depth of the profile in apple orchards of Himachal Pradesh. The surface soils have been reported to have high quantities of organic carbon going upto 5 per cent with a mean value of 1.8 per cent.

Sharma (1991) and Malik (1992) while studying the SOC distribution under chir-pine forests of Solan forest division of Himachal Pradesh observed a decrease in its distribution with profile. Qureshi *et al.* (1996) found the uniform distribution of organic carbon along the depth of the profile.

Lal *et al.* (1998) studied the land use and soil management effect on soil organic matter dynamics in Alfisols of western Nigeria and found that the tillage and intensive cropping, fallowing and deforestation usually decrease soil organic carbon by 25-60 per cent in the top 0.5 cm depth. Cropping systems that maintained favourable soil organic carbon levels in the soil were reported to have high total and below ground root biomass and relatively narrow ratio of carbon to nitrogen, phosphorus and sulphur.

Kumar (2003) while studying the various agroforestry systems of western Himalaya found that the SOC was maximum in surface soils (0-10 cm) which

decreased with depth and minimum was at 30-40 cm profile depth. The SOC content in 0-20 cm layer was found to be significantly higher than 20-40 cm layer (Sanneh, 2007). Minj (2008) also reported maximum SOC at 0-10 cm depth under various land use systems studied in low and mid hills of western Himalaya.

Verma *et al.* (2008) while studying the effect of slope aspects and altitude on SOC content on Himalayan soils observed higher SOC contents on northern than southern aspects. They correlated this effect with better vegetation cover on northern aspects.

Sharma and Kumar (2011) studied the hydrophysical and chemical characteristics of soil under different land uses in Shiwalik hills of Himachal Pradesh. Different land uses were found to differ appreciably for organic carbon content distribution and among land uses, both grass (18.6-23.4 g kg⁻¹) and forest lands (8.4-25.2 g kg⁻¹) had comparatively higher organic carbon contents. All the land uses exhibited a consistent decreasing trend in organic carbon distribution with soil depth. The SOC content in 0.0-15 cm, 15-30 cm and 30-45 cm soil layers of forest land uses were reported to be 17.3 g kg⁻¹, 15.5 g kg⁻¹, 13.2 g kg⁻¹, respectively. Addition of sufficient amount of organic matter i.e. roots and other plant remains in the upper layers were found to be responsible for comparatively higher organic carbon contents than sub-surface layer.

Soil organic carbon stock of different forests

Tiessen *et al.* (1992) studied the carbon sequestration and its turn over in semi arid savannas and dry forests at north-east Brazil and West Africa. In NE Brazil about 40 per cent of the land has near climax native vegetation, less than 10 per cent of the area was affected by shifting cultivation with an average cycle of 5 years arable use, followed by 20 years or more recovery. Litter fall contribute around 1-2 Mg C ha⁻¹ yr⁻¹ was partially decomposed and partially consumed by animals resulting in low average soil C levels near 8 g kg⁻¹ or 20 Mg C ha⁻¹ under cultivation. Carbon sequestration was decreased and soils used to loose approximately half their carbon stock, before being abandoned. In West Africa 50-70 per cent of the land was under a management regime with minimal

carbon returns to the soils. Overgrazing and over exploitation for fuel wood has resulted in land degradation. Short fallow periods on cultivated land have caused serious decline in soil carbon stocks. Both carbon sequestration and stock area, therefore, are lower in West Africa than in NE Brazil.

Hsieh (1992) pointed out that most modern surface soils are believed to contain a pool of very stable SOC with mean age that may reach several thousand years. The remaining SOC pools are much younger, perhaps no older than a few decades. He further observed that since active and stable SOC play a very different role in soil organic matter dynamics, nutrient cycle and suggested to know the pool size in an ecosystem.

According to Eswaran *et al.* (1993) the soil organic carbon pool in the top one meter depth of the world soil ranges between 1462 and 1576 Pg. It is nearly three times than that in the above ground biomass and approximately doubles than in the atmosphere. The tropical soils contribute 32 per cent of SOC towards the total SOC pool of the world is contributed by soils in the tropics. About 40 per cent of the total SOC stock of the global soils resides in forest ecosystem (Eswaran *et al.*, 1999).

A projection of carbon stocks for small holder agroforestry systems in the tropics indicated carbon sequestration rates ranging from 1.5 to 3.5 Mg C ha⁻¹ yr⁻¹ which increased to 70 Mg ha⁻¹ in a twenty years period (Watson *et al.*, 2000).

Concern about rising carbon dioxide trends has prompted considerable interest in these years regarding the sink potential of soil organic carbon. The world's soils are estimated to contain 1500 Gt of SOC in top 1 m soil, roughly double the amount of carbon in atmosphere (Schlesinger, 2000) which however is very low in comparison to the 38000 Gt of C contained in world's ocean, it attracts attention because it is potentially responsive to modification.

Globally carbon stocks in the soil exceed carbon stocks in vegetation by a factor of about 5. The ratio ranges from 1:1 in tropical forests to 5:1 in boreal forest and much larger factors in grasslands and wetlands (IPCC, 2000).

Indeed, though fossil fuel combustion has been the major cause of increasing CO₂ in atmosphere, land modification has been a significant contributor (Kucharik *et al.*, 2001). Carbon stored in agriculture soil is 170 Gt, while entire vegetation contains 550 Gt C. The total carbon lost as a result of bringing land under crop cultivation the world over has been estimated at 54 Gt C, in which the contributions of temperate grasslands and tropical forest soils were substantial (Rastogi *et al.*, 2002).

Shelly *et al.* (2002) argued that regardless of soil characteristics and without minimizing their importance on carbon stocks over the landscape, it is important to remember that soil pools are stable over the long term, and increase slowly even when biomass increase quickly.

Sun *et al.* (2004) investigated variation in carbon stock in soils and detritus (forest floor and woody debris) in chronosequences that represent the forest types in the age group ranging between 13-600 years in the US Pacific north-west. Soil carbon, to a depth of 100 cm, was highest in coastal Sitka spruce/western hemlock forests ($36 \pm 10 \text{ kg C m}^{-2}$) and lowest in semiarid ponderosa pine forests ($7 \pm 10 \text{ kg C m}^{-2}$). Forests distributed across the Cascade mountains had intermediate values between 10 and 25 kg C m^{-2} . Soil carbon stocks were described as a linear function of net primary productivity ($r^2=0.52$), annual precipitation ($r^2=0.51$), and a power function of forest floor mean residence time ($r^2=0.67$). The highest rates of soil and detritus carbon turnover were recorded on mesic sites of Douglas-fir/western hemlock forests in the Cascade Mountains with lower rates in wetter and drier habitats, similar to the pattern of site productivity. The relative contribution of soil and detritus carbon to total ecosystem carbon decreased as a negative exponential function of stand age to a value of 35 per cent between 150 and 200 years across the forest types. These age-dependent trends in the portioning of carbon between biomass and necromass were not different among forest types. Model estimates of soil carbon storage based on decomposition of legacy carbon and carbon accumulation following stand-replacing disturbance showed that soil carbon storage reached an asymptote between 150 and 200 years, which has significant implications to modeling

carbon dynamics of the temperate coniferous forests following a stand-replacing disturbance.

After 10 years of conversion of pasture land to Australian pine (*Casuarina spp.*) forests in the reclaimed mine soils of southern Ohio the SOC pool increased by 6 Mg ha⁻¹ in the top 50 cm layer. However, the nitrogen pool in the top 50 cm was not affected by land use conversion from pasture to Australian pine. Conversion to Black locust increased the SOC pool in the top 50 cm by 24 Mg ha⁻¹ (42 per cent) while the N pool increased by 10 per cent under Black locust in 10 years. Establishment of tree plantation has been reported to have a greater potential for SOC sequestration than pastures in the reclaimed mine soils (Ussiri *et al.*, 2006).

Soil organic carbon (SOC) and total nitrogen stocks in 0-0.3 and 0.3-1 m soil layers were estimated under three vegetation communities viz. Schefflera-Hagenia, Hypericum-Erica-Schefflera and *Erica arborea* (shrub size) at different topographic aspects (east, west, north and south facing) on the Bale Mountains in the south-eastern highlands of Ethiopia. The results showed that SOC and total N in the top 0.3 m depth varied significantly among vegetation communities and aspects. At all aspects studied, the overall mean SOC and total N stocks to a depth of 1 m ranged from 32.67 to 46.03 kg C m⁻² and 2.89 to 3.61 kg N m⁻² among the vegetation communities. The overall mean SOC and total N stocks to a depth of 1 m varied from 35.13 to 44.97 kg C m⁻² and 2.90 to 3.75 kg N m⁻² among aspects. The study pointed out that vegetation community types and microclimatic differences induced by topographic aspects were found to be important factors for the significant variations in SOC and total N stocks in the Bale Mountains. The study revealed that about 45 per cent of the SOC stock was held in the top 0.3 m of the soil layer, and hence this layer was projected to emit CO₂ to the atmosphere or exposed to various disturbances like deforestation, grazing and cultivation (Fantaw *et al.*, 2006).

The soil organic carbon pool is significantly influenced by certain environmental factors, such as elevation, topography, and vegetation type. In this

study, the forest site patch method, divided or merged by elevation (0-1499, 1500-2499, and ≥ 2500 m), aspect (N-NE, E-SE, S-SW and W-NW), slope (0 degrees -15 degrees, 16 degrees -35 degrees, and > 36 degrees) and forest type (plantation and natural forests) was used. The soil organic carbon pool was estimated under different forests grown at various locations, elevations, slopes and aspects. The areas of the Puli and Luanda forestland were about 27132 and 57545 ha, which was compartmented into 55 and 65 patches for the study. The results showed that total contents of soil organic carbon under Puli and Luanda Forest Working Circles of Uganda were about 5.29 Tg and 13.0 Tg, whereas, the contents of fine soil organic carbon were 3.51 Tg and 7.71 Tg, respectively. Soil organic carbon and the fine soil organic carbon content increased with elevation; the highest carbon content was observed at mid-elevations followed by a slow decline at higher elevations. The soil organic carbon content for different aspects was in the order of E-SE > S-SW > W-NW > N-NE (Yen and Shiang, 2007).

Tangsinmankong *et al.* (2007) examined carbon stocks in soil of mixed deciduous forest and teak plantation of 6, 15 and 24 years of age. The study was conducted in 2 areas; mixed deciduous forest at Huay Kha Khaeng Wildlife Sanctuary and teak plantation of Thai Plywood Co. Ltd. in Lansak District, Uthaitхани Province. Results revealed that soil organic carbon from all sites decreased generally with the increasing depth (157.03 t ha^{-1}) from the surface soil down to the level of 100 cm. The highest carbon stocks in soil was recorded under 6-year-old teak plantation followed by the 24-year-old (105.67 t ha^{-1}) and 15-year-old teak (78.78 t ha^{-1}) plantations and mixed deciduous forest (70.96 t ha^{-1}), respectively. They further pointed out that variation in soil organic carbon was due to forest fire, forest management and topographic factors of the area.

Kaonga and Smith (2009) during 2002-2003 studied tree and soil C stocks and their response to different tree species and clay contents in improved fallow of eastern Zambia. During the study significant difference in above ground tree C stocks and net organic C (NOC) intake rates across coppicing tree species at *Msekera* and *Kalunga* were observed. Above ground C stock ranged from 2.9 to 9.8 t ha^{-1} equivalent to NOC intakes of $0.8\text{-}4.9 \text{ t ha}^{-1} \text{ yr}^{-1}$. SOC stock in non

coppiced fallows at *Kalichero* and *Msekeru* differed significantly across treatments. SOC stocks of 200 cm soil layer ranged from 64.7 t C ha⁻¹ under non coppicing fallow at *Kalunga* to 184 t ha⁻¹ in 10 year old coppicing fallow at *Msekeru*. The study recorded that tree and soil C stocks in improved fallow can be increased by planting selected tree species on soils with high clay content.

Bai *et al.* (2011) studied soil organic carbon contents and their vertical distributions in two natural saline-alkalined wetlands (Erbaifangzi and Fulaowenpao) with different hydrological conditions in Xianghai National Nature Reserve of north-east China in 2001. Results showed that mean SOCD of EBFZ from 30 soil profiles was 8.23 ± 1.40 kg C m⁻², but both of them were much lower (43 to 92 per cent) than those in other wetlands in China. Soil organic carbon density was positively significantly correlated with soil organic matter, total nitrogen, total phosphorus, and clay contents ($p < 0.001$) and was negatively significantly correlated with sand contents ($p < 0.001$). There was also a significant correlation between SOCD and soil pH or silt contents at the level of $p < 0.01$. Hydrological regime could impact carbon storage in wetland soils, and water deficit would lead to carbon loss. Ecological water supplement might be necessary to mitigate water shortage and increase carbon storage of wetlands in semi-arid and arid regions.

Gupta and Rao (1994) stated that the present 24.3 Pg stock of carbon in the Indian soils could be increased to 34.9 Pg. Thus there is a potential of 10.3 Pg for sequestering additional carbon in our soils. Garg (1998) observed that establishment of mesquite (*Prosopis juliflora*) plantation on salt affected soils in north-western India increased soil organic carbon pool from 10 Mg ha⁻¹ to 45 Mg ha⁻¹ over an eight-year period.

The amount of carbon in Indian soil is 23.4-27.1 Gt, which is about 1.6 to 1.8 per cent of the carbon stored in world's soil (Rastogi *et al.*, 2002). The total SOC pool in Indian forest soil is 4.13 Pg and 6.81 Pg C in top 50 cm to 100 cm depth, respectively (Chhabra *et al.*, 2003).

Chhabra *et al.* (2003) measured soil organic carbon of different forest types grown at different locations, soil types, soil texture with varying soil bulk density values. The mean soil organic C density for top 50 cm soil layer (based on 175 observations) ranged from 37.5 t ha⁻¹ in tropical dry deciduous forest to 92.1 t ha⁻¹ in littoral and swamp forests. The mean soil organic C density estimates based on 136 observations ranged from 70 t ha⁻¹ in tropical dry deciduous forests to 162 t ha⁻¹ in mountain temperate forests for top 100 cm soil depth. The total soil organic C pools in Indian forests have been estimated to the tune of 4.13 Pg C in top 50 cm and 6.81 Pg C in top 100 cm soil depth.

Kumar (2003) revealed that in western Himalaya SOC was influenced significantly by various agroforestry systems. SOC stock was higher under silvi-pastoral system (74.82 t ha⁻¹) followed by natural grassland (44.33 t ha⁻¹), agro-horti-silvicultural system (43.97 t ha⁻¹), horti-pastoral (42.97 t ha⁻¹), agri-horticultural (27.81 t ha⁻¹) and minimum was under agri-silvicultural (27.33 t ha⁻¹). Another study conducted in wet temperate north-western Himalayan region revealed that forest land use systems contained the maximum SOC stock (108.99 t ha⁻¹), followed by agri-horticultural (51.05 t ha⁻¹), horticulture (46.31 t ha⁻¹), agri-silvicultural (40.40 t ha⁻¹), grass land (36.37 t ha⁻¹) and silvi-pastoral (33.54 t ha⁻¹) in 0-40 cm layer.

Jha and Gupta (2005) studied soil carbon sink under different forest types in Himachal Pradesh (India) during 1984. The study revealed maximum SOC pool of 117.36 Mt under mixed conifer forests, followed by chir-pine (43.80 Mt), upland hardwood (35.07 Mt) and miscellaneous forests (15.04 Mt). However, during a span of 10 years (1984-1994) an increase of 21.6 per cent carbon sink was recorded in silver fir and spruce forest soil followed by 18.55 per cent in deodar, 17.19 per cent in kail, 17.32 per cent in hardwood and conifers and 6.81 per cent in upland hardwood.

Jha and Gupta (2005) compared carbon storage of top one foot of soil under 6 land uses. Forests with highest carbon storage showed the best mitigation potential (120.0 t ha⁻¹) followed by agroforestry (83.6 t ha⁻¹), plantations (80.5 t

ha⁻¹), agriculture (66.0 t ha⁻¹), pasture (40.0 t ha⁻¹) and barren land (20 t ha⁻¹). The study revealed that permanent tall vegetation cover under forest as one of the reason to store more carbon.

Awasthi *et al.* (2005) estimated the soil organic carbon and nutrient stocks under four dominant land uses namely forest, upland maize and millet (Bari), irrigated rice (Khet), and grazed systems along the depth and elevation gradients (1000 to 3000 m), and aspects in the Mardi watershed. The SOC and nutrient concentrations were reported to decrease with increasing profile depth. The SOC and N contents in the 0-15 cm depth of forest soils were significantly greater than the corresponding depth in upland maize, millet, irrigated rice, and grazed systems. Both SOC and N stocks decreased sharply in grassland (54 and 4.5 Mg ha⁻¹) at elevations of 2600 to 2800 m sl compared with undisturbed forest. Above 2800 m sl the cover type changed from grass to coniferous forest, and the SOC and N stocks steadily increased upto 3200 m sl. Further, slope and aspects were reported to influence SOC with the north-west aspect having significantly higher concentrations (46 g kg⁻¹) than other aspects.

Ramchandran *et al.* (2007) studied the carbon stock in the natural forest area of Kolli hills, part of Eastern Ghats of Tamil Nadu using geospatial technology. The estimated biomass carbon was 2.74 Tg and soil carbon was 3.48 Tg. The relatively low soil organic carbon content under the study area was reported to be due to severe degradation and anthropogenic disturbances in the forests.

Jina *et al.* (2008) studied the rate of carbon sequestration of degraded and non-degraded oak and pine forest of central Himalaya and reported that in degraded and non-degraded sites of ban oak the rate of carbon sequestration potential was 1.47 and 6.23 t ha⁻¹ yr⁻¹, respectively. Whereas, in the chir-pine forest the rate of carbon sequestration potential was 1.07 and 6.66 t ha⁻¹ yr⁻¹, respectively.

Rajput (2010) reported that average total biomass in Himalayan temperate forest ecosystem (404.35 t ha⁻¹) was on the higher side than temperate

and boreal forest ecosystems (326.0 t ha^{-1}) of the world (Anon., 1999). He attributed higher average total biomass of temperate forest ecosystem to low population density of the mountain ecosystem and in-accessibility of these landscapes in the past.

Rajput (2010) reported that total biomass carbon storage potential (202.2 t ha^{-1}) recorded in Himalayan temperate forest ecosystem was almost same as given by Singh *et al.* (1994) for Himalayan forest i.e. 190 t ha^{-1} and Sanneh (2007) for wet temperate Himalayan forest ecosystem (185.0 t ha^{-1}). But, the value was higher side in comparison to the average value of 160.0 t ha^{-1} given by Houghton (1995). The variation in the value of Himalayan temperate forest ecosystem and global temperate region coniferous forest was reported mainly due to difference in the nature of the temperate forest. The average annual temperature of Himalayan temperate forest is higher than the temperate forest found in other parts of the world. This was quoted to be one of the reasons for their higher productiveness.

Rajput (2010) while studying the carbon sequestration potential of different land use systems in temperate north-western Himalayas found that soil carbon pool under forests was 98.08 t ha^{-1} which is lower than the world average for temperate evergreen forest i.e. $139.9 \text{ t C ha}^{-1}$ (Houghton, 1995). He reported it mainly due to the nature of temperate forest ecosystem. Higher temperature helped in greater decomposition and loss of the soil organic carbon from our forest land use system. Moreover, the soil of the study site was sandy loam, which is known for lower soil organic carbon content because of its low retentively.

It is evident from the reviewed literature that SOC is highly sensitive to change in forest types and nature of forests. The SOC content declines with increasing depth. The aspects are also reported to influence the distribution of soil organic carbon. However, the literature with respect to effect of aspects on soil organic carbon status is scanty.



MATERIALS AND METHODS



Chapter-3

MATERIALS AND METHODS

The present investigation entitled “**Quantification of soil organic carbon stock of forests in Solan district of Himachal Pradesh**” was conducted in forests of Solan district of Himachal Pradesh, during 2010 – 2011. The details about experimental site, materials used and methodology adopted in undertaking the study are given below:

3.1 DESCRIPTION OF SITE

3.1.1 Location

The Solan district lies between North latitude 30°44’53” to 31°22’01” and East longitude 76°36’10” to 77°15’14”. The Solan is S-W district of Himachal Pradesh bounded by Bilaspur district in North-West & Mandi district in the North, Shimla & Sirmaur district in East & South-East, respectively. District has inter-state boundary in the South and West with State of Haryana and Punjab, respectively. The total forest area of Solan district is 849 km² which is 43.85 per cent of total geographical area (1936 km²) of district. Very dense forests (VDF), Moderately dense forests (MDF) and Open forests (OF) constitute 55, 404 and 390 km², respectively (Anon., 2007). The study was carried out in different forests of Solan district of Himachal Pradesh which comprises four wild life sanctuaries—Shili, Chail, Majathal and Darlaghat, and three forest divisions namely Solan, Kunihar and Nalagarh.

3.1.2 Climate

The climate of the district is sub-tropical in the valley and tends to be temperate in the hilltops. There are four major seasons. The winter season commences from November to February & ends in March; summer season extends from March to June followed by the monsoon period extending from July to September. Maximum precipitation (75 per cent) occurs during the months from July to September. Average annual rainfall in the district is about 1450 mm with average of 64 rainy days. In the winter season precipitation as snowfall also occurs in the higher reaches upto 1000 m elevation and as rainfall in low hills and valleys of the district.

Mean maximum and minimum temperature ranges between 34°C and 4°C. May and June are the hottest months, whereas, December and January are the coldest.

3.1.3 Geomorphology and Soil

Solan district presents an intricate mosaic of high mountain ranges, hills and valleys with altitude ranging from 350 to 3000 m sl. The altitude of the hill ranges is higher in northern parts, whereas, south-western part of the district is represented by low denuded hill ranges of Shiwalik. In the areas underlain by high hill ranges of Himalayas, the valleys are narrow and deep with steep slopes trending in NW-SE direction. The terrain is moderately to highly dissected with steep slopes.

The parent material consist of sand stone, conglomerate, boulders and dolomite. The soil type is inceptisols and typical entrochrepts with gravely sandy loam texture. Soil is generally sandy loam in valley areas of the district and in rest of the hilly and mountainous areas soil is skeletal, soil depth is generally shallow except in areas having good vegetative cover. Landslides are the common features in mountainous terrain. Soils are rich in nutrients and thus are fertile. The description of site is given in table 3.1.

Table 3.1. Locality factors of study area

Latitude	30°44'53" to 31°22'01" N
Longitude	76°36'10" to 77°15'14" E
Altitude	350-3000 m asl
Climate type	Sub tropical and Sub temperate
Texture	Sandy loam to clay loam
Average Annual Rainfall	1450 mm
Average Annual Temperature	19.8°C
Soil pH	Slightly acidic to near neutral

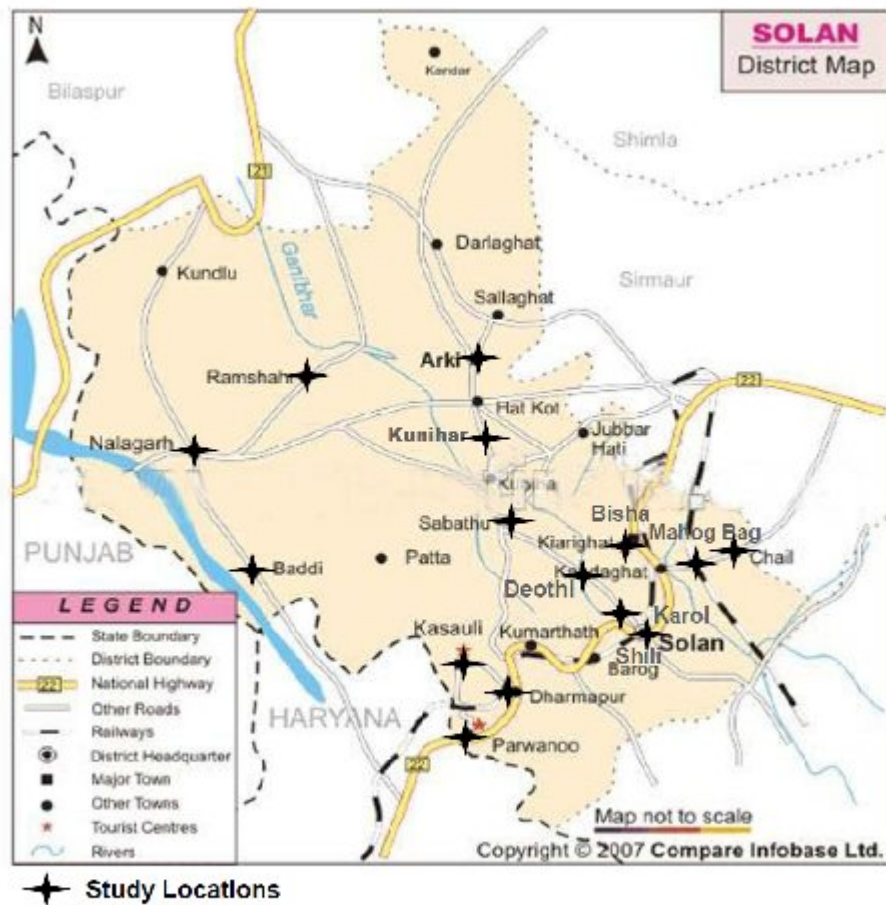


Fig. 1. Map showing study locations in Solan district of HP

3.2 TREATMENT DETAILS

The present investigation was undertaken in Solan district of Himachal Pradesh. The study was conducted for assessing the soil organic carbon under different forest types, aspects and depths. The details of treatments are given below.

3.2.1 Forest Types = 6

Scrub forests

Khair forests

Bamboo forests

Chir-pine forests

Oak forests

Deodar forests

3.2.2 Aspects = 2

NA - Northern aspect

SA - Southern aspect

3.2.3 Soil depths = 2

D₁: 0.0-15 cm

D₂: 15-30 cm

3.2.4

Replications	=	3
Number of treatment combinations of soil related studied	=	24 (6 Forest types) x 2 (aspects) x 2 (soil depths).
Design	=	RBD (Factorial)

Table 3.2. Details of the area under different forest types of Solan district of Himachal Pradesh

Forest Types	Area (ha)
Scrub	2570
Khair	714
Bamboo	6333
Chir-pine	11345
Oak	1635
Deodar	812
Total	23409

(Sharma, 2002 and Singh, 1991)

Sampling procedure

A preliminary survey of different forests of Solan district of Himachal Pradesh was conducted to ascertain the vegetation composition, structure, density and site characteristics. Stratified random sampling technique was used for taking soil samples. The samples were collected from 0-15 cm and 15-30 cm depth for six different forest types viz. scrub, khair, bamboo, chir-pine, oak and deodar forests of the Solan district. Three prominent locations based on spatial variations, occupying larger forest cover and area, under each forest types were selected. At each location, three plots were selected to make location more representative. As per the *good practice*, a composite sample was collected at each plot for surface and sub-surface layer of northern and southern aspects of all the forest types under investigation. The soil samples (about two to four) were collected, mixed and homogenized to make one composite sample at each plot. To estimate the SOC stock, the additional samples were collected for bulk density measurements at each depth, plot, aspect and location for different forest types under study. Forest floor litter at each sampling point was removed and a pit of 30 cm wide, 30 cm deep and 50 cm in length was dug out. Soil from 0-15 cm and 15-30 cm depth of the sides of pit was scrapped and mixed. The soil samples were collected in the month of September and October.

In the laboratory, soil samples were air dried in shade, ground with wooden pestle mortar, passed through 2 mm sieve and further through 0.5 mm sieve and stored in cloth bags. These sieved samples were used for soil organic

carbon estimation. Amount of coarse fragments was estimated in each sample and deducted from the soil weight to get an accurate soil weight on per ha basis and for soil organic carbon pool estimation. Bulk density was determined by core method using metallic core having 8 cm internal diameter and 11 cm height. The core had a sharp edge at one end to facilitate easy penetration into the soil and 1 cm thick open circular cap fitting on the edge of the core at the top. The core was driven into the soil with a hammer. The soil moisture content was estimated by gravimetric method.

Samples were analyzed for different physical and chemical properties of soil viz. soil organic carbon (SOC), bulk density, coarse fragments, pH and electrical conductivity (EC) by using standard methods as given in Table 3.3.

Table 3.3. Soil analysis methods

Sr. No.	Parameter	Method employed
1.	Organic carbon	Rapid titration method (Walkley and Black method 1934)
2.	Bulk density	Core method (Blake and Hartage, 1986)
3.	Coarse fragments	On weight basis
4.	pH	1:2.5 soil water suspension (Jackson, 1973)
5.	EC	1:2.5 soil water suspension (Jackson, 1973)

Carbon stock

The soil organic carbon stock (Mg C ha^{-1}) was calculated by using the following equation as per the IPCC Good Practice Guidance for LULUCF (IPCC, 2003).

$$\text{SOC} = [\text{SOC}] * \text{Bulk Density} * \text{Depth} * \text{Coarse Fragments} * 10$$

where:

SOC = soil organic carbon stock for soil of each forests, Mg C ha^{-1}

[SOC] = concentration of soil organic carbon in a given soil mass, $\text{g C (kg soil)}^{-1}$,
obtained from lab analysis

Bulk Density = soil mass per sample volume, Mg m^{-3}

Depth = sampling depth or thickness or soil layer, m

Coarse Fragments = $1 - (\% \text{ volume of coarse fragments} / 100)$, dimensionless

The final multiplier of 10 is introduced to convert units to Mg C ha^{-1} .

3.6 STATISTICAL ANALYSIS

The data generated from the present investigation were analyzed as per randomized block design in accordance with the procedure outlined by Gomez and Gomez (1984).



EXPERIMENTAL RESULTS



Chapter-4

EXPERIMENTAL RESULTS

The results emerged out of present investigation entitled “**Quantification of soil organic carbon stock of forests in Solan district of Himachal Pradesh**” has been presented in this chapter. The forest types due to their nature of origin, structure, function, tree species, tree density and management to which they have been subjected were found to reflect wide variability in terms of physical and chemical properties which have been described under the following heads.

- 4.1 Soil pH**
- 4.2 Soil electrical conductivity**
- 4.3 Soil organic carbon**
- 4.4 Soil bulk density**
- 4.5 Coarse fragments**
- 4.6 Soil organic carbon stock**

4.1 Soil pH

The perusal of data presented in table 1a evinced that soil pH varied under different forest types and aspects. Significantly, highest soil pH (6.94) was recorded under khair forests followed by scrub (6.90), bamboo (6.72), chir-pine (6.66) and oak (6.08), whereas, the lowest pH (6.04) was noticed under deodar forests. The aspects were found to exert significant influence on soil pH in different forest types under study. The maximum pH (6.57) was recorded on southern, whereas, minimum (6.54) was noticed on northern aspect. The data presented in table 1b revealed that soil pH increased down the profile upto 30 cm. The lowest pH (6.55) recorded at surface layer was however, statistically at par with that of sub-surface soil layer (6.56). The interaction effect of forest types x depths, aspects x depths and forest types x aspects x depths was found statistically non significant.

Table 1a. Effect of different forest types and aspects on pH

Forest type	Aspect		Mean
	Northern	Southern	
Scrub	6.89	6.90	6.90
Khair	6.93	6.96	6.94
Bamboo	6.71	6.72	6.72
Chir-pine	6.66	6.67	6.66
Oak	6.06	6.10	6.08
Deodar	6.02	6.05	6.04
Mean	6.54	6.57	

CD _{0.05}	Forest type	0.01
	Aspect	0.01
	Forest type x Aspect	NS

Table 1b. Effect of different forest types and soil depths on pH

Forest type	Soil depth (cm)		Mean
	D ₁	D ₂	
Scrub	6.89	6.90	6.90
Khair	6.94	6.95	6.94
Bamboo	6.71	6.73	6.72
Chir-pine	6.67	6.66	6.66
Oak	6.07	6.09	6.08
Deodar	6.03	6.04	6.04
Mean	6.55	6.56	

CD _{0.05}	Forest type	0.01
	Depth	0.01
	Forest type x Depth	NS

4.2 SOIL ELECTRICAL CONDUCTIVITY

The EC was found to vary under different forest types and aspects in Solan district of Himachal Pradesh (Table 2a). The highest EC (0.33 dS m⁻¹) was recorded under khair followed by chir-pine (0.31 dS m⁻¹), scrub (0.26 dS m⁻¹), bamboo (0.26 dS m⁻¹) and oak (0.21 dS m⁻¹) forests. The lowest EC (0.19 dS m⁻¹) was noticed under deodar forests. The aspects were found to exert significant influence on soil EC. The highest EC (0.27 dS m⁻¹) was recorded on southern, whereas, lowest (0.25 dS m⁻¹) was noticed on northern aspect. The interaction between forest types and aspects was also found to influence EC of different

forests. The highest EC (0.34 dS m^{-1}) was observed under khair forests of southern aspect, whereas, lowest EC (0.18 dS m^{-1}) was noticed under deodar forests of northern aspect. In general, soils under all the forest types studied were found to have relatively higher EC values in the southern aspects as compared to their corresponding values in the northern aspects (Table 2a). The EC was found to decrease with increase in soil depth under all the forest types (Table 2b). The maximum EC (0.27 dS m^{-1}) was found in surface layer, whereas, minimum (0.25 dS m^{-1}) was noticed in sub-surface layer. The interaction effect of forest types x depths, aspects x depths and forest types x aspects x depths was found statistically non significant.

Table 2a. Effect of different forest types and aspects on soil EC (dS m^{-1})

Forest type	Aspect		Mean
	Northern	Southern	
Scrub	0.25	0.28	0.26
Khair	0.32	0.34	0.33
Bamboo	0.26	0.27	0.26
Chir-pine	0.30	0.33	0.31
Oak	0.20	0.21	0.21
Deodar	0.18	0.19	0.19
Mean	0.25	0.27	

CD _{0.05}	Forest type	0.01
	Aspect	0.01
	Forest type x Aspect	0.01

Table 2b. Effect of different forest types and depths on soil EC (dS m^{-1})

Forest type	Soil depth (cm)		Mean
	D ₁	D ₂	
Scrub	0.27	0.25	0.26
Khair	0.34	0.32	0.33
Bamboo	0.27	0.26	0.26
Chir-pine	0.32	0.31	0.31
Oak	0.21	0.20	0.21
Deodar	0.20	0.18	0.19
Mean	0.27	0.25	

CD _{0.05}	Forest type	0.01
	Depth	0.01
	Forest type x Depth	NS

4.3 SOIL ORGANIC CARBON

4.3.1 Forest wise distribution of SOC

4.3.1.1 Scrub forests

The data presented in table 3a showed that significantly highest SOC content (16.02 g kg^{-1}) was recorded under scrub forests of Nalagarh followed by Parwanoo (15.12 g kg^{-1}) location. However, lowest SOC content (14.80 g kg^{-1}) was noticed in Kunihar location. The SOC content was found to vary with aspects. The highest SOC content (17.29 g kg^{-1}) was recorded on northern, whereas, minimum (13.33 g kg^{-1}) on southern aspect. The interaction between aspects and locations was found to exert significant influence on SOC content under scrub forests. The northern aspect of Nalagarh location was found to have maximum SOC content (18.90 g kg^{-1}). The minimum SOC content (12.35 g kg^{-1}) was however, recorded in Parwanoo location on southern aspect. The table 3b clearly indicated that SOC distribution pattern varied significantly with soil depth. The SOC content was noticed to be the highest (16.11 g kg^{-1}) in surface and lowest (14.51 g kg^{-1}) in the sub-surface layer. However, interaction between locations and depths was found to be statistically non significant. The aspects and depths interactions (Table 3c) were found to influence SOC content of scrub forests. The highest SOC content (18.01 g kg^{-1}) was found in surface layer of northern, whereas, lowest (12.44 g kg^{-1}) was noticed in the sub-surface layer of southern aspect. The three way interaction amongst aspects, locations and depths with respect to SOC content was found statistically significant.

Table 3a. Effect of locations and aspects on SOC content (g kg^{-1}) under scrub forests

Location	Aspect		Mean
	Northern	Southern	
Nalagarh	18.90	13.13	16.02
Parwanoo	17.88	12.35	15.12
Kunihar	15.10	14.50	14.80
Mean	17.29	13.33	

CD _{0.05}	Location	0.15
	Aspect	0.12
	Aspect x Location	0.21

Maximum SOC content (19.53 g kg^{-1}) was recorded in surface layer on northern aspect of Nalagarh followed by Pawanoo location (18.50 g kg^{-1}) in the same layer and aspect, whereas, minimum content (11.50 g kg^{-1}) was recorded in sub-surface layer of southern aspect of Parwanoo location.

Table 3b. Depth wise distribution of SOC (g kg^{-1}) under scrub forests of different locations

Location	Soil depth (cm)		Mean
	D ₁	D ₂	
Nalagarh	16.83	15.20	16.02
Parwanoo	15.85	14.38	15.12
Kunihar	15.65	13.95	14.80
Mean	16.11	14.51	

CD _{0.05}	Location	0.15
	Depth	0.12
	Location x Depth	NS

Table 3c. Effect of locations, aspects and soil depths on SOC content (g kg^{-1}) under scrub forests

Location	Aspect			
	Northern		Southern	
	D ₁	D ₂	D ₁	D ₂
Nalagarh	19.53	18.27	14.13	12.13
Parwanoo	18.50	17.27	13.20	11.50
Kunihar	16.00	14.20	15.30	13.70
Mean	18.01	16.58	14.21	12.44

CD _{0.05}	Aspect x Depth	0.17
	Aspect x Location x Depth	0.30

4.3.1.2 Khair forests

The data with respect to khair forests presented in table 4a revealed that significantly highest SOC content (9.08 g kg^{-1}) was recorded in Kunihar followed by Badi (8.85 g kg^{-1}) location. However, lowest SOC content (8.52 g kg^{-1}) was noticed in Nalagarh location. The SOC content was found to vary with aspects. The highest SOC content (9.76 g kg^{-1}) was recorded on northern, whereas, lowest (7.87 g kg^{-1}) was noticed on southern aspect. The interaction between aspects and locations was found to exert significant influence on SOC content under khair forests. The northern aspect of Badi location was found to have maximum SOC content (10.27 g kg^{-1}). The minimum SOC content (7.43 g kg^{-1}) was recorded at

Badi location on southern aspect. The data presented in table 4b indicated that SOC content varied significantly with soil depth. The highest SOC content (9.92 g kg^{-1}) was recorded in surface layer and lowest (7.69 g kg^{-1}) in sub-surface layer. However, interaction between locations and depths was found to be statistically non significant. The aspects and depths interaction (Table 4c) was found to influence SOC content under the khair forests. The highest SOC content (10.78 g kg^{-1}) was noticed in surface layer of northern, whereas, lowest (6.63 g kg^{-1}) was found in sub-surface layer of southern aspect. The three way interaction amongst aspects, locations and depths also influenced SOC contents of khair forests. Maximum SOC content (11.20 g kg^{-1}) was recorded in surface layer on northern aspect of Badi followed by Kunihar location in the same layer and aspect (10.73 g kg^{-1}), whereas, minimum content (6.20 g kg^{-1}) was recorded in sub-surface layer of southern aspect of the Badi location.

Table 4a. Effect of locations and aspects on SOC content (g kg^{-1}) under khair forests

Location	Aspect		Mean
	Northern	Southern	
Badi	10.27	7.43	8.85
Nalagarh	9.37	7.67	8.52
Kunihar	9.65	8.50	9.08
Mean	9.76	7.87	

CD _{0.05}	Location	0.12
	Aspect	0.09
	Aspect x Location	0.16

Table 4b. Depth wise distribution of SOC (g kg^{-1}) under khair forests of different locations

Location	Soil depth (cm)		Mean
	D ₁	D ₂	
Badi	9.93	7.77	8.85
Nalagarh	9.72	7.32	8.52
Kunihar	10.17	7.98	9.08
Mean	9.92	7.69	

CD _{0.05}	Location	0.12
	Depth	0.09
	Location x Depth	NS

Table 4c. Effect of locations, aspects and soil depths on SOC content (g kg^{-1}) under khair forests

Location	Aspect			
	Northern		Southern	
	D ₁	D ₂	D ₁	D ₂
Badi	11.20	9.33	8.67	6.20
Nalagarh	10.40	8.33	9.03	6.30
Kunihar	10.73	8.57	9.60	7.40
Mean	10.78	8.74	9.10	6.63

CD_{0.05} Aspect x Depth 0.13
 Aspect x Location x Depth 0.23

4.3.1.3 Bamboo forests

Like other forests, SOC was found to vary with locations, aspects and depths under the bamboo forests. The data presented in table 5a revealed that significantly highest soil organic carbon content (18.22 g kg^{-1}) was found under bamboo forests of Parwanoo followed by Kunihar (17.73 g kg^{-1}) location. However, lowest SOC content (17.17 g kg^{-1}) was noticed at Nalagarh location. The SOC content was found to vary with aspects. The highest SOC content (18.32 g kg^{-1}) was recorded on northern, whereas, lowest (17.09 g kg^{-1}) on southern aspect. The interaction between aspect and locations was found to exert significant influence on SOC content under bamboo forests. The northern aspect of Parwanoo location was found to have maximum SOC content (19.12 g kg^{-1}).

Table 5a. Effect of locations and aspects on SOC content (g kg^{-1}) under bamboo forests

Location	Aspect		Mean
	Northern	Southern	
Nalagarh	17.80	16.53	17.17
Parwanoo	19.12	17.32	18.22
Kunihar	18.05	17.42	17.73
Mean	18.32	17.09	

CD_{0.05} Location 0.16
 Aspect 0.13
 Aspect x Location 0.23

The minimum SOC content (16.53 g kg^{-1}) was however, recorded at Nalagarh location on southern aspect. The SOC distribution was found to vary significantly with soil depth (Table 5b). The surface layer was found to have the highest SOC content (18.98 g kg^{-1}). The sub-surface layer, however, was found to contain the lowest SOC content (16.43 g kg^{-1}). The interaction effect of locations x depths, aspects x depths and aspects x locations x depths with respect to SOC content was found statistically non significant.

Table 5b. Depth wise distribution of SOC (g kg^{-1}) under bamboo forests of different locations

Location	Soil depth (cm)		Mean
	D ₁	D ₂	
Nalagarh	18.45	15.88	17.17
Parwanoo	19.53	16.90	18.22
Kunihar	18.95	16.52	17.73
Mean	18.98	16.43	

CD _{0.05}	Location	0.16
	Depth	0.13
	Location x Depth	NS

4.3.1.4 Chir-pine forests

It is evident from the data presented in table 6a that chir-pine forests of Kasauli location contained highest SOC content (16.63 g kg^{-1}) which was followed by SOC content (16.47 g kg^{-1}) of Deothi location. The lowest SOC content (16.43 g kg^{-1}) was noticed at Arki location which however, was statically at par with SOC content (16.47 g kg^{-1}) of Deothi location. The aspects were found to exert significant influence on chir-pine forests of Solan district. The highest SOC content (17.77 g kg^{-1}) was recorded on northern, whereas, lowest (15.24 g kg^{-1}) on southern aspect. Under chir-pine forests, interaction between aspects and locations also influenced SOC content significantly. The northern aspect of Kasauli was found to have maximum SOC content (17.33 g kg^{-1}) which was statistically at par with that of Deothi (17.27 g kg^{-1}) location. The minimum SOC content (15.67 g kg^{-1}) was however, recorded in Deothi location on southern

aspect. SOC under chir-pine forests of Solan district like other forests was also found to decrease with depth (Table 6b). The highest SOC content (17.77 g kg^{-1}) was recorded in the surface layer and lowest (15.24 g kg^{-1}) in sub-surface layer. The interaction between locations and depths was found statistically significant. The highest SOC content (17.90 g kg^{-1}) was observed in surface layer at Kasauli location which was however, statistically at par with that of Arki (17.80 g kg^{-1}) location. However, minimum SOC content (15.05 g kg^{-1}) was recorded in sub-surface layer of Arki location. Under chir-pine forests the aspect and depth interactions (Table 6c) were found statistically non significant. The three way interaction amongst aspects, locations and depths however, resulted in significant influence on SOC content. Maximum SOC content (18.80 g kg^{-1}) was recorded in surface layer of northern aspect of Kasauli region followed by Deothi (18.43 g kg^{-1}) in the same layer and aspect, whereas, minimum content (14.43 g kg^{-1}) was noticed in sub-surface layer of southern aspect of Arki location.

Table 6a. Effect of locations and aspects on SOC content (g kg^{-1}) under chir-pine forests

Location	Aspect		Mean
	Northern	Southern	
Deothi	17.27	15.67	16.47
Arki	16.93	15.92	16.43
Kasauli	17.33	15.92	16.63
Mean	17.18	15.83	

CD _{0.05}	Location	0.15
	Aspect	0.12
	Aspect x Location	0.21

Table 6b. Depth wise distribution of SOC (g kg^{-1}) under chir-pine forests of different locations

Location	Soil depth (cm)		Mean
	D ₁	D ₂	
Deothi	17.62	15.32	16.47
Arki	17.80	15.05	16.43
Kasauli	17.90	15.35	16.63
Mean	17.77	15.24	

CD _{0.05}	Location	0.15
	Depth	0.12
	Location x Depth	0.21

Table 6c. Effect of locations, aspects and soil depths on SOC content (g kg^{-1}) under chir-pine forests

Location	Aspect			
	Northern		Southern	
	D ₁	D ₂	D ₁	D ₂
Deothi	18.43	16.10	16.80	14.53
Arki	18.20	15.67	17.40	14.43
Kasauli	18.80	15.87	17.00	14.83
Mean	18.48	15.88	17.07	14.60

CD_{0.05} Aspect x Depth NS
 Aspect x Location x Depth 0.30

4.3.1.5 Oak forests

The data give in table 7a indicated that highest SOC content (20.36 g kg^{-1}) was recorded under oak forests at Karol location of Solan district which was followed by Shili (20.19 g kg^{-1}) area. However, lowest SOC content (20.03 g kg^{-1}) was noticed under oak forests of Bisha location. The SOC content was found to vary with aspects. The highest SOC content (21.42 g kg^{-1}) was recorded on northern, whereas, lowest (18.97 g kg^{-1}) on southern aspect. The interaction between aspects and locations was found to exert significant influence on SOC content. The northern aspect of Karol location was found to have maximum SOC (22.07 g kg^{-1}), whereas, minimum SOC content (18.65 g kg^{-1}) was recorded at the same location but on southern aspect. SOC content was also found to decrease with depth (Table 7b). The highest SOC content was recorded (21.39 g kg^{-1}) in surface and lowest (18.99 g kg^{-1}) in sub-surface layer. The interaction between locations and depths was found statistically significant. The highest SOC content (21.65 g kg^{-1}) was observed in surface layer at Karol location, whereas, lowest (18.82 g kg^{-1}) in sub-surface layer of Bisha location. Under oak forests the aspects and depths interaction was found statistically non significant. However, three way interaction (Table 7c) amongst aspects, locations and depths with respect to SOC content was found statistically significant. Maximum SOC content (23.53 g kg^{-1}) was observed in surface layer on northern aspect of Karol location followed by Shili location in the same layer and aspect (22.33 g kg^{-1}), whereas, minimum content (17.53 g kg^{-1}) was noticed in sub-surface layer of southern aspect of the same location.

Table 7a. Effect of locations and aspects on SOC content (g kg^{-1}) under oak forests

Location	Aspect		Mean
	Northern	Southern	
Karol	22.07	18.65	20.36
Bisha	20.80	19.25	20.03
Shili	21.38	19.00	20.19
Mean	21.42	18.97	

CD _{0.05}	Location	0.14
	Aspect	0.11
	Aspect x Location	0.19

Table 7b. Depth wise distribution of SOC (g kg^{-1}) under oak forests of different locations

Location	Soil depth (cm)		Mean
	D ₁	D ₂	
Karol	21.65	19.07	20.36
Bisha	21.23	18.82	20.03
Shili	21.28	19.10	20.19
Mean	21.39	18.99	

CD _{0.05}	Location	0.14
	Depth	0.11
	Location x Depth	0.19

Table 7c. Effect of locations, aspects and soil depths on SOC content (g kg^{-1}) under oak forests

Location	Aspect			
	Northern		Southern	
	D ₁	D ₂	D ₁	D ₂
Karol	23.53	20.60	19.77	17.53
Bisha	21.83	19.77	20.63	17.87
Shili	22.33	20.43	20.23	17.77
Mean	22.57	20.27	20.21	17.72

CD _{0.05}	Aspect x Depth	NS
	Aspect x Location x Depth	0.27

4.3.1.6 Deodar forests

The data presented in table 8a demonstrated that SOC content under deodar forests varied with locations and aspects. Significantly, highest SOC content (28.96 g kg^{-1}) was recorded in deodar forests of Chail followed by Mahog Bag (28.72 g kg^{-1}) location. The lowest SOC content (27.31 g kg^{-1}) was noticed at

Shili location. The SOC content varied significantly with aspects. The highest SOC content (29.74 g kg^{-1}) was found on northern, whereas, lowest (26.91 g kg^{-1}) on southern aspect. The interaction between aspects and locations was found to exert significant influence on SOC content of deodar forests. The northern aspect of Chail location was found to have maximum SOC content (30.78 g kg^{-1}), whereas, Shili forests on southern aspect was found to have minimum SOC content (25.97 g kg^{-1}). The SOC content significantly decreased down the soil profile (Table 8b). The highest SOC content (29.48 g kg^{-1}) was recorded in surface layer and lowest (27.17 g kg^{-1}) in sub-surface layer. The interaction between locations and depths was found statistically non significant. However, aspects and depths interaction (Table 8c) was found to influence SOC content of deodar forests. The highest SOC content (30.84 g kg^{-1}) was noticed at surface layer of northern, whereas, lowest (25.70 g kg^{-1}) in sub-surface layer of southern aspect. The three way interaction amongst aspects, locations and depths was statistically non significant.

Table 8a. Effect of locations and aspects on SOC content (g kg^{-1}) under deodar forests

Location	Aspect		Mean
	Northern	Southern	
Chail	30.78	27.13	28.96
Mahog Bag	29.80	27.63	28.72
Shili	28.65	25.97	27.31
Mean	29.74	26.91	

CD _{0.05}	Location	0.10
	Aspect	0.08
	Aspect x Location	0.14

Table 8b. Depth wise distribution of SOC (g kg^{-1}) under deodar forests of different locations

Location	Soil depth (cm)		Mean
	D ₁	D ₂	
Chail	30.08	27.83	28.96
Mahog Bag	29.88	27.55	28.72
Shili	28.48	26.13	27.31
Mean	29.48	27.17	

CD _{0.05}	Location	0.10
	Depth	0.08
	Location x Depth	NS

Table 8c. Effect of locations, aspects and soil depths on SOC content (g kg^{-1}) under deodar forests

Location	Aspect			
	Northern		Southern	
	D ₁	D ₂	D ₁	D ₂
Chail	31.83	29.73	28.33	25.93
Mahog Bag	30.87	28.73	28.90	26.37
Shili	29.83	27.47	27.13	24.80
Mean	30.84	28.64	28.12	25.70

CD_{0.05} Aspect x Depth 0.12
 Aspect x Location x Depth NS

4.3.2 Forest types and SOC distribution

The perusal of data presented in table 9a clearly indicated that SOC content varied with forest types and aspects. Significantly, highest SOC content (28.33 g kg^{-1}) was recorded under deodar forests followed by oak (20.19 g kg^{-1}), bamboo (17.71 g kg^{-1}), chir-pine (16.38 g kg^{-1}) and scrub (15.43 g kg^{-1}) forests. The lowest SOC content (8.81 g kg^{-1}) was noticed under khair forests. The aspects were found to exert significant influence on SOC content of different forest types. The highest SOC (18.91 g kg^{-1}) content was recorded on northern, whereas, lowest (16.71 g kg^{-1}) on southern aspect. The interaction between forest types and aspects with respect to SOC content was significant. The highest SOC content (29.74 g kg^{-1}) was noticed under deodar forests of northern aspect which was followed by the same forest types (26.91 g kg^{-1}) of southern aspect and oak (21.42 g kg^{-1}) forests of northern aspect, whereas, lowest SOC content (7.86 g kg^{-1}) was recorded under khair forests of southern aspect.

The data presented in table 9b revealed that irrespective of forest types, SOC content decreased significantly with increasing soil depth. The maximum SOC (18.90 g kg^{-1}) content was found in surface layer, whereas, minimum (16.71 g kg^{-1}) in sub-surface layer. The interaction between forest types and depth was found to exert statistically significant influence on SOC content. The maximum SOC content (29.48 g kg^{-1}) was recorded in surface layer under deodar forests followed by the same forest types (27.17 g kg^{-1}) of sub-surface layer and oak

(21.39 g kg⁻¹) forests of surface layer. However, minimum SOC content (7.69 g kg⁻¹) was observed under khair forests in sub-surface layer. The interaction effect of aspects x depths, forest types x aspects x depths was found statistically non significant.

Table 9a. Effect of different forest types and aspects on SOC content (g kg⁻¹)

Forest type	Aspect		Mean
	Northern	Southern	
Scrub	17.29	13.57	15.43
Khair	9.76	7.86	8.81
Bamboo	18.32	17.09	17.71
Chir-pine	16.93	15.83	16.38
Oak	21.42	18.97	20.19
Deodar	29.74	26.91	28.33
Mean	18.91	16.71	

CD _{0.05}	Forest type	0.23
	Aspect	0.12
	Forest type x Aspect	0.32

Table 9b. Depth wise distribution of SOC (g kg⁻¹) under different forest types

Forest type	Soil depth (cm)		Mean
	D ₁	D ₂	
Scrub	16.11	14.76	15.43
Khair	9.93	7.69	8.81
Bamboo	18.98	16.43	17.71
Chir-pine	17.53	15.24	16.38
Oak	21.39	18.99	20.19
Deodar	29.48	27.17	28.33
Mean	18.90	16.71	

CD _{0.05}	Forest type	0.23
	Depth	0.13
	Forest type x Depth	0.32

4.4 SOIL BULK DENSITY

The perusal of data presented in table 10a evinced that bulk density of soil varied under different forest types and aspects. Significantly, highest bulk density

(1.19 Mg m⁻³) was recorded under khair forests which remained statistically at par with bulk density of scrub forests (1.18 Mg m⁻³) which was followed by chir-pine (1.13 Mg m⁻³), bamboo (1.09 Mg m⁻³), oak (1.08 Mg m⁻³) and deodar (1.02 Mg m⁻³) forests in descending order. The aspects were found to exert significant influence on soil bulk density. The highest bulk density (1.13 Mg m⁻³) was recorded on southern, whereas, lowest (1.09 Mg m⁻³) on northern aspect. The interaction between forest types and aspects with respect to bulk density was significant. The highest bulk density (1.22 Mg m⁻³) was noticed under khair forests of southern aspect which was followed by scrub (1.19 Mg m⁻³) forests in the same aspect, whereas, lowest (1.00 Mg m⁻³) was recorded under deodar forests of northern aspect.

The data presented in the table 10b revealed that bulk density significantly increased with increase in soil depth. The minimum bulk density (1.10 Mg m⁻³) was found in surface layer, whereas, maximum (1.13 Mg m⁻³) in sub-surface layer. The interaction effect of forest types x depths, aspects x depths and forest types x aspects x depths was found statistically non significant.

Table 10a. Effect of different forest types and aspects on bulk density (Mg m⁻³) of soil

Forest type	Aspect		Mean
	Northern	Southern	
Scrub	1.16	1.19	1.18
Khair	1.17	1.22	1.19
Bamboo	1.06	1.11	1.09
Chir-pine	1.10	1.15	1.13
Oak	1.07	1.10	1.08
Deodar	1.00	1.04	1.02
Mean	1.09	1.13	

CD _{0.05}	Forest type	0.01
	Aspect	0.01
	Forest type x Aspect	0.01

Table 10b. Depth wise variations in soils bulk density (Mg m^{-3}) under different forest types

Forest type	Soil depth (cm)		Mean
	D ₁	D ₂	
Scrub	1.16	1.19	1.18
Khair	1.17	1.22	1.19
Bamboo	1.07	1.11	1.09
Chir-pine	1.11	1.14	1.13
Oak	1.06	1.10	1.08
Deodar	1.00	1.03	1.02
Mean	1.10	1.13	

CD _{0.05}	Forest type	0.01
	Depth	0.01
	Forest type x Depth	NS

4.5 COARSE FRAGMENTS

Data presented in table 11 revealed that the gravel contents in the soil under different forest types of the study area ranged from 24.69 to 38.83 per cent for all the aspects and depths.

Table 11. Depth wise distribution of coarse fragments (%) in the soils under different forest types of northern and southern aspect

Forest types	Northern Aspect			Southern Aspect			Soil depth		Grand mean
	D ₁	D ₂	Mean	D ₁	D ₂	Mean	D ₁	D ₂	
Scrub	32	36	34	36	41	39	34.11	38.94	36.53
Khair	34	39	36	39	44	42	36.11	41.56	38.83
Bamboo	21	25	23	24	29	26	22.39	27.00	24.69
Chir-pine	28	33	30	34	37	35	30.78	34.89	32.83
Oak	23	29	26	26	32	29	24.61	30.44	27.53
Deodar	21	27	24	25	29	27	23.00	28.00	25.50
Mean	27	31	29	30	36	33	28.50	33.47	36.53

4.6 SOIL ORGANIC CARBON STOCK

The data presented in table 12a evinced that SOC stock varied under different forest types and aspects. Significantly, highest SOC stock ($32.20 \text{ Mg C ha}^{-1}$) was recorded under deodar forests followed by oak ($23.59 \text{ Mg C ha}^{-1}$), bamboo ($22.04 \text{ Mg C ha}^{-1}$), chir-pine ($18.48 \text{ Mg C ha}^{-1}$) and scrub forests ($17.30 \text{ Mg C ha}^{-1}$). The lowest SOC stock ($9.69 \text{ Mg C ha}^{-1}$) was noticed under khair forests. The aspects were found to exert significant influence on SOC stock of different forest types. The highest SOC stock ($21.90 \text{ Mg C ha}^{-1}$) was recorded on

northern, whereas, lowest (19.20 Mg C ha⁻¹) was observed on southern aspect. The interaction between forest types and aspect was found significant. The highest SOC stock (33.80 Mg C ha⁻¹) was recorded under deodar forests of northern aspect which was followed by SOC stock (30.61 Mg C ha⁻¹) of the same forests on southern aspect and oak (25.28 Mg C ha⁻¹) forests of northern aspect, whereas, lowest SOC stock (8.40 Mg C ha⁻¹) was recorded under khair forests of southern aspect.

The SOC stock appreciably decreased with increasing soil depth (Table 12b). The maximum SOC stock (22.21 Mg C ha⁻¹) was found in surface layer and minimum (18.89 Mg C ha⁻¹) was noticed in sub-surface layer. The interaction between forest types and depths was found to exert statistically significant influence on SOC stock. The maximum SOC stock (34.15 Mg C ha⁻¹) was recorded in surface layer under deodar forests followed by sub-surface layer (30.25 Mg C ha⁻¹) of the same forest types and oak (25.59 Mg C ha⁻¹) forests of surface layer. However, minimum SOC stock was observed under khair (8.23 Mg C ha⁻¹) forests in sub-surface layer. The interaction effect of aspects x depths, forest types x aspects x depths was found statistically non significant.

Table 12a. Effect of different forest types and aspects on SOC stock (Mg C ha⁻¹)

Forest type	Aspect		Mean
	Northern	Southern	
Scrub	19.59	15.00	17.30
Khair	10.98	8.40	9.69
Bamboo	22.43	21.65	22.04
Chir-pine	19.34	17.61	18.48
Oak	25.28	21.90	23.59
Deodar	33.80	30.61	32.20
Mean	21.90	19.20	

CD _{0.05}	Forest type	0.48
	Aspect	0.28
	Forest type x Aspect	0.68

Table 12b. Depth wise distribution of SOC stock (Mg C ha⁻¹) under different forest types of Solan district

Forest type	Soil depth (cm)		Mean
	D ₁	D ₂	
Scrub	18.44	16.15	17.30
Khair	11.14	8.23	9.69
Bamboo	23.97	20.11	22.04
Chir-pine	19.98	16.97	18.48
Oak	25.59	21.59	23.59
Deodar	34.15	30.25	32.20
Mean	22.21	18.89	

CD _{0.05}	Forest type	0.48
	Depth	0.28
	Forest type x Depth	0.68

Table 13. Soil organic carbon inventory for different forest types of Solan district

Forest type	Depth wise carbon stock		Carbon stock of 0-30 cm layer (Mg C ha ⁻¹)	Total area (ha)	Total carbon stock (Gg C)
	A (D ₁)	B (D ₂)	C = A+B	D	E = C*D
Scrub	18.44	16.15	34.59	3800	131.44
Khair	11.14	8.23	19.37	714	13.83
Bamboo	23.97	20.11	44.08	6333	279.16
Chir-pine	19.98	16.97	36.95	11345	419.20
Oak	25.59	21.59	47.18	1635	77.14
Deodar	34.15	30.25	64.4	812	52.29
Total	-	-	-	24639	973.06

The soil organic carbon stock of 0-30 cm layer under different forest types of Solan district at both northern and southern aspects was found to range between 13.83 to 419.20 Gg C. The highest SOC stock was recorded under chir-pine (419.20 Gg C) followed by bamboo (279.16 Gg C), scrub (131.44 Gg C), oak (77.14 Gg C) and deodar forests (52.30 Gg C). Whereas, minimum SOC stock was observed under khair (13.83 Gg C) forests. The total SOC stock of different forest types covering a total area of 24639 ha in Solan district of Himachal Pradesh was recorded to the tune of 973.06 Gg C in 0-30 cm layer of the soil.



DISCUSSION



Chapter-5

DISCUSSION

The present investigation entitled "**Quantification of soil organic carbon stock of forests in Solan district of Himachal Pradesh**" was carried out during 2010-2011. This chapter has been devoted to examine the results of the current study based on logical arguments in the light of the scientific evidences available in the literature. The results have been proved by establishing the cause and effect relationship wherever necessary and feasible between them to derive out the fruitful conclusions under the following heads.

5.1 Soil pH

5.2 Soil electrical conductivity

5.3 Soil organic carbon

5.4 Soil bulk density

5.6 Soil organic carbon stock

5.1 SOIL pH

In forest soils of Solan district of Himachal Pradesh pH varied from 6.04 to 6.94 under different forest types located at northern and southern aspect (Table 1a, 1b), which indicated that the forest soils are slightly acidic to near neutral in reaction. Among different forest types, the lowest soil pH was recorded under deodar (6.04), whereas, highest was under khair (6.94) forests. It may be ascribed to relatively higher accumulation of leaf litter under deodar forest floor which might have released more organic acids during decomposition as compared to khair forests. The present results are in conformity with the findings of Yadav (1963), Saralch (1994), Bhola (1995) and Nayak (1996). Irrespective of the forest types and aspects, soil pH increased with depth (Table 1c). However, the increase was of low magnitude. The low pH in surface layer as compared to the sub-surface layer can be attributed to higher accumulation of leaf litter and more weathered soil conditions. Similar pH trend was also reported by Sharma (1994), Raina and Kumar (2000) for soils of Himachal Pradesh. Verma *et al.* (1990) and

Sahu and Patnaik (1990) also reported increase in soil pH with the increasing profile depth because of leaching of bases from the surface to the sub-surface layers.

5.2 SOIL ELECTRICAL CONDUCTIVITY

The electrical conductivity of the soils under different forests of Solan district was in normal range (0.19 to 0.33 dS m⁻¹). However, maximum value of soil EC was recorded under khair forests, which was followed by chir-pine, scrub, bamboo, oak and deodar forests. The value of EC decreased with increase in soil depth. Similar findings of decrease in EC with the increasing soil depth in all the aspects and forest types have also been reported by Jayabaskaran *et al.* (2001).

5.3 SOIL ORGANIC CARBON

In Solan district of Himachal Pradesh, scrub forests of Nalagarh area contained the maximum SOC content, whereas, minimum was noticed at Kunihar region (Table 3a). The higher SOC content of Nalagarh area was probably due to relatively more density of shrubs and bushes along with some tree species as compared to Kunihar location. Moreover, in Kunihar area, more grazing pressure was also noticed which might have resulted in low content of SOC in the soil. The higher grazing pressure of Kunihar location has also been reported in the joint working plan of Kunihar and Nalagarh forest divisions of Solan district (Singh, 1991).

The khair forests of Nalagarh location (540-585 m sl) were found to have low SOC content (Table 4a) than Kunihar region (940 to 975 m sl). The low status of khair forests of Nalagarh location was probably due to high intensity of lopping for fuel and fodder as compared to Kunihar location. The highest SOC can also be ascribed to relatively higher temperature in the region (2.5 to 3.0⁰ C) which might have enhanced the mineralization rate of SOC leading to its loss in the form of CO₂. Similar trends of SOC distribution were also observed under chir-pine forests. The chir-pine forests of Arki location (1050-1120 m sl) having relatively higher temperature as compared to Kasauli region (1450-1580 m sl)

contained the low SOC content. The low SOC status under forests situated at low altitudinal ranges has also been reported by Rajput (2010) while working in the forests of Kullu valley of Himachal Pradesh.

The bamboo forests of Parwanoo area recorded the highest SOC content as compared to other locations (Table 5a). The better SOC status of bamboo forests of Parwanoo area may be ascribed to the vegetation structure which was in high density as compared to the Nalagarh location wherein low plant density and high soil degradation can be considered as a reason for low SOC status.

The oak forests of Karol region were registered to have high SOC content than Bisha location. The high population density and subsequent interferences in the form of tree lopping for fodder to the livestock in the Bisha location might have reduced the biomass return to the soil in comparison to Karol location.

Under deodar forests, the maximum SOC content (28.96 g kg^{-1}) was recorded in Chial location, whereas, minimum (27.31 g kg^{-1}) was noticed at Shili location. The highest SOC of Chail location may be attributed to slow rate of mineralization at low temperature prevailing at high altitudinal gradients of this location (1873-1995 m asl) as compared to Shili region (1570-1705 m asl) wherein, relatively higher temperature is experienced. Similar results of higher SOC status of forests at higher elevation were also reported by Rajamanner *et al.* (1979).

The present study conducted to evaluate the status of SOC under different forest types of Solan district of Himachal Pradesh revealed that soil organic carbon varied significantly with forest types and aspects. Among different forest types (Tables 9a), minimum SOC content (8.81 g kg^{-1}) was recorded under khair forests, whereas, maximum (28.33 g kg^{-1}) was observed under deodar forests. The khair forests of Solan district are located at low altitudes, wherein relatively higher temperature is experienced. The relatively higher temperature of these locations might have resulted in less SOC content due to enhanced mineralization. Furthermore, these forests are subjected to heavy lopping by local people for fuel, fodder and animal beddings which may have led to the opening

up of the canopy and exposure as well as degradation of soil and consequent poor SOC status (Singh, 1991). Moreover, high human interferences and low tree density of these forests have further reduced SOC status of these soils.

Among all the forest types deodar forests contained the highest SOC (28.33 g kg^{-1}). The highest SOC content under deodar forests may be attributed to minimum anthropogenic disturbances and slow mineralization rates at higher altitudes due to low temperature prevailing in these regions. The results are in line with the findings of Bhandari and Randhawa (1985) and Sharma and Bhandari (1992) who have also reported an increase in SOC content of soil at higher altitudes because of slow mineralization rate at low temperature ranges. Moreover, among different forests the concentration of soil organic carbon under deodar forests, may also be ascribed to high tree density and thereby incorporation of more leaf litter under these forests. These findings are also in consonance with the findings of Zegeye (1999), Kater *et al.* (1992), Rhodes (1995), Sanneh (2007) and Minj (2008), who have also reported high SOC content in forest soils.

Relatively, higher SOC content under oak forests as compared to chir-pine, bamboo, scrub and khair forests may be due to nature of this climax stage vegetation wherein high organic matter is accumulated at each successional stages. On the other hand, low SOC status of oak forests as compared to deodar forests may probably be due to relatively high degree of human interferences in terms of tree lopping. Whereas, deodar forests of Solan district fall under wildlife sanctuary area where human interferences are negligible which might have also contributed towards increased SOC status of these forests.

The high SOC content under bamboo forests (17.71 g kg^{-1}) in comparison to scrub, khair and chir-pine forests may be due to high biomass accumulation through leaf litter and fine roots (Christanty *et al.*, 1997). Similar results of SOC were also reported by Patil *et al.* (2004), Singh *et al.* (1995), He and Ye (1987), Sun and Ye (1988), Chung and Ramm (1990) and Thomas (1998).

The soil under different forest types of northern aspect at both the soil

layers had higher SOC content as compared to southern aspect (Table 9a). The higher SOC content under northern aspect may be ascribed to more vegetation cover and biomass production and its return to the soil at higher rates. On the other hand; due to harsh conditions (poor soil moisture and reception of direct sun radiations), less biomass production and its relatively less return to the soil for decomposition might have resulted into low SOC status of soils under different forest types of southern aspect. The results are in consonance with the findings of Post *et al.* (1982) who have also reported a decline in SOC status of the soil on southern aspects. Moreover, relatively higher temperature of southern aspect might have enhanced the mineralization rates of soil organic matter and ultimately reduced SOC status (Jenny *et al.*, 1960 and Post *et al.*, 1982).

The carbon fixed by the plant is the primary source of organic matter into the soil, which provides substrate for microbial processes and accumulation of soil organic matter. The belowground allocation of photosynthesis is also an important factor for improving soil organic carbon content (Kaur *et al.*, 2002). The present findings irrespective of forest types and aspects indicated more accumulation of soil organic carbon content (Table 9b) in surface layer which decreased consistently down the profile. The continuous addition of higher amount of plant litter, roots and other biomass to the surface might have resulted in higher organic carbon content in this layer as compared to sub-surface layer. These results are supported by the findings of Kaushal (1992), Saralach (1994), Bhola (1995) and Nayak (1996), who have also reported higher SOC in surface layers. Similar findings i.e. decrease in organic carbon content with increase in soil depth have also been reported by Minhas *et al.* (1997), Dasog and Hadmani (1990), Bhandari and Randhawa (1985) and Bhoumik and Totey (1990).

5.4 SOIL BULK DENSITY

The soils under khair forests registered higher bulk density as compared to other forest types, whereas, minimum bulk density was recorded under deodar forests (Table 10). The changes in bulk density of soils under different forests may be ascribed to varied degree of SOC status. The higher value of bulk density

under khair forests may be due to less organic carbon content of the soils under these forests.

Relatively less value of bulk density under deodar forests than other forest types may be ascribed to high SOC status of these soils. The present findings are in conformity with the observations of Karan *et al.* (1991) and Cihacek and Ulmer (1998).

Contrary to the SOC status of different aspects, the soils of southern aspect were noticed with high bulk density values as compared to northern aspect. The present trend may be ascribed to low organic carbon status of the soils under former aspect. The trend of bulk density of soils under different forest types was in the order of khair > scrub > chir-pine > bamboo > oak > deodar forests. Soil bulk density, in general, increased with increasing profile depth. The lower bulk density value in upper layers of soil profile may be due to dilution of soil matrix (mineral matter) with less dense material (organic matter) and improvement in soil aggregation. Improvement in aggregation encouraged fluffiness and porous conditions in soil which resulted in low bulk density values in surface layer. The reduction of bulk density of soil due to increase in soil organic carbon has been amply reported in literature by Soane (1975), Coote and Ramsey (1983), Sharma and Aggarwal (1984), Sharma *et al.* (1995) and Lav (1998).

5.5 SOIL ORGANIC CARBON STOCK

The soil organic carbon stock was found to be influenced by different forests and aspects at surface and sub-surface soil layers. The highest SOC stock was recorded under deodar forests on northern aspect followed by oak, bamboo, scrub, chir-pine and khair forests (Table 12a). Irrespective of forest types, SOC stock distribution in southern aspect was recorded in following descending order-oak, bamboo, chir-pine, scrub and khair forests. However, relatively higher SOC stock values were recorded on northern as compared to southern aspect. The highest SOC stock under deodar forests in all the aspects and depths may be ascribed to higher SOC status of these soils. Whereas, relatively low SOC content

under oak, bamboo, chir-pine, scrub and khair forests resulted in low SOC stock in descending order. Minimum amount of SOC stock under khair forests is due to low SOC status and high coarse fragments of these soils.

The soil organic carbon stock appreciably decreased (Table 12b) from surface to sub-surface layer. The maximum SOC stock ($22.21 \text{ Mg C ha}^{-1}$) was found in surface layer and minimum ($18.89 \text{ Mg C ha}^{-1}$) was noticed in sub-surface soil layer. The present depth wise trend of SOC stock distribution was due to the pattern of SOC distribution with depth. These results are in tune with the findings of Joao *et al.* (2001), Minhas *et al.* (1997) and Minj (2008).

Finally, the total SOC stock for all the forest types and aspects was calculated for 0-30 cm soil layer (Table 13). The highest SOC stock was recorded under chir-pine forests which was due to more forest area (11345 ha) under these forests followed by bamboo, scrub, oak and deodar forests. The minimum value of SOC stock was recorded under khair forests, which may be attributed to comparatively less area covered (714 ha) by these forests. The SOC stock varied from 13.83 to 419.20 Gg C in the different forest types under study which resulted in a grand total stock of 973.06 Gg C in the dominant forest types of Solan district of Himachal Pradesh. The variation in SOC stock distribution was observed due to area covered and respective SOC status of each forest types.



SUMMARY AND CONCLUSION



Chapter-6

SUMMARY AND CONCLUSION

The present investigation entitled "**Quantification of soil organic carbon stock of forests in Solan district of Himachal Pradesh**" was conducted during 2010-2011 in Solan district of Himachal Pradesh by taking six forest types at northern and southern aspects. The six forest types selected for the study were scrub, khair, bamboo, chir-pine, oak and deodar. Soil attributes viz., pH, EC, SOC, bulk density, coarse fragments and soil organic carbon stock were determined at surface and sub-surface layers.

The soil under different forest types of Solan district was slightly acidic to near neutral in reaction (6.04-6.94), whereas, electrical conductivity was normal and ranged from 0.19 to 0.33 dS m⁻¹. The soil under different forests contained 24.69 to 38.83 per cent coarse fragments. Among different forest types, maximum SOC content (28.33 g kg⁻¹) was found under deodar forests which followed an order of deodar > oak > bamboo > chir-pine > scrub > khair forests in descending order. Irrespective of forest types, the soils of northern aspect of Solan district contained higher SOC (18.91 g kg⁻¹) as compared to southern aspect (16.71 g kg⁻¹). The SOC ranged from 9.76 g kg⁻¹ to 29.74 g kg⁻¹ in northern and 7.86 g kg⁻¹ to 26.91 g kg⁻¹ in southern aspect. The SOC content decreased with increasing soil depth. Among different forest types, highest SOC content (18.9 g kg⁻¹) was recorded in surface and lowest in the sub-surface (16.7 g kg⁻¹) layer.

Bulk density, in general was found to range from 1.02 to 1.19 Mg m⁻³ under different forest types of the district. The bulk density of the soils under different forest types followed the order of khair > scrub > chir-pine > bamboo > oak > deodar forests. The soils under the forests of northern aspect were found to have low bulk density (1.09 Mg m⁻³), whereas, high bulk density value (1.13 Mg m⁻³) was recorded on southern aspect. Contrary to SOC distribution under

different forest types of the district, soil bulk density was found to increase with depth.

In Solan district, soil organic carbon stock under different forest types at both northern and southern aspects was found to range from 13.83 to 419.20 Gg C. The chir-pine forests contained highest SOC stock (419.20 Gg C), followed by bamboo (279.16 Gg C), scrub (131.44 Gg C), oak (77.14 Gg C), deodar (52.30 Gg C) and khair (13.83 g kg⁻¹) forests. The total SOC stock of 24639 ha area under six forest types of Solan district was 973.06 Gg C.

Conclusion

The SOC content under different forest types of Solan district of HP was found in the order of deodar > oak > bamboo > chir > scrub > khair forest. The forests of northern aspect contained relatively higher SOC as compared to southern aspect. The SOC content decreased with increasing soil depth.

The chir-pine forests of the Solan district contained the highest SOC stock (419.20 Gg C), whereas, khair forests were found to have the lowest SOC stock (13.83 Gg C). In the district, the SOC stock of the forest soils was in the order of chir-pine > bamboo > scrub > oak > deodar > khair forests. The contribution of the chir-pine forests towards the total SOC pool of the district was 43.08 per cent followed by 28.69, 13.51, 7.93, 5.37, and 1.42 per cent by bamboo, scrub, oak, deodar and khair forests, respectively. The total SOC stock of the soils under six forest types of Solan district was 973.06 Gg C.



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ABSTRACT



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ABSTRACT

The present investigation entitled **“Quantification of soil organic carbon stock of forests in Solan district of Himachal Pradesh”** was conducted during 2010-2011 under six forest types at both northern and southern aspect of Solan district (30°44'53" to 31°22'01" North latitude and 76°36'10" to 77°15'14" East longitude) of Himachal Pradesh. The six forest types selected for study were scrub, khair, bamboo, chir-pine, oak and deodar forests. The six forest types on northern and southern aspect of Solan district were evaluated for their physical-chemical properties like pH, EC, SOC, bulk density, coarse fragments and finally for their SOC stock. The soils of dominant forest types on both aspects were found slightly acidic to near neutral in reaction, normal in EC and contained 24.69 to 38.83 per cent volume of coarse fragments. The SOC content under different forest types followed the order as deodar > oak > bamboo > chir-pine > scrub > khair forests. The SOC content of these forest types ranged between 9.76 g kg⁻¹ to 29.74 g kg⁻¹ in northern and 7.86 g kg⁻¹ to 26.91 g kg⁻¹ in southern aspect. Among different forest types, highest SOC content (18.9 g kg⁻¹) was recorded in surface and lowest in the sub-surface (16.7 g kg⁻¹) layer. The bulk density ranged from 1.02 to 1.19 Mg m⁻³ under different forest types of the district. It followed the order of khair > scrub > chir-pine > bamboo > oak > deodar forests. Contrary to SOC distribution under different forest types of the district, soil bulk density was found to increase with depth. The results have revealed that chir-pine forests contained the highest stock (419.20 Gg C), whereas, khair forests were found to have the lowest SOC stock (13.83 Gg C). The SOC stock followed the order of chir-pine > bamboo > scrub > oak > deodar > khair forest. The contribution of the chir-pine forests towards the total SOC pool of the district was 43.08 per cent followed by 28.69, 13.51, 7.93, 5.37, and 1.42 per cent by bamboo, scrub, oak, deodar and khair forests, respectively. The total SOC stock of the soils under six forest types of Solan district was 973.06 Gg C.

Signature of Major Advisor

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APPENDICES



APPENDIX-I

Analysis of variance table for effect of different forest types and aspects on pH

Source of Variation	df	Mean sum of square
Forest types	5	1.935128
Aspects	1	0.009038
Error	46	0.000307

APPENDIX-II

Analysis of variance table for effect of different forest types and soil depths on pH

Source of Variation	df	Mean sum of square
Forest types	5	1.935128
Soil depths	1	0.002373
Error	46	0.000307

APPENDIX-III

Analysis of variance table for effect of different forest types and aspects on EC

Source of Variation	df	Mean sum of square
Forest types	5	0.038435
Aspects	1	0.004945
Error	46	0.00006

APPENDIX-IV

Analysis of variance table for effect of different forest types and soil depths on EC

Source of Variation	df	Mean sum of square
Forest types	5	0.038435
Soil depths	1	0.002648
Error	46	0.00006

APPENDIX-V

Analysis of variance table for effect of locations and aspects on SOC content (g kg^{-1}) under scrub forests

Source of Variation	df	Mean sum of square
Locations	2	4.781111
Aspects	1	141.61
Error	22	0.030884

APPENDIX-VI

Analysis of variance table for depth wise distribution of SOC (g kg^{-1}) under scrub forests of different locations

Source of Variation	df	Mean sum of square
Locations	2	4.781111
Soil depths	1	23.04
Error	22	0.030884

APPENDIX-VII

Analysis of variance table for effect of locations, aspects and soil depths on SOC content (g kg^{-1}) under scrub forests

Source of Variation	df	Mean sum of square
Locations	2	4.781111
Aspects	1	141.61
Soil depth	1	23.04
Error	22	0.030884

APPENDIX-VIII

Analysis of variance table for effect of locations and aspects on SOC content (g kg^{-1}) under khair forests

Source of Variation	df	Mean sum of square
Locations	2	0.9469444
Aspects	1	32.300278
Error	22	0.0184596

APPENDIX-IX

Analysis of variance table for depth wise distribution of SOC (g kg^{-1}) under khair forests of different locations

Source of Variation	df	Mean sum of square
Locations	2	0.9469444
Soil depths	1	45.5625
Error	22	0.0184596

APPENDIX-X

Analysis of variance table for effect of locations, aspects and soil depths on SOC content (g kg^{-1}) under khair forests

Source of Variation	df	Mean sum of square
Locations	2	0.9469444
Aspects	1	32.300278
Soil depths	1	45.5625
Error	22	0.0184596

APPENDIX-XI

Analysis of variance table for effect of locations and aspects on SOC content (g kg^{-1}) under bamboo forests

Source of Variation	df	Mean sum of square
Locations	2	3.314444
Aspects	1	13.69
Error	22	0.037551

APPENDIX-XII

Analysis of variance table for depth wise distribution of SOC (g kg^{-1}) under bamboo forests of different locations

Source of Variation	df	Mean sum of square
Locations	2	3.314444
Soil depths	1	58.26778
Error	22	0.037551

APPENDIX-XIII

Analysis of variance table for effect of locations and aspects on SOC content (g kg^{-1}) under chir-pine forests

Source of Variation	df	Mean sum of square
Locations	2	0.133611
Aspects	1	16.26778
Error	22	0.031187

APPENDIX-XIV

Analysis of variance table for depth wise distribution of SOC (g kg^{-1}) under chir-pine forests of different locations

Source of Variation	df	Mean sum of square
Locations	2	0.133611
Soil depths	1	57.76
Error	22	0.031187

APPENDIX-XV

Analysis of variance table for effect of locations, aspects and soil depths on SOC content (g kg^{-1}) under chir-pine forests

Source of Variation	df	Mean sum of square
Locations	2	0.133611
Aspects	1	16.26778
Soil depths	1	57.76
Error	22	0.031187

APPENDIX-XVI

Analysis of variance table for effect of locations and aspects on SOC content (g kg^{-1}) under oak forests

Source of Variation	df	Mean sum of square
Locations	2	0.333333
Aspects	1	54.0225
Error	22	0.025758

APPENDIX-XVII

Analysis of variance table for depth wise distribution of SOC (g kg^{-1}) under oak forests of different locations

Source of Variation	df	Mean sum of square
Locations	2	0.333333
Soil depths	1	51.60028
Error	22	0.025758

APPENDIX-XVIII

Analysis of variance table for effect of locations, aspects and soil depths on SOC content (g kg^{-1}) under oak forests

Source of Variation	df	Mean sum of square
Locations	2	0.333333
Aspects	1	54.0225
Soil depths	1	51.60028
Error	22	0.025758

APPENDIX-XIX

Analysis of variance table for effect of locations and aspects on SOC content (g kg^{-1}) under deodar forests

Source of Variation	df	Mean sum of square
Locations	2	9.528611
Aspects	1	72.25
Error	22	0.014066

APPENDIX-XX

Analysis of variance table for depth wise distribution of SOC (g kg^{-1}) under deodar forests of different locations

Source of Variation	df	Mean sum of square
Locations	2	9.528611
Soil depths	1	48.07111
Error	22	0.014066

APPENDIX-XXI

Analysis of variance table for effect of locations, aspects and soil depths on SOC content (g kg^{-1}) under deodar forests

Source of Variation	df	Mean sum of square
Locations	2	9.528611
Aspects	1	72.25
Soil depths	1	48.07111
Error	22	0.014066

APPENDIX-XXII

Analysis of variance table for effect of different forest types and aspects on SOC content (g kg^{-1})

Source of Variation	df	Mean sum of square
Forest types	5	491.9299
Aspects	1	87.63409
Error	46	0.075788

APPENDIX-XXIII

Analysis of variance table for depth wise distribution of SOC (g kg^{-1}) under different forest types

Source of Variation	df	Mean sum of square
Forest types	5	491.9299
Soil depths	1	86.3152
Error	46	0.075788

APPENDIX- XXIV

Analysis of variance table for effect of different forest types and aspects on soil Bulk Density (Mg m^{-3})

Source of Variation	df	Mean sum of square
Forest types	5	0.05156
Aspects	1	0.027482
Error	46	0.000162

APPENDIX- XXV

**Analysis of variance table for depth wise variations in soils Bulk Density
(Mg m⁻³) under different forest types**

Source of Variation	df	Mean sum of square
Forest types	5	0.05156
Soil depths	1	0.018904
Error	46	0.000162

APPENDIX- XXVI

**Analysis of variance table for effect of different forest types and aspects on SOC
stock (Mg C ha⁻¹)**

Source of Variation	df	Mean sum of square
Forest types	5	672.3894
Aspects	1	131.8764
Error	46	0.342549

APPENDIX-XXVII

**Analysis of variance table for depth wise distribution of SOC stock (Mg C ha⁻¹)
under different forest types of Solan district**

Source of Variation	df	Mean sum of square
Forest types	5	672.3894
Soil depths	1	199.4715
Error	46	0.342549

CURRICULUM VITAE

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