Altitude wise variation in soil carbon stock in Western Himalaya

Param Prakash Singh* and Y.S. Rawat

Department of Botany, DSB Campus, Kumaun University, Nainital, 263002, Uttarakhand, India
email: paramprakash.singh09@gmail.com

Abstract: Soil plays a major role in regulating the world's carbon budget. Even small changes in the magnitude of soil respiration could have a major effect on the concentration of CO_2 in the atmosphere. The present paper deals with the changes in soil carbon status across an altitudinal gradient in Western Himalaya. The study sites were located in outer Himalaya between 29° 25' N to 29° 24' N; 79° 25' E to 79° 20' E in Nainital district, in the Kumaun division of Uttarakhand state in India. The sites were categorized viz., High altitude site (1800-2100m elevation) in *Quercus leucotrichophora* forest, mid altitude site (1000-1400m elevation) in *Pinus roxburghii* mixed broad leaf forest and Low altitude site (350-500m elevation) in *Shorea robusta* forest. Significant variation across different sites and depths were observed (significance at 0.1% level of probability). The results of the present study are similar to the values reported for different central Himalayan forests.

[Param Prakash Singh and Y.S. Rawat. **Altitude wise variation in soil carbon stock in Western Himalaya.** *N Y Sci J* 2013;6(10):140-145]. (ISSN: 1554-0200). http://www.sciencepub.net/newyork. 21

Key words: Soils; carbon; altitudinal; Uttarakhand; significant; Himalayan

1. Introduction

Soil quality is the capacity of soil to sustain plant and biological productivity to maintain environmental quality and to promote plant and animal health. Soil quality and soil health terms incorporate both spatial and temporal scales respectively, which are used to report the physical, chemical, and biological condition of soil. Soil quality indicators are very important step in determining the health of an ecosystem. One of the sensitive chemical indicators identified by Soil Survey Division (1995) is the soil carbon. Soil stores more carbon than is contained in plants and the atmosphere combined. As a matter of fact the world's soil contains 4.5 times the amount of carbon held in the vegetation (Lal, 2004). Gupta and Rao (1984) made first estimate of the organic carbon stock in Indian soils was 24.3 Pg (1 Pg = 10^{15} g) based on 48 soil samples. Worldwide the top soil layer of first 30 cm holds 1500 Pg carbon whereas for India it is 9 Pg (Batjes, 1996; Bhattacharya *et al.,* 2000). There is a significant proportion of carbon in forest litter layer. Lower rates of decomposition in the forests could increase soil organic carbon (SOC) storage in surface soil. The storage of soil organic carbon is controlled by balance of carbon input from plant production and output through decomposition. The total soil organic content increases with precipitation and clay content decreases with temperature (Jobbagy & Jakson, 2000). The climate affects the soil organic carbon storage in shallow layer, while the clay content affects storage in deeper layer of the soil. The effect of vegetation type is more important than the precipitation in the distribution of carbon. Soil on south facing slopes at lower elevation contained significantly less total organic carbon compared with soil from north facing slope at higher elevation (Schmidt et. al., 1993).

Vegetation studies have shown that edaphic factors are important determinants of community structure and its spatial and temporal distribution (Retzer, 1974; Sardinero, 2000). Topography is highly correlated with the physicochemical properties of soils and this in turn affects soil development (Burns & Tonkin, 1982). The spatial variation of snow accumulation affects soil organic matter decay rates (O'Lear & Seastedt, 1994), and organic carbon accumulation (Burns & Tonkin, 1982). Moreover, the duration of snow accumulation also governs the microbial processes, which control biological response to climate change. The global warming has a significant effect on the turnover of soil nutrients and soil microbial communities (Jonasson et al., 1999; Shaw & Harte, 2001; Huber et al., 2007; Pickering & Green, 2009). Even in alpine regions an increased rate of nitrogen deposition with increased atmospheric pollution and CO2 has been reported (Nadelhoffer et al., 1991; Baron & Campbell, 1997; Neff et al., 2002; Schmidt et al., 2004). Therefore, it is important to understand the correlation of major edaphic factors with different communities. Yet around the world, severe soil deterioration and desertification have not only reduced the sustainability and productivity of ecosystems but also degraded both local and off-site environments (Zaho *et al.*, 2005). Persistently high rates of erosion are estimated to affect 1.1 billion hectares of land worldwide (SWCS, 2003), while average rate of soil formation usually falls in the range of 0.5-1.0 t ha^{-1} yr^{-1} (Troeh and Thompson, 1993). The effects of soil degradation therefore last for hundreds of years if not thousand (Pimentel and Sparks, 2000). Soil plays a major role in regulating the world's carbon budget (Johnston *et al*., 2004). Even small changes in the magnitude of soil respiration could have a major effect on the concentration of CO_2 in the atmosphere. Carbon dynamics in the geosphere has attracted many researchers to study its implications in terms of global climate changes associated with increasing CO_2 levels resulting from human activity (Schlesinger and Andrews, 2000).

The present paper deals with the changes in soil carbon status across an altitudinal gradient in Western Himalaya.

2. Materials and Methods

The study sites were located in outer Himalaya between 29° 25' N to 29° 24' N; 79° 25' E to 79° 20' E in Nainital district, in the Kumaun division of Uttarakhand state. The State of Uttarakhand (Latitude: 28° 44′ to 31° 28′ N and longitude: 77 ° 35′ to 81° 01′ E), encompasses an area of 53,485 Km^2. It covers nearly 1.63% of the total land area of India, nearly 64.78 % forest of its total land area (FSI, 2011) and accounts nearly 15.5% of the total geographical area of western Himalaya. The Uttarakhand Himalaya actually acts as an intermediate zone between the Western and Central Himalayas. It has two distinct traditional politico-cultural regions; Garhwal and Kumaun. The Kumaun Himalaya forms the north-western part of the central Himalayan region in continuation with Nepal Himalaya. It includes all the sections of the Himalaya, viz., Siwalik ranges, Lesser Himalaya, and High mountainous peaks. Geologically sites were located in the outer Himalaya (Siwalik Range) as well as central Himalaya between 350-2100 m above mean sea level.

The climate of this region is characterized by monsoon rainfall pattern. A warm and dry spring / summer (March-June) is followed by the monsoon (July-September). During this period nearly 80% of annual precipitation occurs. By the end of September the frequency of the rain decreases. There is little rainfall during October to December. Snowfall occurs during December to February. Typically there are two three days of snowfall mixed with rain above 1800 m altitude.

Three forest types at different altitudes were selected after survey and consultation with working plan of Nainital forest division (Table 1). The selection of forest types was based on classification by Singh and Singh 1992. This classification helps in recognizing the changes along the altitudinal gradient at regional level. All the sites were located in natural forest and considered free from anthropogenic disturbances.

During the study period, the month of September 2009 was characterized by heavy rainfall 41.34 cm, leading to frequent land slide. The total rainfall recorded during June 2008 to May 2009 was 90.23 cm, and from June 2009 to May 2010 was 104.69cm. The mean maximum temperature varies from 10.6 °C (January) to 26.9 °C (June) and the mean minimum from 4.1 °C (January) to 14.3 °C (June) in 2009. The mean maximum temperature varied from 14.1 °c (January) to 26.8 °c (June) and the mean minimum from 4.81 °c (January) to 14.3 °c (June) in 2010.

Table 1: Study sites and type of forests.

Site	Elevation (m)	Classification (Singh and Singh, 1992)
I. High Elevation forest	1800-2100	Banj oak forest
II. Mid Elevation forest	1000-1400	Chir Pine mixed broad leaf forest
III. Low Elevation forest	350-500	Sal forest

Soil carbon

In these selected sites, forest floor was marked for pit digging. The pits were dug out in a random manner after dividing the forest stands into an upslope (top), mid-slope (middle) and valley (base) in each forest sites. The size of each pit was 1 x 1 x 1.5 m (depth 1.5 m). Three pits were dug out in each forest types. Soil samples were taken from 0-10 cm, 10-20 and 20-30 cm soil depths. Soil samples were collected and 300 – 400 g soil was taken from each layer using a digging tool. There were three replicates of each soil sample for each depth. The soil samples were air-dried at 25°C and 20-50% relative humidity (Tandon, 1993).

Walkey's and Blacks titration method (Jackson, 1967) was used to measure soil carbon concentration. 1.0 g soil was kept in a 500 ml of N-potassium dichromate and 20 ml of concentrated sulphuric acid was added successively and swirled the flask for about 30 seconds. The flask was placed on a table for about half hour. Then 200 ml distilled water and 10 ml of orthophosphoric acid was added and allowed the solution to cool. A few drops of diphenyl amine indicator were added (1 ml) and the reductant was titrated with ferrous ammonium sulphate. Amount of N/2 ferrous ammonium sulphate used in titration was recorded (V_2). Blank titration (without soil) was carried out exactly as described above and amount of N/2 ferrous ammonium N sulphate was used in blank titration and recorded (V_1).

Soil Organic Carbon (SOC) percentage was calculated as:

$$SOC\ (\%) = \frac{(V1 - V2) \times 0.3}{\mathrm{W}}$$

W= Weight of soil sample taken

Percentage of organic matter was obtained by multiplying the percent of organic carbon by a factor of 1.724. This factor is based upon the assumption that the organic carbon matter of soil contains 58% carbon (Misra, 1968).

Bulk density of soil determines the degree of compaction of the soil. It reflects the ease of root growth, in addition to the movement of air and water through the soil. For the estimation of soil bulk density, soil samples were collected by means of a special metal core-sample cylinder of known volume. Soil samples were collected using different soil depth (0-10, 10-20 and 20-30 cm). Soil samples were brought to the laboratory and oven dried at 65^{o}C till constant weight. The weight of oven dried soil samples was taken. The weight of oven dried soil samples was divided by its volume to estimate bulk density (Misra, 1968).

$$Bulk\ density\ (\mathrm{g\ cc^{-1}}) = \frac{\text{Weight of Oven dry soil}}{\text{Volume of the soil}}$$

With the help of Bulk density and SOC (%) the SOC stock was calculated for different forests:

$$SOC(\mathrm{t/ha}) = 1000 \times \left\{ \frac{\text{Bulk density}}{100} \times SOC(\%) \right\}$$

Results:

Soil carbon were studied at the selected sites viz., high altitude site (1800-2100m elevation) in *Quercus leucotrichophora* forest, mid altitude site (1000-1400m elevation) in *Pinus roxburghii* mixed broad leaf forest and low altitude site (350-500m elevation) in *Shorea robusta* forest. The data collected on each of the parameters were subjected to statistical analysis using the statistical package- *Genstat 5 release 3.22*. The findings of the analysis are given below in the Table 2.

Table 2: Soil bulk density and carbon status

Site (a.s.l.) (m)	**Soil Depth (cm)**	**Bulk density (gm cc^{-1})**	**SOC (%)**	**SOC (t/ha)**
Site I (1800-2100)	0 -10	1.21±.00	3.85±0.32	46.6±3.8
	10-20	1.22±.00	3.36±0.13	40.8±1.6
	20-30	1.23±.00	2.55±0.3	31.5±3.1
Site II (1000-1400)	0-10	1.22±.00	3.83±0.2	46.9±2.1
	10-20	1.23±.01	3.09±0.1	37.9±1.5
	20-30	1.24±.01	3.03±0.1	37.6±1.2
Site III (350-500)	0-10	1.17±.01	2.15±0.4	25.2±4.5
	10-20	1.17±.01	1.92±0.2	22.4±2.8
	20-30	1.21±.01	1.54±0.2	18.9±2.2

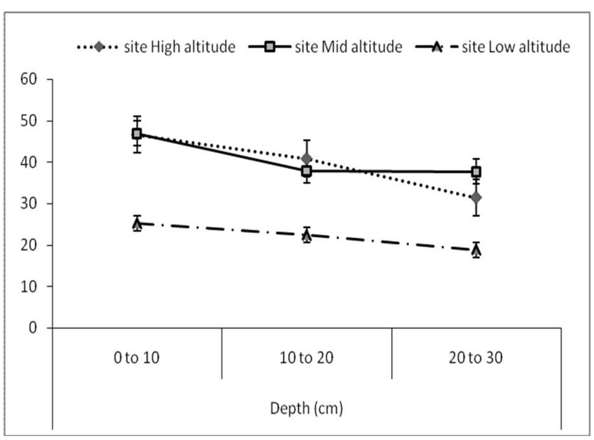

Fig1: Variations in soil carbon stock (t/ha) across depth and site.

A decreasing trend in soil organic carbon (SOC) was observed with increased soil depths in all the sites except site-II of the mid altitude, where organic carbon was highest in the top layer (0–10 cm) but found nearly equal in middle (10-20 cm) and lowest (20-30 cm) layers of soil.

Maximum soil carbon in the top soil layer (0-10 cm) was exhibited by high altitude forest site (3.85%) followed by mid altitude forest site (3.83%) and low altitude forest site (2.15%). In the lower layer of 10-20 cm high altitude forest site exhibited maximum soil carbon percent (3.36%) followed by mid altitude forest site (3.09%) and low altitude forest site (1.92%). In the 20-30 cm layer the mid altitude forest site showed maximum carbon percentage (3.03%) followed by high altitude forest site (2.55%) and low altitude forest site (1.54%)

(Fig. 1). Significant variation across different sites and depths were observed (significance at 0.1% level of probability).

Discussion:

Forest soils are entities within themselves, self organized and highly resilient over time. The transfer of energy bound in carbon (C) molecules drives the organization and functions of this biological system (Fisher and Binkley, 2000; Paul and Clark, 1996). Interest in the ability of forest soils to store atmospheric C derived from anthropogenic sources has grown in recent years (Johnson, 1992; Heath and Smith, 2000; Cardon *et al*., 2001; Johnson and Curtis, 2001). Much of soil degradation in the planet is assumed to take place in tropical and subtropical lands, particularly from deforestation and conversion of forests into cropland and cultivated pastures. Accordingly, a considerable research effort has been devoted to the understanding of this process and its implications in terms of C dynamics (Fernandes *et al*., 1997).

In the present study the soil organic carbon (SOC) decreased with increasing soil depths in all the sites except in mid altitude forest where the SOC of second (10-20cm) layer was similar to SOC of third (20-30cm) layer. Maximum soil carbon in the top soil layer (0-10 cm) was exhibited by mid altitude forest site (46.9±2.1 t/ha) followed by high altitude forest site (46.6±3.8 t/ha) and low altitude forest site (25.2±4.5 t/ha). In the lower layer (10-20 cm) high altitude forest site exhibited maximum soil carbon content (40.8±1.6 t/ha) followed by mid altitude forest site (37.9±1.5 t/ha) and low altitude forest site (22.4±2.8 t/ha). In the 20-30 cm layer the mid altitude forest site showed maximum carbon content (37.6±1.2 t/ha) followed by high altitude forest site (31.5±3.1 t/ha) and low altitude forest site (18.9±2.2 t/ha). Significant variation across different sites and depths were observed.

In terms of percentage maximum soil carbon in the top soil layer (0-10 cm) was exhibited by high altitude forest site (3.85%) followed by mid altitude forest site (3.83%) and low altitude forest site (2.15%). In the lower layer of 10-20 cm soil depth high altitude forest site exhibited maximum soil carbon percent (3.36%) followed by mid altitude forest site (3.09%) and low altitude forest site (1.92%). In the 20-30 cm layer the mid altitude forest site showed maximum carbon percentage (3.03%) followed by high altitude forest site (2.55%) and low altitude forest site (1.54%) The results of the present study are similar to the values reported for different central Himalayan forests (Table3).

Table 3: Comparison between soil carbon (%) in different forest types of Central Himalaya (based on Singh *et al*., 2006[1], KTGAL[2], Singh, 2008[3] and Sah, 2005[4])

Past studies in Himalayan forests						
Depth	**SR[1]**	**PR[2]**	**CD[3]**	**QF[4]**	**QS[1]**	**QL[2]**
0-10	2.03	2.4	1.23	2.29	3.9	2.2
10-30	1.17	1.6	0.99	2.10	2.9	1.4
30-60	0.95	1.2	0.87	2.02	1.9	1.2
Present study in Nainital						
Depth	**QL**	**PB**	**SR**			
0-10	3.85	3.8	2.1			
10-20	3.36	3.1	1.9			
20-30	2.60	3.0	1.5			

SR= Young *Shorea robusta* forest; PR= *Pinus roxburghii* forest with busy banj oak; CD= Pure *Cedrus deodara* forest; QF= Pure *Quercus floribunda* forest; QS= Pure *Quercus semecarpifolia* forest and QL= Pure *Quercus leucotrichophora* forest, PB= *Pinus roxburghii* mixed broad leaf forest.

The study had reported that in terms of carbon stock mid altitude forest had the highest SOC content (46.9±2.1 t/ha) whereas in terms of percentage of carbon high altitude forest had the maximum carbon (3.85%). This uniqueness was due to higher average bulk density (1.22 gm/cc) of mid altitude forest.

The maximum carbon stock was reported in high altitude (*Quercus leucotrichophora*) forest soils. The higher percent of soil organic carbon in *Quercus leucotrichophora* forest may be due to dense canopy and higher input of litter in to the soil which resulted in maximum storage of carbon stock. First and second layers have more stored carbon than third layer. The higher organic carbon content in the top layer may be due to rapid decomposition of forest litter in a favorable environment. This may be because of higher rate of microbial activities releasing carbon in upper layers of soil than third layer (20-30cm) of soil. According to Kimble *et. al.* (1990**)** SOC is an important pool of carbon within the biosphere.

In *Pinus roxburghii* mixed broad leaf (mid altitude) forest carbon stock was not much lower than high altitude forest. This was because the canopy is dense, even though sparsely distributed than high altitude (*Quercus leucotrichophora*) forest site. Litter from well developed shrubs might maintain the carbon stock. Top layer (0-10cm) soil had highest level of stored carbon. At the third layer of soil (20-30cm) level of carbon stock was found equal to 10-20cm layer. Here also higher carbon level in top layer of soil can be explained by higher microbial activity. Higher concentration of SOC in third (20-30cm) layer shows that soil is less porous and adhesive in nature; therefore, carbon is accumulated and trapped in third layer of soil.

In Sal (low altitude) forest the carbon stock was reported the lowest among the three forest sites. This may be attributed to high rate of litter removal by people living in nearby areas. Due to the removal of litter and minor forest produce by people reduces the carbon stock from the forest floor and thus resulting into less microbial activity. Removal of minor forest produces from the forest is common phenomenon in these areas. Otherwise in the present study the SOC decreased with increasing depth.

The trend of decreasing SOC content with increase in depth is an indication of higher biological activity associated with top layers. The results of present study are in accordance with some earlier studies (Table3) which supported higher concentration of SOC in upper layer of soil.

According to Havelin *et al.* (2003) residue application had a positive influence on SOC content. The addition of litter and the extensive root system of plants probably influenced the carbon concentration in different soil layers (Lal, 1989; Blevines and Frye, 1993). It reflects positive correlation of SOC with the quantity of litter fall (Singh G, 2005). The decomposition rate of forest woody detritus depends partially on climatic conditions (Woodall and Liknes, 2008) and rate of microbial activity.

Corresponding Author:
Param Prakash Singh
Department of Botany, DSB Campus, Kumaun University, Nainital, 263002, Uttarakhand, India
Email: paramprakash.singh09@gmail.com

References

1. Baron JS, Campbell DH. Nitrogen fluxes in a high elevation Colorado Rocky Mountain basin. Hydrological Processes 1997; 11(7): 783-99.
2. Batjes NH. Total C and N in soils of the world. Eur J Soil Sci, 1996; 47: 151-163.
3. Bhattacharya T, Pal DK, Mondal C, Velayutham M. Organic carbon stock in Indian soils and their geographical distribution. Current Science 2000; 79(5):655-660.
4. Blevines RL, Frye WW. Conservation tillage: An ecological approach in soil management. Advances in Agronomy 1993; 51:33-78.
5. Burns SF, Tonkin PJ. Soil-geomorphic models and the spatial distribution and development of alpine soils. In: Thorne, C.E. (ed.), Space and Time in Geomorphology. Allen & Unwin, London, UK 1982; pp. 25–43.
6. Cardon ZG, Hungate BA, Cambardella CA, Chapin III FS, Field CB, Holland EA, Mooney HA. Contrasting effects of elevated CO2 on old and new soil carbon pools. Soil Biol. Biochem 2001; 33: 365-373.
7. Fernandes ECM, Montavalli PP, Castilla C, Mukurumbira L. Management control of soil organic matter dynamics n tropical land-use systems. Geoderma 1997; 79: 49–67.
8. Fisher RF, Binkley D. Ecology and Management of Forest Soils. John Wiley and Sons, N.Y. 2000.
9. FSI (Forest Survey of India). India state Forest Report 2011. Ministry of Environment & Forest, Government of India.
10. Gupta RK, Rao DLN. Potential of wastelands for sequestering carbon by reforestation. Current Science 1984; 66:378-380.
11. Havelin JL, Kissel DE, Maddux LD, Classe MM, Long JH. Crop rotation and tillage effects on soil carbon and nitrogen. Soil Sci Soc Am J 2003; 54:448-452.
12. Heath LS, Smith JE. An assessment of uncertainty in forest carbon budget projections. Environ. Sci. Policy 2000; 3: 73-82.
13. Huber E, Wanek W, Gottfried M, Pauli H, Schweiger P, Arndt S, Reiter K, Richter A. Shift in soil–plant nitrogen dynamics of an alpine–nival ecotone. Plant and Soil 2007; 301(1), 65-76.
14. Jackson ML. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd. 1967; New Delhi.
15. Jobbagy EG, RB Jackson. The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecological Applications 2000;10(2), pp. 423–436.
16. Johnson DW. Effects of forest management on soil carbon storage. Water, Air, Soil Pollution 1992; 64: 83-120.
17. Johnson DW, Curtis PS. Effects of forest management on soil C and N storage: meta-analysis. For. Ecol. Mgmt. 2001; 140: 227-238.
18. Johnston CA, Groffman P, and Breshears DD. Carbon cycling in soil. Front Ecol Environ 2004; Vol. 2 pp. 522-28.
19. Jonasson S, Michelsen A, Schmidt IK, Nielsen EV. Responses in microbes and plants to changed temperature, nutrient, and light regimes in the arctic. Ecology 1999; 80, 1828-43.

20. Kimble JM, Eswaran H, Cook T. Organic carbon on a volume basis in tropical and temperate soils. 14th International Soil Science Congress 1990; 5: 248-258. Kyoto Japan.
21. KTGAL, Project report. Central Himalayan Environment Association, submitted to ICIMOD, Kathmandu, Nepal 2003-04; pp. 32 -33.
22. Lal R. Conservation tillage for sustainable agriculture: tropics vs. temperate environment. Advances in Agronomy 1989; 42: 186-197.
23. Lal R. Soil carbon sequestration impacts on global climate change and food security. Science 2004; 304: 1623-1627.
24. Misra R. Ecology Work Book. Oxford and IBH Publishing 1968; New Delhi.
25. Nadelhoffer KJ, Giblin AE, Shaver GR, Laundre JA. Effects of temperature and substrate quality on element mineralization in six arctic soils. Ecology 1991; 72(1): 242-53.
26. Neff JC, Townsend AR, Gleixner G, Lehman SJ, Turnbull J, Bowman WD. Variable effects of nitrogen additions on the stability and turnover of soil carbon. Nature 2002; 419(6910): 915-17.
27. O'Lear HA, Seastedt TR. Landscape patterns of litter decomposition in alpine tundra. Oecologia 1994; 99: 95-101.
28. Paul EA, Clark FE. Soil Microbiology and Biochemistry. Academic Press 1996; San Diego, CA.
29. Pickering CM, Green K. Vascular plant distribution in relation to topography, soils and micro-climate at five GLORIA sites in the Snowy Mountains, Australia. Australian Journal of Botany 2009; Vol. 57(3), pp. 189-99.
30. Pimental D, Sparks DL. Soil as endangered ecosystem. Bioscience 2000; Vol. 50.pp. 947.
31. Retzer JL. Apine soils. In: Ives JD, Barry RG(eds) Arctic and Alpine Environments. Metheun, Londonn 1974; pp 771-802.
32. Sah M. Assessing carbon sequestration rate of medium and old growth *Quercus floribubnda* (Moru oak) forest in Uttaranchal Himalaya. M.Sc. dissertation submitted in partial fulfillment of degree of Master of Science in Forestry 2005; Kumaun University, Nainital.
33. Santiago sardinero. Classification and ordination of plant communities along an altitudinal gradient on the Presidential Range, New Hampshire USA. Plant Ecology 2000; 148: 81-103.
34. Schlesinger WH, Andrews JA. Soil respiration and the global carbon cycle. Biogeochem. 2000; 48: 7-20.
35. Schmidt MG, Schreier H, Shah PB. Factor affecting the nutrient statue of forest sites in a mountain Watershed in Nepal. Journal of Soil science 1993; 44: 417-425.
36. Schmidt SK, Lipson DA, Ley RE, Fisk MC, West AE. Impacts of chronic nitrogen additions vary seasonally and by microbial functional group in tundra soils. Biogeochemistry 2004; 69(1): 1-17.
37. Shaw MR, Harte J. Response of nitrogen cycling to simulated climate change: differential responses along a subalpine ecotone. Global Change Biology, 2001; 7(2): 193-210.
38. Singh C. Carbon Stock and Sequestration Rate in an Old Growth Forest Dominated by *Cedrus Deodara* in Uttarakhand Himalaya. Master's thesis in Botany 2008; Kumaun University, Nainital.
39. Singh G. Carbon sequestration under an Agri-silvicultural system in the Arid region. Indian Forester 2005; 147: 543-552.
40. Singh V, Tewari A, Gupta M. The pre logged stocks of carbon in *Shorea robusta* and *Quercus semecarpifolia* forests of Uttaranchal and their C sequestration rates –a tradable NTFP. Int. J. For. Usuf. Mngt. 2006; 7(1): 1-5.
41. Singh JS, Singh SP. Forests of Himalaya: Structure, Functioning and impact of Man. Gyanodaya Prakashan 1992; Nainital India.
42. Soil Survey Division. Soil quality national committee report. National cooperative soil survey. Conference on soil quality / soil health in San Diego, California, July 10-14, 1995.
43. SWCS (Soil and Water Conservation Society) 2003: Conservation implications of climate change: Soil erosion and runoff from cropland. Ankeny, Iowa: Soil and water conservation society.
44. Tandon H L S. Methods of analysis of soils, plants, waters, fertilizers and organic manures. Publ. Fertiliser development and consultation organization 1993; New Delhi, India.
45. Steiner, K.G. (Eds.) 1998: Towards Sustainable Land Use. Advances in Geoecology 31. Catena Verlag, Reiskirchen, pp. 415–422.
46. Troeh, F.R., and Thompson, L.M. 1993: Soils and Soil Fertility, 5th edn. New York, NY: Oxford University Press.
47. Woodall C, Liknes G 2008: Climatic regions as an indicator of forest coarse and fine woody debris carbon stocks in the United States. Carbon Balance and Management, 3:5.
48. Zaho, W. Z., Xiao, H.L., Liu, Z.M., and Li, J. 2005: Soil degradation and restoration as affected by land use change in semi arid Bshang area, northern China. Catena, 59: 173-86.

10/22/2013