Range Mgmt. & Agroforestry 39 (1) : 8-13, 2018
ISSN 0971-2070

Soil organic carbon density under different agroforestry systems along an elevation gradient in north-western Himalaya

Matber Singh[1,2]*, Bupender Gupta[2] and Shaon kumar Das[1]
[1]ICAR-National Organic Farming Research Institute, Gangtok-737102, India
[2]Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni-173 230, India
*Corresponding author e-mail: matber_singh@yahoo.co.in
Received: 4th May, 2017 Accepted: 26th April, 2018

Abstract
The present study was carried out to understand the variation in soil organic carbon (SOC) density under different agroforestry systems (agri-silviculture, agri-horticulture, agri-horti-silviculture, agri-silvi-horticulture, silvipasture and grasslands) prevailing at three elevations of E_1 (900-1300m; mixed deciduous forest), E_2 (1301-1700 m; chirpine forest) and E_3 (1701-2100 m; oak forest) in Giri catchment of Himachal Pradesh, Himalaya. The results revealed that significantly higher mean SOC was observed in agri-horticulture system (2.22%) as compared to other systems. The bulk density of soil was significantly higher at elevation E_3 (1.28 g cm^{-3}) as compared to other elevation ranges. Mean maximum soil organic carbon density upto 30 cm soil depth was observed in grassland (53.45 t C ha^{-1}) followed by agri-horti-silviculture (52.57 t C ha^{-1}), agri-horticulture (51.88 t C ha^{-1}), agri-silvi-horticulture (51.18 t C ha^{-1}) and agri-silviculture (50.01 t C ha^{-1}). Higher SOC density (53.91 t C ha^{-1}) was recorded at elevation E_3.

Keywords: Agroforestry systems, Bulk density, Elevation, Soil carbon density

Introduction
The Clean Development Mechanism (CDM) protocol has highlighted aboveground carbon sequestration through reforestation and afforestation practices, but soils might be serving as largest reservoir of carbon in terrestrial ecosystem (Jha *et al.,* 2003; Hashimoto *et al*., 2009; Shukla *et al*., 2017). It has three times higher carbon than vegetation systems of the world and plays a crucial role in carbon cycle (Bohra *et al*., 2014). Regular addition of leaf litter from aboveground and dead fine roots from belowground has been studied over the past few decades on which soil carbon stock (SOC) depends (Becker *et al*., 2015; Shukla *et al*., 2017). It also acts as a carbon sink 1,500-1,550 Pg (Sheikh *et al.,* 2009) and source of carbon depending on the availability and decomposition changes in organic matter (Dey, 2005). Topographical factors and elevation gradient have an effect on properties of soil through soil erosion and runoff. These processes accelerates the nutrient depletion, decline in soil pH and acidification, build-up of salts in the root zone, nutrient/ elemental imbalance and disruption in elemental cycles; reduction in activity and species diversity of soil fauna, decline in biomass C and depletion of SOC pool (Lal, 2004). Temperature and rain fall varies along with elevation change which impacts soil organic carbon stock through addition of organic matter and changing decomposition rate (Zhang *et al*. 2009).

Carbon management through afforestation and reforestation in degraded natural forests is a useful option, but agroforestry is attractive because the agroforestry systems are promising management practices to increase aboveground and soil C stocks to mitigate greenhouse gas emissions (Makundi and Sathaye, 2004). The C sequestration potential of tropical agroforestry systems in recent studies has been reported to vary between 12 and 228 Mg ha^{-1}, with a median value of 95 Mg ha^{-1}. Therefore, based on the global estimates of the area suitable for the agroforestry (585-1215 $\times$ 10^6 ha), 1.1-2.2 Pg C could be stored in the terrestrial ecosystems over the next 50 years (Albrecht and Kandji, 2003). In India, average sequestration potential in agroforestry has been estimated to be 25 tonnes carbon per ha over 96 million ha (Sathaye and Ravindranath, 1998), but there is a considerable variation in different regions based on biomass production (Dhyani *et al*., 2009; Ram newaj *et al*., 2013). However, information on sub-tropical to temperate agroforestry interventions in Giri catchment of Himachal Pradesh on the above discussed parameters of vegetation is meager. Hence, the present investigation was aimed to identify efficient agroforestry systems and to evaluate the agroforestry systems for higher carbon stock in soil pool.

Materials and Methods

Study site and sampling: The present investigation was carried out in sub-tropical to temperate region of Giri catchment during the years 2011 and 2012 under the Department of Silviculture and Agroforestry of Dr. Y.S. Parmar University Nauni, Solan, Himachal Pradesh. Catchment located between 30° 33' 48" and 31° 16' 08" N latitude and 77° 02' 32" to 77° 38' 22" E longitude with an area of 2389 km^2 (Rao *et al.,* 1989). Catchment is distributed in Shimla, Sirmour and Solan districts of Himachal Pradesh that includes 135 sub-watersheds. Six agroforestry systems were explored for estimation of soil organic carbon densities at each elevation in selected sub-watersheds, which were as follows: S_1 : Agri-silviculture system (AS), S_2: Agri-horticulture system (AH), S_3 : Agri-horti-silviculture system (AHS), S_4 : Agri-silvi-horticulture system (ASH), S_5 : Silvipasture system (SP), and S_6 : Grassland (GS). Stratified random sampling was used for selection of sub-watershed and delineated into three elevations for further investigations *viz.*, elevation E_1 (900-1300 m), E_2 (1301-1700 m) and E_3 (1701-2100 m). Thus, total 39 numbers of experimental sites (treatments) were taken for recording the observations (13 sub-watersheds x 03 elevations).

Soil and data analysis: The composite soil samples from each plot were collected from 0-30 cm depth. Samples were air dried, crushed and passed through 2 mm sieve and stored in cloth bags for analysis. Bulk density of each soil sample was determined by RD bottle method (Singh, 1980). The organic matter in the soil was oxidized by chromic acid (potassium dichromate + conc. H_2SO_4) utilizing the heat of dilution of H_2SO_4. The un-reacted dichromate was determined by back titration with ferrous sulphate for organic carbon determination (Walkley and Black method, 1934).The soil organic carbon density was computed by using the formula of Nelson and Sommers, (1996), which was as follows:
SOC density (t/ha) = [Soil bulk density (g cm^{-3}) x Soil depth (m) x SOC (%)] x 100

The data obtained was subjected to statistical analysis as per the procedure suggested by Gomez and Gomez (1984). Analysis was carried out by using statistical package 'Statistics'.

Results and Discussion

Soil organic carbon: Soil organic carbon (SOC) contents were determined in samples from three elevations selected for each agroforestry system (Table 1). The data revealed that soil organic carbon content was significantly influenced by the systems. The soil organic carbon (%) in agroforestry systems decreased in order of agrihorticulture (2.22%)> agrihortisilviculture (2.20%)> agrisilvihorticulture (2.17%)> agrisilviculture (2.16%). Significantly higher mean soil organic carbon was recorded in agri-horticulture (S_2: 2.22%) and minimum soil organic carbon was recorded in silvi-pasture system (S_5: 2.08%). However, the SOC obtained in agri-silviculture and agri-silvi-horticulture systems were statistically at par. The difference in soil organic carbon content among different agroforestry systems might be related to difference in structure and composition of vegetation, climatic variation and management inputs.

Table 1. Variation in soil organic carbon (%) relative to elevations and agroforestry systems

Systems (S)	Elevation (E)			
	E_1 (900-1300 m)	E_2 (1301-1700 m)	E_3 (1701-2100 m)	Mean (S)
S_1	2.17	2.22	2.10	2.16
S_2	2.22	2.16	2.29	2.22
S_3	2.21	2.12	2.27	2.20
S_4	2.12	2.21	2.17	2.17
S_5	1.98	2.16	2.10	2.08
S_6	2.26	2.26	2.06	2.19
Mean (E)	2.16	2.19	2.16	
Factors	**$CD_{0.05}$**	**SEm±**		
E	NS	0.020		
S	0.078	0.028		
E×S	0.136	0.049		

Elevation had no significant effect on SOC. However, mean maximum soil organic carbon was observed at elevation E_2 (2.19%) which was higher than E_3 and E_1. The interaction effect of systems and elevations was significant on the soil organic carbon content and revealed that maximum soil organic carbon was observed with S_2E_3 (2.29%) and minimum soil organic carbon (1.98%) was obtained in S_5E_1. Soil is the most effective sequestration reservoir for C in any ecosystems because of the long turnover time of soil organic matter compared with most plant tissues, and because of less inter-annual variability or disturbance-driven losses (Lal, 2004). Generally, soil carbon shares two-third of the total carbon stored by tree based systems. IPCC (2000) has recognized soil organic carbon as one of the five major carbon pools for LULUCF (Land Use, Land Use Change and Forestry). In the present vegetation systems, the SOC varied between 2.08 to 2.22 %. The range of SOC in soils ranging from 1.16 to 3.49 % in grasslands and 1.68 to 3.83 % in chir pine forests were reported earlier by Goswami (2014). While in the similar agroforestry systems, Bhardwaj *et al.*(2013) observed SOC contents ranging from 0.89 to 1.22% only.

Soil organic carbon in grasslands is equivalent to tree based systems and is attributed to its intensive root cycling system, which has high content of lignin (Martens, 2000). In the long-term, areas under grasslands have similar potential to store total organic carbon as areas under tree-based systems (Franzluebbers *et al.,* 2000). However, in chir pine silvi-pasture, SOC content was less when compared to other systems. This might be due to two reasons; first in Giri catchment like that of whole Himachal Pradesh, the grasslands and chir pine forests are subjected to frequent fire every year to enhance the forage yield. Hence, the litter in these ecosystems is often burnt. Second, in chir pine silvi-pastures, people collect pine needle litter lying on forest floor every year for its domestic and industrial use. Hence, there is depleted organic matter turnover in these forests, which might have reduced soil organic carbon in chir pine silvi-pasture. Murthy *et al.* (2006) also reported more carbon storage (3.94 t C ha^{-1}) in soils from pure pasture as compared to silvipasture (1.89-3.45 t C ha^{-1}), which was attributed to the high diversity of vegetation.

Table 2. Variation in soil bulk density (g cm^{-3}) relative to elevations and agroforestry systems

Systems (S)	Elevation (E)			
	E_1 (900-1300 m)	E_2 (1301-1700 m)	E_3 (1701-2100 m)	Mean (S)
S_1	1.24	1.10	1.26	1.20
S_2	1.24	1.12	1.26	1.21
S_3	1.26	1.13	1.27	1.22
S_4	1.24	1.12	1.27	1.21
S_5	1.27	1.15	1.30	1.24
S_6	1.29	1.19	1.33	1.27
Mean (E)	1.26	1.14	1.28	
Factors	**$CD_{0.05}$**	**SEm±**		
E	0.007	0.003		
S	0.010	0.004		
E×S	NS	0.006		

Bulk density of soil: The mean maximum bulk density of soil was recorded in grassland (1.27 g cm^{-3}) which was significantly higher than rest of the systems (Table 2). Among the elevations, the mean maximum bulk density (1.28 g cm^{-3}) of soil was observed at elevation E_3 which was significantly higher than elevation E_1 (1.26 g cm^{-3}) and E_2 (1.14 g cm^{-3}). In the present study, the bulk density of soil in different agroforestry systems decreased in the order: grassland (1.27 g cm^{-3}) > silvipasture (1.24 g cm^{-3}) > AHS (1.22 g cm^{-3}) > ASH (1.21g cm^{-3}) > AH (1.21 g cm^{-3}) > AS (1.20 g cm^{-3}). Similar range of bulk density (0.97 to 1.25 g cm^{-3}) in agroforestry systems of Himachal Pradesh was reported earlier (Gowsami *et al.,* 2014; Bhardwaj *et al.,* 2013). They observed that bulk density in grassland varied from 1.07 to 1.22 g cm^{-3} and in silvipasture systems from 0.94 to 1.22 g cm^{-3}. But the interaction between systems and elevation exhibited non-significant effect on soil bulk density.

***Soil organic carbon density*:** Elevation and agroforestry systems significantly affected soil organic carbon density (SOCD). Significantly higher SOCD (53.45 t C ha^{-1}) was observed in grassland over silvipasture, agrihortisilviculture and agrisilviculture but at par with agri-horti-silviculture and agri-horticulture (Table 3). Minimum SOCD (49.76 tha^{-1}) was recorded in silvi-pasture system. Among elevation, the higher mean SOCD was observed at elevation E_3 (53.91 t C ha^{-1}) which was significantly higher than mean SOCD at elevations E_1 (52.37 t C ha^{-1}) and E_2 (48.15 t C ha^{-1}). The interaction effect of elevation and systems on SOCD revealed that maximum SOCD was recorded in S_3E_3 (56.70 t C ha^{-1}), it was statistically alike with S_6E_1 (56.02 t C ha^{-1}), S_2E_3 (55.64 t C ha^{-1}), S_4E_3 (54.06 t C ha^{-1}) and S_3E_1 (54.04 t C ha^{-1}). Minimum SOCD was recorded in S_2E_2 (47.02 t C ha^{-1}). The SOCD up to 30 cm soil layer under agroforestry systems showed the decreasing precedence as: agrihortisilviculture (52.57 t C ha^{-1}) >agrihorticulture (51.88 t C ha^{-1}) >agrisilvihorticulture (51.18 t C ha^{-1}) >agrisilviculture (50.01 t C ha^{-1}). The effectiveness of agroforestry systems in storing carbon depends on both environmental and socio-economic factors.

Table 3. Variation in soil carbon density (t C ha^{-1}) relative to elevations and agroforestry systems

Systems (S)	Elevation (E)			
	E_1 (900-1300 m)	E_2 (1301-1700 m)	E_3 (1701-2100 m)	Mean (S)
S_1	51.66	47.20	51.19	50.01
S_2	52.97	47.02	55.64	51.88
S_3	54.04	46.96	56.70	52.57
S_4	51.27	48.20	54.06	51.18
S_5	48.25	47.92	53.12	49.76
S_6	56.02	51.57	52.75	53.45
Mean (E)	52.37	48.15	53.91	
Factors	**$CD_{0.05}$**	**SEm±**		
E	1.42	0.51		
S	2.01	0.72		
E×S	3.49	1.25		

In humid tropics, agroforestry systems have the potential to sequester over 70 Mg C/ha in the top 20 cm of the soil and in degraded soils of the sub-humid tropics, agroforestry practices can increase top soil carbon stocks up to 1.6 Mg C $ha^{-1}yr^{-1}$ (Mutuo *et al.,* 2005).The soil carbon storage in an agroforestry system is regulated by its structural components and their management (Samra and Singh, 2000), soil type (Gupta *et al.,* 2009) and age of the agroforestry plantations (Maikhuri *et al*., 2000; Saha *et al*., 2007). Soil carbon density range of 41.05 to 51.04t C ha^{-1} in agroforestry systems were recorded by Goswami *et al*. (2014) and Kanime *et al*. (2013). In Giri catchment under chir pine forests, Negi and Gupta (2010) observed SOC density (up to 30 cm depth) was varied between 29.71 to 89.03 t C ha^{-1} with an average value of 57.33 t C ha^{-1}. Likewise, Mahato (2013) and Rajput (2016) also recorded SOC in chir pine silvipasture and grasslands of Himachal Pradesh, which varied between 26.37 to 78.57 t C ha^{-1} and 31.10 to 43.71 t C ha^{-1}, respectively. Variation in aboveground and belowground biomass carbon (t C ha^{-1}) of vegetation relative to elevations and systems in Giri catchment was also recorded (Table 4 & 5). It was observed that with increase in elevation aboveground biomass carbon increased ($E_1<E_2<E_3$), being maximum in E_3. Similarly belowground biomass carbon increased with increase in elevation ($E_1<E_2<E_3$). On the other hand, the maximum aboveground biomass carbon was found in S_5 as compared to others, while the maximum belowground biomass carbon was found in S_4 and the findings were in agreement of earlier report (Chaturvedi *et al.,* 2016).

Table 4. Variation in aboveground biomass carbon (t C ha^{-1}) of vegetation relative to elevations and agroforestry systems

Systems (S)	**Elevation (E)**			
	E_1 (900-1300 m)	**E_2 (1301-1700 m)**	**E_3 (1701-2100 m)**	**Mean (S)**
S_1	20.72	23.79	28.44	24.32
S_2	20.79	23.42	26.06	23.42
S_3	27.66	29.78	33.98	30.48
S_4	28.74	29.99	35.96	31.56
S_5	31.47	35.67	38.81	35.32
S_6	1.69	1.50	1.51	1.57
Mean (E)	21.85	24.02	27.46	
Factors	**$CD_{0.05}$**	**SEm±**		
E	0.420	0.151		
S	0.594	0.214		
E×S	1.028	0.370		

Table 5. Variation in belowground biomass carbon (t C ha^{-1}) of vegetation relative to elevations and agroforestry systems

Systems (S)	**Elevation (E)**			
	E_1 (900-1300 m)	**E_2 (1301-1700 m)**	**E_3 (1701-2100 m)**	**Mean (S)**
S_1	6.33	7.05	8.36	7.25
S_2	6.31	6.63	7.65	6.86
S_3	8.30	8.62	10.10	9.01
S_4	8.73	8.87	10.69	9.43
S_5	8.70	8.62	10.59	9.30
S_6	0.93	0.89	0.87	0.90
Mean (E)	6.55	6.78	8.04	
Factors	**$CD_{0.05}$**	**SEm±**		
E	0.106	0.038		
S	0.150	0.054		
E×S	0.260	0.094		

S_1: Agrisilviculture; S_2: Agrihorticulture; S_3: Agrihortisilviculture; S_4: Agrisilvihorticulture; S_5: Silvipasture; S_6: Grassland

Conclusion

Present findings indicated that maximum soil organic carbon density (56.70 t C ha^{-1}) was observed in agri-horti-silviculture system at higher elevation. Therefore, conversion of grassland pasture into agri-horti-silviculture systems is recommended for sequestration of the atmospheric CO_2 in the soil pool at higher elevation. But at lower elevations, grasslands had higher soil organic carbon densities and thus grasslands needs to be conserved and restored.

Acknowledgement

The first author is thankful to the Director, ICAR Research Complex for NEH Region, Umiam, Meghalaya for providing financial facility during his Ph.D work as well as Department of Silviculture and Agroforestry of Dr. Y.S. Parmar University Nauni, Himachal Pradesh for providing necessary facilities.

References

Albrecht, A. and S. T. Kandji. 2003. Carbon sequestration in tropical agroforestry systems. *Agriculture, Ecosystem & Environment* 99: 15-27.

Becker, J., H. Pabst, J. Mnyonga and Y. Kuzyakov. 2015. Annual litter fall dynamics and nutrient deposition depending on elevation and land use at Mt. Kilimanjaro. *Biogeosciences* 12: 5635-5646.

Bhardwaj, D. R., A. Sanneh, B. S. Rajput and S. Kumar. 2013. Status of soil organic carbon stocks under different land use systems in wet temperate north western Himalaya. *Journal of Tree Sciences* 32: 15-22.

Bohra, C.S., S. K. Tewari and M. D. Bhatt. 2014. Trends in soil carbon stockpile of three major forests along an altitudinal gradient in Indian central Himalaya. *Ecoprint* 21: 7-13.

Chaturvedi, O.P., A. K. Handa, R. Kaushal, A. R. Uthappa, S. Sarvade and P. Panwar. 2016. Biomass production and carbon sequestration through agroforestry. *Range Management and Agroforestry* 37: 116-127.

Dey, S. K. 2005. A preliminary estimation of carbon stock sequestrated through rubber (*Hevea brasiliensis*) plantation in North Eastern regional of India. *Indian Forester* 131: 1429-1435.

Dhyani, S., K. Ramnewaj and A. R. Sharma. 2009. Agroforestry, its relation with agronomy, challenges and opportunities. *Indian Journal of Agronomy* 54: 249-266.

Franzluebbers, A. J., J. A. Stuedemann, Schomberg, H. H. and S. R. Wilkinson. 2000. Soil organic C and N pools under long-term pasture management in the Southern Piedmont USA. *Soil Biochemistry* 32: 469-478.

Gomez, K. A. and A. A. Gomez. 1984. *Statistical Procedures for Agricultural Research*. 2nd edn. John Wiley and Sons, Inc: New York. pp. 680.

Goswami, S., K. S, Verma and R. Kaushal. 2014. Biomass and carbon sequestration in different agroforestry systems of a western Himalayan watershed. *Biological Agriculture & Horticulture* 30: 88-96.

Gupta, B., R. Mehta and V. K. Mishra. 2009. Fire ecology of ground vegetation in *Pinus roxburghii* Sargent plantations in north-west Himalaya: Floristic composition and species diversity. *Caspian Journal of Environmental Science* 7: 71-78.

Hashimoto, T., S. Miura and S. Ishizuka. 2009. Temperature controls temporal variation in soil CO_2 efflux in a secondary beech forest in Appi Highlands. *Journal of Forest Research* 14: 44-50.

IPCC. 2000. Land use, land use change and forestry: a special report of the Inter Governmental Panel on Climate change. Cambridge University press. Cambridge, UK. pp. 375.

Jha, M. N., M. K. Gupta, A. Saxena and R. Kumar. 2003. Soil organic carbon store in different forest in India. *Indian Forester* 129: 715-724.

Kandji, S. T., L. V. Verchot, J. Mackensen and C. Palm. 2006. Opportunities for linking climate change adaptation and mitigation through agroforestry systems. In: *World Agroforestry in to the Future*. World Agroforestry Centre, Nairobi. pp. 113-121.

Kanime, N., R. Kaushal, S. K. Tewari, K. P. Raverkar, S. Chaturvedi and O. P. Chaturvedi. 2013. Biomass production and carbon sequestration in different tree based systems of Central Himalayan region. *Forests, Trees and Livelihoods* 1: 38-50.

Lal, P. 2004. Integrated development of farm forestry plantation and wood based industries. *Indian Forester* 130: 71-78.

Lal, R. 2004. Soil carbon sequestration to mitigate climate change. *Geoderma* 123: 1-22.

Mahato, D. 2013.Vegetation dynamics of chir pine forests along altitudinal gradient in Giri catchment of Himachal Pradesh. *Ph.D Thesis*. Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.), India. pp. 247.

Maikhuri, R. K., R. L. Semwal, K. S. Rao, K. Singh and K. G. Saxena. 2000. Growth and ecological impacts of traditional agroforestry tree species in Central Himalaya, India. *Agroforestry Systems*. 48: 257-272.

Martens, D. A. 2000. Plant residue biochemistry regulates soil carbon cycling and carbon sequestration. *Soil Biology and Biochemistry* 32: 361-369.

Makundi, W. R. and J. A. Sathaye. 2004. GHG mitigation potential and cost in tropical forestry-relative role for agroforestry. *Environment, Development and Sustainability* 6: 235-260.

Murthy, I. K., D. M. Bhat, G. T. Hegde, B. C. Nagaraj and K. S. Murali. 2006. Tree diversity and carbon sinks: role of village agro-ecosystems in the Western Ghats, Karnataka, India. *International Journal of Agricultural Sustainability* 3: 114-121.

Mutuo, P. K., G. Cadisch, C. A. Albrecht Palm and L. Verchot. 2005. Potential of agroforestry for carbon sequestration and mitigation of greenhouse gas emissions from soils in the tropics. *Nutrient Cycling in Agroecosystems* 71: 43-54.

Negi, S. S. and M. K. Gupta. 2010. Soil organic carbon store under different land uses system in Giri catchment of Himachal Pradesh. *Indian Forester* 7: 1147-1154.

Nelson, D. W. and L. E. Sommers. 1996. Total carbon, organic carbon, and organic matter. In D.L Sparks (eds.). *Methods of Soil Analysis. Part 3. Chemical Methods*. SSSA Book Series No. 5, SSSA and ASA, Madison, WI. pp. 961-1010.

Rajput, B. S., D. R. Bhardwaj and N. A. Pala. 2016. Factors influencing biomass and carbon storage potential of different land use systems along an elevational gradient in temperate north-western Himalaya. *Agroforestry Systems*. DOI 10.1007/s10457-016-9948-5.

Ram, N., S. Chavan and R. Prasad. 2013. Agroforestry as a strategy for climate change adaptation and mitigation. *Indian Journal of Agroforestry* 15: 41-48.

Rao, C. S., C. V. Shyamala and T. V. S. Rao. 1989. Evaluation of integrated watershed management programme: flood prone river-upper Yamuna-UP and HP. Sponsored by National Land Use and Conservation Board, Ministry of Agriculture, Govt. of India, Agriculture and Rural Development Area, Administrative Staff College of India-Hyderabad. pp.1-157.

Saha, R., J. M. S. Tomar and P. K. Ghosh. 2007. Evaluation and selection of multipurpose tree for improving soil hydro-physical behaviour under hilly eco-system of north-east India. *Agroforestry Systems*. 69: 239-247.

Samra, J. S. and S. C. Singh. 2000. Silvopasture systems for soil, water and nutrient conservation on degraded land of Shiwalik foothills (sub-tropical northern India). *Indian Journal of Soil Conservation* 28: 35-42.

Sathaye, J. A. and N. H. Ravindranath. 1998. Climate change mitigation in the energy and the forestry sectors of developing countries. *Annals of Review on Energy and Environment* 23: 387-437.

Sheikh, M. A., K. Munesh and R. W. Bussmann 2009. Altitudinal variation in soil organic carbon stock in coniferous subtropical and broadleaf temperate forests in Garhwal Himalaya. *Carbon Balance and Management* 4: 1-6.

Shukla, G., N. A. Pala and S. Chakravarty. 2017. Quantification of organic carbon and primary nutrients in litter and soil in a foothill forest plantation of eastern Himalaya. *Journal of Forest Research*. DOI 10.1007/s11676-017-0394-7.

Singh, R. A. 1980. *Soil Physical Analysis*. Kalyani Publishers, New Delhi.

Walkley, A. and I. A. Black. 1934. An examination of the Degtjareff method for determining organic carbon in soils: effect of variations in digestion conditions and of inorganic soil constituents. *Soil Science* 63: 251-263.

Zhang, Z. S., X. R. Li, L. C. Liu, R. L. Jia, J. G. Zhang and T. Wang. 2009. Distribution, biomass and dynamics of root in revegetated plantation of Caraganakorshinskii in the Tengger Desert, north-western China. *Journal of Plant Research* 122: 109-119.