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RESEARCH ARTICLE

GROWTH, BIOMASS, CARBON SEQUESTRATION AND SOIL NUTRIENT DYNAMICS UNDER PINE FOREST IN NORTH-WEST HIMALAYAS.

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Abstract

Pinus roxburghii is the most dominant forest type present in North-West Himalayas. Pine forest accounted for the total vegetation biomass of 156.7 Mg/ha/year during present study. Total carbon stock in pine forest was 69.52 Mg/ha/year which accounted for carbon sequestration of 255.13 Mg/ha/year. Carbon allocation in different components of *Pinus roxburghii* was 54.22 per cent, 53.74 per cent, 53.07 per cent and 50.75 per cent in stem, roots, branches and leaves, respectively. Phyto-sociological studies revealed that *Parthenium hysterophorus* had lowest frequency (0.3%) while *Chrysopogon montanus* (1.35%) had maximum frequency. Species abundance varied from 1.0/25m^2 or 400 herbs or shrubs/ha to 3.28/25m^2 or 1312 herbs/shrubs or grasses/ha. A/F ratio ranged from 1.11 (*Rubus ellipticus*) to 10.0 (*Partheniumhysterophorus* and *Veronica cinerea*). Soil organic carbon, N, P, K, pH, Electrical conductivity and bulk density were analysed from top soil profile (0-15 cm) to sub-soil profile (30-60 cm). Soil organic carbon varied from 0.24% to 0.77% and it decreased depth wise.Nitrogen, potassium and electrical conductivity at various soil depths varied from 194.32 to 280.0 kg/ha, 128.1 kg/ha to 269.2 kg/ha and1.09 dSm^{-1} to 1.22 dSm^{-1}, respectively and they also decreased depth wise. Soil pH was acidic and it ranged from 6.50 to 6.72. Available phosphorus and bulk density varied from 0.18 to 0.30 kg/ha and 0.43-1.23g cm^{-3}, respectively and increased depth wise.

Introduction:-

Trees play a vital role in mitigating the diverse effects of environmental carbon degradation and increasing concentration of carbon dioxide in the atmosphere. Trees promote sequestration of carbon into soil and plant biomass. Therefore tree based land use practices could be viable alternatives to store atmospheric carbon dioxide due to their cost effectiveness, high potential of carbon uptake and associated environmental as well as social benefits (Dhruw *et al*., 2009). Increasing levels of carbon dioxide in the atmosphere during the past few decades has drawn the attention of the scientific community towards the process of carbon storage and soil organic carbon store. Concentration of atmospheric carbon dioxide can be lowered either by reducing emissions or by enabling the storage of carbon dioxide in the terrestrial ecosystem. An ecosystem plays very important role in storing and cycling of carbon. Soil also plays very important role in the carbon cycle by storing it in the form of soil organic carbon. Most of the carbon enters the ecosystem through the process of photosynthesis in the leaves. After the litter fall, the detritus is decomposed and forms soil organic carbon by microbial process (Post and Kwon, 2000). The Himalayan forest vegetation ranges from tropical deciduous forests in the foothills to timberline. *Pinus roxburghii* is the most important resin pine sp. of India and also a source of fuelwood. In India chir pine covers are of 8,69,000 hectares that extends from J&K, Himachal, Uttar Pradesh, West Bengal and Arunachal Pradesh (Anon, 2004). In Himachal Pradesh about 1346 km^2 area is under chir pine forest.

Carbon sequestration potential depends upon the biological productivity, which in turn depends upon interaction between species, climate, topography and management practices imposed. Thus carbon density and sequestration potential varies from place to place, which needs to be worked out on region to region and species to species basis. Carbon sequestration potential differs with the kind of land use system. Finding low-cost methods to sequester carbon is emerging as a major international policy goal in the context of global climate change (Montagnini and Nair, 2004). Therefore, the need is to assess the potential of different land- management options which can fulfill both environmental and economic goals. The need is to find a suitable land-use system which, on the one hand, will fulfill our requirements of food, fodder and timber and on the other has environmental benefits. Carbon sequestration depends upon biomass production capacity, which in turn depends upon interaction between edaphic, climatic and topographic factors of an area. Hence results obtained at one place may not be applicable to another. Therefore, region-based potential of different land use needs to be worked out.

In the present investigation it has been postulated that pine forest in Himachal Pradesh have different impacts, especially in terms of carbon sequestration, productivity and nutrient distribution. The need is to study these aspects, which have been envisaged in the present study. In addition the allocation pattern of carbon, nutrients dynamics (N, P and K) in the soils and phyto-sociological attributes for shrub and herb layers in pine forest were also investigated.An attempt was made for analyzing the pine forest in relation to physico-chemical properties of soil and carbon sequestration potential in North-West Himalaya.

Materialsand methods:-

Study site:-

The present study on growth, biomass, carbon allocation and carbon sequestration was undertaken in the Pine forest inBajhol village, Solan district (H.P.), during the growing seasons (July-November) of the years 2010 and 2011. Solan district lies between 30^0 50'30" N-30^0 52'30" N latitudes and 77^0 8'30" E-$77^0$11'30" E longitude. The vegetation mainly comprises of sub-alpine Chir-pine types (Verma *et al*., 2007). The forests in Solan district have pure and mixed stands of Chir-pine. The area is a transitional zone between sub-tropical to sub-temperate with maximum temperature risings up to 37.8^0 C during summer. Annual rainfall varies from 1000-1400 mm, majority of which is received during monsoons, i.e. July to mid-September. The minimum and maximum temperature varies from 3^0 C during winter (January) to 33^0 C during summer (June), whereas mean annual temperature is 19^0 C. Soil is inceptisols and typic entrochrepts type and texture is gravelly, sandy and loamy (Devi *et al*., 2013).

Tree growth and biomass estimation:-

The study area was divided equally into five replications of 10x10 m and in each replication all trees were selected.Total 42 trees were enumerated in order to determine the various morphological attributes, diameter at breast height (Dbh), height of the trees, crown length, crown spread and crown index by using standard methods.Aboveground tree biomass was estimated using volumetric equations given by Forest Survey of India (FSI, 1996) as it was not possible to excavate trees manually. Volume was transformed into biomass by multiplying with specific gravity of 0.49 (FSI, 1996). Belowground biomass (root) of *Pinus roxburghii* was determined by multiplying aboveground biomass with a factor of 0.20 (IPCC, 2003). Various species of shrubs, grasses and herbs present in the pine forest, were alsocollected, identified and their phytosociological analysis (density, frequency, abundance and A/F ratio) was done by using the method given by Phillips (1959) and Misra (1969). Biomass of shrubs, grasses, herbs and litter in pine forest was calculated by harvesting them from the five quadrates of 50x50 cm laid in triplicates by randomized sampling.

Carbonallocation in different tree components:-

It was estimated by dry combustion method given by Gallardo and Merino (1993)using Muffle furnace. In this method plant components (branch, leaves, stem wood and root) were oven dried and crushed. 5 g of plant sample was taken in silica crucible and kept at 800^o C for 5 hours in muffle furnace for combustion. After cooling, sample was weighed and percent organic carbon was calculated.

$$\text{Percent Organic Carbon} = \frac{\text{Weight of loss x 0.58}}{\text{Sample weight}} \text{ x 100}$$

Soil analysis:-

Soil samples were collected randomly from five sites in three replications (50x50 cm) from pine forest at three different soil depths of 0-15 cm, 15-30 cm and 30-60 cm. Samples from all the five sites at each soil depth from study site were analyzed for the distribution of nutrient elements and other parameters. Collected soil samples were dried and sieved through 2 mm mesh before analysis. Soil was analyzed for % organic carbon, available N, available P, available K, pH, electrical conductivity and bulk density. Different soil parameters studied and the methods adopted to analyze them are given in Table 1.

Table 1:- Parameters and methods adopted for the analysis of Soil.

S. N.	Parameters	Methods
1.	% Organic carbon	Walkely and BlackMethod (1934)
2.	Available N	Micro-Kjeldhal method by Chapmann and Pratt (1961)
3.	Available P	Spectrophotometer method by Watambe and Olsen (1965)
4.	Available K	Flame photometer method by Jackson (1967)
5.	pH	pH meter method by Jackson (1973)
6.	Electrical conductivity	Digital conductivity meter method by Jackson (1973)
7.	Bulk density	Specific gravity bottle method by Singh (1980)

Carbon sequestration:-

The aboveground (AGB) and belowground (BGB) tree biomass was summed to get the total biomass. Carbon stock was obtained by multiplying biomass with a factor of 0.45 (Woomer, 1999; Sheikh *et al.*, 2011b). Carbon stock of pine forest was determined by adding carbon stock of trees, shrubs, herbs, and litter. Carbon inventory of pine forest was calculated by using the formula given below.

Carbon stock = Biomass x 0.45 (Woomer, 1999 and Sheikh *et al.*, 2011b)
Carbon sequestered = Biomass carbon stock x 3.67 (Rajput, 2010)
Soil carbon pool inventory= [Soil bulk density (g cm^{-3}) x soil depth (cm) x C (%)] x 100 (Nelson and Sommers,1996).

Statistical analysis:-

The data on soil parameterswas subjected for two-way analysis of variance (ANOVA) to determine the significance of results between different five study sites at three soil depths in pine forest and Bonferroni's multiple comparison post-test were performed at the significance level of $p<0.05$.

Results and discussion:-

Tree morphology, biomass and carbon allocation:-

Within the pine forest, five sites were selected randomly and trees were measured for morphological features. Results on tree growth and biomass attributes viz; dbh, height, clear bole height, number of branches, crown length, crown spread, crown index, total tree biomass and total vegetation biomass in the pine forest are given in Tables 2 and 3. It is evident from former table that mean height and crown spread in *Pinus roxburghii* were 20.58 m and 1.55 m, respectively. Crown length and crown index were 5.83 m and 4.88 m, respectively. On an average tree had a dbh of 20.3 cm with a clear bole of 14.59 m. The biomass of different components of trees as well as of understorey shrubs, grasses etc. is given in Table 3. Tree biomass, shrub biomass and herb/grass biomass in pine forest was 144.9, 1.41 and 5.86 Mg/ha/year, respectively, while litter biomass was 4.56 Mg/ha/year. Total vegetation biomass was 156.7 Mg/ha/year and which contributed for the total carbon stock (69.52 Mg/ha/year) in pine forest. Carbon sequestered by the pine forest was 255.13 Mg/ha/year.

Biomass of leaf litter, herbs and grass recorded was found low in pine forest. This could be because of acidic nature of pine forest soil which inhibits the growth of other vegetation. Nautiyal and Singh (2013) reported higher carbon stock densities for AGTB (above ground tree biomass), BB (below-ground biomass), LHG (leaf litter, herbs and grass), DWS (dead wood and fallen stumps), AGSB (above-ground sapling biomass) and soil organic carbon compared to present studies. Total carbon density of 986.93 Mg/ha was found in pine forest of Nandprayag. However it is evident that the above-ground biomass in chir-pine forest is higher than the range reported by Chaturvedi and Singh (1987) and Sharma *et al*. (2010) for Himalayan *Pinus roxburghii*. The carbon stock values vary according to the location, plant species, age of the stand, aboveground input received from leaf litter, decomposition of fine roots below ground, management practices and other operating ecological factors. Land use and soil management practices can significantly influence soil organic carbon dynamics and carbon flux of the soil (Batjes, 1996; Tian *et al.*, 2002; Rasse *et al.*, 2006; Van *et al*., 1997).

Table 2:-Morphological attributes of trees under pine forest during two years of study.

Sites	dbh (cm)	Height (m)	Clear bole (m)	Number of branches	Crown Spread (m)	Crown length (m)	Crown Index (m)
S1	23.95±3.89	20.24±0.71	13.87±0.38	25.33±7.69	1.74±0.34	5.58±0.21	3.54±0.88
S2	23.42±3.03	20.69±0.49	15.77±0.48	20.33±6.89	1.84±0.69	4.92±0.97	3.59±1.45
S3	25.54±4.67	21.34±0.81	15.79±0.52	19.67±5.33	1.74±0.40	5.54±1.11	3.58±1.00
S4	20.99±4.24	21.50±0.30	16.19±0.45	26.67±7.26	1.57±0.74	5.31±0.74	5.01±1.72
S5	7.63±0.66	19.17±0.47	11.36±0.05	20.67±7.45	0.90±0.02	7.82±0.43	8.70±0.35
Mean ± S.E.	20.30±3.2	20.58±0.55	14.59±0.37	22.53±6.92	1.55±0.43	5.83±0.69	4.88±1.08

Values are Mean ± standard error

In the present study, shrub and herb/grass biomass varied under the influence of the Pine trees. These variations can be due to variation in the light interception, moisture regime, nutrient dynamics, acidic pH of soil etc. In general, shrub, herb/grass biomass was maximum under the sites which had higher humus content. The presence of humus play important role in under storey biomass as reported by Adhiakri *et al*. (1995) and Zhu *et al*. (2010). Rana and Singh (1990) showed that the understorey (shrubs + herbs) accounted for 1.5% of the total forest biomass (432.8 t/ha) in *Pinus roxburghii* plantation located in Kumaun Himalaya of Uttarakhand.

Table 3:-Biomass and carbon stock in trees under pine forest during two years of study.

Sites	Tree above ground biomass (Mg/ha)	Tree below ground biomass (Mg/ha)	Total treebio mass (above+ below) Mg/ha	Above ground carbon stock (Mg/ha)	Below ground carbon stock (Mg/ha)	Total carbon stock (above+ below) Mg/ha	Shrub biomass (Mg/ha)	Herb/ grass biomass (Mg/ha)	Total vegetation biomass (Mg/ha)	Total vegetation carbon stock
S1	113.2 ±10.4	22.64 ±2.09	135.8 ±12.5	50.94 ±4.71	10.19 ±0.94	61.13 ±5.65	1.41 ±0.02	5.67 ±0.01	142.92	64.31
S2	123.2 ±0.81	24.64 ±0.16	147.8 ±0.97	55.45 ±0.36	11.09 ±0.07	66.54 ±0.44	1.37 ±0.03	5.34 ±0.03	166.91	75.10
S3	124.4 ±1.85	24.89 ±0.37	149.3 ±2.22	56.0 ±0.83	11.20 ±0.17	67.20 ±1.00	1.52 ±0.02	6.78 ±0.02	157.64	70.93
S4	124.7 ±0.09	24.59 ±0.02	149.6 ±0.10	56.13 ±0.04	11.23 ±0.01	67.36 ±0.05	1.48 ±0.02	6.13 ±0.02	157.3	70.78
S5	118.3 ± 3.61	23.6 ±0.72	141.9 ±4.33	53.24 ±1.63	10.65 ±0.33	63.88 ±1.95	1.27 ±0.01	5.39 ±0.01	148.62	66.87
Mean ± S.E	120.7 ±3.36	24.08 ±0.67	144.9 ±4.03	54.35± 1.51	10.87 ±0.30	65.22 ±1.81	1.41 ±0.02	5.86 ±0.01	154.5 ±2.95	72.27 ± 1.42

Values are Mean ± standard error

Carbon allocation observed in different components of *P. roxburghii* for the two years of study is presented in Table 4. The carbon allocation varied in terms of site, components and year of study. In *P. roxburghii* averagecarbon allocation was maximum in the stem (54.22%)> roots (53.74%)> branch (53.07%) and leaves (50.75%) during two years of study. Average carbon allocation in stem varied from 53.03 to 55.42 percent, in roots from 51.33 to 56.16 percent, in branches from 51.80 to 54.34 percent and in leaves from 47.69 to 53.82 percent, respectively, from year 2010 to 2011. These results are in conformity with Ganeshaiah *et al*. (2003) who reported that carbon allocation in *P. roxburghii* and *P. wallichiana* was highest in stem wood (46.32% and 46.18%) followed by leaves (43.46% and 43.08%) and bark (44.07% and 42.06%). Wani and Qaisar (2014) reported carbon allocation in *Cedrus deodara* was in the order: stem wood (46.39%)> root (46.17%)> branch (46.05%)> and leaf (42.81%). Similarly, in *Fraxinusfloribunda* and *Ulmuswallichiana* carbon allocation was in order of: stem wood (43.21% and 43.66%, respectively)> root (43.01% and 43.21%, respectively)> branch (42.42% and 43.03%, respectively)> leaf (36.70% and 36.41%, respectively).

Table 4:-Carbon allocation in different components of *Pinus roxburghii*during two years of study.

Sites	Leaf carbon (%)		Stem carbon (%)		Branch carbon (%)		Root carbon (%)	
	2010	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
S1	41.82 ±0.04	54.85 ±0.70	53.89 ±0.12	56.27 ±0.07	51.30 ±0.28	55.14 ±0.50	51.61 ±0.03	56.40 ±0.04
S2	48.79 ±1.10	54.99 ±0.54	53.62 ±0.62	56.13 ±0.17	51.41 ±0.18	54.62 ±0.82	53.01 ±0.69	56.47 ±0.07
S3	47.69 ±1.46	51.94 ±0.94	51.55 ±0.42	56.03 ±0.25	52.36 ±0.16	53.53 ±0.90	50.81 ±0.96	56.60 ±0.07
S4	45.34 ±1.21	53.41 ±0.77	51.85 ±0.40	54.91 ±0.53	52.17 ±0.20	54.01 ±0.55	50.17 ±1.37	56.39 ±0.04
S5	46.94 ±1.41	53.90 ±0.43	52.55 ±0.23	53.78 ±1.20	51.61 ±0.14	54.40 ±0.20	49.73 ±0.35	54.96 ±0.75
Mean ± S.E.	47.69 ±0.75	53.82 ±0.55	53.03 ±0.72	55.42 ±0.47	51.80 ±0.20	54.34 ±0.27	51.33 ±0.69	56.16 ±0.30

Values are Mean ± standard error

The present study results are in agreement with trends observed by many other workers like Shephered and Montagnini (2001), Dhruw *et al*. (2009), Jana *et al*. (2009), Navar (2009) and Fonseca *et al*. (2012), who reported carbon per cent was higher in stem wood, followed by root, branch, bark and leaf. Kraenzel *et al*. (2003) reported that woody tissues like trunk, roots, branches and twigs have higher carbon content than soft tissues like leaves, flowers and fine roots.

Phyto-sociological attributes for shrub and herb layer:-

In pine forest the biodiversity in terms of grasses, herbs and shrubs were studied and results are presented in Table 5. Fifteen species of herbs, shrubs and grasses were observed in the pine forest under study. Species density was 4556 herbs, shrubs or grasses/ha. Individual species density ranged between 160 herbs or shrubs/ha (Lepidium sp., *Murraya koiengii*, *Parthenium hysterophorus*, *Viola serpens*and *Veronica cinerea*) to 424 herbs or shrubs/ha (*Adiantum pedatum*). Minimum frequency was of *Parthenium hysterophorus* (0.3%) while *Chrysopogon montanus* (1.35%) had maximum frequency. Abundance varied from 400 herbs or shrubs/ha (*Carrisa carandus* and *Rubus ellipticus*) to 1312 herbs or shrubs or grasses/ha (*Themada anathera*). A/F ratio ranged from 1.11 (*Rubus ellipticus*) to 10.0 (*Parthenium hysterophorus* and *Veronica cinerea*). Singh *et al*. (2009) reported the quantitative information of pine forest in Garhwal Himalayas and found that the associated ground floras with pine trees were *Asparagusracemosus*, *Rhus parviflora*, *Lantana camara*, *Carrisa spinarum*, *Mallotus phillipensis*, *Nepta hindostana*, *Artemisia scorpia* and *Colebrookia appositifolia*. Singh *et al*. (2013) also reported that the most dominating shrub species associated with pure chir pine forest was *Eupatorium cannabinum* (6200 shrubs/ha) followed by *Asparagusracemosus*. Inspite of the fact that chir pine forests in western Himalaya and Central Himalaya grew as natural monoculture there was variability with respect to under storey species. This is attributed to facts like geology of region, tree species age and density aspect, etc.

Table 5:-Phytosociological attributes of vegetation in pine forest during two years of study.

Sr. No.	Species	Density(Herb or shrub/25 m^2)	Frequency (F) (%)	Abundance (A) Herb or shrub/25m^2	A/F ratio
1	*Adiantum pedatum*	1.06 (424)	0.75	3.20 (1280)	4.26
2	*Bidens alba*	0.26 (104)	0.45	1.30 (520)	2.95
3	*Carrisa carandus*	0.26 (104)	0.60	1.00 (400)	4.26
4	*Cheilanthes lanosa*	0.73 (292)	0.75	3.20 (1280)	4.26
5	*Chrysopogon montanus*	1.86 (744)	1.35	3.11 (1244)	2.30
6	*Lepidium sp.*	0.40 (160)	0.60	1.50 (600)	2.50
7	*Myrsine africana*	0.50 (200)	0.60	2.00 (800)	3.33
8	*Murraya koiengii*	0.40 (160)	0.45	3.00 (1200)	6.60
9	*Parthenium hysterophorus*	0.40 (160)	0.30	3.00 (1200)	10.00
10	*Potentilla indica*	0.60 (240)	0.60	2.25 (900)	3.75
11	*Rubus ellipticus*	0.46 (184)	0.90	1.00 (400)	1.11
12	*Themada anathera*	3.06 (1224)	2.10	3.28(1312)	1.56
13	*Veronica cinerea*	0.40 (160)	0.60	1.50 (600)	10.00
14	*Viola serpens*	0.40 (160)	0.45	3.00 (1200)	6.60
15	*Woodfordia fruiticosa*	0.60 (240)	0.90	1.50 (600)	1.66
Total value		11.39 (4556)	12.40	25.45 (13536)	65.14
Mean value		0.75 (303.73)	0.82	2.12 (902.4)	4.34

Data given in parenthesis are quantification per hectare (density and abundance are of shrubs or herbs per hectare):-

Soil characteristics:-

Soil pH, bulk density and available phosphorus increased from top to bottom while soil organic carbon, available nitrogen, available potassium and electrical conductivity decreased from top to bottom during both years of study as shown in Table 6.The organic carbon in pine forest during present study varied from 0.24% to 0.77%. It decreased from top soil profile (0-15 cm) to sub-soil profile (30-60 cm). Soil organic carbon showed a significant variation between different study sites and soil depths. In the earlier studies, Dalai (1997) studied soil of Chirpine forest of Oachghat and Kandaghat areas of Solan District (HP) and found organic carbon of 1.34 and 1.05%, respectively. Sharma (1991) analysed the soil under Chirpine forest of Solan forest division and found soil organic carbon between 0.17 to 3.37%. Jina *etal*. (2011) reported that organic carbon ranged from 1.65to 2.76%, respectivelyin degraded and non-degraded pine forest in Kumaun Himalayas which is higher in comparison to present study. The influence of topography, climatic conditions, soil composition, litter quality and its decomposition rate and species composition or vegetation type affect spatial distribution of soil organic carbon (Schulp *et al*., 2008).

Nitrogen measured at various soil depths in different sites in pine forest showed non- significant variation and it ranged from 194.32 to 280.0 kg/ha and decreased depth wise. Malik (1992) reported that available N varied from 94.0 to 233.0 ppm in Chirpine forests of Solan district. Many other researchers found variability in nitrogen in chir pine forests of Himachal Pradesh (Sud and Sharma, 1982; Murthy *et al*., 1985). Dalai (1997) analysed soil nitrogen under Chirpine forest of Oachghat and Kandaghat and found average nitrogen of 337.98 kg ha^{-1} and 324.05 kg ha^{-1}, respectively, which is higher in comparison to present work. Available phosphorus in pine forest varied from 0.18 to 0.30 kg/ha significantly during the present study. Phosphorus content increased with depth in soil layers of pine forest. Singh *et al*. (1990) found the same trend in chir pine forest of Doon valley. Dalai (1997) reported high phosphorus (30.42 and 27.33 kg ha^{-1} for Oachghat and Kandaghat, respectively) compared to present study.

Potassium ranged from 128.1 kg/ha to 269.2 kg/ha significantly during two years of study anddecreased from top soil profile to sub-soil profile. Dalai (1997) reported average potassium content of 562.95 kg ha^{-1} and 425.98 kg ha^{-1} for Oachghat and Kandaghat, respectively in the chir pine forest. Singh *et al*. (2009) reported potassium ranged from 89.98 to 116.48 per cent in pine-mixed forest in Garhwal Himalaya. Kaushal (1992) reported more available K in surface than sub-surface soils of Kinnaur district of Himachal Pradesh. The variability in K is understandable as it is a known fact that the Himalayan topography and soil structure varies from place to place.

Table 6:- Physico-chemical properties at different soil layers in Pine forest.

Soil depth / Parameters	Depth 0-15 cm		Depth 15-30 cm		Depth 30-60 cm	
	1st year	2nd year	1st year	2nd year	1st year	2nd year
% Organic carbon	0.47±0.03# (0.03)*	0.77±0.10 (0.001)	0.34±0.02 (0.003)	0.59±0.11 (0.002)	0.24±0.03 (0.005)	0.36±0.05 (0.001)
Available Nitrogen	267.8±27.4 (9.33)	280.0±28.9 (9.33)	212.64±10.0 (0.75)	227.7±17.1 (9.33)	194.32±7.46 (0.98)	224.76±13.2 (9.33)
Available Phosphorus	0.18±0.03 (0.01)	0.23±0.01 (0.01)	0.24±0.01 (0.01)	0.24±0.01 (0.01)	0.30±0.01 (0.01)	0.30±0.03 (0.01)
Available Potassium	215.8±28.05 (0.001)	269.21±12.0 (0.001)	166.4±31.33 (0.002)	257.2±12.9 (0.002)	128.1±26.7 (0.003)	242.33±14.2 (0.003)
pH	6.50±0.11 (0.01)	6.58±0.06 (0.02)	6.63±0.13(0.02)	6.66±0.08 (0.02)	6.72±0.03 (0.01)	6.67±0.06 (0.03)
Bulk density	1.15±0.01 (0.02)	0.40±0.02 (0.02)	1.18±0.01 (0.01)	0.43±0.02 (0.02)	1.23±0.01 (0.03)	0.48±0.01 (0.01)
Electrical conductivity	1.17±0.01 (0.01)	1.22±0.01 (0.02)	1.14±0.01 (0.01)	1.16±0.01 (0.01)	1.09±0.03 (0.02)	1.14±0.20 (0.03)

#Values are Mean ±Standard error
***Values inside the parenthesis are p<0.05= Significant**

Soil pH in the present investigation varied significantly from 6.50 to 6.72. It increased from the top soil profile to sub-soil profile. Slightly acidic to neutral pH could be ascribed to pine needles rich in resins which on decomposition release organic acids in soil. Sharma (1991) analysed the soil under Chirpine forest of Solan forest division and found that the soil had 5.0 to 8.0 pH. Malik (1992) reported pH value ranged from 5.1 to 7.9 and increased with depth under all Chirpine association in forest of Solan Division. Dalai (1997) found that the Chirpine forest soil had average pH value between 5.87 and 5.74 for Oachghat and Kandaghat forests, respectively. The reduction in pH can be attributed to accumulation and subsequent slow decomposition of organic matter, which releases acids (de Hann 1977; Singh *et al*., 2009). The electrical conductivity in pine forest varied from1.09dSm^{-1}to 1.22dSm^{-1}. Electrical conductivity decreased depth wise and showed significant variation between study sites and soil depth. Similar results were reported earlier by Shah *et al*. (2013) in pine forest in Solan district of Himachal Pradesh. Bulk density ranged from 0.43-1.23g cm^{-3}.

Conclusion:-

The present study reveals that study area under investigation is rich in carbon stock both in terms of plantation as well as soil. Total vegetation carbon stock in pine forest was 69.52 Mg/ha/year which accounted for carbon sequestration of 255.13 Mg/ha/year. Soil carbon inventory pool was 1117.8 Mg/ha/year. Forest based land use systems could be among the best methods for storing atmospheric CO_2 because of its cost effectiveness and other social and economic benefits. Among the tree components stem wood contributed for 54.22%, roots contributed for 53.74%, branches contributed for 53.07% and leaves for the 50.75% carbon allocation. Nutrient storage ranged from 0.24-0.77% organic carbon, 194.32 to 280.0 kg N ha^{-1}, 0.18 to 0.30 kg P ha^{-1}, 128.1 to 269.2 kg K ha^{-1}, 6.50 to 6.72 pH, 1.09 to 1.22 dSm^{-1} electrical conductivity and 0.43 to 1.23 g cm^{-3} bulk density. Therefore it can be concluded from the present research that pine forests plays very potent and promising role in the building up of carbon stock and consequently climate change mitigation. Pine forests are very vital natural carbon reserve that has to be protected and conserved. The further study is needed on tree-soil interactions and litterfall with different tree management practices for maximizing sequestration of carbon and attaining sustainable production from Pinus roxburghii stands.

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