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

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**Manuscript Info**

**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 1.0/25m² or 400 herbs or shrubs/ha to 3.28/25m² or 1312 herbs/shrubs or grasses/ha. A/F ratio ranged from 1.11 (*Rubus ellipticus*) to 10.0 (*Parthenium hysterophorus* 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 and 1.09 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 0.43-1.23 g cm⁻³, respectively and increased depth wise.

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**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 km² 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 in Bajhol village, Solan district (H.P.), during the growing seasons (July-November) of the years 2010 and 2011. Solan district lies between 30° 50'30" N-30° 52'30" N latitudes and 77° 8’30” E-77°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°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°C during winter (January) to 33°C during summer (June), whereas mean annual temperature is 19°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 also collected, 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.

Carbon allocation 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°C for 5 hours in muffle furnace for combustion. After cooling, sample was weighed and percent organic carbon was calculated.

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\text{Percent Organic Carbon} = \frac{\text{Weight of loss} \times 0.58}{\text{Sample weight}} \times 100
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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 Black Method (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 parameters was 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. Total vegetation biomass was 156.7 Mg/ha/year and which contrib-
uted 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).
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 tree biomass (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) | 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.                          | ± 3.36                          | ± 4.03                                | ± 1.51                          | ± 0.30                           | ± 1.81                               | ± 0.02               | ± 0.01                         | ± 2.95 ± 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_ average carbon 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 Ganeshiah 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 ± 0.52   | 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  | 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 Shepered 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 herbes, shrubs or grasses/ha. Individual species density ranged between 160 herbes or shrubs/ha (*Lepidium sp.*, *Murraya koenigii*, *Parthenium hysterophorus*, *Viola serpens* and *Veronica cinerea*) to 424 herbes 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 herbes or shrubs/ha (*Carrisa carandus* and *Rubus ellipticus*) to 1312 herbes 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 *Asparagus racemosus*, *Rhus parviflora*, *Lantana camara*, *Carrisa spinarum*, *Mallotus philipensis*, *Nepta hindostana*, *Artemisia scopia* 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 *Asparagus racemosus*. 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.
during present study varied from 0.24% to 0.77%. It decreased 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 in mixed forest in Garhwal Himalaya. Kaushal (1992) reported high available K in degraded pine forest in Kumaon Himalayas which is higher in comparison to present study.

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

| Sr. No. | Species                  | Density (Herb or shrub/25 m²) | Frequency (F) (%) | Abundance (A) Herb or shrub/25m² | 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 carandas         | 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 koengii          | 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 fruticosa     | 0.60 (240)                    | 0.90             | 1.50 (600)                       | 1.66      |
| Total   |                          | 11.39 (4556)                  | 12.40            | 25.45 (13536)                    | 65.14     |
| Mean    |                          | 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 division and found soil organic carbon between 0.17 to 3.37%. Jina et al. (2011) reported that organic carbon ranged from 1.65% to 2.76%, respectively in 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 and decreased 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.
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 contributed for 53.07% and leaves for the 50.75% carbon allocation. Nutrient storage ranged from 0.24 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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