BIOMASS AND CARBON STOCK OF *Pinus roxburghii* Sarg. IN JAMMU & KASHMIR

by
Kuldeep Joshi
(J-18-D-340-A)

Thesis submitted to
Faculty of Agriculture
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

IN

AGROFORESTRY

Division of Agroforestry
Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu
Main Campus, Chatha, Jammu 180 009

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CERTIFICATE - I

This is to certify that the thesis entitled **"Biomass and Carbon Stock of *Pinus roxburghii* Sarg. in Jammu & Kashmir"** submitted in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Agroforestry** to the Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, is original work and has similarities with published work not more than minor similarities as per UGC norms of 2018 adopted by the University. Further, the level of minor similarities has been declared after checking the manuscript with Urkund software provided by the University.

The work has been carried out by **Mr. Kuldeep Joshi,** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma. It is further certified that help and assistance received during the course of thesis investigation have been duly acknowledged.

Sandeep Sehgal

Dr. Sandeep Sehgal
(Major Advisor)

Place: Chatha, Jammu
Date: 03-08-2022

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CERTIFICATE-II

We, the members of Advisory Committee of **Mr. Kuldeep Joshi,** Registration Number **J-18-D-340-A,** a candidate for the degree of **Doctor of Philosophy in Agroforestry,** have gone through the manuscript of thesis entitled **"Biomass and Carbon Stock of *Pinus roxburghii* Sarg. in Jammu & Kashmir"** and recommend that it may be submitted by the student in partial fulfillment of the requirements for the degree.

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This is to certify that thesis entitled **"Biomass and Carbon Stock of *Pinus roxburghii* Sarg. in Jammu & Kashmir"**, submitted by **Mr. Kuldeep Joshi**, Registration No. **J-18-D-340-A**, to the Faculty of Agriculture, Sher-e- Kashmir University of Agricultural Sciences and Technology, Jammu, in partial fulfilment of the requirements for the degree of **Doctor of Philosophy** in **Agroforestry**, was examined and approved by the advisory committee and external examiner (s) on 28-10-2022

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To the sovereign God, I give all the glory". Emotions cannot be adequately expressed in words. Because then, emotions are transferred into mere formality and formalities have to be completed. Acknowledgement in true essence, gives us an opportunity to remember and express our feelings for those whom we have and revere. When going gets tough and with gratitude, tougher, the helping hand offered then by all the near and dear ones is always remembered

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Place: Jammu
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Kuldeep Joshi

ABSTRACT

Title of the thesis	:	Biomass and Carbon Stock of *Pinus roxburghii* Sarg. in Jammu & Kashmir
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ABSTRACT

The present study entitled **"Biomass and Carbon Stock of *Pinus roxburghii* Sarg. in Jammu & Kashmir"** was carried out in the *Pinus roxburghii* dominated forests of Jammu division, J&K in the year 2020-2021. The objective of the study was to estimate the tree biomass and carbon stock of *Pinus roxburghii* and its capacity in sequestering CO_2. The study sites were located in the district Jammu, Samba, Kathua, Udhampur and Reasi. Two sites from Lower or Siwalik Chir Pine forest ($9/C_{1a}$) (Site I & III) and two sites from Upper or Himalayan Chir Pine forest ($9/C_{1b}$) (Site II & IV) were selected. Ten quadrates of 20 x 20 m^2 were laid out randomly at each site. Diameter at breast height (dbh) and tree height were measured. The mean tree volume was determined with the help of species specific regression equation.

The results showed that the maximum (51.21 cm) mean tree diameter was recorded at site I. Tree height at all sites was non-significant. Mean stem volume and mean tree density was recorded highest (293.14 m^3 ha^{-1} and 342 trees ha^{-1}) from site II, whereas, mean tree basal area was maximum (41.22 m^2 ha^{-1}) at site IV. Biomass and Carbon content in per unit volume of plant part i.e. above and below was significantly different among the forest types. Himalayan Chir Pine forest recorded comparatively higher biomass and carbon stock than Siwalik Chir Pine forest. Above ground biomass density (AGBD), below ground biomass density (BGBD) and total biomass density (TBD) was recorded highest (174.10 Mg ha^{-1}, 48.75 Mg ha^{-1} and 222.85 Mg ha^{-1} respectively) from the site II. The distribution of carbon stock in various components of tree also followed the same trend as that of biomass. Potential of sequestering CO_2 was observed high in Himalayan Chir Pine forest which was maximum (384.39 Mg ha^{-1}) at site II.

Significant differences were observed in soil physico-chemical properties from different sites in *Pinus roxburghii* forests except for soil bulk density and soil electrical conductivity. The soils at all the sites were acidic in nature. Soil organic carbon (SOC) varied significantly at both the soil depths (0-30 cm and 30-60 cm), where highest (13.38 gm kg^{-1} and 9.80 gm kg^{-1}) values of mean SOC for both the soil depth were recorded from site II. Nitrogen and Potassium were recorded highest from site II. Soil texture analysed at all the sites was mostly clayey.

Keywords: Biomass, carbon stock, carbon sequestration, *Pinus roxburghii*, Jammu J&K

Signature of Major Advisor

Signature of the student

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INTRODUCTION

CHAPTER-1

INTRODUCTION

Global warming has become a major issue in today's time, which is responsible for the global climate change. It refers to the gradual rise in the earth's temperature due to green house effect. Though, six greenhouse gases (GHGs) (carbon dioxide, chlorofluro carbons, ozone, methane, water vapour and nitrous oxide) have been listed for this change, out of them carbon dioxide ($CO_{2)}$ is about 76%, (EPA, 2017) making it the major contributor. Different anthropogenic activities such as burning of fossils fuel, deforestation and change in land use and land cover (LULC) are responsible for this increase in CO_2 level. CO_2 act as one of the major carbon pool in the atmosphere and its rising level from the required optimum level is of concern. In the last decade (2010-21) the concentration of CO_2 in the atmosphere has increased from 391 to 414.66 ppm (NOAA, 2021). Growing global concern over increasing levels of CO_2 in the atmosphere has led to underlining the various mitigation options.

Forest carbon sequestration is one of the key approaches to reducing atmospheric carbon, they act as a living biomass that in traps CO_2 through photosynthesis, stores it in the form of wood for a longer period and act as one of the major option for climate change mitigating. Biomass can be defined as the total quantity of organic matter, above and below ground (AGB and BGB) expressed in terms of dry matter per unit area. Approximately carbon constitutes 50% of the dry weight of biomass which is used for estimating the amount of CO_2 in trapped from the atmosphere. Globally, forests cover an area of 4.06 billion ha i.e. 31% of total land area, that contains 557 billion m^3 of growing stock with a total of 606 gigatonnes of living and 59 giagatonnes of dead wood (FAO, 2020). Both living and dead biomass are used for measuring structure and function of a forest hence this measurement is important for scientific studies on ecology and carbon budgeting.

Geographical location, vegetation type, its structure, age gradation and its composition will determine the forest carbon stock. Primarily there are three types of forest in India i.e. tropical, subtropical and temperate. In Jammu and Kashmir (J&K) we have subtropical to temperate forest types resulting into large plant diversity. The dominant forest tree species of J&K are *Cedrus deodara*, *Picea smithiana*, *Abies pindrow*, *Pinus wallichiana*, *Quercus leucotrichophora*, *Betula utlis*, *Platinus* *orientalis*, *Salix alba*, *Pinus roxburghii*, *Acacia catechu*, *Acacia modesta* etc. Among these tree species *Pinus roxburghii* Sarg. is distributed very well in the subtropical belt of the union territory covering an area of 1.92 lac ha and confined to Jammu province (Anonymous, 2013). Therefore knowledge of this species with respect to its carbon sequestration potential at a particular location is essential.

Pinus roxburghii Sarg. or commonly known as Chir Pine or Himalayan long needle pine is a evergreen, gregarious species belonging to the family Pinaceae, distributed in the outer Himalayan ranges and on the ridges of Shivalik hills at an elevation of 900-1800 m in pure form mostly on quartzite soil and descending down to 500 m and ascending up to 2200 m in mixed form. It has a wide distribution, stretching from Afghanistan in west to Bhutan in the east, extending over an estimated area of 8.90 lac ha (Jasrotia and Raina, 2017). In India it is found in the state of Jammu and Kashmir, Himanchal Pradesh, Uttarakhand, West Bengal, Sikkim and Aruanchal Pradesh (Fule *et al*., 2021). It is an indigenous tree species preferring hotter slopes and drier areas in the higher elevations. In the Siwalik area it is found in groups in the form of strips in association with broad-leaved species (Sharma and Baduni, 1998). It is a strong lighter demander fast growing; frost, fire and drought hardy tree. Chir Pine trees can grow from 30 to 50 m in height with a trunk diameter that can exceed 2 m. Height up to 54 m and girth up to 3 m have been reported from the Tons valley in Uttarakhand. Chir Pine is an economically very important tree species in the Himalayan region it is used as a timber, fuel wood, for packing cases, charcoal making, dye, herbicide, ink, and resin. As a timber it’s not a preferred species but is used as a torchwood, bark as fuel for rural furnaces, needles as broom and as thatching material moreover they are also used for bedding purpose for cattle. Oleo-Resin tapped from this species is internationally very important product; India is one of the top oleo-resin producing nations (Cunningham, 2012) Therefore, its quantification in regard to carbon sequestration is essential. Also it is useful for achieving the targets of $REDD^+$ (Reducing Emission from Deforestation and Forest Degradation) policy initiated at the Kyto Protocol (Djomo *et al*., 2010).

Soils also act as sink for carbon, different plant material (soil organic matter SOM) such as leaves, twigs, branches and roots get decomposed on forest floor, add organic matter and nutrient to the soil. Carbon present in the soil, is in the form of soil organic carbon (SOC). It is the largest carbon reservoir in many terrestrial ecosystems comprising as much as 98% of ecosystem carbon stocks (Harmon, 1986). It has been estimated that SOC sequestration has the potential to mitigate 5-14% of total annual greenhouse gas emissions for the next 50-100 years (Chan, 2008), therefore accumulation and turnover of SOM is the major factor in soil fertility and ecosystem functioning and determining whether soils act as sink or source of carbon in global carbon cycle. Continuous accumulation of forest litter and its decomposition tends to increase the soil carbon in the top soil strata up to a depth of about 100 cm which is maximum at 30 cm depth. According to Lal (2004) soil stores 4.5 time more carbon than vegetation, therefore its estimation is very essential. Soil carbon sequestration is a long-term, cost-effective and efficient approach for enhancing soil characteristics and quality. SOC, SOM and their correlations with bulk density are frequently used to estimate carbon pools. Bulk density values are inversely related to soil organic matter: as SOM increases, bulk density (BD) decreases (Curtis and Post, 1964).

Attempts have been made by many researchers to estimate the biomass and carbon stocks of different species in the country and their active role in sequestering the atmospheric $CO_{2.}$ In the Union territory of Jammu & Kashmir (JKUT) *Pinus roxburghii* forms one of the primary tree species but still there is a lack of availability of data in this regard. Therefore the present study was taken up in the two sub type Pine forests to estimate the total carbon stock and their role in sequestering the atmospheric CO_2 with their future potentials in mitigating climate change.

Thus, the proposed research **"Biomass and Carbon Stock of *Pinus roxburghii* Sarg. in Jammu & Kashmir"** was carried out in the subtropics of Jammu division with the following objectives:

- To estimate the biomass and carbon stock of *Pinus roxburghii* in subtropical pine forests of Jammu division, J&K.
- To analyse the physical and chemical properties of soil in the study area.

CHAPTER-II
REVIEW OF LITERATURE

CHAPTER-2

REVIEW OF LITERATURE

Forests are the major sink of carbon that provides long term storage. Different forest types, species composition, its density and site quality are the basic parameters which determine the rate at which the forest are responsible of sequestering the atmospheric CO_2. Same species will behave differently under different climatic condition and geographical location. Considering this, an attempt has been made to review the available literature on carbon stock in *Pinus roxburghii* under following sub-headings:

2.1 Biomass and carbon stock in *Pinus roxburghii* and related species.

2.2 Soil physico-chemical properties of Himalayan forests.

2.1 Biomass and Carbon stock in *Pinus roxburghii* and related species

Sharma and Singh (2010) carried out a field study in Solan forest division of Himanchal Pradesh to determine the carbon sequestration potential of six type of land use namely Chir Pine (1200-1500 m), Deodar (1500-2100 m), Ban Oak (1500-2100 m), broadleaved (900-1200 m), cultivable and un-cultivable. They reported that the current annual increment (CAI) increased with increase in elevation. Among all the species Chir Pine reported the highest (2.50 CAI ha^{-1}) CAI followed by Deodar (1.22 CAI ha^{-1}), broadleaves (0.78 CAI ha^{-1}) and Ban Oak (0.73 CAI ha^{-1}) respectively. However, they also reported that among all the four forest type, broadleaved forest will have higher carbon (920.60 t ha^{-1}), followed by Deodar (681.80 t ha^{-1}), Ban Oak (443.00 t ha^{-1}) and Chir Pine (204.35 t ha^{-1}) respectively.

Lodhiyal and Lodhiyal (2012) conducted a field study in the Lohaghat, Champawat district of Uttarakhand to compare the biomass and carbon stock within the *Pinus roxburghii* (Chir Pine) and *Quercus leucotrichophora* (Ban Oak) in the study area. Ban Oak reported to have significantly higher biomass and carbon stock of 101.45 t ha^{-1} and 59.41 t ha^{-1}, whereas, Chir Pine reported to have 26.64 t ha^{-1} and 13.45 t ha^{-1} respectively. Carbon sequestration potential of Chir Pine was also very low compared to that of Ban Oak.

Comparative study between the sub tropical Chir Pine forest and sub tropical broadleaved forest was done by Nizami (2012) to estimate the carbon stock in

Pakistan's sub tropical forests. Pine forest included Ghoragali (site-I) and Lethterar (site-II) sites whereas, broadleaved (*Acacia modesta* and *Olea ferrugines*) forest included Sohawa (site-III) and Kherimurat (site-IV) sites. Chir Pine represented higher stem density (878 trees ha^{-1} in site-I and 776 trees ha^{-1} in site-II) from broadleaved forest which is due to its straight growing nature. The mean baSal area was also comparably higher in Chir Pine forest than broadleaved. Similarly, total tree biomass and total tree carbon stock were also higher in chir forests. For site I and II total tree biomass and total tree carbon stock was 237 t ha^{-1}, 119 t ha^{-1} and 186 t ha^{-1}, 92 t ha^{-1} respectively.

Chir Pine forests are the large reservoir of carbon but at the same time they act as a source for atmospheric carbon due the accidental or intentional fires. An attempt was made by Guleria *et al*. (2013) to study the loss of carbon by fire in the Chir Pine forest of Nurpur range of Himanchal Pradesh. The data was collected for four years after the incidence of fire and according to the result obtained by them it reveals that there was no significant variation in tree biomass. However, unevenness was found in the annual growth rings at some interval which could be due to the fluctuation in temperature around the trees. Significant variation was recorded in biomass and carbon stock of Chir Pine needles fallen on ground. It was recorded very less (2.16 Mg ha-^{1}) in the current year after the fire and considerably higher (7.20 Mg ha^{-1}) after five years. Similarly, the same trend was also observed for grasses and shrubs whose population increased gradually with the time after the incidence of fire, hence biomass and carbon stock increased with time.

Joshi *et al*. (2013) carried out a field study to estimate the carbon stock after forest fires in the two forest types (Himalayan moist temperate Oak forest and subtropical Pine forest) of Lamgara developmental block in Almora district of Kumaun Uttarakhand. The study area was managed by Dhaili and Toli van panchayat under community forests and the two slope aspect (south-west and north-west) were considered in them. Chir Pine reported to have maximum tree density and maximum baSal area in south west aspact of both the van panchayat. Whereas, the north-west aspect were dominated by Oak. Regular forest fire had a positive correlation with the tree density and baSal area of Chir Pine whereas, it was negative for other species. On the other hand regular outbreak of forest fires reduced the number of seedlings and saplings. Biomass production and carbon stock was reported maximum from north-west (Oak mixed) aspect than south-west (Pine mixed). The south-west aspects are highly prone to forest fires and moisture is the limiting factor in them which reduces the plant density and diversity. Overall Toli van panchayat recorded the maximum biomass and carbon stock.

Northern aspects are reported to have higher biomass than southern aspects as it is less exposed to solar radiation and less or no forest fire, which results in higher plant density and diversity. Pant and Bargali (2013) reported that Khahalqueera-Shyamkhet Chir Pine forest (northern aspect) had higher biomass than Khurpatal Chir Pine forest (southern aspect) of Nainital Uttarakhand. Biomass ranged from 317.86 t ha^{-1} to 530.66 t ha^{-1} at Khahalqueera-Shyamkhet which higher than 59.99 t ha^{-1} to 333.89 t ha^{-1} at Khurpatal. Carbon sequestration rate was also higher in north aspect than south which ranged from 2.7 t ha^{-1} yr^{-1} to 10.82 t ha^{-1} yr^{-1} at Khalaqueera-Shyamkhet and 0.54 t ha^{-1} yr^{-1} to 3.7 t ha^{-1} yr^{-1} at Khurpatal Pine forest. Similar type of results have been reported by Pant and Tewari (2013) while studying the role of aspects in determining the carbon stock of *Pinus roxburghii* forests of Kumaun Himalaya between 1650-1860 m elevations.

Pant and Tewari (2014) studied variations in tree biomass and carbon sequestration rates of Chir Pine forest in three categories of forest disturbance, viz. protected, moderately disturbed, and highly disturbed. The sites were Kailakhan forest (protected), Pine area forest (moderately disturbed) and Baliya Nala forest (highly degraded) located near to Nainital town in Kumaun central Himalaya, Uttarakhand. In the first year, total biomass was 14.7 t ha^{-1} in highly disturbed site, 94.46 t ha^{-1} in moderately disturbed forest, and 112.0 t ha^{-1} in protected forest. The soil organic carbon in the top 20 cm of soil ranged from 0.63 to 1.2%. The rate of carbon sequestration was 0.60 t ha^{-1} yr^{-1} on the highly disturbed site, 1.03 t ha^{-1} yr^{-1} on the moderately disturbed site, and 4.3 t ha^{-1} yr^{-1} on the protected site.

A field survey was done by Shah *et al*. (2014) to access the temporal change in carbon stock from 1956 to 2011 in the Chir Pine forest of Dharampur and Solan range of Solan forest division of Himanchal Pradesh. Total carbon stock variation in the Solan range for the year 1956, 1984, 2002 and 2011 was 6152.38 t ha^{-1}, 4235.93 t ha^{-1}, 4371.56 t ha^{-1} and 5359.91 t ha^{-1}. Whereas, for the Dharampur range it was 14756.28 t ha^{-1}, 7796.86 t ha^{-1}, 13862.57 t ha^{-1} and 15229.78 t ha^{-1} respectively. From the year 1956 to 1984 there was a significant reduction in the carbon stock in both the ranges, whereas, the reverse trend was observed in between 1984 to 2002 and from 2002 to 2011 which was due the complete ban on green feeling by the state government in 1990 which prevented further deterioration of forest cover and facilitated new regeneration.

Vikrant and Chauhan (2014) reported that conifer dominated forest have higher carrying capacity of carbon stock than broad leaf dominated forests. As ground vegetation is limited in Pine forests due to which grazing is less and the dependency of villagers for livelihood is less as compared to Oak forests. Therefore the human disturbances also influence the carbon stock of the forest.

Living biomass is actively involved in sequestering the atmospheric carbon where as the dead biomass act as a sink and retains it for a very long time and release it through nutrient cycling. Kumar (2015) made an attempt to study the volume, biomass and carbon entrapped by dead standing Chir Pine trees in Tehri Garhwal region of Uttarakhand. The site selected by him had standing dead Pine trees only on the southern aspect while they were absent on other aspects. Dead tree density varied from 11.00 to 17.75 trees ha^{-1}. Volume of dead trees ranged from 16.39 to 28.53 m^3 ha^{-1}. The above ground carbon among dead standing Chir Pine trees varied from 7.79 t ha-1 to 13.55 t ha-1. Whereas, the maximum and minimum below ground carbon measured was 4.46 t ha^{-1} and 2.61 t ha^{-1} respectively.

Ahmed and Sharma (2016) estimated the biomass and carbon stock in the Ponda watershed region of the Rajouri forest range in Rajouri, Jammu and Kashmir, India. 52.46 % of the watershed area was covered by the Chir Pine forest. The total growing stock, total biomass and total carbon stock in dense Pine forest was 141420.25 m^3, 69414.57 t and 31229.79 t. Similarly for open Pine forest it was reported as 55785.37 m^3, 27386.37 t, 12320.30 t, and for degraded Pine forest it was reported as 2032.98 m^3, 997.18 t, 447.68 t respectively.

In a field study of Chir Pine forest in the Bajhol village of Solan district in Himanchal Pradesh, Kaur and Kaur (2016) estimated a total of 144.90 Mg ha^{-1} tree biomass with 120.70 Mg ha^{-1} and 24.08 Mg ha^{-1} of AGB and BGB tree biomass respectively. Whereas, the total tree carbon stock estimated was 65.22 Mg ha^{-1} with a total forest vegetation biomass and carbon stock of 154.50 Mg ha^{-1} and 72.27 Mg ha^{-1}

respectively. The potential of Chir Pine forest in sequestering atmospheric carbon was estimated to be 255.13 Mg ha^{-1} Yr^{-1}

Shaheen *et al*. (2016) carried out a study in the five forest types in Muzaffaradbad district of Kashmir (POK) to estimate the biomass and carbon stock in standing trees. AGB was calculated using species specific allometric equations. The total average biomass and carbon stock was 151.38 t ha^{-1} and 186.27 t ha^{-1}. Among all the tree species *Pinus roxburghii* contributed the highest (63.35%), followed by *Olea cuspidate* (22.76%), *Dalbergia sissoo* (3.96%) and least biomass and carbon stock was reported in *Melia azedarach* (0.37%).

Banday *et al*. (2017) did a comparative study between the different forest types present in the district of Solan, Bilaspur and Hamirpur of Himanchal Pradesh falling within the altitudinal range of 600-1500 m. Surveying 0.1 ha area in each forest type they reported that lowest carbon stock was present in northern mixed dry deciduous forest < lower Shivalik Pine < planted Chir Pine < Himalayan Chir Pine < Sal forest respectively. They reported that tree biomass had positive relationship with average DBH, carbon density, stem volume and ecosystem carbon density.

Jasrotia and Raina (2017) estimated the temporal variation in carbon biomass storage of *Pinus roxburghii* forests of Rajouri forest division in Jammu & Kashmir between 1995-96 and 2015-16. Results of the study revealed that despite an increase in Chir Pine tree density from 132.60 trees/ha during 1995-96 to 197.61 trees/ha during 2015-16, the growing stock as well as aboveground tree biomass of Chir Pine forests, was 16.28 lac m^3 and 9.73 lac t in 1995-96, declined to 12.10 lac m^3 and 7.24 lac t, respectively by 2015-16. Similarly, the total C stocks of Chir Pine forests (aboveground + belowground), which stood at 5.90 lac t during 1995-96, declined to 4.39 lac t, a decrease of 25.59% in assessment period. In line with these changes, the C density of these forests also witnessed a decline from 58.95 Mg ha^{-1} to 43.84 Mg ha^{-1}. Such declining trends definitely indicated forest degradation and poor forest health, due to increased anthropogenic pressure on forests in the division**.**

A field survey in Ukhimath block of Rudraprayag district in Uttarakhand to estimate the biomass and carbon stock of standing trees and soil in *Pinus roxburghii* forests of Garhwal was conducted by Mishra (2017). Carbon stock of the standing tree was estimated using species-specific allometric equations. *Pinus roxburghii* (327 tree ha^{-1}) dominated the forest with the presence of fewer individuals of *Rhododendron arboreum* (33 tree ha^{-1}), *Myrica esculenta* (20 tree ha^{-1}), *Pyrus pashia* (13 tree ha^{-1}) and *Lyonia ovalifolia* (10 tree ha^{-1}). Above Ground Biomass ranged from 85.17 Mg ha^{-1} to 144.30 Mg ha^{-1}, Belowground biomass from 19.47 Mg ha^{-1} to 31.73 Mg ha^{-1}. Total carbon in the standing trees ranged from 49.18 Mg C ha^{-1} to 82.73 Mg C ha-^{1}.

Amir *et al*. (2018) carried out an inventory in the Pine forest of Muree hills of Pakistan to study the distribution pattern of biomass and carbon allocation across a chronosequence. The study revealed that the range of average tree density in younger stand varied from 636 ± 93.70 trees ha^{-1} and in over matured it ranged 147 ± 56.70 trees ha^{-1}. Similarly the baSal area in over matured (>75 years), matured (50-75 years) and younger (<50 years) stand was 45.91 ± 15.10 m^{2} ha^{-1}, 35.57 ± 18.00 m^{2} ha^{-1} and 15.51 ± 1.60 m^{2} ha^{-1} respectively, with higher total volume in over matured stand and lowest in younger stand. Total tree biomass for younger, matured and over matured estimated was 80.00 ± 12.40 t ha^{-1}, 343.10 ± 167.60 t ha^{-1} and 529.50 ± 176.8 t ha^{-1} respectively, whereas mean living tree carbon was 40.00 ± 6.20 t ha^{-1}, 171.50 ± 83.50 t ha^{-1} and 264.50 ± 88.40 t ha^{-1}. An earlier study done by Hashmi *et al*. (2014) in the subtropical Pine forest of Karore forest in Rawalpindi Pakistan reported an average volume of 43276.56 ft^{3}, 3029588.76 kg of biomass and 15146.79 tons ppm of carbon content in Chir Pine.

In a study by Biswas *et al*. (2018) it was reported that *Quercus leucotrichophora* forests stores more carbon stock than the *Pinus roxburghii* forests. A field survey was done to compare both the forests in respect to carbon stock potential. The study was carried out in the Mussoorie forest division lying within the district of Dehra Dun and Tehri Garhwal Uttarakhand. Study revealed that due to favourable microclimate, *Quercus leucotrichophora* forests had rich biodiversity than the Chir Pine forests. In the four sites selected for study *Quercus leucotrichophora* reported to have higher carbon stock than *Pinus roxburghii* forests. The total carbon stock of 53.11 t h^{-1} in *Quercus leucotrichophora* forests was comparably higher than carbon stock of 39.90 t ha^{-1} in *Pinus roxburghii* forests.

Pariyar *et al*. (2019) conducted a field study on community forest (CF) dominated by *Pinus roxburghii* in the Phalebas region of Nepal. The study was aimed at measuring the impact of stand composition and geographic aspect on AGC of mixed and monospecific stand of *Pinus roxuburghii* by destructive sampling method using species specific allometric equations. They reported 106.20 Mg C ha^{-1} in above ground tree biomass in monospecific stand which was higher than 73.10 Mg C ha^{-1} in mixed stand. They also reported that the northern aspects stored significantly more carbon than southern aspects. In another field survey in Nepal Ghimire (2019) reported 213.05 t ha^{-1} of total carbon stock with 140.56 t ha^{-1} of above ground carbon stock and 27.14 t ha^{-1} below ground carbon stock and 45.35 t ha^{-1} SOC in *Pinu roxburghii* forest of Makawanpur district in Nepal.

Yadav *et al*. (2019) estimated the carbon stock under different land use systems in the Uttarkashi district of Uttarakhand. Maximum biomass and carbon stock was reported from Chir Pine Forest > Mango Orchard > Peach Orchard > Agri-horticulture > Agri-silviculture > Agri-silvi-horticulture > Lemon-Pomegranate > Apple Orchard > Guava Orchard respectively. They concluded that carbon storage can be increased by restoration of degraded lands into forest and also by reducing the intensity of land use.

Ghimire (2020) reported that southern aspect favours better growth of Chir Pine forest compared to the northern aspect. He carried out a field survey on two aspects in the Mahabharat region of Makawanpur district of Nepal. Southern aspect recorded significantly higher above ground biomass of 140.20 t ha^{-1} compared to northern aspect with only 46.65 t ha^{-1}.

Temporal change in forest cover and carbon stock in sub tropical Pine forest of Azad Jammu & Kashmir, Pakistan from 1989-2018 was estimated with the combination of remote sensing and field inventory by Khan *et al*. (2020). They reported an increase in forest cover of 561 ha in last 30 years with an increase of 40.39 Kt of above ground carbon stock and 147.83 Kt of CO_2 sequestration over the study area.

A three years study was done by Pandey *et al*. (2020) to assess the effect of disturbance level between an elevation gradient of 1400 to 2300 m on Pine and Oak mixed forest in the Ramgarh block of Nainital district of Uttarakhand. The disturbance levels were selected on the basis of canopy covers which were classified as 1). Undisturbed-UN (>70% canopy cover), 2). Moderately disturbed-MA (<55-70%), 3). Moderately disturbed-MB (>40-55%) and 4) Degraded-D (>40%). Chir Pine had a positive relation with respect to disturbance. Its density and baSal area was found to be more in degraded site than any other tree species. Whereas, *Quercus leucotrichophora* showed a negative relationship with increasing level of disturbance, its density and baSal area was higher in undisturbed site which decline to 50% in degraded site. Significant declination of more than 50% in biomass and carbon stock was reported in degraded site. Overall they concluded that moderate level of disturbance is favourable for better carbon sequestration rate, survival of seedlings and tree density.

Pant and Tewari (2020) did a comparative study in Chir Pine forest of Nainital district in Uttarakhand, at an altitudinal range between 1540-1860 msl between two slope (northern and southern) aspects, both these aspects had two sites one undisturbed and another moderately disturbed. All total four sites differentiated into ridge top, mid-hill slope and hill base. Tree density and total baSal area ranged from 390 to 3050 trees ha^{-1} and 36.79 to 83.58 m^2 ha^{-1}. Maximum tree density was reported from the southern undisturbed hill base and minimum from southern undisturbed ridge top. Maximum of 95.40 m^2 ha^{-1} of total baSal area was recorded from northern undisturbed hill base and minimum of 16.47 m^2 ha^{-1} at hill base in southern undisturbed site. Tree biomass and tree carbon for two consecutive years was maximum at mid-slope in the northern moderately disturbed site, while it was lowest at ridge top in southern undisturbed site.

Sharma *et al*. (2020) carried out a study in Chir Pine plantation at Adinath community forest in Kathmandu, Central Nepal. Tree density of 335.00 trees ha^{-1} and baSal area of 32.10 ± 1.00 m^2 ha^{-1} was recorded. Increase in diameter up to a certain limit showed a positive correlation with the stem density which further declined with increasing stem diameter. The AGB and BGB recorded for Pine plantation was 167.70 ± 6.60 Mg ha^{-1} and 33.50 ± 1.30 Mg ha^{-1} respectively, with a total of 201.20 ± 7.90 Mg ha^{-1} biomass. Further they reported that trees with high diameter stores more amount of carbon. Diameter, tree height and baSal area were reported to be positively correlated with Carbon stock.

Dhakal *et al*. (2021) did a comparative study between *Schima wallichii–Castonopsis indica* (*Schima-Castonopsis*) and *Pinus roxburghii* in community forest of Bhaktapur district Nepal to determine the carbon stock and mean annual carbon increment. Generally Pine was found in pure form or mixed but other two species were only found in mixed form. Tree carbon stock was higher in *Schima-Castonopsis* ranging from 13.59 to 28.49 t ha^{-1}. Whereas, for Pine it ranged from 11.08 to 14.76 t ha^{-1}. Similarly the total above ground biomass and total below ground biomass for *Schima-Castonopsis* was also higher which varied from 28.96 – 42.41 t ha^{-1} and 4.35 – 6.36 t ha^{-1}. Whereas, for Chir Pine it ranged between 23.77 – 28.44 t ha^{-1} respectively. Overall their study revealed that *Schima-Castonopsis* contains (71.52 t ha^{-1}) higher carbon stock than Pine (58.52 t ha^{-1}). The mean annual carbon increment also followed the same trend.

Gwal *et al*. (2021) carried out a field survey in the tree Chir Pine dominated van panchayat of Nainital district of Uttarakhand. According to them southern east aspect which was mixed aspect is better in comparison to other aspects in terms of growth and maturity. Tree density ha^{-1} ranged from 450 to 650 in all three van panchyat, whereas, the baSal area reported to vary from 31.16 to 56.32 m^2 ha^{-1}. They reported that net biomass accumulated on the southern east aspect was 10.53 t ha^{-1} yr^{-1} and on eastern aspect it was 8.05 t ha^{-1} yr^{-1} and 7.96 t ha^{-1} yr^{-1} on southern aspect respectively.

Joshi *et al*. (2021$_a$) conducted a field survey to estimate the tree biomass and carbon stock in the four forest types of Nainital district in Uttarakhand. The four type of forest stands distributed along the elevation gradient (300-3250 m) were dominated by I- *Shorea robusta*, II- *Pinus roxburghii*, III- *Quercus leucotrichophora* and IV- *Quercus lanuginosa* (mixed-Oak). Circumference at breast (CBH) of each tree falling under the quadrate (10 x 10 m) was recorded in random sampling method. The maximum biomass of 577.16 Mg ha^{-1} was found in *Shorea robusta* followed by *Pinus roxburghii* (285.27 Mg ha^{-1}), *Quercus leucotrichophora* (230.12 Mg ha^{-1}) and minimum in *Quercus lanuginosa* (mixed-Oak) (227.23 Mg ha^{-1}). Similar trend was also found in total carbon stock. However, the net primary productivity (NPP) was recorded maximum in *Pinus roxburghii* (10.17 Mg ha^{-1} yr^{-1}), followed by *Shorea robusta* (9.75 Mg ha^{-1} yr^{-1}), *Quercus lanuginosa* (mixed-Oak) (9.42 Mg ha^{-1} yr^{-1}) and *Quercus leucotrichophora* (8.40 Mg ha^{-1} yr^{-1}) respectively.

Kaushal and Baishya (2021) studies carbon stock in different forest types of central Garhwal Himalaya in the state of Uttarakhand. Total eight forest types were studies including Moist Siwalik Sal forest (3C/C2a), Bhabar-Dun Sal forest (3C/C2b (i)), Upper or Himalayan Chir Pine Forest (9/CIb), Ban Oak Forest (12/CIa), Moist temperate deciduous forest (12/CIe), Moist Deodar Forest (12/CIc), Kharsu Oak

Forest (12/C2a) and West Himalayan Fir Forest (14/CIb). Maximum stem density of 457 trees ha^{-1} was reported from Bhabar-Dun Sal forest and minimum of 153 trees ha^{-1} from Himalayan Chir Pine Forest. Pine forest also reported the least total baSal area of 37.40 m^3 ha^{-1} while it was highest (94.75 m^3 ha^{-1}) in Kharsu Oak Forest. Above ground biomass density and below ground biomass density was reported highest from Moist Siwalik Sal forest while lowest from Bhabar-Dun Sal forest. Similar was the case for total biomass density and total carbon density. Among the coniferous forests, Moist Deodar Forest > Himalayan Fir Forest > Upper or Himalayan Chir Pine Forest had total biomass density and total carbon density respectively.

An attempt was made by Khan *et al*. (2021) to associate diameter to growing stock and biomass of *Pinus roxburghii* in the field study at Duredhkela village situated in the Hindu Kush mountain region dominated by Chir Pine forest in the district swat KPK of Pakistan. According to the study they reported that stem density had a polynomial relation with the diameter. Whereas, tree height and diameter had a linear relationship. Similarly, tree volume, bole biomass and baSal area were positively correlated with diameter. Maximum (166.11 ± 21.63 trees $ha^{-1)}$ tree density was reported from the diameter class 23-40 cm. Whereas, mean height (16.65 ± 1.56 m ha^{-1}), mean baSal area (14.19 ± 3.67 m^2 ha^{-1}), mean stand volume (16.69 ± 4.64 m^3 ha^{-1}) and mean total tree biomass (12.76 ± 1.43 t ha^{-1}) was higher in diameter class 41-60 cm.

Kumar *et al*. (2021) carried out a field study in the Chir Pine forest at different elevaions in the Garhwal Himalayas. According to their study the there was variation in height, density, volume and baSal area at different altitude in Chir Pine but had no correlation with it. The area for the study covered 3 districts (Pauri, Rudraprayag and Tehri) at different altitude ranging from <1000 m, 1001-1400 m, 1401-1800 m and >1801 m. Maximum tree density of 575 ± 90.14 trees ha^{-1} was reported at an altitude > 1801 msl and minimum of 135 ± 5.00 trees ha^{-1} at 1001 – 1400 msl. Highest AGC (96 ± 18.36 t ha^{-1}) and BGC stock (28.58 ± 4.81 t ha^{-1}) was recorded at an altitude range between 1001-1400 m. Whereas, lowest AGC and BGC stock of 26.68 ± 9.48 t ha^{-1} and 9.19 ± 2.87 t ha^{-1} respectively was recorded at an altitude range between 1401-1800 m.

A filed study was done in the Khyber Pakhtunkhwa region of Pakistan by Naqash *et al*. (2021) to estimate the biomass and carbon stock in two Chir Pine forest stands one natural forests Shinkiari and another man-made plantation Parachinar. Average mean stem ha^{-1} was higher in man-made plantation whereas, total stem number ha^{-1} was more in natural stand. Diameter range in natural stand was comparatively higher ranging from 18.94 to 59.21 cm, while in plantation it ranged from 13.80 to 21.75 cm. Similarly, overall 30 plot selected in both the system resulted into comparatively higher total biomass and total carbon stock in natural forests than man-made plantation.

Rashid *et al.* (2016) estimated the changes (1980-2013) in above ground biomass and carbon stock of Lidder valley in Kashmir Himalayas of India, mainly dominated by coniferous tree species such as *Pinus wallichiana*, *Cedrus dedara, Abies pindrow* and *Picea smithiana*. They collected the data from multi-sensor satellites, the data was highly distorted which was organised by radiometric and geometric techniques. The processed image was visually interpreted and accordingly land use and land cover (LULC) types were delineated using false colour composite (FCC) at the scale of 1:50000 in GIS (Geographical Information System). Using allometric models and phytosociological data they reported that 6.00% (74.50 km^2) of dense evergreen forest had been degraded. Degraded forest and settlement increased by 20 and 52.8 km^2 respectively. A total of 1.018 Megatons of aboveground biomass and 0.50 Megatons of above ground carbon were estimated to have been lost in the last 33 years.

Dar and Sahu (2018) investigated the Gulmarg forest range in Baramullah district of Jammu and Kashmir, India. They reported that *Pinus wallichiana* (PW) forest recorded the highest density and least was observed in *Cedrus deodar* (CD) forest. Whereas, CD recorded the maximum baSal area of 63.03 m^2 ha^{-2} and smallest of 33.36 m^2 ha^{-2} in *Betula utlis* (BU) forest. Tree volume, above ground biomass, below ground biomass, total biomass and total carbon stock was also maximum in CD forest and minimum in BU forest. Among the tree species CD recorded the maximum biomass among all the other tree species in CD forest type. They concluded that various factors such as altitude, species composition, tree diameter class and stand area are responsible for variation in carbon stock among different forest types.

Singh and Verma (2018) did a comparative study between the coniferous and broad leaved-forests. They revealed that coniferous forests have more carbon stock than broad-leaved forests. Among the conifers *Cedrus deodara* has the highest potential to sequester carbon from atmosphere. Biomass and carbon stocks are affected by elevation. Whereas, slope aspect does not have considerable impact on biomass and carbon stock. Carbon stock varies among forest types due to species diversity, altitude and forest management activities. Carbon stock increases with altitude, reaches maximum at mid-elevation and decreases with further increase in elevation.

A field survey was done by Sheikh *et al*. (2021) in Anantnag district of Kashmir region of Jammu and Kashmir. Total carbon stock was found higher in *Pinus wallichiana* > *Cedrus deodara* > *Picea smithiana* > *Abies pindrow*. Similar trend was followed for carbon increment. Out of three season selected for the study maximum carbon increment was recorded in spring > summer > autumn.

2.2 Soil physico-chemical properties of Himalayan forests.

Kumar *et al*. (2013) reported that high litter accumulation in Chir Pine forest does not allow any other species to grow. Low amount of organic matter and clayey soil in Chir Pine forest makes the soil compact hence, increases bulk density. Soil moisture is high in Oak forest than Chir Pine due to close and dense canopy. Due to lower amount of litter decomposition and low soil moisture, there is low level of nutrients in Chir Pine forests as compared to Oak forests. Increasing altitude reduces the amount of soil organic carbon, while bulk density increases with altitude.

Kaur and Kaur (2016) carried out a field study in the Chir Pine forests of the Solan district of Himanchal Pradesh and reported that soil properties such as soil pH, soil bulk density and available phosphorus increased with increasing soil depth up to a certain level while % organic carbon, available nitrogen, available potassium, and electrical conduct decreases with depth.

In a study by Guleria *et al*. (2017) it was reported that forest fires in Chir Pine forests not only burns the vegetation but is responsible for removing the soil carbon stock. It was observed that there is a significant difference in the soil carbon stock just immediately after forest fire and after four years of fire. Both soil organic and inorganic carbon are affected by fires and more than 50% of the soil carbon stock is lost immediately after the fires in compression to four year stored carbon stock after the fire. Depth wise soil carbon released will depend on the intensity and speed of fire.

Mishra (2017) reported that soil organic carbon decreases with increasing soil depth in Chir Pine forest. He estimated that total soil carbon stock ranged from 50.26 Mg C ha^{-1} to 66.17 Mg C ha^{-1} in the Chir Pine forest of Rudraprayag district in Uttarakhand. Highest carbon percentage was found in the top 10 cm layer of soil.

In a field study carried out at Muree hills of Pakistan, Amir *et al*. (2019) reported that soil depth had a polynomial and linear relationship with soil organic carbon in Chir Pine forest. The younger stand reported to store more soil organic carbon in the top soil layer (0-20 cm), the value decreased with increasing depth and with increase in stand age. Opposite trend was observed in soil bulk density which increased with soil depth and stand age.

Ghimire (2019) carried out a field study in natural Chir Pine forest of Okhe community forest of Makawanpur district in Nepal. He reported that soil bulk density increased with soil depth. Total soil organic carbon reported was 45.35 t ha^{-1} which decreased with increasing in soil depth. Upper soil layer (0-20 cm) reported 1.64 times higher soil carbon than other soil layers due to rapid decomposition of forest litter in the top layer. Total Soil carbon stock was 21.00% of the total carbon stock present in the forest.

Manral *et al*. (2020) tried to estimate and compare the changes in soil properties of Oak forests which are being reported to be replaced by Chir Pine due to different anthropogenic activities. Three forests stand i.e. Chir Pine, Oak and mixed Pine-Oak forests were studied. The study indicated that there was a significant decrease in soil microbial biomass nitrogen (SMBN), and soil microbial biomass phosphorus (SMBP) from Oak forests, which was reported highest among all followed by mixed Pine-Oak forest and least in Chir Pine pure stand. Lower SMBN and SMBP creates poor nutrient site in Chir Pine stand. Soil organic carbon, total nitrogen and total phosphorus were reported higher in mixed Pine-Oak forest followed by Oak and least in the Chir Pine forest which indicates that mixed Pine-Oak forest can be better in terms of sustaining soil fertility because of high litter fall, high tree density and diversity, as these factors affect the decomposition process.

Pandey *et al*. (2020) studied the effect of disturbance level in Pine and mixed Oak forest on soil properties. Disturbance level increased the soil bulk density (Degraded-D (>40% canopy cover) > Moderately disturbed-MB (>40-55%) >

Moderately disturbed-MA (<55-70%) > Undisturbed-UN (>70%). Whereas, opposite trend was reported for total soil carbon stock which decreases with an increasing level of disturbance.

Among all the forest types in the western Himalayan region, Chir Pine forests falls under medium range in terms of soil organic carbon. Thakur *et al*. (2020) performed a field study at Dr. Y.S. Parmar University of horticulture and Forestry, Nauni, Solan (Himanchal Pradesh) to estimate the total soil organic carbon in the seven different forest types. These forest types were Ban Oak, Chir Pine forest, low level blue Pine, northern dry mixed deciduous forest, moist deodar, Kharsu Oak and Mohru Oak forest. Maximum mean soil organic carbon (g kg^{-1}) was found in Deodar forest (27.80), followed by blue Pine (18.70) and chir (15.80) respectively, whereas, the minimum (11.70) was reported from mixed deciduous forest. Among all the forest types mixed deciduous (1.13 Mg m^{-3}) and Chir Pine (1.11 Mg m^{-3}) reported maximum soil bulk density at all the soil depth whereas, minimum was reported from Kharsu Oak forest, the bulk density in all the forest type increased with soil depth. Overall the total mean soil organic carbon (Mg C ha^{-1}) was maximum in Kharsu Oak forest (41.50) and minimum in dry deciduous forest (16.50), Chir Pine recorded in medium range of 22.90 among all the forest types.

Joshi *et al*. (2021_b) investigated four forest types for their soil physico-chemical properties. Average pH reported to be lowest (5.91) in mixed-Oak forest and highest (6.65) in Sal forest. There was an increasing trend in soil pH with increasing dept in all forest types. Soil organic carbon was highest in banj-Oak forest > mixed-Oak forest > Chir Pine forest > Sal forest. Highest nitrogen % was recorded in mixed-Oak forest, whereas, lower in Sal forest. Phosphorus % was similar in both Oak forests, but Sal forest reported highest and Chir Pine the lowest of all. Potassium % was also higher in mixed-Oak forest, equal in both Sal and Chir Pine and least in Banj-Oak forest.

Khan *et al*. (2021) reported that in Chir Pine forest, smaller diameter class (6-22 cm) sequesters more carbon than other higher diameter classes. However, the forest litter and dead wood was more in higher diameter classes. According to their study, they reported that soil bulk density has a positive linear relationship with the diameter class, also the soil bulk density increased with soil depth. Soil organic carbon has a negative linear relationship with the soil depth. Whereas, the soil carbon value increases with increase in diameter classes.

Shapkota and Kafle (2021) carried out a field survey in four forest types (Oak forest 2300-2700 m, lower mixed hardwood forests 1000-1500 m, upper mixed hardwood forests 1500-2700 m and Chir Pine forest 1000-1600 m) of Shivapuri Nagarjun National Park in Nepal to study the soil organic carbon at various soil depths. Bulk density ranged from 0.6 to 0.9 gm cm^{-1}, lowest bulk density was reported from Oak and upper mixed hard wood forest whereas, Chir Pine forest reported the maximum bulk density. Bulk density increased with soil depth in all the forest types. Similarly, soil organic carbon content was found maximum on the upper soil layer of depth 0-20 cm which gradually decreased with increasing soil depth. Soil organic carbon content was found maximum in Oak forest > upper mixed hardwood > lower mixed hard wood > Chir Pine. Maximum total of 149.6 t ha^{-1} of soil organic carbon stock was found in Oak forest and least of 50.8 t ha^{-1} in Chir Pine forest.

CHAPTER-III

MATERIALS AND METHODS

CHAPTER-3

MATERIALS AND METHODS

The material and methods used for the present study entitled **"Biomass and Carbon Stock of *Pinus roxburghii* Sarg. in Jammu & Kashmir"** are presented under following sub-headings in this chapter.

3.1 Experimental Site

3.1.1 Location

The present study was carried out in the *Pinus roxburghii* dominant forests of Jammu division of Jammu and Kashmir, India. The sampling sites were located in the district Jammu, Samba, Kathua, Udhampur and Reasi. The map of the study area is presented in figure 1.

3.1.2 Site description

The study was carried out in the two sub types of Himalayan subtropical pine forest ($9/C_1$) (as per Champion and Seth, 1935). The two sites were selected in each sub type:

1) Site-I & III, Lower or Siwalik Chir Pine forest ($9/C_{1a}$) (500 - 900 m).
2) Site- II & IV, Upper or Himalayan Chir Pine forest ($9/C_{1b}$) (above 900 m up to 1800 m).

3.1.2.1 Site-I: (Surnisar & Mansar)

This site lies within the Bahu and Jindarh range of Jammu forest division (some portion of which is now in the newly formed Samba forest division). The prominent towns near the sampling plots were Bajalta, Surinsar and Mansar. The sampling plots were laid within an altitudinal range between 500 to 900 m. The sampling area stretches from 32^0 42.09" N to 32^0 46.78" N latitude and 75^0 00.77" E to 75^0 09.24" E longitude. The mean minimum and maximum temperature for Jammu Shivaliks under winter, summer and monsoon season is 4^0C, 23^0C and 18^0C, 40^0C and 14^0C, 32^0C (Goyal and Rai, 2000). The average annual rainfall is about 1140 mm per annum, of which 70% is received during the monsoon period. Terrain is rocky and generally shallow. On gradual increase in altitude the vegetation changes from mixed broadleaved to dominant Chir Pine in the upper zone. Some common tree species found in this area were *Dalbergia sisso*, *Acacia modesta*, *Butea monosperma*, *Lannea* *coromendalica*, *Mallotus philippensis*, *Ficus glomerata*, *Pinus roxburghii*, *Dendrocalamus stritus*, *Bombax ceiba*, *Ficus religiosa*, *Phoenix sylvesteis*, *Cassia fistula*, *Eucalyptus teriticornis*, etc. Shrub and grasses included *Euphorbia royleana*, *Woodfordia fruiticosa*, *Adhatoda vasica*, *Dodonea viscosa*, *Murraya koenigii*, *Lantana camara*, *Parthenium hysterophorus*, *Rumex hastatus* and *Cymbopogan spp*.

3.1.2.2 Site-II: (Billawar)

This site lies within Billawar range of the Billawar forest division. The geographical stretch for sampling points are 32^0 38.68" N to 32^0 40.09" N latitude and 75^0 35.17" E to 75^0 37.70" E longitude. Sampling points were laid along the altitudinal gradient from 1000 m to 1800 m till the upper limit of Chir Pine. Climate is subtropical in the lower altitude while it is temperate in the higher altitude. The mean annual rainfall is around 1500 mm. The famous spot around the sampling plots were Sukrala Mata temple and Machedi Mata temple. The site had almost pure Chir Pine forest but in some patches species like *Phoenix sylvesteis* was also found. Towards the upper limit of Chir Pine, it was associated with temperate tree species such as *Quercus leucotrichophora*, *Quercus semicarpifolia*, *Rhododendron arboretum*, *Lyonia ovilifolia*, *Populus ciliate* and *Pyrus pashia*.

3.1.2.3 Site-III: (Reasi & Kalidhar)

The study area was located within the Jammu and Reasi forest divisions stretching from 32^0 32.23" N to 33^0 04.26" N latitude and 74^0 34.76’’ E to 74^0 56.33" E longitude. The sampling plots were laid between an altitude of 500 m to 900 m. The spots around the sampling sites were Domel, Pouni, Bhamla, Kalidhar and Chauki Chaura. Climatic conditions are almost similar to site I, average annual rainfall varies from 1500-2000 mm in the Reasi region. Vegetation was also similar to site I, Chir Pine was mixed with broadleaved species like *Acacia modesta*, which gradually changed to pure Chir Pine forest.

3.1.2.4 Site-IV: (Chenani & Udhampur)

This sampling site was located within the Dudu and Udhampur range of Udhampur forest division. The sapling points were taken from the Chir Pine forest adjoining Kud, Sudh Mahadev, Chenani and Krimichi. Geographical stretch of the sapling site is 32^0 59.07" N to 33^0 04.08" N latitude and 75^0 07.36" E to 75^0 19.36" E longitude. Lower areas of the division has subtropical climate while the upper region

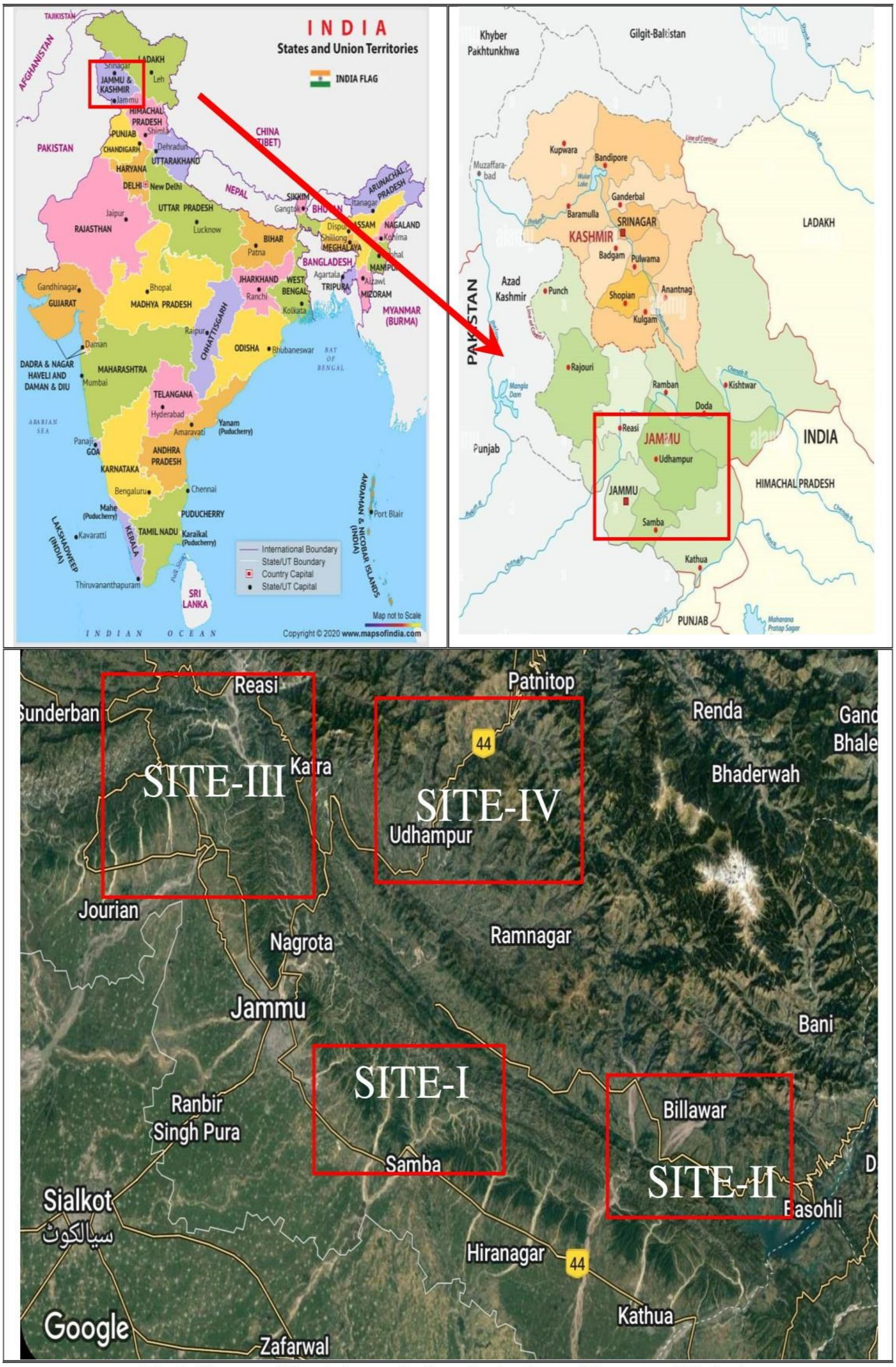

Fig. 1: Site map of the study area in the union territory of Jammu and Kashmir

have moist-temperate climate with snow fall in winters. The maximum and minimum temperature goes up to 39.50^{0}C to below 0^{0}C, average annual rainfall is 1496.62 mm. The sampling points were selected according to the altitudinal gradient from 1000-1600 m. In the lower limit, Chir was found in pure form whereas towards the upper limit species such as *Cedrus deodara*, *Pinus wallichiana*, *Quercus leucotrichophora*, *Quercus floribund*a and *Toona ciliata* were found. Deodar is distributed well and is a dominant tree species beyond the upper limit of Chir Pine forest.

3.2 Experimental Methodology

3.2.1 Site selection

Selection of sites was done after going through topographical maps of the Chir Pine dominated areas. Sites were selected on the basis of two forest type a) Lower or Siwalik Chir Pine forest (9/C_{1a}) (500-900 m) and b) Upper or Himalayan Chir Pine forest (9/C_{1b}) (>900 m). A pre-survey of the selected sites was also done prior to the data collection. Garmin e-trex Vista model of Global Positioning System (GPS) was used for recording the geo-coordinates, altitude and aspect of the sampling plot (Table 1).

3.2.2 Laying out quadrates or sampling plots

Laying out of sampling plots was based on the accessibility. Steep slopes and rocky terrain were not included in sampling. Simple Random sampling method was used for laying out quadrates. Ten quadrates of 20 x 20 m^2 were laid out in each site and a total 40 quadrates (0.04 ha area in each) were selected. The trees within the selected quadrate were painted with yellow colour band at the breast height (1.37 m) and their diameter at breast height was measured with help of tree calliper. Tree height was recorded with the help Nikon Forestry Pro Laser Rangefinder 8381.

3.2.3 Collection of soil samples

To analyse the soil physical and chemical properties, a composite soil sample was collected from each quadrate at two depths i.e. 0-30 cm and 30-60 cm. The soil samples were shade dried, sieved with 2 mm sieve and stored in zip lock poly bags which were further analysed at the laboratories of the Division of Agroforestry and Division of Soil Science & Agricultural Chemistry, SKUAST-Jammu.

Table 1: Latitude, Longitude, Altitude and Aspect of quadrates in the sampling area

Quadrate No.	Latitude (N)	Longitude (E)	Altitude (m)	Aspect
Site – I: (Surnisar & Mansar)				
Quadrate No.	**Latitude (N)**	**Longitude (E)**	**Altitude (m)**	**Aspect**
1	32^0 44.340"	75^0 05.362"	727	NE
2	32^0 43.890"	75^0 05.725"	778	NE
3	32^0 44.565"	75^0 04.549"	689	SE
4	32^0 46.501"	75^0 01.386"	561	SE
5	32^0 45.875"	75^0 03.397"	609	NE
6	32^0 43.257"	75^0 07.184"	599	SW
7	32^0 46.780"	75^0 00.777"	631	NE
8	32^0 46.551"	75^0 01.601"	620	NE
9	32^0 42.657"	75^0 07.743"	631	NE
10	32^0 42.093"	75^0 09.248"	652	NE
Site – II: (Billawar)				
Quadrate No.	**Latitude (N)**	**Longitude (E)**	**Altitude (m)**	**Aspect**
1	32^0 40.096"	75^0 37.167"	1790	SW
2	32^0 39.445"	75^0 37.420"	1716	SW
3	32^0 39.444"	75^0 37.581"	1674	SE
4	32^0 39.201"	75^0 37.156"	1630	SE
5	32^0 38.863"	75^0 35.296"	1228	SE
6	32^0 39.223"	75^0 37.707"	1564	SE
7	32^0 38.763"	75^0 36.940"	1487	NE
8	32^0 38.685"	75^0 36.013"	1325	SW
9	32^0 38.989"	75^0 35.395"	1186	NW
10	32^0 38.976"	75^0 35.175"	1061	NW
Site-III: (Reasi & Kalidhar)				
Quadrate No.	**Latitude (N)**	**Longitude (E)**	**Altitude (m)**	**Aspect**
1	32^0 54.603"	74^0 56.339"	617	NE
2	32^0 56.522"	74^0 55.391"	661	NE
3	33^0 02.715"	74^0 51.320"	681	NW
4	33^0 04.267"	74^0 43.670"	533	NW
5	33^0 02.362"	74^0 34.768"	743	NE
6	33^0 02.737"	74^0 36.567"	701	NW
7	33^0 03.125"	74^0 39.208"	839	NW
8	33^0 02.756"	74^0 38.129"	831	SE
9	33^0 02.324"	74^0 38.941"	742	SE
10	32^0 32.231"	74^0 51.755"	506	SE
Site-IV: (Chenani & Udhampur)				
Quadrate No.	**Latitude (N)**	**Longitude (E)**	**Altitude (m)**	**Aspect**
1	33^0 04.088"	75^0 17.684"	1601	SE
2	33^0 03.303"	75^0 17.539"	1446	SE
3	33^0 02.763"	75^0 19.361"	1503	SE
4	33^0 02.439"	75^0 18.558"	1380	NE
5	33^0 02.328"	75^0 18.361"	1317	SE
6	33^0 01.759"	75^0 18.053"	1239	SE
7	33^0 02.244"	75^0 16.433"	1251	SW
8	33^0 03.085"	75^0 16.141"	1531	NW
9	32^0 59.531"	75^0 07.766"	1023	NE
10	32^0 59.070"	75^0 07.367"	1135	NE

3.3 Observations recorded

3.3.1 Tree Parameters

3.3.1.1 Diameter at Breast Height (dbh) (cm)

The diameter in centimetre at the breast height was measured at 1.37 m with the help of tree calliper.

3.3.1.2 Tree Height (m)

The tree height in meters was directly measured with help of Nikon Forestry Pro Laser Rangefinder 8381.

3.3.1.3 Tree Volume (m^3)

Tree volume (stem volume) was estimated by using the regression equation developed for *Pinus roxburghii* of western Himalayas by the Forest Survey of India (FSI, 1981)

$$\sqrt{V} = 0.05131 + 3.9859D - 1.0245\sqrt{D}$$

Where, V = Volume, D = Diameter of tree at breast height,

3.3.2 Biomass and Carbon Stock of *Pinus roxburghii*

3.3.2.1 Above Ground Biomass Density (AGBD)

For estimating the AGBD (complete tree volume including stem, branches, leaves and twigs), first stem biomass density was calculated as:

$$Stem\ Biomass = Stem\ Volume * Wood\ Density$$

Wood density of *Pinus roxburghii* was taken as 0.46 gm cm^{-3} (Uniyal *et al*. 2002). Now AGBD was calculated as:

$$AGBD = Stem\ Biomass * Biomass\ Expansion\ Factor$$

The value for BEF (Biomass expansion factor) used was 1.3 (Brown, 1997)

3.3.2.2 Below Ground Biomass Density (BGBD)

For estimating BGBD, the ratio of below ground biomass to above ground biomass was used as suggested by Mokany *et al*., 2006. For AGBD < 20 Mg ha^{-1} the value of this ratio was taken as 0.56 and for AGBD > 20 Mg ha^{-1} the value of this ratio was taken as 0.28.

3.3.2.3 Total Biomass Density (TBD)

$$TBD = AGBD + BGBD$$

3.3.2.4 Above Ground Carbon Density (AGCD) and Below Ground Carbon Density (BGCD)

For estimating AGCD and BGCD, 0.47 factor was multiplied to AGBD and BGBD respectively (IPCC, 2006).

3.3.2.5 Total Carbon Density (TCD)

$$TCD = AGCD + BGCD$$

3.3.2.6 Carbon Dioxide Equivalent (eCO_2)

Carbon dioxide equivalent was estimated in order to calculate the amount of CO_2 assimilated by the biomass. For this following formula was used:

$$\boldsymbol{eCO_2} = TCD * 3.67$$

Factor 3.67 is used since the ratio of CO_2 to C is 3.67 (Siraj 2019).

3.3.3 Soil Physical and Chemical Properties

3.3.3.1 Soil Texture

Soil texture was analysed by Bouyoucous Hydrometer method proposed by Piper, 1996. Soil organic matter was digested with the help of H_2O_2 overnight, next day the samples were treated with sodium hexametaphosphate which act as a dispersion agent for soil particles. Percent of these dispersed particles were measured with help of soil hydrometer.

3.3.3.2 Soil Bulk Density (gm cm^{-3})

Core tube method was used to determine soil bulk density as prescribed by Johnson, 1962**.** The soil sample taken from the core was oven dried at 100 ± 5 ^oC till all the moisture content was removed. This dried weight of the core was divided with its initial volume to give soil bulk density on dry weight basis.

3.3.3.3 Soil pH

Soil pH was determined in 1:2.5 soil: water suspension with the help of glass rod pH meter (Jackson, 1973).

3.3.3.4 Electrical Conductivity (dSm^{-1})

Same soil: water suspension used for determining soil pH was kept overnight and next day without shaking it electrical conductivity was measured with the help of EC meter (Jackson, 1973).

3.3.3.5 Available Nitrogen (Kg ha^{-1})

The available Nitrogen was determined in the automatic Kjeldhal distillation unit following the modified alkaline potassium permanganate method as proposed by Subbiash and Asija, 1956. Potassium permanganate is used as oxidising agent which extracts the oxidizable organic nitrogen (Ammonia) from the soil sample. This ammonia evolved is absorbed in excess boric acid to form ammonium borate which is titrated against the standard acid to estimate the amount of ammonium absorbed.

3.3.3.6 Available Phosphorous (Kg ha^{-1})

Method described by Olsen *et al.* (1954) was used to determine the available phosphorus. $NaHCO_3$ act as a extracting agent for phosphorous from Al and Fe phosphates.

3.3.3.7 Available Potassium (Kg ha^{-1})

Using 1N Ammonium Acetate as the extracting agent the available potassium was determine on flame photometer as suggested by Jackson, 1973. Soil sample are shaken with the neutral 1N Ammonium Acetate, which release potassium ions in the solution. These ions in the sample solution are measured with the help of flame photometer.

3.3.3.8 Cation Exchange Capacity (C.Mole. P^{+} Kg^{-1})

It was determined by Sodium acetate method as described by Chapman (1965).

3.3.3.9 Soil Organic Carbon (%)

Wet digestion method proposed by Walkley and Black (1934) was used for determining soil organic carbon content. A known quantity of soil sample was treated with excess of standard potassium dichromate solution in the presence of concentration H_2SO_4. The reaction slowly digests the soil and oxidizes the soil organic carbon to CO_2. The excess of unused potassium dichromate was back titrated against the standard solution of ferrous ammonium sulphate in the presence of diphenylamine indicator and sodium fluoride which makes colour change from violet to bright green on titration.

Statistical Analysis

Experimental data were analysed by the procedure suggested by Gomez and Gomez, 1984 and by statistical software such as OPSTATE and SPSS-16.

CHAPTER-IV

RESULTS

CHAPTER-4

RESULTS

The present investigation entitled **"Biomass and Carbon Stock of *Pinus roxburghii* Sarg. in Jammu & Kashmir"** was carried out in the Chir Pine growing areas of Jammu division restricted to five districts namely, Jammu, Samba, Kathua, Udhampur and Reasi. *Pinus roxburghii* is estimated to grow in an area of about 8.90 lac ha out of which Jammu and Kashmir account for 1.92 lac ha (Jasroti and Raina, 2017). Covering a large area within the Union territory, Chir Pine is one of the main tree species of this region, hence it is important to know it contribution in sequestering atmospheric CO_2.

The survey was carried out in two sub type Chir Pine forests i.e. (i) Siwalik Chir Pine forest ($9/C_{1a}$) falling with in an altitudinal range of 500-900 m (Site I and III), (ii) Upper or Himalayan Chir Pine forest ($9/C_{1b}$) falling with in an altitudinal range >900-1800 m (Site II and IV). The results obtained are presented in this chapter under the following heads:

4.1 Tree growth parameters

4.2 Biomass and carbon stock of *Pinus roxburghii*

4.3 Soil physical and chemical properties

4.1 Tree growth parameters

4.1.1 Diameter at breast height (dbh) (cm)

The data collected with regard to the mean tree diameter of *Pinus roxburghii* at different sites in Jammu division are presented in table 2.

Maximum Tree diameter (67.13 cm) was recorded in quadrate 9 at site IV whereas, the minimum tree diameter (13.69 cm) was recorded in quadrate 2 at site III (Table 2). Overall the mean diameter at different site was highest (51.21 cm) at site I and lowest (25.24 cm) at site III. Among all the sites, site IV showed a maximum range in diameter from 14.41 cm to 67.13 cm. Whereas, the minimum range in diameter from 27.04 cm to 42.80 cm was recorded at site II (Table 2).

There was a significant difference in mean tree diameter among all the sites. However, site II was at par with site III and site IV (Table 2).

Table 2: Mean tree diameter (cm) of *Pinus roxburghii* at different sites

Quadrates	Site I	Site II	Site III	Site IV
	Mean tree diameter (cm)			
Quadrate 1	52.79	26.84	15.54	54.92
Quadrate 2	52.93	42.80	13.69	54.10
Quadrate 3	59.87	30.66	41.13	57.29
Quadrate 4	55.20	27.04	15.45	24.56
Quadrate 5	61.91	33.29	30.57	19.29
Quadrate 6	51.83	42.15	41.36	15.31
Quadrate 7	40.61	26.65	22.35	14.41
Quadrate 8	59.16	33.49	15.76	23.01
Quadrate 9	52.68	33.90	14.59	67.13
Quadrate 10	25.13	30.86	42.00	57.04
Mean	**51.21**	**32.77**	**25.24**	**38.71**
SE±	3.45	1.84	3.88	6.63
SD	10.90	5.81	12.28	20.95
CV (%)	21.28	17.75	48.63	54.13
CD (5%)	13.00			

4.1.2 Tree height (m)

Tree height was directly recorded with the help of Nikon Forestry Pro Laser Rangefinder 8381. The data pertaining to the mean tree height of *Pinus roxburghii* at different sites in Jammu division are represented in table 3.

Site I recorded maximum tree height (30.58 m) at quadrate 5 followed by (29.78 m) site IV at quadrate 9 (Table 3). Whereas, the minimum tree height (9.73 m) was recorded from site III in quadrate 8, followed by (11.35 m) site I in quadrate 7 respectively. Over all the mean tree height at different sites was recorded highest from site I (19.79 m) followed by (19.40 m) site IV, (17.19 m) site II and lowest (15.85 m) in site III respectively. Maximum variation in tree height from 11.35 m to 30.58 m was observed at site I, followed by 12.54 m to 29.78 m at site IV, 9.73 m to 21.89 mat site III and least 13.80 m to 18.49 m at site II respectively (Table 3).

Statistically there was no significant difference in mean tree height among all the sites (Table 3).

Table 3: Mean tree height (m) of *Pinus roxburghii* at different sites

Quadrates	**Site I**	**Site II**	**Site III**	**Site IV**
	Mean tree height (m)			
Quadrate 1	14.70	13.80	11.44	16.58
Quadrate 2	17.20	16.98	13.18	18.73
Quadrate 3	23.20	16.23	21.44	24.18
Quadrate 4	18.93	16.31	11.98	18.45
Quadrate 5	30.58	17.88	19.41	17.48
Quadrate 6	27.26	21.02	21.89	14.10
Quadrate 7	11.35	15.12	14.93	14.26
Quadrate 8	18.50	17.74	9.73	12.54
Quadrate 9	19.00	18.37	13.49	29.78
Quadrate 10	17.20	18.49	21.02	27.91
Mean	**19.79**	**17.19**	**15.85**	**19.40**
SE±	1.82	0.63	1.46	1.88
SD	5.75	2.00	4.63	5.94
CV (%)	29.05	11.64	29.19	30.61
CD (5%)	NS			

4.1.3 Tree volume (m^3 ha^{-1})

Tree volume (stem) of *Pinus roxburghii* was derived from the volume equation ($\sqrt{V} = 0.05\overline{1}31 + 3.9859D - 1.0245\sqrt{D}$) developed by FSI (1981) for the western Himalayas. The data obtained for the tree volume are represented in table 4.

Tree volume (403.00 m^3 ha^{-1}) was observed maximum from quadrate 9 at site II, whereas, the minimum tree volume (63.98 m^3 ha^{-1}) was reported from quadrate 1 at site III (Table 4). Site II (291.14 m^3 ha^{-1}) recorded highest mean tree volume followed by site IV (269.26 m^3 ha^{-1}), site III (166.09 m^3 ha^{-1}) and site I (157.17 m^3 ha^{-1}) respectively. Maximum range in tree volume from 127.74 m^3 ha^{-1} to 403.00 m^3 ha^{-1} was observed at site II, followed by 63.98 m^3 ha^{-1} to 291.85 m^3 ha^{-1} at site III, 134.62 m^3 ha^{-1} to 343.02 m^3 ha^{-1} at site IV and minimum 91.45 m^3 ha^{-1} to 236.10 m^3 ha^{-1} at site I respectively (Table 4).

Mean tree volume m^3 ha^{-1} at different site showed a significant difference with each other. However, site I was at par with site III and site II was at par with site IV respectively (Table 4).

Table 4: Mean tree (stem) volume (m^3 ha^{-1}) of *Pinus roxburghii* at different sites

Quadrates	Site I	Site II	Site III	Site IV
	Mean stem volume (m^3 ha^{-1})			
Quadrate 1	118.47	203.57	63.98	332.39
Quadrate 2	147.41	127.74	253.45	270.99
Quadrate 3	159.24	307.13	177.25	279.76
Quadrate 4	91.45	230.74	128.15	305.12
Quadrate 5	162.95	330.96	291.85	134.62
Quadrate 6	234.04	281.21	172.51	201.27
Quadrate 7	150.32	361.15	180.02	228.97
Quadrate 8	124.02	266.21	84.81	256.61
Quadrate 9	147.67	403.00	180.96	343.02
Quadrate 10	236.10	399.65	127.95	339.84
Mean	**157.17**	**291.14**	**166.09**	**269.26**
SE±	14.65	27.84	22.10	21.17
SD	46.34	88.04	69.89	66.95
CV (%)	29.48	30.24	42.08	24.86
CD (5%)	64.65			

4.1.4 Mean tree density (trees ha^{-1})

Observation regarding mean tree density of *Pinus roxburghii* at different sites in Jammu division is illustrated in the fig 2.

Mean tree density was maximum at site II (342.5 trees ha^{-1}), followed by site IV (317.5 trees ha^{-1}), site III (265 trees ha^{-1}) and minimum at site I (150 trees ha^{-1}) (Fig. 2).

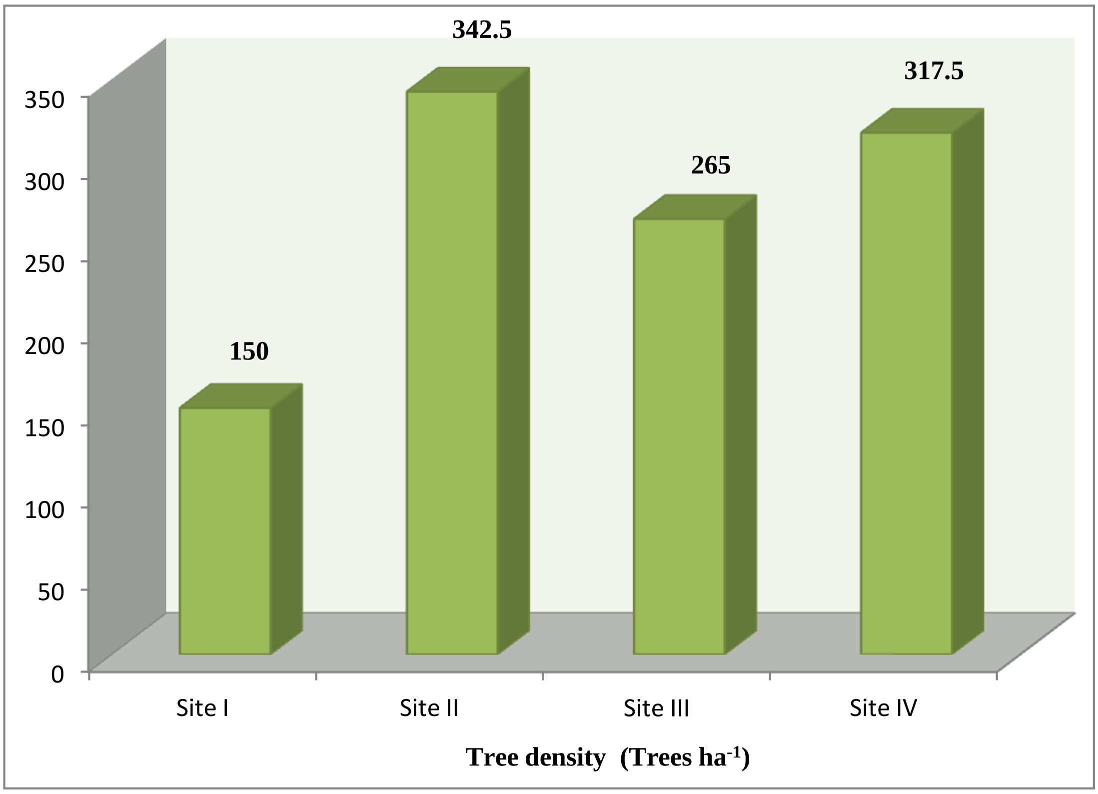

Fig. 2: Mean tree density (Trees ha^{-1}) of *Pinus roxburghii* at different sites

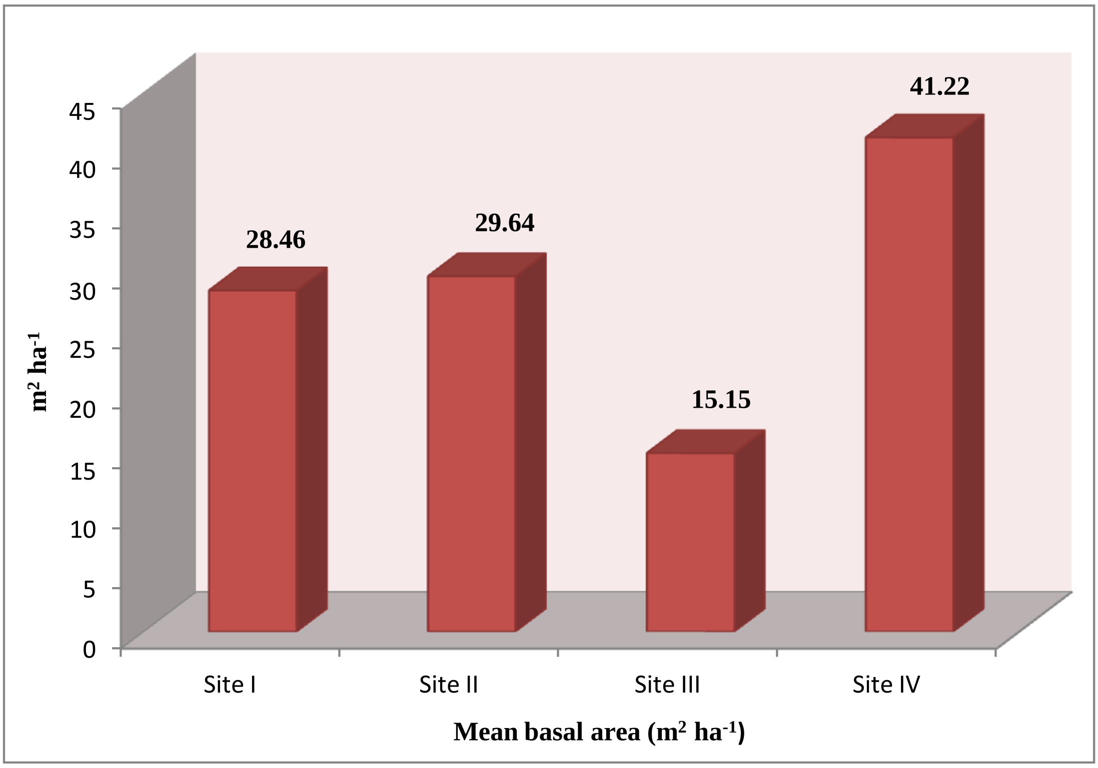

Fig. 3: Mean basal area (m^{2} ha^{-1}) of *Pinus roxburghii* at different sites

4.1.5 Mean basal area ($m^2\ ha^{-1}$)

Basal area is the average amount of an area occupied by a tree stem. Data pertaining to mean basal area of *Pinus roxburghii* at different site in Jammu division is represented in fig. 3.

Maximum mean basal area was recorded at Site IV (41.22 $m^2\ ha^{-1}$), followed by site II (29.64 $m^2\ ha^{-1}$), site I (28.46 $m^2\ ha^{-1}$) and least at site III (15.15 $m^2\ ha^{-1}$) respectively (Fig. 3).

4.2 Biomass and carbon stock of *Pinus roxburghii*

4.2.1 Above ground biomass density (AGBD) (Mg ha^{-1})

Above ground biomass refers to the amount of above ground standing dry mass of live or dead matter from tree, whereas, biomass density mean presence of biomass in per unit area. The data with respect to the AGBD of *Pinus roxburghii* at different site in Jammu division is presented in table 5.

The maximum AGBD (240.99 Mg ha^{-1}) in *Pinus roxburghii* was observed in quadrate 9 at site II, whereas, quadrate 1 at site III recorded minimum AGBD (38.26 Mg ha^{-1}) (Table 5). The average AGBD at different sites was highest (174.10 Mg ha^{-1}) at site II, followed by site IV (161.02 Mg ha^{-1}), site III (99.32 Mg ha^{-1}) and least at site I (93.99 Mg ha^{-1}) respectively. Similarly, range wise maximum variation in AGBD was observed at site II from 76.39 Mg ha^{-1} to 240.99 Mg ha^{-1}, followed by 38.26 Mg ha^{-1} to 174.53 Mg ha^{-1} at site III, 80.50 Mg ha^{-1} to 205.13 Mg ha^{-1} at site IV and minimum 54.69 Mg ha^{-1} to 141.19 Mg ha^{-1} at site I (Table 5).

Significant difference was observed in the mean AGBD at different sites, however, site I was at par with site III and site II was at par with site IV respectively (Table 5).

4.2.2 Below ground biomass density (BGBD) (Mg ha^{-1})

Below ground biomass is the dry mass of the entire living or dead roots of a tree, generally measured as BGBD. For estimating BGBD, the ratio of below ground biomass to above ground biomass was taken as 0.28 as suggested by Mokany *et al.*,

2006. Table deals with the data pertaining to the BGBD of *Pinus roxburghii* at different sites in Jammu division table 5.

Site II at quadrate 9 recorded maximum BGBD (67.48 Mg ha^{-1}), whereas, site III at quadrate 1 recorded minimum BGBD (10.71 Mg ha^{-1}) (Table 5). The mean BGBD of *Pinus roxburghii* was observed maximum at site II (48.75 Mg ha^{-1}), followed by site IV (45.08 Mg ha^{-1}), site III (27.81 Mg ha^{-1}) and minimum at site I (26.32 Mg ha^{-1}) respectively. Highest range in BGBD was recorded from 21.39 Mg ha^{-1} to 67.48 Mg ha^{-1} at site II, followed by 10.71 Mg ha^{-1} to 48.87 Mg ha^{-1} at site III, 22.54 Mg ha^{-1} to 57.44 Mg ha^{-1} at site IV and lowest 15.31 Mg ha^{-1} to 39.53 Mg ha^{-1} at site I respectively (Table 5).

Critical difference in the mean BGBD among different sites was statistically significant, however, site I was at par with site III and site II was at par with site IV respectively (Table 5).

4.2.3 Total biomass density (TBD) (Mg ha^{-1})

The total biomass is the sum of above and below ground biomass, its value in per unit area is expressed as TBD Mg ha^{-1}. The data dealing in TBD of *Pinusroxburghii* at different sites in Jammu division is presented in the table 5.

TBD (308.47 Mg ha^{-1}) was observed maximum in quadrate 9 at site II, whereas, it was observed minimum (48.97 Mg ha^{-1}) in quadrate 1 at site III (Table 5). Likewise maximum average TBD (222.85 Mg ha^{-1}) was recorded at site II, followed by site IV (206.10 Mg ha^{-1}), site III (127.14 Mg ha^{-1}) and minimum at site I (120.30 Mg ha^{-1}) respectively. Similarly, the maximum range in TBD from 76.39 Mg ha^{-1} to 240.99 Mg ha^{-1} was observed in site II, followed by 48.97 Mg ha^{-1} to 223.40 Mg ha^{-1} at site III, 103.04 Mg ha^{-1} to 262.56 Mg ha^{-1} at site IV and minimum from 70.00 Mg ha^{-1} to 180.72 Mg ha^{-1} at site I respectively (Table 5).

The statistical difference in the average TBD among different sites was significant. Site I was at par with site III, similarly, site II was at par with site IV respectively (Table 5).

Table 5: Above ground biomass density (AGBD) (Mg ha^{-1}), below ground biomass density (BGBD) (Mg ha^{-1}) and total biomass density (TBD) (Mg ha^{-1}) in *Pinus roxburghii* at different sites

Quadrates	**Site I**			**Site II**			**Site III**			**Site IV**		
	AGBD (Mg ha^{-1})	**BGBD (Mg ha^{-1})**	**TBD (Mg ha^{-1})**	**AGBD (Mg ha^{-1})**	**BGBD (Mg ha^{-1})**	**TBD (Mg ha^{-1})**	**AGBD (Mg ha^{-1})**	**BGBD (Mg ha^{-1})**	**TBD (Mg ha^{-1})**	**AGBD (Mg ha^{-1})**	**BGBD (Mg ha^{-1})**	**TBD (Mg ha^{-1})**
Quadrate 1	70.85	19.84	90.68	121.73	34.09	155.82	38.26	10.71	48.97	198.77	55.66	254.43
Quadrate 2	88.15	24.68	112.84	76.39	21.39	97.78	151.56	42.44	194.00	162.05	45.37	207.42
Quadrate 3	95.22	26.66	121.89	183.66	51.43	235.09	106.00	29.68	135.67	167.30	46.84	214.14
Quadrate 4	54.69	15.31	70.00	137.98	38.63	176.62	76.63	21.46	98.09	182.46	51.09	233.55
Quadrate 5	97.44	27.28	124.72	197.91	55.42	253.33	174.53	48.87	223.40	80.50	22.54	103.04
Quadrate 6	139.96	39.19	179.14	168.16	47.09	215.25	103.16	28.89	132.05	120.36	33.70	154.06
Quadrate 7	89.89	25.17	115.06	215.97	60.47	276.44	107.65	30.14	137.80	136.92	38.34	175.26
Quadrate 8	74.17	20.77	94.93	159.19	44.57	203.77	50.72	14.20	64.92	153.45	42.97	196.42
Quadrate 9	88.31	24.73	113.03	240.99	67.48	308.47	108.22	30.30	138.52	205.13	57.44	262.56
Quadrate 10	141.19	39.53	180.72	238.99	66.92	305.91	76.51	21.42	97.93	203.22	56.90	260.13
Mean	**93.99**	**26.32**	**120.30**	**174.10**	**48.75**	**222.85**	**99.32**	**27.81**	**127.14**	**161.02**	**45.08**	**206.10**
SE±	8.76	2.45	11.22	16.65	4.66	21.31	13.22	3.70	16.92	12.66	3.54	16.21
SD	27.71	7.76	35.47	52.65	14.74	67.39	41.79	11.70	53.49	40.04	11.21	51.25
CV (%)	29.48	29.48	29.45	30.24	30.24	30.24	42.08	42.08	42.08	24.86	24.86	24.86
CD (5%)	AGBD	38.66		BGBD	10.83		TBD	49.49				

AGBD: Above ground biomass density BGBD: Below ground biomass density TBD: Total biomass density

4.2.4 Above ground carbon density (AGCD) (Mg ha^{-1})

Carbon content with in the biomass was calculated by multiplying the biomass with factor 0.47 (IPCC, 2006). The data illustrating AGCD in *Pinus roxburghii* at different locations in Jammu division are presented in the table 6.

The maximum AGCD (113.27 Mg ha^{-1}) in *Pinus roxburghii* was observed in quadrate 9 at site II, whereas, quadrate 1 at site III recorded minimum AGCD (17.98 Mg ha^{-1}) (Table 6). The average AGCD at different sites was highest (81.83 Mg ha^{-1}) at site II, followed by site IV (75.68 Mg ha^{-1}), site III (46.68 Mg ha^{-1}) and least at site I (44.17 Mg ha^{-1}) respectively. Similarly, range wise maximum variation in AGCD was observed at site II from 35.90 Mg ha^{-1} to 113.27 Mg ha^{-1}, followed by 17.98 Mg ha^{-1} to 82.03 Mg ha^{-1} at site III, 37.84 Mg ha^{-1} to 96.41 Mg ha^{-1} at site IV and minimum 25.70 Mg ha^{-1} to 66.36 Mg ha^{-1} at site I (Table 6).

Significant difference was observed in the mean AGCD at different sites, however, site I was at par with site III and site II was at par with site IV respectively (Table 6).

4.2.5 Below ground carbon density (BGCD) (Mg ha^{-1})

The results pertaining to BGCD in *Pinus roxburghii* at different locations in Jammu division are presented in the table 6.

Site II at quadrate 9 recorded maximum BGCD (31.71 Mg ha^{-1}), whereas, site III at quadrate 1 recorded minimum BGCD (5.04 Mg ha^{-1}) (Table 6). The mean BGCD of *Pinus roxburghii* was observed maximum at site II (22.91 Mg ha^{-1}), followed by site IV (21.19 Mg ha^{-1}), site III (13.0.7 Mg ha^{-1}) and minimum at site I (12.37 Mg ha^{-1}) respectively. Highest range in BGCD was recorded from 10.05 Mg ha^{-1} to 31.71 Mg ha^{-1} at site II, followed by 5.04 Mg ha^{-1} to 22.97 Mg ha^{-1} at site III, 10.59 Mg ha^{-1} to 26.99 Mg ha^{-1} at site IV and lowest 7.20 Mg ha^{-1} to 18.58 Mg ha^{-1} at site I respectively (Table 6).

Critical difference in the mean BGCD among different sites was statistically significant, however, site I was at par with site III and site II was at par with site IV respectively (Table 6).

4.2.6 Total carbon density (TCD) (Mg ha^{-1})

TCD is the sum of AGCD and BGCD. The table 6 reveals the data pertaining to the TCD in *Pinus roxburghii* at different sites in Jammu division.

TCD (144.98 Mg ha^{-1}) was observed maximum in quadrate 9 at site II, whereas, it was observed minimum (23.02 Mg ha^{-1}) in quadrate 1 at site III (Table 6). Likewise maximum average TCD (104.74 Mg ha^{-1}) was recorded at site II, followed by site IV (96.87 Mg ha^{-1}), site III (59.75 Mg ha^{-1}) and minimum at site I (56.54 Mg ha^{-1}) respectively. Similarly, the maximum range in TCD from 45.96 Mg ha^{-1} to 144.98 Mg ha^{-1} was observed in site II, followed by 23.02 Mg ha^{-1} to 105.00 Mg ha^{-1} at site III, 48.43 Mg ha^{-1} to 123.40 Mg ha^{-1} at site IV and minimum from 32.90 Mg ha^{-1} to 84.94 Mg ha^{-1} at site I respectively (Table 6).

The statistical difference in the average TCD among different sites was significant. Site I was at par with site III, similarly, site II was at par with site IV respectively (Table 6).

Table 6: Above ground carbon density (AGCD) (Mg ha^{-1}), below ground carbon density (BGCD) (Mg ha^{-1}) and total carbon density (TCD) (Mg ha^{-1}) in *Pinus roxburghii* at different sites

Quadrates	Site I			Site II			Site III			Site IV		
	AGCD (Mg ha^{-1})	**BGCD (Mg ha^{-1})**	**TCD (Mg ha^{-1})**	**AGCD (Mg ha^{-1})**	**BGCD (Mg ha^{-1})**	**TCD (Mg ha^{-1})**	**AGCD (Mg ha^{-1})**	**BGCD (Mg ha^{-1})**	**TCD (Mg ha^{-1})**	**AGCD (Mg ha^{-1})**	**BGCD (Mg ha^{-1})**	**TCD (Mg ha^{-1})**
Quadrate 1	33.30	9.32	42.62	57.21	16.02	73.23	17.98	5.04	23.02	93.42	26.16	119.58
Quadrate 2	41.43	11.60	53.03	35.90	10.05	45.96	71.24	19.95	91.18	76.16	21.33	97.49
Quadrate 3	44.76	12.53	57.29	86.32	24.17	110.49	49.82	13.95	63.77	78.63	22.02	100.65
Quadrate 4	25.70	7.20	32.90	64.85	18.16	83.01	36.02	10.09	46.10	85.76	24.01	109.77
Quadrate 5	45.80	12.82	58.62	93.02	26.05	119.07	82.03	22.97	105.00	37.84	10.59	48.43
Quadrate 6	65.78	18.42	84.20	79.04	22.13	101.17	48.49	13.58	62.06	56.57	15.84	72.41
Quadrate 7	42.25	11.83	54.08	101.51	28.42	129.93	50.60	14.17	64.76	64.35	18.02	82.37
Quadrate 8	34.86	9.76	44.62	74.82	20.95	95.77	23.84	6.67	30.51	72.12	20.19	92.32
Quadrate 9	41.50	11.62	53.12	113.27	31.71	144.98	50.86	14.24	65.10	96.41	26.99	123.40
Quadrate 10	66.36	18.58	84.94	112.33	31.45	143.78	35.96	10.07	46.03	95.52	26.74	122.26
Mean	**44.17**	**12.37**	**56.54**	**81.83**	**22.91**	**104.74**	**46.68**	**13.07**	**59.75**	**75.68**	**21.19**	**96.87**
SE±	4.12	1.15	5.27	7.83	2.19	10.02	6.21	1.74	7.95	5.96	1.67	7.62
SD	13.02	3.65	16.67	24.75	6.93	31.67	19.64	5.50	25.14	18.82	5.27	24.09
CV (%)	29.48	29.48	29.48	30.24	30.24	30.24	42.08	42.08	42.08	24.86	24.86	24.86
CD (5%)	AGCD	18.17		BGCD	5.09		TCD	23.26				

AGCD: Above ground carbon density BGCD: Below ground carbon density TCD: Total carbon density

4.2.7 Carbon dioxide equivalent (eCO_2) (Mg ha^{-1})

The data revealing eCO_2 (Mg ha^{-1}) of *Pinus roxburghii* at different sites in Jammu division are presented in table 7.

Maximum eCO_2 (532.08 Mg ha^{-1}) at different site in *Pinus roxburghii* was recorded in quadrate 9 at site II, whereas, minimum eCO_2 (84.47 Mg ha^{-1}) was reported from quadrate 1 at site III (Table 7). Site II recorded overall highest average eCO_2 (384.39 Mg ha^{-1}), followed by site IV (355.50 Mg ha^{-1}), site III (219.30 Mg ha^{-1}) and least in site I (207.51 Mg ha^{-1}) respectively. Similarly, maximum range in eCO_2 from 168.66 Mg ha^{-1} to 532.08 Mg ha^{-1} was recorded at site II, followed by 84.47 Mg ha^{-1} to 385.64 Mg ha^{-1} at site III, 452.89 Mg ha^{-1} to 177.74 Mg ha^{-1} at site IV and minimum from 120.74 Mg ha^{-1} to 311.72 Mg ha^{-1} at site I respectively (Table 7).

Statistically there was a significant difference in eCO_2 Mg ha^{-1} in *Pinus roxburghii* at different site. However, site I was at par with site III and sited II was at par with site III respectively (Table 7).

Table 7: Carbon dioxide equivalent (eCO_2) (Mg ha^{-1}) in *Pinus roxburghii* at different sites

Quadrates	**Site I**	**Site II**	**Site III**	**Site IV**
	Carbon dioxide equivalent (eCO2) (Mg ha^{-1})			
Quadrate 1	156.42	268.77	84.47	438.86
Quadrate 2	194.63	168.66	334.64	357.79
Quadrate 3	210.24	405.50	234.02	369.38
Quadrate 4	120.74	304.65	169.20	402.85
Quadrate 5	215.14	436.97	385.34	177.74
Quadrate 6	309.00	371.29	227.77	265.73
Quadrate 7	198.47	476.83	237.69	302.31
Quadrate 8	163.75	351.48	111.98	338.80
Quadrate 9	194.97	532.08	238.93	452.89
Quadrate 10	311.72	527.66	168.93	448.69
Mean	**207.51**	**384.39**	**219.30**	**355.50**
SE±	19..35	36.76	29.18	27.95
SD	61.18	116.25	92.27	88.40
CV (%)	29.48	30.24	42.08	24.86
CD (5%)	85.37			

4.3 Soil physical and chemical properties

4.3.1 Soil bulk density (gm cm^{-3})

Soil bulk density refers to the compactness of soil, which is calculated by dividing dry weight of soil to its volume. The data dealing with soil bulk density at different soil depths in *Pinus roxburghii* forest at different sites in Jammu division are illustrated in table 8.

At soil depth 0-30 cm, maximum soil bulk density (1.73 gm cm^{-3}) was recorded in quadrate 3 at site I, whereas, minimum soil bulk density (0.69 gm cm^{-3}) was observed in quadrate 3 at site II (Table 8). Mean soil bulk density (1.39 gm cm^{-3}) among different sites at 0-30 cm soil depth, was highest at site I, followed by site III (1.26 gm cm^{-3}), site II (1.20 gm cm^{-3}) and least at site IV (1.16 gm cm^{-3}) respectively. Similarly, maximum range in soil bulk density (0.69 gm cm^{-3} to 1.58 gm cm^{-3}) at 0-30cm soil depth was reported from site II, whereas, minimum range in soil bulk density (0.93 gm cm^{-3} to 1.38 gm cm^{-3}) was reported from site IV respectively (Table 8).

At soil depth 30-60 cm, maximum soil bulk density (1.76 gm cm^{-3}) was observed in quadrate 5 at site II, whereas, minimum soil bulk density (0.91 gm cm^{-3}) was also observed from site II in quadrate 4 (Table 8). Average soil bulk density (1.42 gm cm^{-3}) at 30-60 cm soil depth among different site was recorded highest from site I, followed by site III (1.38 gm cm^{-3}), site IV (1.38 gm cm^{-3}) and least in site II (1.35 gm cm^{-3}) respectively. Likewise, maximum range in soil bulk density (1.01 gm cm^{-3} to 1.71 gm cm^{-3}) at 30-60 cm depth was noticed at site I, whereas, minimum range (1.21 to 1.69 gm cm^{-3}) was observed at site respectively (Table 8).

The data revealed in Table 8 clearly indicate that there is an increase in soil bulk density with increasing soil depth in all the sites. Statistically soil bulk density at 0-30 cm is not significant among all the sites, similarly, also at soil depth 30-60 cmthe data was insignificant with respect to sites (Table 8)

Table 8: Soil bulk density (gm cm^{-3}) in *Pinus roxburghii* forest at different sites

Quadrates	Soil depth (0-30 cm)				Soil depth (30-60 cm)			
	Site I	**Site II**	**Site III**	**Site IV**	**Site I**	**Site II**	**Site III**	**Site IV**
Quadrate 1	1.27	1.09	1.46	0.93	1.01	1.22	1.59	1.48
Quadrate 2	1.49	1.20	1.52	1.28	1.39	1.38	1.41	1.49
Quadrate 3	1.73	0.69	1.02	1.32	1.30	1.32	1.32	1.30
Quadrate 4	1.58	1.41	1.40	1.03	1.38	0.91	1.21	1.35
Quadrate 5	1.26	1.47	1.19	1.36	1.34	1.76	1.22	1.30
Quadrate 6	1.32	0.98	1.21	1.08	1.22	1.73	1.26	1.09
Quadrate 7	1.40	1.14	1.05	1.16	1.60	1.33	1.36	1.20
Quadrate 8	1.42	1.58	1.18	1.38	1.60	1.49	1.69	1.50
Quadrate 9	1.23	1.02	1.16	1.07	1.71	1.39	1.37	1.71
Quadrate 10	1.23	1.39	1.42	0.97	1.62	0.99	1.32	1.37
Mean	**1.39**	**1.20**	**1.26**	**1.16**	**1.42**	**1.35**	**1.38**	**1.38**
SE±	0.05	0.09	0.06	0.05	0.07	0.09	0.05	0.06
SD	0.17	0.27	0.18	0.17	0.22	0.27	0.15	0.17
CV (%)	11.89	22.53	14.00	14.33	15.22	20.26	11.28	12.67
CD (5%)	0-30 cm		NS		30-60 cm		NS	

4.3.2 Soil pH

Soil pH is the measure of acidity or basicity of a soil. The data pertaining to soil pH at different soil depths in *Pinus roxburghii* forest at different sites in Jammu division are represent in the table 9.

At soil depth 0-30 cm, soil pH (7.64) was recorded maximum in quadrate 3 at site III, whereas, minimum soil pH (4.07) was recorded in quadrate 4 at site II (Table 9). Mean soil pH (6.93) at soil depth 0-30 cm among all the sites was highest at site III, followed by site I (6.47), site IV (6.03) and least at site II (4.94) respectively. Similarly, maximum range in soil pH (5.84 to 7.64) at soil depth 0-30 cm wasobserved in site III, whereas, minimum range in soil pH (5.64 to 7.17) was observedat site I respectively (Table 9).

Soil pH (7.80) was observed maximum in quadrate 3 at site III at soil depth 30-60 cm, whereas, minimum soil pH (4.15) was observed in quadrate 4 at site II (Table 9). Likewise, average soil pH (7.06) at soil depth 30-60 cm was highest at site III, followed by site I (6.44), site IV (5.98) and least at site II (4.90) respectively. Similarly, maximum range in soil pH (4.15 to 5.83) at soil depth 30-60 cm was noticed at site II, whereas, minimum range in soil pH (5.53 to 6.91) at 30-60 cm soil depth was observed at site IV respectively (Table 9).

It was observed that soil pH increased with soil depth at all the sites except at site III where it increased with soil depth. At soil depth 0-30 cm the data with regard to soil pH was statistically significant, however, site I was at par with site III and site IV. Similarly, for soil depth 30-60 cm the soil pH among different site was significant, however, site I was at par with site IV respectively (Table 9).

Table 9: Soil pH in *Pinus roxburghii* forest at different sites

Quadrates	Soil depth (0-30 cm)				Soil depth (0-30 cm)			
	Site I	Site II	Site III	Site IV	Site I	Site II	Site III	Site IV
Quadrate 1	7.17	4.65	6.95	5.96	6.05	4.75	7.33	5.67
Quadrate 2	5.98	5.76	6.91	5.86	6.92	5.83	7.25	5.53
Quadrate 3	6.86	4.98	7.64	5.30	5.50	4.99	7.80	5.70
Quadrate 4	5.64	4.07	6.64	6.87	6.83	4.15	6.43	6.91
Quadrate 5	6.45	5.10	7.61	6.37	6.58	4.42	7.50	6.40
Quadrate 6	6.70	4.37	5.84	6.24	6.40	5.11	6.20	5.92
Quadrate 7	6.21	4.81	7.43	5.59	6.41	4.71	7.44	5.72
Quadrate 8	6.46	5.13	6.07	6.23	6.52	5.26	6.21	6.36
Quadrate 9	6.57	5.14	7.32	5.86	6.72	4.51	7.44	6.01
Quadrate 10	6.61	5.38	6.92	5.98	6.50	5.28	7.01	5.59
Mean	**6.47**	**4.94**	**6.93**	**6.03**	**6.44**	**4.90**	**7.06**	**5.98**
SE±	0.14	0.16	0.19	0.14	0.13	0.16	0.18	0.14
SD	0.44	0.49	0.61	0.43	0.46	0.49	0.58	0.45
CV (%)	6.76	9.90	8.84	7.21	7.15	10.08	8.18	7.45
CD (5%)	0-30 cm		0.49		30-60 cm		0.50	

4.3.3 Electrical conductivity (dSm^{-1})

The date recorded for electrical conductivity (Electrical Conductivity (dSm^{-1}) at different soil depth in *Pinus roxburghii* forest at different site in Jammu division are represented in table 10.

Maximum soil electrical conductivity (0.39 dSm^{-1}) at 0-30 cm soil depth was observed in quadrate 4 at site IV, whereas, minimum (0.06 dSm^{-1}) was observed in quadrate 2 at site I and Q6 at site III (Table 10). Mean electrical conductivity (0.17 dSm^{-1}) at different site at 0-30 cm depth was recorded maximum from site II, followed by site IV (0.16 dSm^{-1}), site III (0.14 dSm^{-1}) and minimum at site I (0.13 dSm^{-1}) respectively (Table 10).

At soil depth 30-60 cm, soil electrical conductivity (0.20 dSm^{-1}) in *Pinus roxburghii* forest at different sites was maximum in quadrate 10 at site I, whereas, minimum soil electrical conductivity (0.04 dSm^{-1}) was recorded in quadrate 7 and quadrate 8 at site I, Q6 at site III and quadrate 9 at site IV respectively (Table 10). Overall at soil depth 30-60 cm, the maximum average soil electrical conductivity (0.12 dSm^{-1}) noted at different site was at site I, followed by site III (0.11 dSm^{-1}), site IV (0.09 dSm^{-1}) and minimum at site II (0.07 dSm^{-1}) respectively (Table 10).

The data pertaining soil electrical conductivity in *Pinus roxburghii* forest at different site in both the soil depth i.e. 0-30 cm and 30-60 cm was statistically insignificant (Table 10).

Table 10: Soil electrical conductivity (dS m^{-1}) in *Pinus roxburghii* forest at different sites

Quadrates	Soil depth (0-30 cm)				Soil depth (30-60 cm)			
	Site I	Site II	Site III	Site IV	Site I	Site II	Site III	Site IV
Quadrate 1	0.14	0.14	0.14	0.16	0.16	0.05	0.12	0.09
Quadrate 2	0.06	0.24	0.15	0.11	0.05	0.07	0.13	0.07
Quadrate 3	0.13	0.25	0.19	0.16	0.10	0.09	0.15	0.06
Quadrate 4	0.08	0.12	0.11	0.39	0.04	0.17	0.07	0.15
Quadrate 5	0.16	0.08	0.16	0.11	0.14	0.04	0.12	0.08
Quadrate 6	0.16	0.34	0.06	0.16	0.18	0.05	0.04	0.06
Quadrate 7	0.12	0.15	0.16	0.17	0.06	0.04	0.12	0.10
Quadrate 8	0.09	0.10	0.09	0.16	0.06	0.04	0.06	0.13
Quadrate 9	0.17	0.12	0.19	0.07	0.17	0.06	0.14	0.04
Quadrate 10	0.19	0.12	0.18	0.12	0.20	0.06	0.13	0.09
Mean	**0.13**	**0.17**	**0.14**	**0.16**	**0.12**	**0.07**	**0.11**	**0.09**
SE±	0.01	0.03	0.01	0.03	0.02	0.01	0.01	0.01
SD	0.04	0.08	0.05	0.09	0.06	0.04	0.03	0.03
CV (%)	31.91	50.0 9	31.52	53.34	51.10	56.40	34.55	38.92
CD (5%)	0-30 cm		NS		30-60 cm		NS	

4.3.4 Soil organic carbon (gm kg^{-1})

The data with regard to soil organic carbon at different soil depth in *Pinus roxburghii* forest at different sites in Jammu division are present in (table 11).

At 0-30 cm soil depth, soil organic carbon (21.90 gm kg^{-1}) was found to be maximum in quadrate 7 at site IV, whereas minimum soil organic carbon (4.80 gm kg^{-1}) was reported from quadrate 8 at site I (Table 11). The highest average soil organic carbon (13.38 gm kg^{-1}) at soil depth 0-30 cm was recorded from site II, followed by site IV (13.14 gm kg^{-1}), site III (7.16 gm kg^{-1}) and least at site I (6.31 gm kg^{-1}) respectively. Similarly, maximum range in soil organic carbon (7.80 gm kg^{-1} to 21.90 gm kg^{-1}) at soil depth 0-30 cm was recorded from site IV, whereas, minimum range insoil organic carbon (4.80 gm kg^{-1} to 7.80 gm kg^{-1}) was recorded from site I (Table 11).

Soil organic carbon (14.40 gm kg^{-1}) at soil depth 30-60 cm was recorded maximum in quadrate 7 from site IV, whereas, minimum soil organic carbon (2.30 gm kg^{-1}) was recorded in quadrate 7 from site I (Table 11). Likewise, mean soil organic carbon (9.80 gm kg^{-1}) at 30-60 cm soil depth was recorded maximum in site II, followed by site IV (6.52), site I (4.08 gm kg^{-1}) and minimum at site III (3.80 gm kg^{-1})respectively Table 11. Maximum range in soil organic carbon (2.70 gm kg^{-1} to 14.40 gm kg^{-1}) at soil depth 30-60 cm was observed at site IV, whereas, minimum soil organic carbon (3.00 gm kg^{-1} to 4.80 gm kg^{-1}) was observed at site III (Table 11).

The critical difference at both the soil depth indicates that there was a significant difference in soil organic carbon in *Pinus roxburghii* forest among different sites. However, for soil depth 0-30 cm site I was at par with site III and siteII was at par with site IV respectively. Likewise for soil depth 30-60 cm, site I was at par with site III (Table 11).

Table 11: Soil organic carbon (gm kg^{-1}) in *Pinus roxburghii* forest at different sites

Quadrates	Soil depth (0-30 cm)				Soil depth (30-60 cm)			
	Site I	Site II	Site III	Site IV	Site I	Site II	Site III	Site IV
Quadrate 1	5.90	15.60	6.00	15.00	4.30	9.60	3.00	6.30
Quadrate 2	7.10	9.90	6.30	8.40	5.30	6.60	2.70	6.40
Quadrate 3	5.10	12.60	6.60	7.80	2.50	10.10	3.60	6.90
Quadrate 4	6.50	13.20	6.00	17.40	3.00	12.60	3.60	7.80
Quadrate 5	6.00	11.10	7.80	7.80	5.50	9.60	3.50	2.70
Quadrate 6	7.80	19.80	7.20	15.00	5.70	9.30	4.20	5.40
Quadrate 7	6.00	15.60	8.50	21.90	2.30	12.00	4.50	14.40
Quadrate 8	4.80	11.10	9.80	15.00	3.20	8.90	4.80	4.50
Quadrate 9	6.80	14.10	6.90	10.50	4.10	10.10	4.80	4.80
Quadrate 10	7.10	10.80	6.50	12.60	4.90	9.20	3.20	6.00
Mean	**6.31**	**13.38**	**7.16**	**13.14**	**4.08**	**9.80**	**3.80**	**6.52**
SE±	0.30	0.95	0.39	1.46	0.40	0.52	0.24	0.98
SD	0.93	3.01	1.22	4.62	1.27	1.65	0.75	3.11
CV (%)	14.80	30.69	16.88	35.15	31.06	16.87	19.39	47.71
CD (5%)	0-30 cm		2.40		30-60 cm		1.79	

4.3.5 Available soil nitrogen (kg ha^{-1})

Available nitrogen (kg ha^{-1}) present in different soil depths in *Pinus roxburghii* forest at different sites in Jammu division is presented in table 12.

Maximum available nitrogen (388.34 kg ha^{-1}) at 0-30 cm soil depth wasreported from quadrate 10 at site IV, whereas, quadrate 8 from site I reported minimum available nitrogen (100.35 kg ha^{-1}) (Table 12). The value for mean availablenitrogen (272.83 kg ha^{-1}) at 0-30 cm soil depth was observed highest from site II, followed by site IV (225.11 kg ha^{-1}), site I (201.44 kg ha^{-1}) and least at site III (176.92kg ha^{-1}) respectively. Similarly, maximum range in available nitrogen (163.07 kg ha^{-1} to 388.34 kg ha^{-1}) at 0-30 cm soil depth was reported from site IV, whereas, minimum available nitrogen (213.25 to 301.06) was reported from site II (Table 12).

At soil depth 30-60 cm, maximum available nitrogen (275.97 kg ha^{-1}) was reported from quadrate 1 at site II, whereas, minimum available nitrogen (31.36 kg ha^{-1}) was reported from quadrate 1 at site III (Table 12). Likewise, Average available nitrogen (220.15 kg ha^{-1}) at soil depth 30-60 cm was reported highest from site II, followed by site IV (161.19 kg ha^{-1}), site I (117.29 kg ha^{-1}) and least at site III (105.79 kg ha^{-1}) respectively (Table 12). Both, site II (119.17 kg ha^{-1} to 275.97 kg ha^{-1}) and site IV (64.08 kg ha^{-1} to 250.88 kg ha^{-1}) reported maximum range in available nitrogen at soil depth 30-60 cm, whereas, minimum range in available nitrogen (56.45kg ha^{-1} to 200.70 kg ha^{-1}) was reported from site I (Table 12).

Both the soil depth i.e. 0-30 cm and 30-60 cm showed a significant difference in available nitrogen, however, at soil depth 0-30 cm site I was at par with site III. Similarly, for soil depth 30-60 cm again site I was at par with site III (Table 12).

Table 12: Available soil nitrogen (kg ha^{-1}) in *Pinus roxburghii* forest at different sites

Quadrates	Soil depth (0-30 cm)				Soil depth (30-60 cm)			
	Site I	**Site II**	**Site III**	**Site IV**	**Site I**	**Site II**	**Site III**	**Site IV**
Quadrate 1	200.70	301.06	106.62	238.34	150.53	275.97	31.36	175.62
Quadrate 2	175.62	250.88	219.52	163.07	94.08	213.25	150.53	119.17
Quadrate 3	112.90	269.70	181.89	188.11	56.45	213.25	94.08	94.08
Quadrate 4	283.34	282.24	137.98	175.62	200.70	175.62	94.08	106.62
Quadrate 5	244.61	213.25	188.16	188.16	119.17	119.17	131.71	137.98
Quadrate 6	213.25	288.51	219.52	175.62	131.71	244.61	100.35	163.07
Quadrate 7	225.79	294.78	181.89	250.88	62.72	250.88	137.98	238.34
Quadrate 8	100.35	294.78	194.43	244.61	81.54	275.97	119.17	181.89
Quadrate 9	232.06	269.70	156.80	238.34	144.26	219.52	100.35	144.26
Quadrate 10	225.79	263.42	182.40	388.34	131.71	213.25	98.32	250.88
Mean	**201.44**	**272.83**	**176.92**	**225.11**	**117.29**	**220.15**	**105.79**	**161.19**
SE±	18.12	8.32	11.06	20.95	14.03	14.94	10.44	16.57
SD	57.31	26.32	34.97	66.26	44.35	47.26	33.03	52.40
CV (%)	28.45	9.65	19.76	29.44	37.82	21.47	31.22	32.51
CD (5%)	0-30 cm		47.02		30-60 cm		43.18	

4.3.6 Available soil phosphorus (kg ha^{-1})

The data representing the amount of available phosphorous in *Pinus roxburghii* forest at different sites in Jammu division is presented in table 13.

The maximum amount of available phosphorus (31.70 kg ha^{-1}) at soil depth 0-30 cm in *Pinus roxburghii* forest was found in quadrate 5 at site I, whereas, minimum value of available phosphorous (6.61 kg ha^{-1}) was reported from quadrate 5 at site IV (Table 13). Overall the mean value for available phosphorous (26.50 kg ha^{-1}) was highest at site I, followed by site II (20.80 kg ha^{-1}), site III (19.78 kg ha^{-1}) and lowest at site IV (18.07 kg ha^{-1}) respectively. Similarly, the maximum range in available phosphorous (6.61 kg ha^{-1} to 29.34 kg ha^{-1}) at soil depth 0-30 cm was observed at site IV, whereas, minimum range in available phosphorous (22.74 kg ha^{-1} to 29.68 kg ha^{-1}) was noticed at site I (Table 13).

At soil depth 30-60 cm, maximum amount of available phosphorous (24.75 kg ha^{-1}) was recorded from quadrate 8 at site I, whereas, minimum amount of available phosphorous (3.58 kg ha^{-1}) was recorded from quadrate 4 at site III (Table 13). Average value of available phosphorus (17.60 kg ha^{-1}) at soil depth 30-60 cm was found highest at site I, followed by site II (12.11 kg ha^{-1}), site III (11.89 kg ha^{-1}) and lowest at site IV (10.71 kg ha^{-1}) respectively. Likewise, maximum range in available phosphorous (3.58 kg ha^{-1} to 21.06 kg ha^{-1}) was found at site III, whereas, minimum range in available phosphorous (4.48 kg ha^{-1} to 18.14 kg ha^{-1}) was recorded from site II (Table 13).

Statistically the data for the available phosphorous at different soil depth i.e. 0-30 cm and 30-60 cm in *Pinus roxburghii* forest at different sites in Jammu division was significant. However, at soil depth 0-30 cm site II, site III and site IV was at par with each other. Similarly, for soil depth 30-60 cm also site II, site III and site IVwere at par with each other (Table 13).

Table 13: Available soil phosphorus (kg ha^{-1}) in *Pinus roxburghii* forest at different sites

Quadrates	Soil depth (0-30 cm)				Soil depth (30-60 cm)			
	Site I	Site II	Site III	Site IV	Site I	Site II	Site III	Site IV
Quadrate 1	29.68	23.63	30.69	24.08	18.26	13.22	13.22	16.91
Quadrate 2	22.96	25.20	19.26	13.89	20.16	18.14	9.30	13.44
Quadrate 3	25.20	27.22	14.78	11.42	14.45	7.17	8.51	8.74
Quadrate 4	28.22	17.47	18.93	19.26	13.33	4.48	3.58	9.97
Quadrate 5	31.70	24.98	24.08	6.61	14.67	11.20	21.06	4.70
Quadrate 6	22.74	28.11	15.01	26.43	14.22	17.70	14.56	11.42
Quadrate 7	28.45	15.68	24.08	23.52	23.07	6.72	13.89	9.30
Quadrate 8	25.98	15.34	18.37	29.34	24.75	13.89	12.32	16.58
Quadrate 9	26.99	11.65	17.14	15.68	14.11	11.31	12.99	9.63
Quadrate 10	23.07	18.70	15.42	10.42	18.93	17.25	9.47	6.38
Mean	**26.50**	**20.80**	**19.78**	**18.07**	**17.60**	**12.11**	**11.89**	**10.71**
SE±	0.97	1.81	1.61	2.41	1.29	1.53	1.46	1.26
SD	3.06	5.72	5.08	7.61	4.08	4.85	4.61	3.99
CV (%)	11.56	27.51	25.71	42.14	23.21	40.04	38.78	37.26
CD (5%)	0-30 cm		5.13		30-60 cm		3.68	

4.3.7 Available soil potassium (kg ha^{-1})

The value for the amount of available potassium at different soil depth in *Pinus roxburghii* forest at different locations in Jammu division are presented in table 14.

For soil depth 0-30 cm, maximum amount of available potassium (204.30 kg ha^{-1}) was reported from quadrate 1 at site IV, whereas, minimum amount of available potassium (40.63 kg ha^{-1}) was reported from quadrate 1 site III (Table 14). The mean value for the amount of available potassium (134.76 kg ha^{-1}) in soil depth 0-30 cm at different site was highest at site II, followed by site IV (120.23), site III (76.21 kg ha^{-1}) and least at site I (56.66 kg ha^{-1}) respectively. Likewise, maximum range in available potassium (23.63 kg ha^{-1} to 169.31 kg ha^{-1}) was observed at site II, whereas, minimum value (16.88 kg $ha^{-1}$to 81.11 kg ha^{-1}) was observed from site I (Table 14).

At soil depth 30-60 cm, the maximum value for the amount of available potassium (132.08 kg ha^{-1}) was observed at site II, whereas, site III recorded the minimum value (50.76 kg ha^{-1}) in quadrate 1 at site III (Table 14). Similarly, the highest average value for the available potassium (79.61 kg ha^{-1}) at soil depth 30-60 cm was recorded from site II, followed by site IV (54.37 kg ha^{-1}), site I (44.04 kg ha^{-1})and lowest at site III (35.61 kg ha^{-1}) respectively. The maximum range in available potassium (27.11 kg ha^{-1} to 132.08 kg ha^{-1}) at soil depth 30-60 cm was observed atsite IV. Whereas, minimum (14.06 kg ha^{-1} to 76.95 kg ha^{-1}) from site I (Table 14).

The data with respect to the available potassium at different soil depth in *Pinus roxburghii* forest at different sites in Jammu division was statistically significant. However, for soil depth 0-30 cm, the data observed at site I was at par with site III and site II was at par with site IV respectively. Likewise, for soil depth 30-60 cm, site I, site III and site IV were at par with each other respectively (Table 14).

Table 14: Available soil potassium (kg ha^{-1}) in *Pinus roxburghii* forest at different sites

Quadrates	Soil depth (0-30 cm)				Soil depth (30-60 cm)			
	Site I	Site II	Site III	Site IV	Site I	Site II	Site III	Site IV
Quadrate 1	45.68	192.71	40.63	204.30	41.63	86.85	39..05	132.08
Quadrate 2	43.65	133.09	48.15	60.30	42.53	97.20	36.90	27.11
Quadrate 3	46.58	109.46	64.69	68.85	43.65	66.71	21.60	38.59
Quadrate 4	53.55	109.58	47.81	127.80	46.80	87.41	23.29	42.19
Quadrate 5	81.11	122.85	43.99	64.91	72.90	41.85	29.48	37.58
Quadrate 6	46.80	190.69	104.18	107.66	40.28	113.85	32.63	40.39
Quadrate 7	54.90	93.49	132.08	198.79	45.90	83.59	59.96	92.14
Quadrate 8	51.75	94.50	169.31	123.08	47.93	47.36	82.80	48.94
Quadrate 9	71.66	127.91	61.99	75.26	64.13	92.25	27.11	34.31
Quadrate 10	70.88	173.36	66.24	171.34	61.88	78.98	29.31	50.40
Mean	**56.66**	**134.76**	**76.21**	**120.23**	**50.76**	**79.61**	**35.61**	**54.37**
SE±	4.15	11.91	14.30	17.44	3.58	6.99	6.53	10.29
SD	13.13	37.66	45.22	55.16	11.31	22.12	20.65	32.54
CV (%)	23.17	27.95	59.34	45.88	22.28	27.79	57.98	59.85
CD (5%)	0-30 cm		37.67		30-60 cm		23.87	

4.3.8 Cation exchange capacity (c. mol. P^+)

The result pertaining cation exchange capacity at different soil depth in *Pinus roxburghii* forest at different locations of Jammu division are presented in the table 15.

The date in the table 15 reveals that at a soil depth 0-30 cm, maximum cation exchange capacity (35.01 c. mol. P^+) was recorded in quadrate 7 at site IV, whereas, minimum (15.66 c. mol. P^+) was reported from quadrate 8 at site I (Table 15). Overall, the average cation exchange capacity (29.93 c. mol. P^+) at soil depth of 0-30 cm was found highest at site IV, followed by site II (29.31 c. mol. P^+), site III (19.71 c. mol. P^+) and least at site I (18.26 c. mol. P^+), respectively. Similarly, the maximum range in cation exchange capacity (20.65 c. mol. P^+ to 35.01 c. mol. P^+) was observed at site IV, whereas, minimum (15.66 c. mol. P^+ to 20.11 c. mol. P^+) range was observed at site I (Table 15).

At a soil depth of 30-60 cm, the value for cation exchange capacity (30.81 c. mol. P^+) was maximum in quadrate 7 at site II, whereas, minimum (12.11 c. mol. P^+) value was recorded in quadrate 8 at site I (Table 15). The mean value for cation exchange capacity (26.89 c. mol. P^+) was recorded maximum from site II, followed by site IV (20.58 c. mol. P^+), site III (15.80) and least at site I (15.39 c. mol. P^+) respectively. Likewise, maximum range for cation exchange capacity (18.72 c. mol. P^+ to 30.81 c. mol. P^+) was observed from site II, whereas, lowest value (14.48 c. mol.P^+ to 18.75 c. mol. P^+) were observed from site III (Table 15).

There was a significant difference for the cation exchange capacity at different soil depth in *Pinus roxburghii* forest at different sites in Jammu division. However, for soil depth 0-30 cm, site I was at par with site III. Similarly, for soil depth 30-60 cm, site I and site III were at par with each other (Table 15).

Table 15: Cation exchange capacity (c. mol. P+) in *Pinus roxburghii* forest at different sites

Quadrates	Soil depth (0-30 cm)				Soil depth (30-60 cm)			
	Site I	Site II	Site III	Site IV	Site I	Site II	Site III	Site IV
Quadrate 1	17.52	30.64	18.65	31.23	15.31	28.55	15.56	20.34
Quadrate 2	19.46	27.98	18.11	29.75	18.94	18.72	14.87	19.62
Quadrate 3	16.87	28.35	17.62	26.42	12.52	29.08	14.48	20.05
Quadrate 4	18.38	29.12	18.29	30.52	15.46	26.15	14.87	22.53
Quadrate 5	18.74	28.06	20.68	20.65	16.57	27.43	15.62	15.16
Quadrate 6	20.11	33.26	19.74	32.98	18.62	29.93	15.97	20.47
Quadrate 7	17.44	31.38	21.85	35.01	13.39	30.81	17.05	25.66
Quadrate 8	15.66	27.94	25.52	32.05	12.11	27.09	18.75	19.97
Quadrate 9	18.61	28.47	17.95	29.64	14.25	25.61	15.05	19.48
Quadrate 10	19.83	27.86	18.69	31.02	16.74	25.55	15.78	22.53
Mean	**18.26**	**29.31**	**19.71**	**29.93**	**15.39**	**26.89**	**15.80**	**20.58**
SE±	0.44	0.58	0.77	1.25	0.75	1.07	0.40	0.85
SD	1.40	1.84	2.44	3.96	2.37	3.39	1.27	2.70
CV (%)	7.66	6.30	12.37	13.24	15.40	12.59	8.01	12.12
CD (5%)	0-30 cm		2.27		30-60 cm		2.42	

4.3.9 Soil texture

The results obtained in regard to soil texture at different soil depth of *Pinus roxburghii* forest at different locations in Jammu division are represented in the table 16, table 17, table 18 and table 19.

Site I

At site I, of soil depth 0-30 cm, major soil textural classes observed was clay, clay loam and loam was found (Table 16). Maximum value of sand (41.88%) particle was observed at quadrate 6, whereas, minimum (18.74%) value was recorded from Q1. Similarly, highest value for silt (42.07%) particle was observed at quadrate 4 and lowest (23.57%) at quadrate 2. Likewise, maximum clay (57.05%) content was recorded from quadrate 2, whereas, minimum (20.47%) was observed from quadrate 4 respectively (Table 16).

Soil depth 30-60 cm at site I included textural classes such as clay, clay loam, loam, sandy clay loam and sandy loam respectively (Table 16). Sand content was reported maximum (57.38%) from quadrate 1, whereas, minimum (13.52%) was observed in quadrate 10. Likewise, silt content was maximum (44.00%) from quadrate 6 and minimum (27.14%) from quadrate 2. The clay percent was recorded maximum (48.12%) in quadrate 10, whereas, it was minimum (14.76%) in quadrate 1 (Table 16).

Site-II

In case of site II at a soil depth of 0-30 cm, different soil textural classes found. They included clay, clay loam and sandy clay loam. Maximum sand (57.88%) content was reported in quadrate 10, whereas, minimum (13.88%) was recorded from quadrate 7 (Table 17). Silt content was highest (38.00%) at quadrate 7 and lowest (4.00%) in quadrate 4. Similarly, clay content was maximum (52.12%) in quadrate 4, whereas, in quadrate 10 it was minimum (30.12%) (Table 17).

The soil textural classes identified at site II in soil depth 30-60 cm were clay, clay loam and sandy clay loam. The maximum (57.88%) value for sand content was observed from quadrate 10, whereas, quadrate 6 reported the lowest (21.88%) value (Table 17). Likewise, the maximum amount of silt (28.00%) particles was found at quadrate 7, whereas, minimum was reported from quadrate 8. Similarly, maximum (52.12%) clay content was observed at quadrate 6 and lowest from quadrate 2 respectively (Table 17).

Table 16: Soil texture at site I

Quadrates	Site I							
	Soil Depth							
	0-30 cm				30-60 cm			
	% Sand	% Silt	% Clay	Soil textural class	% Sand	% Silt	% Clay	Soil textural class
Quadrate 1	18.74	30.36	50.90	Clay	57.38	27.86	14.76	Sandy loam
Quadrate 2	19.38	23.57	57.05	Clay	49.38	27.14	23.47	Sandy clay loam
Quadrate 3	39.24	27.64	33.12	Clay loam	39.38	29.71	30.90	Clay loam
Quadrate 4	37.46	42.07	20.47	Loam	45.24	29.36	25.40	Loam
Quadrate 5	27.24	41.93	30.83	Clay loam	39.53	35.57	24.90	Loam
Quadrate 6	41.88	28.00	30.12	Clay loam	23.88	44.00	32.12	Clay loam
Quadrate 7	33.88	38.00	28.12	Clay loam	39.88	32.00	28.12	Clay loam
Quadrate 8	35.88	28.00	36.12	Clay loam	39.88	32.00	28.12	Clay loam
Quadrate 9	41.52	26.00	32.48	Clay loam	27.16	34.36	38.48	Clay loam
Quadrate 10	29.16	24.36	46.48	Clay	13.52	38.36	48.12	Clay
Mean	**32.44**	**30.99**	**36.57**		**37.52**	**33.04**	**29.44**	
SE±	2.69	2.22	3.59		4.06	1.65	2.85	
SD	8.52	7.03	11.34		12.84	5.22	9.02	
CV (%)	26.26	22.69	31.00		34.21	15.79	30.62	

Table 17: Soil texture at site II

Quadrates	Site II							
	Soil Depth							
	0-30 cm				30-60 cm			
	% Sand	**% Silt**	**% Clay**	**Soil textural class**	**% Sand**	**% Silt**	**% Clay**	**Soil textural class**
Quadrate 1	27.52	34.00	38.48	Clay loam	26.44	26.72	46.84	Clay
Quadrate 2	40.44	24.72	34.84	Clay loam	42.44	24.72	32.84	Clay loam
Quadrate 3	42.44	20.72	36.84	Clay loam	43.88	14.00	42.12	Clay
Quadrate 4	43.88	4.00	52.12	Clay	43.88	10.00	46.12	Clay
Quadrate 5	39.88	16.00	44.12	Clay	37.88	12.00	50.12	Clay
Quadrate 6	23.88	30.00	46.12	Clay	21.88	26.00	52.12	Clay loam
Quadrate 7	13.88	38.00	48.12	Clay	25.88	28.00	46.12	Clay
Quadrate 8	27.88	32.00	40.12	Clay	33.88	24.00	42.12	Clay
Quadrate 9	31.88	32.00	36.12	Clay loam	49.88	2.00	48.12	Sandy clay
Quadrate 10	57.88	12.00	30.12	Sandy clay loam	57.88	4.00	38.12	Sandy clay
Mean	**34.96**	**24.34**	**40.70**		**38.39**	**17.14**	**44.46**	
SE±	3.94	3.46	2.14		3.62	3.13	1.83	
SD	12.46	10.94	6.78		11.46	9.90	5.79	
CV (%)	35.64	44.96	16.66		29.84	57.74	13.02	

Site III

Various soil textural classes were identified at site III in 0-30 cm soil depth. They are as clay loam, loam, silty clay loam, sandy clay loam and silt loam. Maximum value of sand (50.08%) particle were reported from quadrate 8, whereas, minimum was reported from quadrate 3 (Table 18). Silt (60.29%) content was highest in quadrate 9 and lowest (27.08%) at quadrate 8. Similarly, clay (34.84%) value was maximum in quadrate 2, whereas, minimum (18.84%) in quadrate 7 respectively (Table 18).

For soil depth 30-60 cm, various soil textural classes found were clay, clay loam, loam and silty clay loam respectively. The maximum sand (42.08%) particle account in quadrate 4. Whereas, minimum was (9.88%) recorded at quadrate 9 (Table 18). Likewise, silt (62.07%) particle was highest at quadrate 9 and lowest (35.08%) at quadrate 4. Similarly, for clay (40.48%) particle maximum value was observed at quadrate 2, whereas, lowest value was reported from quadrate 4 respectively (Table 18).

Site IV

Site IV recorded alteration in soil textural classes in 0-30 cm soil depth. These classes were clay loam, loam, silty clay loam and sandy clay loam. Maximum (69.88%) value of sand particle were reported from quadrate 10, whereas, minimum (11.88%) was reported from quadrate 3 (Table 19). Silt content was highest (51.93%) in quadrate 3 and lowest (10.00%) at quadrate 10. Similarly, clay value was maximum(44.12%) in quadrate 9, whereas, minimum (20.12%) in quadrate 10 respectively (Table 19).

In case of soil depth of 30-60 cm, different soil textural classes found were clay, clay loam, loam, sandy clay loam and silty clay loam respectively. The maximum sand (73.88%) particle account in quadrate 10 Whereas, minimum was (11.80%) recorded at quadrate 8 (Table 19). Likewise, silt (49.93%) particle was highest at quadrate 2 and lowest (8.00%) at quadrate 10 Similarly, for clay (46.12%) particle maximum value was observed at quadrate 9, whereas, lowest (18.12%) value was reported from quadrate 10 respectively (Table 19).

Table 18: Soil texture at site III

Quadrates	Site III							
	Soil Depth							
	0-30 cm				30-60 cm			
	% Sand	% Silt	% Clay	Soil textural class	% Sand	% Silt	% Clay	Soil textural class
Quadrate 1	13.88	57.64	28.48	Silty clay loam	11.88	57.64	30.48	Silty clay loam
Quadrate 2	33.16	32.00	34.84	Clay loam	23.16	36.36	40.48	Clay
Quadrate 3	13.16	54.36	32.48	Silty clay loam	11.16	56.00	32.84	Silty clay loam
Quadrate 4	43.16	36.36	20.48	Loam	42.08	35.08	22.84	Loam
Quadrate 5	22.08	49.01	28.91	Clay loam	14.08	47.01	38.91	Silty clay loam
Quadrate 6	22.80	48.36	28.84	Clay loam	32.44	38.72	28.84	Clay loam
Quadrate 7	48.44	32.72	18.84	Loam	39.20	35.96	24.84	Clay loam
Quadrate 8	50.08	27.08	22.84	Sandy clay loam	33.16	36.00	30.84	Clay loam
Quadrate 9	13.52	60.29	26.19	Silt loam	9.88	62.07	28.05	Silty clay loam
Quadrate 10	19.16	50.36	30.48	Silty clay loam	19.16	44.00	36.84	Silty clay loam
Mean	**27.94**	**44.82**	**27.24**		**23.62**	**44.88**	**31.50**	
SE±	4.63	3.73	1.63		3.87	3.25	1.84	
SD	14.65	11.80	5.16		12.23	10.29	5.83	
CV (%)	52.42	26.32	18.93		51.76	22.92	18.50	

Table 19: Soil texture at site IV

Quadrates	Site IV							
	Soil Depth							
	0-30 cm				30-60 cm			
	% Sand	% Silt	% Clay	Soil textural class	% Sand	% Silt	% Clay	Soil textural class
Quadrate 1	29.88	33.93	36.19	Clay loam	23.88	41.93	34.19	Clay loam
Quadrate 2	23.88	47.93	28.19	Clay loam	11.88	49.93	38.19	Silty clay loam
Quadrate 3	11.88	51.93	36.19	Silty clay loam	21.88	41.93	36.19	Clay loam
Quadrate 4	31.88	41.86	26.26	Loam	23.88	37.93	38.19	Clay loam
Quadrate 5	23.88	37.93	38.19	Clay loam	21.88	39.93	38.19	Clay loam
Quadrate 6	31.88	39.86	28.26	Clay loam	29.88	35.86	34.26	Clay loam
Quadrate 7	13.88	47.86	38.26	Silty clay loam	29.88	25.86	44.26	Clay
Quadrate 8	23.88	38.00	38.12	Clay loam	11.88	44.00	44.12	Silty clay
Quadrate 9	23.88	32.00	44.12	Clay	13.88	40.00	46.12	Silty clay
Quadrate 10	69.88	10.00	20.12	Sandy clay loam	73.88	8.00	18.12	Sandy loam
Mean	**28.48**	**38.13**	**33.39**		**26.28**	**36.54**	**37.18**	
SE±	5.07	3.72	2.31		5.69	3.72	2.50	
SD	16.03	11.76	7.30		17.98	11.77	7.91	
CV (%)	56.28	30.84	21.87		68.43	32.22	21.27	

CHAPTER-V

DISCUSSION

CHAPTER-5

DISCUSSION

The findings of the present research entitled **"Biomass and Carbon Stock of *Pinus roxburghii* Sarg. in Jammu & Kashmir"** are discussed in this chapter. Attempts have been made to provide suitable arguments with scientific reasons after going through the available literature. The present study will highlight the current status of the Chir Pine forests in the study area and its potential in carbon sequestration. The relevant data obtained in the present research are discussed under the following headings.

5.1 Growth parameters of *Pinus roxburghii*

5.2 Biomass and carbon stock of *Pinus roxburghii*

5.3 Soil physico-chemical properties in *Pinus roxburghii* forest

5.1 Growth parameters of *Pinus roxburghii*

5.1.1 Tree diameter (cm) and tree height (m)

The data pertaining to the tree diameter at breast height are given in the table 2. During the present study, it was observed that mean tree diameter at breast height was maximum (51.21 cm) at site I followed by site IV (38.71 cm), site II (32.77 cm) and site III (25.24 cm), respectively (Table 2). Values for mean tree diameter at site II and III are low as compared to site I and IV, it may be because the trees of same age growing in groups have smaller diameter and more height increment due to greater competition among them for space and sunlight, on the other hand, trees growing in isolation or lower density have more lateral growth as compared to height due to less competition from its neighbour. Variation in tree diameter and tree height from site to site may be due to the variation in the age of trees and also due to site quality factors. Similar results have also been reported by Ghimire *et al*. (2018) and Sharma *et al*. (2020) from Nepal and are slightly higher from the study done by Kaur and Kaur (2016) from Solan forest division

5.1.2 Tree volume (m^3 ha^{-1})

The data in the table 4 pertains to the tree volume at different sites in the study area. Mean tree volume was highest (291.14 m^3 ha^{-1}) from site II followed by (269.26 m^3 ha^{-1}) site IV, (166.09 m^3 ha^{-1}) site III and (157.17 m^3 ha^{-1}) site II. The data from site I and II falling under shiwalik pine forest are similar to the value (153.85 m^3 ha^{-1}) reported by Ahmed and Sharma (2016) from the shiwalik forest of Rajouri, J&K. For Himalayan forest i.e. site II and IV the data were close to the findings of Kumar *et al*. (2021) for Garhwal forests. Tree volume is directly related to the tree diameter and tree height, better diameter increment and more height growth will leads to higher volume of wood production (Table 4).

5.1.3 Tree density (Trees ha^{-1})

The observation for tree density are present in the fig. 2 at different sites in the study area. Mean tree density was lowest (150 Trees ha^{-1}) at site I, whereas, it was (342) higher for site II, (265) site III and (317) site IV (Fig 2). Variations in tree density of *Pinus roxburghii* at different site are due to the variation in age of forests, conservation, management activities and also due to anthropogenic disturbances (Banday *et al*. 2017).

5.1.4 Tree basal area (m^2 ha^{-1})

The data related to the tree basal area at the different sites in the study area is presented in fig. 3. Mean basal area was reported highest (41.22 m^2 ha^{-1}) from site IV followed by (29.64 m^2 ha^{-1}) site II, (28.46 m^2 ha^{-1}) site I and least from (15.15 m^2 ha^{-1}) site III (Fig 3). The differences in the mean basal area from different parts of the Himalayan Chir Pine forests is mainly due to the variation in diameter classes, age of the forests, mean tree density and site quality factors at a different sites. The same has been reported by many workers, Kumar *et al*. (2021) reported mean basal area of 23.17 m^2 ha^{-1} from Garhwal, Mishra (2017) reported 31.64, 27.30, 35.70, 31.56 and 24.75 m^2 ha^{-1} from Rudraparyag, uttarakhand.

5.2 Biomass and carbon stock of *Pinus roxburghii* in the two sub type pine forests

Determination of tree biomass in the forest is of major significance for assessing the amount of carbon that can be stored in biomass. Biomass determination in different forest types enables to estimate the amount of carbon dioxide that can be sequestered from the environment by them. There are different methods to estimate the forest biomass i.e. through field measurement and remote sensing and GIS (Ravindranath and Ostwald, 2008). The data presented in the table 5, 6 and 7 are corresponding to the biomass and carbon stock at different sites in the study area.

Many factors are responsible for the production of biomass and carbon stock i.e. photosynthesis rate, forest type, solar radiation, temperature, moisture, soil physic-chemical properties and duration of growing seasons (Wang *et al*. 2004). In the present study it was observed that biomass and carbon content per unit volume in different parts of tree (*Pinus roxburghii*) among the two Pine forest types was significantly different. Site II (Table 5, 6 and 7) recorded maximum AGBD, BGBD, TBD, AGCD, BGCD, TCD and eCO_2 (174.10 Mg ha^{-1}, 48.75 Mg ha^{-1}, 222.85 Mg ha^{-1}, 81.83 Mg ha^{-1}, 22.91 Mg ha^{-1}, 104.74 Mg ha^{-1}, and 384.39 Mg ha^{-1} respectively) biomass and carbon stock whereas, site VI, site I and site III recorded the least. The tree biomass is related to tree volume and hence followed the similar trend.

For lower shiwalik Chir Pine forest the total tree biomass reported by many researcher was comparatively higher than the present study such as (167.87 Mg ha^{-1}) Banday *et al*. (2017). Similarly, for upper Himalayan pine forest tree biomass and carbon stock reported in the current study was similar to as reported by (175.5-245.6 Mg ha^{-1} and 83.36-116.6 C Mg ha^{-1}) Singh (2019). Higher than as reported by (113 Mg ha^{-1} and 53.67 C Mg ha^{-1}) Chaturvedi and Singh (1987), (103.23 Mg ha^{-1} and 56.61 C Mg ha^{-1}) Pant *et al*. (2013), (144.63 Mg ha^{-1} and 67.98 C Mg ha^{-1}) Mishra (2017), (169.2 Mg ha^{-1} and 77.80 C Mg ha^{-1}) Sharma *et al*. (2010), (154 Mg ha^{-1} and 73 C Mg ha^{-1}) Lal and Lodhiyal (2016), (299.10 Mg ha^{-1} and 140.56 C Mg ha^{-1}) Ghimire (2019) and (97.87-158.97 Mg ha^{-1} and 46.48-74.66 C Mg ha^{-1}) Pant and Tiwari (2020). Likewise, few researcher have also reported higher values than from the present study like (285.27 Mg ha^{-1} and 135.50 C Mg ha^{-1}) Joshi *et al*. (2021), (237.97 Mg ha^{-1}) Banday *et al*. (2017), (596.18 Mg ha^{-1} and 272.52 C Mg ha^{-1}) Kaushal and Baishya (2021). These variation in biomass and carbon stock from site to site in different Himalayan subtropical pine forests may be due to the difference in the tree age, site quality factors, soil factors, and variation in altitudes (Bhardwaj *et al*. 2016).

The results (Table 5, 6 and 7) clearly indicate that the biomass production and carbon stock in different sub type Pine forest is influenced by age and diameter class of trees. The higher production of biomass in different components of trees is attributed to their higher potential for transforming the solar radiation into carbohydrate. Increase in biomass with tree age and diameter has also been reported by Kanime *et al*. (2013), Baishya (2011), Sundarapandian *et al*. (2013), Devi and Yadava (2015) and Justine *et al*. (2015).

5.3 Soil physico-chemical properties in *Pinus roxburghii* forest

Variation in soil physico-chemical properties were observed in both the forest types which may be attributed to altitudinal variation, climatic conditions, vegetation density etc.

5.3.1 Soil bulk density (gm cm^{-3})

From the table 8 it is clear that soil bulk density did not vary with respect to the forest type. However, there was increase in soil bulk density with increase in soil depth at all the sites, site I and III recorded the highest soil bulk density. Higher soil bulk density is inversely prepositional to soil organic matter, it makes the soil compact and lower down the pore space. Infiltration of water and root penetration in soil is inhibited due to higher soil bulk density (Singer and Munns, 2002). Lower soil bulk density at top soil layer indicates better plant growth compared to other soil depth which may be due to the higher concentration of soil organic matter in this layer (Sharma and Kafle, 2020). Various researchers have reported an increase in soil bulk density with soil depth under different soil types such as Barreto *et al*., 2010, Singh *et al*., 2013 and Sharma *et al*., 2014. Comparatively lower soil bulk density was reported by Thakur *et al*. (2020) and Kaur and Kaur (2016) in upper Himalayan Chir Pine forest of Himachal Pradesh due to the higher accumulation of organic matter.

5.3.2 Soil pH (1:2.5:: Soil : Water)

The data presented in the table 9 indicates that there was a slight variation in soil pH among the two Pine forest types. Soil pH showed a non-significant decrease with soil depth. The variation in soil pH was from slightly acidic (Shivalik Pine forest) to highly acidic (Upper Himalayan Pine forest). This variation in soil pH could be due to the higher decomposition of organic matter, which reduces the soil pH. On the other hand the pine needles are having lower pH therefore on combing with soil it lowers down its pH. The results are similar to the findings of Sharma *et al*. (2014) and Sarkar *et al*. (2001).

5.3.3 Soil electrical conductivity (DS m^{-1})

The data for electrical conductivity at different site in the study area are presented in the table 10. Electric conductivity (EC) decreased with soil depth, however, there was no significant difference in EC among the different forest type. The decline in EC with soil depth might be due to slow mobility of salts of various ions (carbonates, bicarbonates, sodium, potassium, calcium, sulphate etc) to the lower soil layers may the reason for decreasing EC (Sondhi, 1992 and Nazir, 1993).

5.3.4 Soil organic carbon (gm kg^{-1})

The data for the soil organic carbon (SOC) estimated through Walkley and Balck (1934) method at different sites in the study area are presented in the table 11. Significant difference in SOC among the forest types was observed. SOC was higher (13.38 gm kg^{-1}) at sites II and (13.14 gm kg^{-1}) IV i.e. upper Himalayan Chir Pine forest reported to have higher SOC, however, there was reduction in SOC with soil depth at all sites (Table 11). Increased SOC under high tree density may be attributed to more leaf litter decomposition and root turnover from trees (Zegeye, 1999).

In upper Himalayan Chir Pine forest Thakur *et al*. (2020) from Himachal Pradesh have reported higher SOC than the present study whereas, Kaur and Kaur (2016) have reported lower SOC. In the current study Himalayan Chir Pine forest reported higher SOC as compared to Shiwalik Chir Pine forest, this may be due the effect of altitude on the decomposition of soil organic matter (SOM). Decomposition rate of SOM are higher in lower altitude than upper, as a result there is loss of SOC through leaching and run off in the lower altitude. Whereas, in the upper altitude there is high deposition of undecomposed SOM, due to slower rate of decomposition of SOM, it forms a layer of humus, this humus act as sponge and prevent runoff, hence SOC are higher in high altitudes. Maximum SOC was found on the top layer which decreased with increase in soil depth in both the forest types. This higher accumulation of SOC in the top soil surface is attributed due to the accumulation of leaf litter, decomposition of fine roots and addition of humus in this layer. Various workers have also reported decrease in SOC with increasing soil depth such as Nair and Chumuah (1998), Minhas *et al*., (1991) and Sharma *et al*., (2014).

5.3.5 N, P, K (kg ha^{-1}) status in Chir Pine forest soils

The data presented in the table 12 shows the value for the available nitrogen (N) in two different Pine forest types. Available N was recorded higher (272.83 kg ha^{-1}) from the site II and (225.11 kg ha^{-1}) IV from the Himalayan pine forests than Shiwalik Pine forests. Available nitrogen was also observed to decrease with increase in soil depth under both the forest types. Nitrogen concentration in the soil is associated (93–97%) with soil organic matter (Meysner, *et al.,* 2006) therefore, Himalyan Pine forest recorded higher available nitrogen. Similarly Shiwalik Pine forest recorded lower available nitrogen due to lower SOM, Sharma *et al.,* (2009) have also reported low available nitrogen from the Jammu Shiwaliks. This could be due to high soil erosion due to run off and higher rate of decomposition of organic matter and its leaching (Haag and Kaupenjohann, 2001).

Significant variation was also observed for the available phosphorous (P) in the two forest types (Table 13). Higher (26.50 kg ha^{-1}) available P was reported from site I whereas, lower (18.07 kg ha^{-1}) from the site IV respectively. Decrease in available P with increase in soil depth was also observed from both the forests types. The available P is lower in the Himalayan Pine forest which may due to the fact that soils here are acidic which affect its availability Sharma *et al*., (2009).

Table 14 represents the data pertaining to the available potassium K at the different sites in the study area. Significant variation in the available K among the forest type was observed. Site II (134.76 kg ha^{-1}) followed by site IV (120.23 kg ha^{-1}) recorded higher available K. Significant decrease in available K was observed with soil depth in both the forest type. Higher available K in the Himalayan Pine forest may be due to the higher tree density which contributes to high litter fall, its decomposition contributes to higher K back into the soil from litter (Rao *et al*., 2000) and also due to pimping of K by trees from sub-0soil (Moges and Holden, 2008)

5.3.6 Cation exchange capacity (c. mol. P^+)

The data for cation exchange capacity are presented in the table 15. Significant difference was observed for cation exchange capacity with respect to the forest type. Site II (29.31 c. mol. P^+) and site IV (20.58 c. mol. P^+) reported higher cation exchange capacity from the upper Himalayan Chir Pine forest. There was a decrease in cation exchange capacity with increase in soil depth at all the sites in the study area. Higher cation exchange capacity from the Himalayan Pine forest might be due to higher organic matter content which is influenced by the tree density. The results are in conformity with Minahas *et al*., 1997 and Nega and Heluf, 2009.

CHAPTER-VI

SUMMARY AND CONCLUSIONS

CHAPTER-6

SUMMARY AND CONCLUSIONS

The present investigation entitled **"Biomass and Carbon Stock of *Pinus roxburghii* Sarg. in Jammu & Kashmir"** was carried out in the Chir Pine growing areas of Jammu division in five districts namely, Jammu, Samba, Kathua, Udhampur and Reasi in year 2020-21. The objective of the study was to estimate the biomass and carbon stock present in the two sub type of Chir Pine forest i.e. Lower or Siwalik Chir Pine forest ($9/C_{1a}$) and Upper or Himalayan Chir Pine forest ($9/C_{1b}$). Two sites in each forest type were selected (Site I and II in Shiwalik Pine forest and site II and IV in Himalayan Chir Pine forest). Randomized sampling plots (10 in each) of size 20 x 20 m^2 were laid in each site. Diameter at breast height and tree height were measured as primary data and were further used for estimating biomass and carbon stock. Composite soil samples were collected from each sampling plots at soil depth 0-30 cm and 30-60 cm and were analysed for soil physico-chemical properties. A brief summary of the results derived from the present study are represented in the following headings.

6.1 Tree growth parameters

6.2 Biomass and carbon stock of *Pinus roxburghii*

6.3 Soil physical and chemical properties

6.1 Tree growth parameters

The results obtained for various growth parameters of tree indicate that there is a significant difference between the two forest type i.e. Shiwalik Pine forest and Himalayan Pine forest. Various factors such as climatic, topography, edaphic and biotic are responsible for this differentiation. Growth parameters such as tree diameter and tree height were high under Shiwalik Pine forest. Whereas, tree density was lower in Shiwalik as result it recorded lower mean tree volume and mean tree basal area. On the other hand Himalayan Pine forest recorded lower tree diameter and low tree height but the tree density was comparatively higher than Shiwalik Pine forest. High tree density per hector in the Himalayan Pine forest resulted into higher mean tree volume and higher mean tree basal area per hector.

6.2 Biomass and carbon stock of *Pinus roxburghii*

Biomass accumulation and carbon stock under the two Pine forest was significantly differential. Biomass accumulated in Mg ha^{-1} in the various components of *Pinus roxburghii* such above ground biomass density (AGBD), below ground biomass density (BGBD) and total biomass density (TBD) was comparatively higher under Himalayan Pine forest than Shiwalik Pine forest. Among the sites, Site II recorded the maximum AGBD, BGBD and TBD due to higher tree density and better growing environment. Similarly, the carbon content in the per unit volume of *Pinus roxburghii* i.e. above ground carbon density (AGCD), below ground carbon density (BGCD) and total carbon density (TCD) was higher under Himalayan Pine forest than Shivalik Pine forest. The amount of CO_2 sequestered by the *Pinus roxburghii* under two forest types also varied significantly. Carbon dioxide equivalent (eCO_2) was recorded higher under the Himalayan Pine forest than Shiwalik Pine forest. Among the sites, site II and site IV recorded higher carbon dioxide equivalent than other sites.

6.3 Soil physical and chemical properties

The data for the soil physico-chemical properties under the two Pine forest showed a significant variation. Soil properties such as soil bulk density and soil electrical conductivity was found to be non-significant with respect to the sites and forest type. However, there values decreased with soil depth at all the sites. Soils under Shiwalik Pine forest were slightly acidic while they were highly acidic under Himalayan Pine forest. Soil pH decreased with soil depth under both the forest type. Soil organic carbon reported from the study area varied significantly not only under the different sites but also among the two different forest types. Himalayan Pine forest recorded comparatively higher soil organic carbon than Shiwalik Pine forest. Soil organic carbon was reported to decrease with increase in soil depth at the all the sites. The data with respect to soil NPK status under the different sites in different forest types showed a significant variation. Available NPK at all the sites decreased with increase in soil depth. Available nitrogen was found to be higher in Himalayan Pine forest, site II and IV recorded maximum amount of available nitrogen than other sites. Similarly, the available phosphorus also varied with the forest types and with different sites. In case of available phosphorus, site I showed comparatively higher values of phosphorus than other sites. Available phosphorus was recorded higher under the

Shiwalik Pine forest than Himalayan Pine forest. Likewise, the available potassium also varied with sites and forest types. Site II and site IV under Himalayan Pine forest recorded higher available potassium than Shiwalik Pine forest. Cation exchange capacity was also found higher at site II and site IV in the Himalayan Pine forest than Shiwalik Pine forest. Soil textures at all the sites were almost clay.

6.4 CONCLUSIONS

Pinus roxburghii is a dominant tree species of the subtropical hills of the Himalayas. It has a vast attitudinal stretch from 500 m to 2300 m. The environmental conditions are completely different under the different altitudinal gradients. The effects of climate on the physiology of tree due to change in altitude directly or indirectly affects the production of biomass and carbon stock in the forest. In present study **"Biomass and Carbon Stock of *Pinus roxburghii* Sarg. in Jammu & Kashmir"**, Chir Pine was found mixed with other broad leaved species in the lower altitude, and its density increased with increase in altitude in, whereas, It formed a pure forest in the mid altitude and had maximum tree density in this region which decreased after certain altitudes and was gradually replaced by temperate species. Therefore, it can be concluded that the production of biomass and carbon stock of *Pinus roxburghii* Sarg. are higher under Himalayan Chir Pine forest ($9/C_{1b}$) as compared to that of Siwalik Chir Pine forest ($9/C_{1a}$). Similarly, the soil organic carbon (SOC) is also higher in Himalayan Chir Pine forest. Therefore the maximum potential of *Pinus roxburghii* in sequestering the atmospheric carbon in the subtropical Himalayan belt is higher under the Himalayan Chir Pine forest, acting as substantial species for mitigating the climate change.

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CERTIFICATE-IV

Certified that all necessary corrections as suggested by the external examiner and advisory committee have been duly incorporated in the thesis entitled **"Biomass and Carbon Stock of *Pinus roxburghii* Sarg. in Jammu & Kashmir"**, submitted by **Mr. Kuldeep Joshi**, Registration No, **J-18-D-340-A.**

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