# STUDIES ON BIOMASS PARTITIONING AND SOIL ENRICHMENT IN PLANTATIONS OF DIFFERENT TREE SPECIES UNDER MID HILL CONDITIONS OF HIMACHAL PRADESH

*Thesis*

**by**

**SANYAM**

*Submitted in partial fulfilment of the requirements for the degree of*

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(FORESTRY)

**PLANTATION TECHNOLOGY**

**COLLEGE OF FORESTRY**
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# CERTIFICATE-I

This is to certify that the thesis entitled, **"Studies on biomass partitioning and soil enrichment in plantations of different tree species under mid hill conditions of Himachal Pradesh"** submitted in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE (FORESTRY) PLANTATION TECHNOLOGY** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) is a record of bonafide research work carried out by **Ms. Sanyam (F-2010-32-M)** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigations has been fully acknowledged.

**Place : Nauni**, **Solan**
**Dated:**

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# CERTIFICATE-II

This is to certify that the thesis entitled, **"Studies on biomass partitioning and soil enrichment in plantations of different tree species under mid hill conditions of Himachal Pradesh" submitted by Ms. Sanyam (F-2010-32-M)** College of Forestry, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE (FORESTRY) PLANTATION TECHNOLOGY** has been approved by the Advisory Committee after the thesis viva-voce examination in collaboration with the internal examiner.

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This is to certify that all the mistakes and errors pointed out by the internal examiner have been incorporated in the thesis entitled**, "Studies on biomass partitioning and soil enrichment in plantations of different tree species under mid hill conditions of Himachal Pradesh"** submitted to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) by **Ms. Sanyam (F-2010-32-M)** in partial fulfillment of the requirements for the award of degree of **MASTER OF SCIENCE (FORESTRY) PLANTATION TECHNOLOGY.**

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**Place: Nauni, Solan** **(Sanyam)**
**Dated: 2012**

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# ABBREVIATIONS USED

| | |
|---|---|
| BA | basal area |
| C | Celsius |
| cm | centimetre |
| $cm^2$ | centimetre square |
| $cm^3$ | centimetre cube |
| dia. | diameter |
| etc. | *et cetera* |
| g | gram |
| ha | hectare |
| Ht. | height |
| i.e. | *id. est.* |
| Kg | kilogram |
| m | metre |
| $m^2$ | metre square |
| $m^3$ | metre cube |
| mg | milligram |
| mm | millimeter |
| no. | number |
| pH | *Puissance de Hydrogen* |
| Spp. | Species |
| Sp. | Specific |
| viz. | *videlicet* |
| Vol. | volume |

# *Chapter 1*

# INTRODUCTION

Forests, the renewable source for wood, timber and other forest products are the most demandable natural resources throughout the world and thus have stimulated research in growth both volume and biomass as well as productivity at all stages of stand development. Forests are vital asset of the country and play a major role towards the socio-economic development of its people by meeting out daily needs for goods and services. India’s unique topography, terrain, climate and vegetation brings out natural diversity that cannot be witnessed anywhere else in the world. Forests in India have always been one of the richest resources and are ancient in nature and composition. The nation has a rich and varied heritage of biodiversity. The forest cover of India is assessed as 67.83 million hectares which constitute to 20.64% of the country’s geographical area, ranging from Himalayan temperate to dry zone forests. Per capita forest area is only 0.1ha and average forest productivity continues to be low i.e. 0.7cu.m./ha/year as against the world average of 2.5cu.m./ha/year (Sharma and Sharma, 2004). Forests are the major source of timber, fuelwood, fodder and food for the native people of the Himalayan region. Here, dependency of human population on the forest biomass for running their livelihood is tremendously high and it is a centuries old practice. Forest biomass consumption varies from 13 Kg/day/household (fuelwood) and 12 Kg/day/household (fodder) in the lower elevation (1150m) to 28 Kg/day/household (fuelwood) and 34 Kg/day/household (fodder) in the higher elevation (1900m) (Sati and Song, 2012). India has maintained approximately 64 M ha of forest cover for the last decade. The rate of afforestation in India is one of the highest among tropical countries. The annual productivity has increased from 0.7 $m^3$ per hectare in 1985 to 1.37 $m^3$ per hectare in1995. Increase in annual productivity directly indicates an increase in forest biomass (Prasad *et al*., 2003).

The biomass of all the components of the ecosystem should be considered the live mass above ground and below ground of trees, shrubs, palms, etc. as well as the herbaceous layer on the forest floor including inert fraction in debris and litter. Biomass is defined as the total amount of live and inert organic matter above and below ground expressed in tons of dry matter per unit area. Forest biomass withdrawn and consumption depends on the geo-environmental and socio-economic conditions of the people of the area. Biomass in forestry is the total weight of living material of all plants. Biomass measurements of individual trees and whole stands have long been of principle interest but complete tree utilization concept including biomass assessment of individual tree components is one of recent approaches in Indian context. Biomass determination provides the estimates of total yield and basis for determining the feasibility of complete tree utilization. Under changing environmental conditions, biomass development of the tree and stand may differ. Under these conditions tree biomass cannot be derived from tables based on former investigations but has to be defined from particular biomass investigations, which generally calculate tree and stand biomass from sample branches using allometric relationships (Grote, 2002). Therefore, sample measurements on harvested tree are needed. The knowledge of biomass partitioning is essential for estimating spatial patterns and temporal dynamics of aerial and root biomass in terrestrial ecosystems (Yang and Lou, 2011).

The biomass production potential of a forest stand is correlated with the capacity of the stand to intercept light (Albaugh *et al.,* 1998). Biomass allocation is the distribution of biomass to each individual plant component and allocation patterns are a function of source-sink interactions. Generally, biomass allocation is controlled by plant factors (i.e. growth pattern of different plant component) and environmental conditions (Friend *et al.,* 1994). Trees undergo a hierarchy of allocation, where new foliage has priority followed by new roots and stem growth (Waring and Schlesinger, 1985), (Oliver and Larson, 1990). This accumulation and allocation of above- and below ground biomass has generated a great deal of theoretical and experimental interest among the forest managers and specialists. The knowledge of biomass in forestry is important for understanding the dynamic forest ecosystem and different forms of productivity. Volume and biomass assessment through different growth parameters is a new approach in practical forestry. Earlier volume tables/yield tables were used to assess the total volume of the standing crop but today mathematical equations are being used on a large scale. The non-destructive technique to assess the forest biomass has become a handy tool for foresters particularly in ecologically and environmentally threatened areas.

Trees and stands also affect soil properties through several pathways. They alter inputs to the soil system by increasing capture of wetfall and dryfall and by adding to soil N via $N_2$ fixation. They affect the morphological and chemical conditions of the soil as a result of characteristic of above and below ground litter inputs. From an ecological perspective, soil patches found beneath tree canopies are important local and regional nutrient reserves that influence community structure and ecosystem function (Rhoades, 1996).

*Quercus leucotrichophora*, *Pinus roxburghii*, *Eucalyptus tereticornis*, *Melia azedarach* and *Ulmus villosa* and are some of the important tree species of Western Himalayas which are used for one or the other purposes. *Q. leucotrichophora*, *E. tereticornis* and *M. azedarach* are used extensively as fuelwood species having calorific values 4600 Kcal/Kg, 4700-4800 Kcal/Kg and 5043 Kcal/Kg respectively. *Q. leucotrichophora* and *U. villosa* are extensively lopped for fodder and *Q. leucotrichophora* alongwith *M. azedarach* is also used in manufacture of paper. *P. roxburghii* is the most common resin producing pine of India (Luna, 1995). The species is also found suitable for paper-pulp production. Turpentine oil and rosin are two commercially important products obtained from resin. So keeping in view the economic and ecological importance of these species the present investigation entitled "Studies on biomass partitioning and soil enrichment in plantations of different tree species under mid hill conditions of Himachal Pradesh" was carried out to explain the following objectives:-

1) To study the growth parameters of different species namely *Quercus leucotrichophora*, *Pinus roxburghii*, *Eucalyptus tereticornis*, *Melia azedarach* and *Ulmus villosa* and

2) To carry out variability analysis and evaluation of factors responsible for biomass production.

# *Chapter 2*

# REVIEW OF LITERATURE

The cohesiveness in representation of the related research has been reviewed to the present investigation entitled "Studies on biomass partitioning and soil enrichment in plantations of different tree species under mid hill conditions of Himachal Pradesh" in this chapter under the following headings:

2.1 Growth parameters of different species

2.2 Variability analysis for growth factor

## 2.1 GROWTH PARAMETERS OF DIFFERENT SPECIES

Peichl and Arain (2007) studied the allometry and partitioning of above- and below ground tree biomass in age-sequence of four eastern white pine (*Pinus strobus* L.) forests (2-, 15-, 30- and 65 years old). Biomass in each tree component i.e. foliage, branch (live and dead), bark, stem and root was quantified by destructive tree harvesting. Mean above- and belowground tree biomass was 0.3, 54, 105 and 529 Kg/tree and 0.1, 13, 17 and 99 Kg/tree in the 2, 15, 30 and 65 year old stands. The relative portion of stem biomass to total tree biomass increased from 25% for the 2 year old stand to 69% for the 65 year old stand, whereas the relative contribution of canopy biomass components (foliage and branches) decreased with stand age. Root to shoot biomass ratio decreased from 0.32 in the 2 year old stand to 0.24, 0.16 and 0.22 in the 15, 30 and 65 year old stands. The relationship between tree component biomass and stem volume, expressed as biomass expansion factor (BEF), decreased for all above- and belowground tree components and total tree biomass with increasing stand age.

Gupta and Bhardwaj (2005) studied above ground biomass production of Black Wattle in mid-hills of Himachal Pradesh. Some easily measurable attributes such as plant height and diameter at breast height (dbh), were used to develop a set of regression equation models for the production of above ground biomass of Black Wattle. Regression analysis showed that dbh was the best predictor variable for total above ground biomass (controlling more than 80% variability) and the inclusion of height as variable in the model slightly improved the adequacy of the model.

Bhatt and Todaria (1991) studied biomass production in some leguminous taxa under a short rotation cycle. Biomass production data was given for one year old plantation of six species.

Effect of planting density on growth efficiency and biomass partitioning on *Pinus* spp. was studied by Burkes *et al*. (2003). The partitioning to stem growth increased relative to foliage or fine roots as stand density increased. Therefore, the limitation in stem biomass growth on per hectare basis that occurred as stand density increased was not due to partitioning changes but due to NPP.

Schall *et al.* (2012) investigated the effect of light availability and soil moisture on growth and biomass partitioning of Norway spruce and European beech seedlings in a three (light availability levels) × two (soil moisture levels) factorial greenhouse experiment. In both tree species, growth and biomass allocation to above and belowground plant components were affected by light availability. European beech showed a distinct increase in allocation to leaves, stem and branch biomass at the expense of fine and coarse roots with decreasing light availability. For Norway spruce, only allocation to stem biomass increased and allocation to fine root biomass decreased under low light. European beech seedlings appear better able to adjust biomass partitioning to resource availability. In contrast Norway spruce responded languidly. The results indicated that biomass partitioning is not only driven by ontogeny, and thus tree size, but is environmentally determined to a substantial degree.

Feikema *et al*. (2012) undertook a comparative study of the partitioning of above-ground biomass (AGB) to examine biomass and chloride (Cl) allocation of trees growing on two saline-irrigated sites in south-eastern Australia. *Eucalyptus camaldulensis* × E. *globulus* had a higher proportion of AGB in leaves (20-29% cf. 15-16%), and lower proportion in live branches (3-10% cf. 6-14%) than *E. camaldulensis* × E. *grandis*. The concentration of Cl was highest in the stembark (4.2-9.6 g $kg^{-1}$) and lowest in the stemwood (0.6-2.0 g $kg^{-1}$), suggesting that trees can export Cl through bark shedding. Total Cl content was strongly related to volume under bark ($R^2$ = 0.99), and differences in partitioning of Cl into tree components differed between the hybrids in the same way as AGB.

Prasad *et al*. (2011) evaluated the biomass productivity, intercrop yields and profitability of *Eucalyptus tereticornis* clonal and *Leucaena leucocephala* variety K-636 based systems. Trees were planted at a spacing of 3 × 2 m and evaluated at three locations. Height growth was significantly higher in leucaena during the 4 year where as difference in diameter growth was not significant. Biomass partitioning to the bole was high in case of leucaena, ranged from 83% in 2.5-5 cm diameter at breast height (DBH) trees to 89% in 12.5-15 cm DBH trees and in eucalyptus clones the corresponding values were 71% in 2.5-5 cm DBH trees and 83% in 12.5-15 cm DBH trees. Marketable biomass productivity was higher with leucaena (95 Mg $ha^{-1}$) in comparison to eucalypts (87 Mg $ha^{-1}$).

Henri *et al*. (2010) evaluated the accumulation and partitioning of above-ground biomass in 16 native and two exotic tree species growing under humid and dry regional environments. Seven of the 18 species accumulated greater total biomass at the humid site than at the dry site over a two-year period. Species-specific biomass partitioning among leaves, branches and trunks was observed. However, a wide range of total biomass found among species (from 1.06 kg for *Dipteryx panamensis* to 29.84 kg for *Acacia mangium* at Soberania) justified the used of an Aitchison log ratio transformation to adjust for size. When biomass partitioning was adjusted for size, a majority of these differences proved to be a result of the ability of the tree to support biomass components rather than the result of differences in the regional environments at the two sites. In these comparisons, basal diameter, height and diameter at breast height were robust predictors of biomass for the pooled data from both the sites.

Carlson and Allan (2001) studied that the stemwood density decreases with increasing stem height in *Pinus patula* stand. The study was conducted to determine whether allometric relationships could be used to predict different biomass components.

A method was given for estimating crown and wood volume from easily measured tree parameters by Carbyn *et al*. (1988) and reported that total wood volume could be predicted very accurately from dbh alone, while inclusion of height added extra precision.

Konôpka *et al*. (2010) destructively sampled young European beech, sessile oak, Scots pine and Norway spruce trees approximately 0-10 yr old in a range of naturally regenerated forest stands in Central Europe. Diameter at base, height, dry biomass of foliage, branches, stems and roots was measured. Allometric relations were used to calculate biomass allocation coefficients (BAC) and growth efficiency (GE) patterns in young trees. Both BAC and GE are strongly age-specific in young trees, their rapidly changing values reflecting different growth strategies in the earliest stages of growth. The linear relationships describing biomass allocation in older trees are not applicable in young trees. To accurately predict forest biomass and carbon stocks, forest growth models need to include species and age-specific parameters of biomass allocation patterns.

Zenedie *et al*. (2009) analyzed data from 10 different *Eucalyptus globulus* stands, with plantation age ranging from 11 to 60 years and with coppice shoot age from 1 to 9 years. Aboveground tree biomass of 7-10 trees was observed destructively. A negative relation was observed between the aboveground biomass production and total plantation age. Total aboveground biomass increased from 11t/ha at a stand age of 1 year to 153t/ha at 9 years. The highest dry weight was allocated to stemwood and decreased in the following order:

stemwood > leaves > stembark > twigs > branches

Live aboveground biomass (AGB) is an important source of uncertainty in the carbon balance from the tropical regions in part due to scarcity of reliable estimates of live AGB and its variation across landscapes and forest types. Alves *et al*. (2010) studied forest structure and biomass stocks of Neotropical forests and findings showed that intact Atlantic forest sites stored substantial amounts of carbon aboveground. The live tree AGB of the stands was found to be lower than Central Amazonian forests. The comparative data suggests that differences in live tree AGB among Neotropical forests are probably related to the heterogeneous distribution of large and medium-sized diameter trees within forests and how the live biomass is partitioned among those size classes, in accordance with general trends found by previous studies. In addition, the elevational variation in live AGB stocks suggests a large spatial variability over coastal Atlantic forests in Brazil, clearly indicating that it is important to consider regional differences in biomass stocks for evaluating the role of this threatened tropical biome in the global carbon cycle.

Socha and Wezyk (2004) constructed empirical equations for estimating the foliage biomass of Scots pine from easy to measure parameters. The dependence of the foliage biomass of Scots pine on stem diameter, height, age, crown length, basal area increment of the trees was analyzed. Using the biometric characteristics such as tree diameter at breast height (dbh), basal area increment, age, height, and crown length empirical equations for estimating the foliage biomass of Scots pine were established. The variability varies between 65 and 85%, it depends on the number of variables applied in the equation.

Massada *et al*. (2006) used photogrammetric methods to measure tree height and crown diameter in a semi arid forest between 1978 and 2003. Height and crown-diameter measurements were transformed to biomass using an allometric equation generated from 28 harvested Aleppo pine (*Pinus halepensis*) trees. Mean tree biomass increased from 6.37 kg in 1978 to 97.01 kg in 2003. Mean plot biomass in 2003 was 2.48 $kg/m^2$ and aboveground primary productivity over the study period ranged between 0.14 and 0.21 $kg/m^2$ per year. The estimated biomass was significantly related to field-measured biomass, with an $R^2$ value of 0.78.

In one study comparing dominant and suppressed loblolly pines of the same size Naidu *et al.* (1998) studied that dominant loblolly pines allocated 63.4, 11.3, 13.2, and 12.0% of their total biomass to stem, needle, branch, and root components, respectively. Suppressed trees allocated 75.6, 5.6, 6.7, and 11.7% to those same components.

Ammer (2003) studied effects of shading levels on beech and oak stand. He reported a strong decrease in height, diameter, stem, branch, leaf and root dry mass with decreased light quantity in case of *Fagus sylvatica*. Neither growth rates nor total yield indicated an impact of slightly changed light quality on growth and biomass partitioning. In case of oak relative growth rate of main stem dry mass was considerably higher for the seedlings of shade treatment with the reduced R:FR ratio than for control and other shade treatment whereas branch dry biomass exposed to changed light quality and quantity was reduced resulting in lower branch: stem ratio.

Chmura *et al*. (2007) studied growth and crown characteristics of 2 families of *Pinus taeda* and one in *Pinus elliottii*. The families differed in crown and needle traits and biomass partitioning patterns. Aboveground biomass accumulation was related to crown structure among families but biomass partitioning was independent of the crown traits.

The nitrogen-induced changes in allocation of dry matter between foliage and root components, together with changes in specific leaf area, had a larger influence on seedling growth rate than did changes in net rate of carbon gain per unit leaf area as studied by Cromer and Jarvin (1990) in *Eucalyptus* plantations.

Forslund and Peterson (1994) compared two methods of estimating the total outside – bark stem volume of all trees in young plantation of jack pine (*Pinus banksiana*) and black spruce (*Picea mariana*) using destructive and non-destructive methods. The results indicated that total plantation volume estimates ranged within $\pm$5 per cent by using the power function model and two stem measurements: diameter and relative height of 30 per cent from the base of stem and total stem height. The power function model offered a good alternative for accurately assessing plantation volume.

Jack and Long (1991) compared the data for two conifers, lodge-pole pine (*Pinus contorta*) and subalpine fir (*Abies lasiocarpa*) with different crown forms and found out that mean crown size of the lodge-pole pine was altered much more by density than mean grown size of subalpine fir, primarily due to the different relative shade tolerances of two species.

An attempt to predict biomass in *Populus tremuloides*, Ker (1980) used logarithmic equations for total aboveground biomass as well as for 12 biomass variables from dbh, height, crown diameter and crown length.

Kolb and Steiner (1990) compared the first year biomass, biomass relative growth rate and biomass partitioning in 8 open pollinated families of *Quercus rubra* under crossed levels of light intensity and grass root competition. Grass root competition reduces seedling biomass at both levels of light intensity but shading reduces seedling biomass only in absence of grass. Biomass partitioning to leaf area and to shoot weight relative to root weight decreases during seedling development. Both root shoot ratio and leaf area ratio were greater in the shaded than in full sun environments, while grass root competition had an opposite effect on both ratios.

Onyekwelu *et al*. (2006) studied that in *Gmelina arborea* plantations the standing biomass ranged from 81.5 to 392.1 t/ha in youngest and oldest stands respectively. Regardless of stand age, biomass partitioning was about 83.0, 13.5 and 3.5 % to stem, branches and foliage respectively. Na, Ca and Mg contents in tree tissues increased in order of foliage>stem>branches while K and P increased in order of foliage>branches>stem.

The relationship between diameter and form factor was studied by Singh (1976) for *Pinus roxburghii*, *Pinus wallichiana*, *Cedrus deodara* and *Abies pindrow* and calculated the value of form factor for dominant deodar trees and compared with those for co-dominant and suppressed trees. Suppressed trees generally showed better form.

An attempt was made by Singh (1977) to study the relationship between tree height (h), standard stem timber bole length ($h_1$), stem timber form factor (fst) and diameter at breast height (d) in randomly selected 22 sample trees in wide range of diameter class of deodar and correlation of high order was found between $h/h_1$ and $1/d_{fst}$. The actual volume was also compared, which was having error of 0.18 per cent only.

Zeng (2003) studied the effects of pruning on aboveground biomass partitioning of subtropical trees. The partitioning pattern was positively correlated with pruning intensity. Pruning reduced the aboveground biomass to leaves and less to wood growth in most cases, irrespective of species and growing season.

## 2.2 VARIABILITY ANALYSIS FOR GROWTH FACTORS

Xing *et al* (2005) sampled Balsam fir (*Abies balsamea*) to investigate the effects of forest management practices, site location, within-crown position, tree component (i.e., stem, foliage, branches and roots) and tree classes on biomass and carbon (C) partitioning at the individual tree level and across ecological regions. Three allometric equations of biomass and C that account for partitioning among different parts of the tree were developed and compared: (1) a third-order polynomial, (2) a modified inverse polynomial and (3) a modified Weibull equation. Diameter at breast height (DBH) was used as the only explanatory variable to describe fresh biomass, dry biomass and C content. All regressions derived showed a high correlation with DBH, with most $R^2$ values > 0.95. A comparison of the equation results showed that the modified Weibull equation gave consistent results with the best overall fit and was the simplest of the three equations investigated.

In Waimanalo Research Station, Hawaii, Austin *et al*. (1988) concluded that stem diameter was best predictor of tree biomass and height explained significant additional variation only for leucaena among various NFT’s. Separate allometric equations were developed for different parameters viz., height, DBH, leaf biomass and leaf+stem biomass. Separate equations to predict biomass were developed. It is concluded that mixtures of eucalypts with N-fixing trees can equal biomass yields of pure eucalypts.

Kushalpa (1991), Pande *et al*. (1986) and Tandon *et al*. (1988) also worked out correlation coefficients and regression models for each biomass components, total above ground biomass and total biomass in different aged plantations. Diameter at breast height was found to be most reliable parameter for biomass prediction.

To determine the most appropriate predictor variables to produce a general allometric relationship, Montagu *et al*. (2005) examined *Eucalyptus pilularis* aboveground biomass data from seven contrasting sites. Predictor variables included diameter at breast height (dbh), stem volume, $dbh^2 \times H$, dbh × H and height (H). The data set contained 105 trees, ranging from 6 to over 20,000 kg $tree^{-1}$, with dbh ranging from 5 to 129 cm. Significant site differences were observed in (1) partitioning of biomass between the stem, branch wood and foliage; (2) stem wood density and (3) relationship between dbh and height. For all predictor variables, site had a significant effect on the allometric relationships. Examination of the model residuals of the site-specific and general relationship indicated that using dbh alone as the predictor variable produced the most stable general relationship and the inclusion of height as a second predictor variable decreased the performance of the general model.

Russell *et al*. (2009) studied stand conditions influencing the partitioning of biomass to stem, needle, branch and root components. Multivariate analysis of variance concluded that row and column spacing did not have significant effect on the relative amount of biomass among tree components. Root/shoot and height/diameter ratios differed across densities indicating occurrence of allometric tradeoff.

Variation in aboveground biomass partitioning (between the stem, branches, and foliage) of mature trees is a key determinant of growth potential. Steven *et al*. (2002) initiated a study to compare the relationships of crown structure to aboveground allocation and stemwood growth for mature planted slash pine (*Pinus elliottii*) and naturally regenerated longleaf pine (*P. palustris*) trees. Total tree height, diameter at breast height, height to base of the live crown, and bark thickness were measured. Average (per tree) stem biomass production was not statistically different between longleaf pine and slash pine, nor were average projected leaf areas. Average growth efficiency of longleaf pine was significantly greater than that of slash pine ($P < 0.10$); graphical examination of individual tree data, however, did not indicate strong or significant differences in growth efficiency between species when comparing trees of equal size.

Gargalione *et al*. (2010) determined biomass accumulation and allometric relationships in the partitioning of biomass between aboveground woody biomass, leaves and roots in *Nothofagus antarctica*. Above and belowground biomass across different ages (5-220 years) and crown classes (dominant, co dominant, intermediate and suppressed) in 3 site classes was measured. The biomass allocation patterns were studied by fitting allometric function in biomass partitioning between leaves, stem and branches and roots. Biomass accumulation varied with crown class and site quality. The root component represented 26 – 72% of the total biomass depending on age and site. The crown class effect on biomass partitioning was almost negligible.

Senelwa and Sims (1997) harvested five species of eucalypts and developed regression equations for non-destructive estimations of total tree dry weight when grown under a short rotation regime. The best-fit equation for a group of *Eucalyptus* spp. incorporated the product of the square of the diameter ant the ratio of height to tree dry weight. This equation predicted the aboveground tree dry weight to within 20 per cent accuracy.

Veiga *et al*. (2000) studied seven regression models and compared them to estimate the tree total-stem wood volume outside bark (tvob), as a function of tree dbh outside bark (d) and total height (h). Meyer's modified model was selected, resulting in the following tree volume equation: $tvob= -83781 +38100 d –3373.92 d^2 –1182.12 dh +180.49d^2h$ in which volumes are expressed in $dm^3$, diameter in cm and height in m.

The need to understand relationship between many variables makes multivariate analysis an inherently interesting, difficult and extremely useful subject. With the advance in computer programming, multivariate techniques are increasingly being used in biological research for investigating the response of organism considered as a whole, since most of statistical techniques concentrate on only one variable at a time. Multivariate analysis takes into account the interdependence and relative importance of the various characters involved and yields more meaningful information.

According to Morrison (1976) now a days the multivariate statistical techniques are used to investigate the response whereas established statistical methods are usually concerned with measured characteristics considered one at a time. The basic aim of multivariate analysis is to condense the data by reducing the number of variables in to manageable number of variables. This can be done by employing suitable linear transformation and to choose a very limiting number of resulting linear combinations in an optimum manner. However, multivariate techniques allow simultaneous analysis of multiple measurements of individuals being investigated (Hair *et al.,* 1987). The basic aim of multivariate analysis is to condense the data by reducing the number of variables in to manageable number of variables. This can be done by employing suitable linear transformation and to choose a very limiting number of resulting linear combinations in same optimum manner.

Bohra and Lodhiyal (2010) studied species density, diversity, dry matter production and nutrients (soil and plant) under canopy of *Eucalyptus* plantation. Soil bulk density increased whereas the soil pH decreased with increase in plantation age. The percentage concentration and content of soil nutrients (N, P and K) decreased with increase in plantation age. Dry matter production decreased with increase in plantation age.

Four species namely scrub oak (*Quercus dumosa*), chamise (*Adenostoma fasciculatum*), ceanothus (*Ceanothus crassifolia*) and coulter pine (*Pinus coulteri*) were studied by Ulery *et al*. (1995) to investigate their short term effects on soil properties. A mass balance approach was used to measure changes in C, N, exchangeable base cations and exchangeable acidity to a depth of 1 m over a 41 year period. The C content increased in all of the soils but the greatest change was in the soil under oak (3.7 $Kg/m^3$ more than doubling the original amount). Exchangeable Ca increased by 25.7 $mol/m^3$ in the soil under oak while the maximum increase in exchangeable Mg was 5.5 $mol/m^3$ also under oak.

Prithcett (1979) reported that pH is the most commonly used method for expressing soil acidity or alkalinity. Most often forest soils have a pH range varying from 3.5-6.5.

Murthy *et al*. (1985) reported pH values in the range of 5.4 – 6.1 for the soil of Garhwal Himalayas under Pine forest and was noticed to increase with soil depth.

Sharma (1991) and Malik (1992) found soil pH values ranging from 5.0 – 8.4 and 5.1 – 7.9 respectively under chir pine forest of Solan division and noticed progressive increase in pH down the profile. They also found out that the organic carbon was in the range of 0.17 – 3.37 and 0.33 – 3.27 per cent respectively and they further observed a decreasing trend in its distribution down the soil profile. Chonglu *et al*. (1998) indicated that there was significant correlation between soil pH and annual average tree height increment.

Tree and soil interactions may result changes in the soil carbon and nutrient contents. Forest plantations made up of monoculture stands of 17 different species, some native, some exotic and some mixed native species were investigated by Nsabimana *et al.* (2008). Results revealed that total soil C and N, C:N ratio, available P, pH and CEC differed significantly. Increase in level of soil C, total N, CEC and base saturation were observed in mixed native species. pH declined slightly under *Eucalyptus* species. High nutrient uptake was observed in fast growing species.

Kadeba and Advayi (1985) studied soil properties upto a depth of 90 cm under stands of 14 year old *Pinus caribaea* var. *hondurensis* and adjacent savannah forest were compared. No significant soil differences were observed except modest increase in top soil bulk under pine. But soil chemical properties, viz. Organic C, total N, extractable P and exchangeable K, Ca and Mg showed statistically significant decline in upper 10 cm of the mineral soil.

Roy *et al*. (2010) evaluated and compared soil organic carbon and nutrient content between plantations of mixed native species, *Shorea robusta*, *Dalbergia sissoo*, *Dendrocalamus* spp., certain agroforestry species and some exotics. Soil C levels were highest under mixed native species, *Dendrocalamus* and *Tectona* and lowest under *Dalbergia sissoo* and *Terminalia arjuna.* Total N was highest under *Dendrocalamus* and *Pongamia pinnata* and lowest under *Dalbergia sissoo.*

C/N ratios of soil varied between 9.2 and 13.5. $Ca^{2+}$ showed maximum and $Na^{2+}$ showed lowest levels.

Turner and Lambert (2000) studied soil effects on soil carbon of estate forest plantations. Two chromo sequences were studied; one located in series of relatively fertile *Pinus radiata*, unthinned plantation 0-24 years age and other 0-35 years of age of *Eucalyptus grandis*. There was rapid decline in organic carbon in surface soil (0-10 cms) for 12 years after plantation establishment. There was a larger loss of carbon from deeper horizon within 2 years after plantation. Net accumulation in total system does not occur for nearly 10-20years after plantation establishment.

Berthrong *et al.* (2009) studied that across diverse plantation types (153 sites) to a depth of 30 cm of mineral soil, significant decrease in nutrient cations (Ca, K and Mg), increases in sodium (Na) or both is observed. Afforestation reduced soil concentrations of the macronutrient Ca by 29% on average. Afforestation by *Pinus* alone decreased soil K by 23%. Mean pH decreased 0.3 units with afforestation. Afforestation caused a 6.7% and 15% decrease in soil C and N content respectively, though the effect was driven principally by *Pinus* plantations. C to N ratios in soils under plantations was 5.7-11.6%.

Leaf area index can be defined as the leaf area per units of soil surface as studied by Daughtry (1990) and is a unitless value.

Biomass production depends upon amount of light passing in to the canopy. Hazara and Tripathi (1986), Thakur and Sehgal (2003) observed that biomass production is a function of photosynthetically active radiation (PAR) in an agroforestry system.

# *Chapter-3*

# MATERIALS AND METHODS

Investigations entitled "Studies on biomass partitioning and soil enrichment in plantations of different tree species under mid hill conditions of Himachal Pradesh", was carried out in different sites in the campus of Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan. The materials and methods used are described in the following segments.

## 3.1 STUDY AREA

### 3.1.1 Location

The experimental area is located in the mid hill zone of Himachal Pradesh with an elevation of about 900-1300 m above mean sea level. The area lies about 13 kilometres from Solan, between latitude $30^{o}\ 50'30''$ to $30^{o}52'0''$ N latitude and the longitude $77^{o}8'30''$ and $77^{o}11'30''$ E (Survey of India Toposheet No. 53F/1) according to survey of India. The study was conducted in selected plantations of *Quercus leucotrichophora*, *Eucalyptus tereticornis*, *Melia azedarach*, *Ulmus villosa and Pinus roxburghii* raised during the year 1987-88.

### 3.1.2 Climate

The area is transitional zone between sub-tropical and moist temperate. There is a considerable variation in the seasonal and diurnal temperature of experimental site. In general, May and June are the hottest months and December and January, are the coldest ones and the area experiences severe frost during the winter. On an average the annual rainfall varies from 1000-1400 mm, bulk of which is received during monsoons i.e. July-September with few pre-monsoon showers. Precipitation during winter is common but in low quantum. Occurrence of snowfall is a rare phenomenon. The mean minimum and mean maximum temperature varies from $3^{o}$C during winter (January) to $33^{o}$C during summer (June), whereas mean annual temperature (MAT) is $19^{o}$C.

### 3.1.3 Description of the sites

The study sites were selected in main campus of the university in the separate plantations of each species raised during 1987-88 by Department of Silviculture and Agroforestry at different locations.

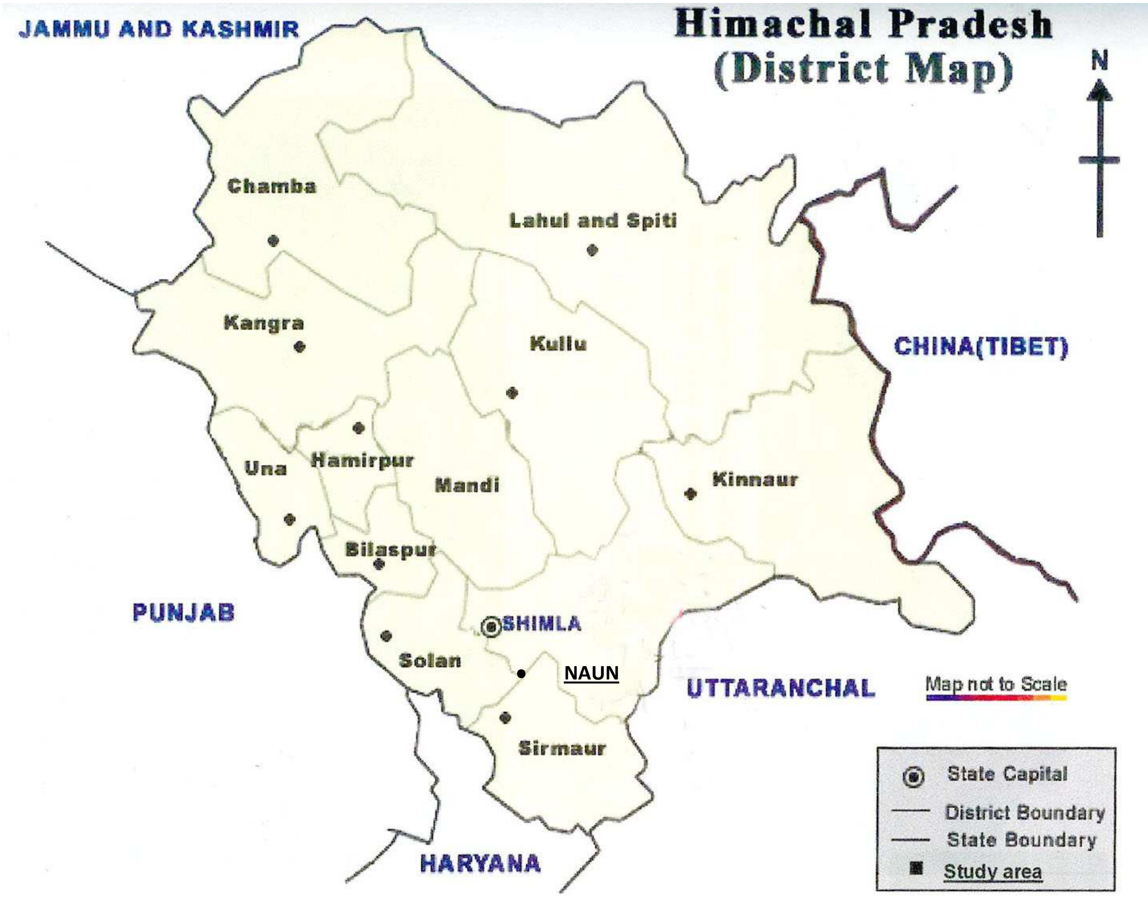


**Fig. 1 Map showing study area**

## 3.2 DEMARCATION AND ENUMERATION FOR MEASUREMENTS

### 3.2.1 Estimation of growth and standing volume

For estimation of different parameters of growth and standing volume, firstly the sites were properly inspected for different plantations and trees were counted and numbered. The trees selected through random number table were measured for different growth characteristics. Out of total tree population, only

30 per cent representative sample was selected from each site and from each sample 10 trees were chosen for further studies.

**Individual tree measurement**

All the trees were enumerated to determine the stand density on number of plants per hectare.

**Diameter at breast height**

The stem diameter over bark was measured (mean of two right angle measurements) at 1.37 m above ground level with the help of tree calliper according to method given by Chaturvedi and Khanna (1982).

**Collar diameter**

Collar diameter of selected trees was also measured at 15cm above ground with tree calliper at collar level according to method given by Chaturvedi and Khanna (1982).

**Tree height**

The height from base to tip of the trees was measured with the help of Ravi Multimeter and expressed in meters according to method given by Chaturvedi and Khanna (1982).

**Bole height**

The bole height of standing trees was measured with the help of Spiegel Relaskop and expressed in meters according to method given by Chaturvedi and Khanna (1982).

**Crown width**

The crown width (m) was measured in two directions (North-south and East-west) and average was calculated as suggested by Assmann (1970) and Chaturvedi and Khanna (1982).

$$CW = \frac{D_1 + D_2}{2}$$

Where,

CW - Crown width (m)

$D_1$ - First measured crown basal diameter in meters

$D_2$ - Second measured crown basal diameter right angle to the first measurement in meters

The secondary parameters related to crown were measured using the following formulae (Assmann, 1970):

**Crown per cent**

Crown per cent is given by the following formula:

$$\text{Crown per cent} = \frac{\text{Crown length}}{\text{Tree height}} \times 100$$

**Crown fullness ratio**

Crown fullness ratio is given by the following formula:

$$\text{Crown fullness ratio} = \frac{\text{Crown width}}{\text{Crown length}}$$

**Crown projection ratio**

Crown projection ratio is given by the following formula:

$$\text{Crown projection ratio} = \frac{\text{Crown width}}{\text{Tree diameter}}$$

**Crown quotient to ground cover area**

Crown quotient to ground cover area is given by the following formula:

$$\text{Crown quotient to ground cover area} = \frac{(\text{Crown width})^2}{(\text{Tree diameter})^2}$$

**Crop diameter**

Crop diameter is the diameter (cm) of the trees corresponding to mean basal area (Chaturvedi and Khanna, 1982).

$$\text{Mean basal area} = \frac{n_1s_1 + n_2s_2 + n_3s_3 + \ldots}{n_1 + n_2 + n_3 + \ldots}$$

Where,

$n_1, n_2, n_3$ - Number of trees in each diameter class.

$s_1, s_2, s_3$ - Basal area of mean trees of these diameter classes

**Crop height**

It is the height (m) of a regular crop determined as per the Lorey's formula given below (Husch *et al.*, 1982 and Chaturvedi and Khanna, 1982).

$$\text{Crop height} = \frac{s_1h_1 + s_2h_2 + s_3h_3 + \ldots}{s_1 + s_2 + s_3 + \ldots}$$

Where,

$s_1, s_2, s_3$ - Total basal area of each diameter class

$h_1, h_2, h_3$ - mean height of trees of these diameter classes.

**Form factor**

The form factor was calculated using the formula given by Pressler (1865) and Bitterlich (1984).

$$ff = \frac{2h_1}{3h}$$

Where,

ff - form factor

$h_1$ - Height at which the diameter is half of dbh, measured by Speigel Relaskop

h - Total height of the tree measured by Speigel Relaskop

**Volume of standing trees**

Volume of standing trees was calculated by Pressler's formula (1865) and expressed in cubic meters.

$$V = ff \times h \times g$$

Where

V - Volume

ff - Form factor

h - Total height

g - Basal area

**Solar flux (Transmission of photosynthetically active radiation)**

Photosynthetically active radiation (PAR) was recorded with PAR sensor attached to CI-301 Portable photosynthesis system. PAR interception by canopy of different multipurpose tree species was computed by recording one open reading and 4 below the crown of each plant. At random three plants of one species constituted one replication and each value is the mean of three replications (in total 9 readings were taken). Light transmission ratio (LTR) was calculated from the PAR readings taken in the open and below canopy in shade on the basis of following formula:

$$\text{LTR (\%)} = \frac{\text{Total solar radiation below the canopy}}{\text{Total solar radiation in the open}} \times 100$$

**Leaf area index**

Leaf area index was measured with Plant canopy analyzer-2000. Three trees from each diameter class were taken for canopy analysis. One reading above the canopy (open) and four below the canopy were taken. Leaf area index is itself computed by the instrument.

**Biomass estimation**

The above ground biomass estimation of each species was done by non-destructive method on sample basis by selecting the trees randomly.

**Sampling technique for stem biomass**

Biomass estimation for each species was carried out by choosing three trees per diameter class. The tree stem measurements were done according to the standard procedures and Pressler's increment borer was used to cut the core to find out specific gravity of wood. The volume of the stem was then multiplied by specific gravity to find out biomass, the green weight was taken in the field separately with the help of spring balance and then brought to the laboratory for further studies.

Biomass of stem = Volume of stem X Specific gravity

**Specific gravity**

Observation on specific gravity is confined to main stem only. Specific gravity was determined by maximum moisture method (Smith, 1954). The weight of samples was taken at maximum moisture content. Then these samples were kept in oven at 102$\pm$1$^{o}$C until a constant weight was obtained, dried samples were weighed and specific gravity of these samples was determined separately by applying the following formula:

$$G_f = \frac{1}{\left(\frac{(M_m - M_o)}{M_o} + \frac{1}{GS_o}\right)}$$

Where,

| | | |
|---|---|---|
| $G_f$ | - | Specific gravity of wood |
| $M_m$ | - | Constant weight of sample having maximum moisture content |
| $M_o$ | - | Oven dried constant weight of sample |
| $GS_o$ | - | Average density of wood, a constant having value of 1.53 |

The final value was determined by taking out the average of these samples (base and breast height). The final value was determined by taking out the average of these samples (Lower and upper).

**Sampling technique for branch biomass**

Three randomly selected branches representing different crown position were removed from three trees from each diameter class. Diameter at the base of each branch, length of branches and total number of branches on these selected trees were recorded. The sample branches were weighed in the field and representative samples were taken to laboratory for moisture and dry weight determination. The data thus obtained was used to develop regression equations both for green as well as dry biomass.

**Sampling technique for leaf and twig biomass**

The leaves alongwith twigs from above mentioned branches were removed and weighed. This was done just after cutting so as to minimize moisture loss. Sample leaves and twigs were placed in separate paper bags and kept in oven for drying at 80$\pm$5$^{o}$C and reweighed until constant weight is reached (Chidumayo, 1990). Total moisture percent, green and dry biomass was calculated using following formulae.

$$\text{Total dry biomass} = \frac{\text{Dry weight of sample}}{\text{Green weight of sample}} \times \text{Total green weight of branch/ leaves}$$

Total green biomass = Average green weight of sample x number of branches.

$$\text{Moisture per cent} = \frac{\text{Green weight – oven dry weight}}{\text{Green weight}} \times 100$$

**Soil studies**

**Soil chemical analysis**

The observations were also recorded on different soil properties in order to access the species influence on soil.

**Collection of soil samples**

The composite soil samples were collected from two depths viz. 0-15cm and 15-30cm for studying the different soil parameters and distribution of nutrient elements in all types of plantations. The composite soil samples were dried, ground with mortar and pestles and sieved with 2mm mesh sieve before analysis.

**Method employed for soil chemical analysis**

The details of methods employed for estimating different soil chemical parameters are given in table:

**Table 1. Details of methods for soil chemical analysis**

| Particular | Method employed |
|---|---|
| **Soil pH** | 1:2.5 soil: water suspension, with the help of digital pH meter (Jackson, 1973). |
| **Organic carbon** | Walkley and Black method (1934). |
| **Bulk density** | Core method of USDA (1954). |
| **Particle density** | Pycnometer method of USDA (1954). |
| **Available nitrogen** | Alkaline potassium permanganate method of Subbiah and Asija (1956). |
| **Available phosphorus** | Olsen *et al*. (1954). |
| **Available potassium** | Ammonium acetate method of Merwin and Peech (1951). |
| **Exchangeable calcium** | Ammonium acetate method of Merwin and Peech (1951). |
| **Exchangeable magnesium** | Ammonium acetate method of Merwin and Peech (1951). |

## Analytical Framework

### Variability analysis

In order to compare the consistency, the coefficient of variation has been worked out for each of the observed characteristics considered for volume estimation as given below (Gupta and Kapoor, 1996):

$$CV = (\sigma / \bar{X}) \times 100$$

Where,

$\bar{X}$ - Arithmetic mean

$\sigma$ - Standard deviation

### Bartlett $\chi^2$ test for comparison of variances

If there are *k* samples with size $n_i$ and sample variances $S_i^2$ then Bartlett's test statistic is

$$X^2 = \frac{(N-k)\ln(S_p^2) - \sum_{i=1}^{k}(n_i - 1)\ln(S_i^2)}{1 + \frac{1}{3(k-1)}\left(\sum_{i=1}^{k}\left(\frac{1}{n_i - 1}\right) - \frac{1}{N-k}\right)}$$

Where $N = \sum_{i=1}^{k} n_i$ and $S_p^2 = \frac{1}{N-k}\sum_i (n_i - 1)S_i^2$ is the pooled estimate for the variance.

Bartlett $\chi^2$ test is used to compare the variances between 5 species when sample size is large (> 30).

### Correlation analysis

Karl Pearson's coefficient between stem volume and various tree growth parameter (dbh, height, crown diameter, crown width, crown length, crown area, bark thickness, number of branches and stem volume) was worked out as per Gomez and Gomez (1984). The significance of correlation coefficient (r) values was tested against (n-2) degree of freedom.

### Criteria for the selection of appropriate function

A function is said to be an appropriate one if the sign and magnitude of the estimated parameters are consistent with the theory.

Adjusted $\bar{R}^2$ (Gujrati, 1998) calculated as under

$\bar{R}^2$ = 1- (1-$\bar{R}^2$) (n-1) / n-k

Where,

n = Number of observations and

k = Number of parameter

Adjusted $\bar{R}^2$ is an appropriate tool to decide the selection of fundamental form. Usually, the function with higher adjusted $\bar{R}^2$ is selected for the purpose.

3. A function with more significant explanatory variables is considered a better function compared to other functions.

**Regression analysis**

On the basis of the adjusted $\bar{R}^2$ values different regression equations *viz*. linear, polynomial, logarithmic, exponential and power, were further developed for tree stem volume with diameter at breast height, tree height and form factor and also for branch (green and dry) biomass with branch length and branch diameter. Further multi-linear regression equations were also developed for all the five species.

# *Chapter-4*

# EXPERIMENTAL RESULTS

The results of present investigation entitled “Studies on biomass partitioning and soil enrichment in plantations of different tree species under mid hill conditions of Himachal Pradesh” are presented in this chapter under the following heads:

4.1 Evaluation and comparison of growth parameters of different tree species

4.1.1 Growth behaviour

4.1.2 Crown characteristics

4.2 Variability analysis

4.2.1 Variation among different growth characters

4.2.2 Correlation and regression analysis

4.2.3 Other studies (soil, solar flux, LAI)

## 4.1 EVALUATION AND COMPARISON OF GROWTH PARAMETERS OF DIFFERENT TREE SPECIES

### Growth behaviour

In the present study the data was recorded for 40 randomly selected trees for each species i.e. *Q. leucotrichophora*, *P. roxburghii*, *E. tereticornis*, *M. azedarach* and *U. villosa* by grouping 10 trees in four diameter classes with 5cm class interval. The results for the field data pertaining to diameter at breast height, tree height, form factor, collar diameter, basal area, average volume, crop height, crop diameter, specific gravity, volume/ha, and number of trees/ha was collected for each tree with respect to dbh over bark and mean values are presented in table 2-6. Table 2 shows effect of average diameter under different diameter classes on various tree and stand characters of *Quercus leucotrichophora*. All the characters showed an increasing trend with increase in diameter and maximum values were obtained in >20cm diameter class viz. tree height (10.04m), form factor (0.44), basal area (0.036$m^2$), volume (0.159$m^3$), crop height (10.08m), crop diameter

(21.47cm), and specific gravity (0.72). Specific gravity of *Q. leucotrichophora* was maximum among all the five species (Table 2-6). Out of the total number of plants per hectare, 10% were found in 5-10cm diameter class whereas 60%, 20% and 5% were found in 10-15cm, 15-20cm and >20cm diameter class respectively. The average number of trees were more in 10-15cm diameter class so the volume/ha was also maximum (37.00m$^3$) in this diameter class. The statistical analysis was done for different parameters namely diameter at breast height, collar diameter, tree height, basal area and volume and significant differences were obtained in case of all the parameters under study.

**Table 2. Effect of diameter classes on different tree and stand parameters of *Quercus leucotrichophora***

| Dia. Class (cm) | Proportion of trees (%) | Average no. of trees/ ha | dbh (cm) | Collar diameter (cm) | Tree height (m) | Form factor | BA (m$^2$) | Vol. (m$^3$) | Sp. gravity | Vol./ ha (m$^3$) | Crop Ht. (m) | Crop dia. (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **5-10** | 15 | 250.00 | 8.82 | 12.01 | 4.90 | 0.37 | 0.006 | 0.017 | 0.65 | 4.25 | 4.98 | 8.85 |
| **10-15** | 60 | 1000.00 | 12.48 | 16.14 | 7.36 | 0.40 | 0.012 | 0.037 | 0.69 | 37.00 | 7.45 | 12.55 |
| **15-20** | 20 | 333.33 | 17.00 | 21.30 | 8.64 | 0.44 | 0.023 | 0.086 | 0.70 | 28.67 | 8.66 | 17.03 |
| **>20** | 5 | 83.35 | 21.44 | 24.29 | 10.04 | 0.44 | 0.036 | 0.159 | 0.72 | 13.25 | 10.08 | 21.47 |
| **CD Value** | | | 0.61 | 1.01 | 0.75 | | 0.002 | 0.020 | | | | |

In *Pinus roxburghii* the maximum values i.e., tree height (9.33m), form factor (0.46), basal area (0.045m$^2$), volume (0.205m$^3$), crop height (9.44m), crop diameter (23.93cm) and specific gravity (0.50) were obtained in >20cm diameter class as shown in table 3. Out of the total number of trees per hectare, 25%, 30%, 20% and 25% were found in 5-10cm, 10-15cm, 15-20cm and >20cm diameter class respectively. Volume/ha was maximum (85.42m$^3$) in >20cm diameter class although maximum number of trees were found in 10-15cm diameter class. The statistical analysis was done for different parameters namely diameter at breast height, collar diameter, tree height, basal area and volume and significant differences were obtained in case of all the parameters under study.

**Table 3. Effect of diameter classes on different tree and stand parameters of *Pinus roxburghii***

| Dia. Class (cm) | Proportion of trees (%) | Average no. of trees/ ha | dbh (cm) | Collar diameter (cm) | Tree height (m) | Form factor | BA ($m^2$) | Vol. ($m^3$) | Sp. gravity | Vol./ ha ($m^3$) | Crop Ht. (m) | Crop dia. (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **5-10** | 25 | 416.67 | 8.66 | 10.96 | 4.87 | 0.36 | 0.006 | 0.011 | 0.45 | 4.58 | 4.96 | 8.7 |
| **10-15** | 30 | 500.00 | 13.91 | 16.38 | 6.53 | 0.39 | 0.015 | 0.039 | 0.48 | 19.50 | 6.54 | 13.93 |
| **15-20** | 20 | 333.33 | 17.49 | 19.98 | 8.14 | 0.46 | 0.024 | 0.089 | 0.45 | 29.67 | 8.11 | 17.55 |
| **>20** | 25 | 416.67 | 23.78 | 27.37 | 9.33 | 0.46 | 0.045 | 0.205 | 0.50 | 85.42 | 9.44 | 23.93 |
| **CD Value** | | | 0.61 | 1.01 | 0.75 | | 0.002 | 0.020 | | | | |

Similarly in *Eucalyptus tereticornis,* tree height (15.28m), form factor (0.46), basal area (0.044m$^2$), volume (0.311m$^3$), crop height (15.28m), crop diameter (23.66cm) and specific gravity (0.70) were maximum in >20cn diameter class as shown in table 4. Out of the total number of trees per hectare, 5%, 15%, 30% and 45% were found in 5-10cm, 10-15cm, 15-20cm and >20cm diameter class respectively. The maximum number of trees were found in >20cm diameter class so the volume/ha was also maximum (233.25m$^3$) in this diameter class. The statistical analysis was done for different parameters namely diameter at breast height, collar diameter, tree height, basal area and volume and significant differences were obtained in case of all the parameters under study.

**Table 4. Effect of diameter classes on different tree and stand parameters of *Eucalyptus tereticornis***

| Dia. Class (cm) | Proportion of trees (%) | Average no. of trees/ ha | dbh (cm) | Collar diameter (cm) | Tree height (m) | Form factor | BA ($m^2$) | Vol. ($m^3$) | Sp. gravity | Vol./ ha ($m^3$) | Crop Ht. (m) | Crop dia. (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **5-10** | 5 | 83.33 | 8.00 | 11.38 | 6.20 | 0.37 | 0.005 | 0.012 | 0.65 | 0.99 | 6.29 | 8.06 |
| **10-15** | 15 | 250.00 | 12.48 | 15.59 | 7.75 | 0.42 | 0.012 | 0.041 | 0.69 | 10.25 | 7.68 | 12.54 |
| **15-20** | 35 | 583.33 | 16.66 | 21.38 | 9.60 | 0.44 | 0.022 | 0.096 | 0.67 | 55.99 | 9.72 | 16.73 |
| **>20** | 45 | 750.00 | 23.57 | 30.68 | 15.28 | 0.46 | 0.044 | 0.311 | 0.70 | 233.25 | 15.48 | 23.66 |
| **CD Value** | | | 0.61 | 1.01 | 0.75 | | 0.002 | 0.020 | | | | |

*Melia azedarach* showed higher values of tree height (14.1m), form factor (0.51), basal area (0.047m$^2$), volume (0.340m$^3$), crop height (14.27m), crop diameter (24.29cm) and specific gravity (0.69) in >20cm diameter class as shown in table 5. Basal area and crop diameter were maximum in *M. azedarach* among all the five species. Out of the total number of trees per hectare, 7.82%, 12.78%, 17.79% and 24.29% were found in 5-10cm, 10-15cm, 15-20cm and >20cm diameter class respectively. Volume/ha was maximum in >20cm diameter class because of more number of trees per hectare in this diameter class. The statistical analysis was done for different parameters namely diameter at breast height, collar diameter, tree height, basal area and volume and significant differences were obtained in case of all the parameters under study.

**Table 5. Effect of diameter classes on different tree and stand parameters of *Melia azedarach***

| Dia. Class (cm) | Proportion of trees (%) | Average no. of trees/ ha | dbh (cm) | Collar diameter (cm) | Tree height (m) | Form Factor | BA ($m^2$) | Vol. ($m^3$) | Sp. gravity | Vol./ ha ($m^3$) | Crop Ht. (m) | Crop dia. (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **5-10** | 17 | 283.33 | 7.68 | 11.83 | 7.90 | 0.45 | 0.005 | 0.018 | 0.60 | 5.10 | 8.22 | 7.82 |
| **10-15** | 21 | 350.00 | 12.74 | 16.19 | 10.58 | 0.48 | 0.013 | 0.066 | 0.64 | 23.10 | 10.69 | 12.78 |
| **15-20** | 28 | 466.67 | 17.76 | 22.26 | 13.57 | 0.50 | 0.025 | 0.168 | 0.66 | 78.40 | 13.48 | 17.79 |
| **>20** | 34 | 566.67 | 24.22 | 27.82 | 14.10 | 0.51 | 0.047 | 0.340 | 0.69 | 192.67 | 14.27 | 24.29 |
| **CD Value** | | | 0.61 | 1.01 | 0.75 | | 0.002 | 0.020 | | | | |

The different tree parameters viz. tree height (16.65m), form factor (0.54), basal area (0.040$m^2$), volume (0.365$m^3$), crop height (16.60m), crop diameter (22.63cm) and specific gravity (0.65) were maximum in >20cm diameter class in case of *Ulmus villosa* as shown in table 6. The tree parameters like tree height, volume and crop height were maximum in *U. villosa* among all five species as shown in table 6. Out of the total number of trees per hectare, 5%, 15%, 30% and 45% were found in 5-10cm, 10-15cm, 15-20cm and >20cm diameter class respectively. Volume/ha was maximum in >20cm diameter class followed by 10-15cm diameter class as more number of trees per hectare was present in this diameter class. The statistical analysis was done for different parameters namely diameter at breast height, collar diameter, tree height, basal area and volume and significant differences were obtained in case of all the parameters under study.

**Table 6. Effect of diameter classes on different tree and stand parameters of *Ulmus villosa***

| Dia. Class (cm) | Proportion of plants (%) | Average no. of trees/ ha | dbh (cm) | Collar diameter (cm) | Tree height (m) | Form factor | BA ($m^2$) | Vol. ($m^3$) | Sp. Gravity | Vol. / ha ($m^3$) | Crop Ht. (m) | Crop dia. (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **5-10** | 33.33 | 833.25 | 7.93 | 11.57 | 5.67 | 0.40 | 0.005 | 0.012 | 0.56 | 9.99 | 5.91 | 8.04 |
| **10-15** | 38.88 | 972.00 | 12.76 | 18.02 | 10.70 | 0.50 | 0.015 | 0.083 | 0.59 | 80.68 | 10.88 | 14.04 |
| **15-20** | 16.66 | 416.50 | 16.52 | 19.45 | 12.47 | 0.51 | 0.022 | 0.138 | 0.61 | 57.48 | 12.55 | 16.57 |
| **>20** | 11.11 | 277.75 | 22.6 | 28.28 | 16.65 | 0.54 | 0.040 | 0.365 | 0.65 | 101.39 | 16.60 | 22.63 |
| **CD Value** | | | 0.61 | 1.01 | 0.75 | | 0.002 | 0.020 | | | | |

In all the species an increasing trend was observed in both green as well as dry biomass which increased with an increasing diameter. In *Q. leucotrichophora* the maximum values of green biomass of stem, branch, leaf and twig were 74.46Kg, 43.05, 18.30 and 8.30Kg respectively in >20cm diameter class. Similar trend was observed in dry biomass of stem, branch, leaf and twig were 47.29Kg, 27.88, 9.14 and 5.96Kg in same diameter class.

**Table 7. Diameter wise biomass partitioning (green and dry) in *Quercus leucotrichophora***

| | Green biomass (Kg/tree) | | | | | Dry biomass (Kg/tree) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Dia. Class (cm)** | **Stem** | **Branch** | **Leaves** | **Twigs** | **Total** | **Stem** | **Branch** | **Leaves** | **Twigs** | **Total** |
| 5-10 | 5.94 (38) | 4.38 (28) | 3.42 (21.86) | 1.90 (12.13) | 15.63 (10.85) | 3.40 (36.32) | 2.18 (23.27) | 2.84 (30.25) | 0.95 (10.16) | 9.37 (10.38) |
| 10-15 | 11.07 (35.97) | 9.23 (29.99) | 7.20 (23.39) | 3.28 (10.65) | 30.78 (21.36) | 9.42 (40.82) | 7.29 (31.62) | 4.71 (20.43) | 1.64 (7.13) | 23.06 (25.54) |
| 15-20 | 36.98 (50.77) | 18.95 (26.02) | 11.75 (16.13) | 5.15 (7.07) | 72.83 (50.54) | 23.48 (53.27) | 11.84 (26.87) | 5.79 (13.14) | 2.96 (6.72) | 44.07 (48.82) |
| >20 | 74.46 (51.67) | 43.05 (29.87) | 18.30 (12.69) | 8.30 (5.76) | 144.11 | 47.29 (52.39) | 27.88 (30.88) | 9.14 (10.12) | 5.96 (6.6) | 90.27 |

Figure in parentheses are per cent contribution towards total biomass

The maximum per cent contribution towards green biomass by stem, branch, leaves and twigs was 51.67(>20cm), 29.99(10-15cm), 23.39(10-15cm) and 12.13(5-10cm) respectively in *Q. leucotrichophora*. Similarly in case of dry biomass maximum per cent contribution by stem, branch, leaves and twigs was

53.27 (15-20cm), 31.62 (10-15cm), 30.25 (5-10cm) and 10.16 (5-10cm) respectively as shown in table 7.

In *P. roxburghii* the maximum values of green biomass of stem, branch, leaves and twigs were 90.27Kg, 45.88, 35.88 and 17.59Kg in >20cm diameter class. Similar trend was observed in dry biomass of stem, branch, leaves and twigs where maximum values are 53.87Kg, 39.68, 25.32 and 10.36Kgrespectively in same diameter class.

**Table 8. Diameter wise biomass partitioning (green and dry) in *Pinus roxburghii***

| | Green biomass (Kg/tree) | | | | | Dry biomass (Kg/tree) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Dia. Class (cm)** | **Stem** | **Branch** | **Leaves** | **Twigs** | **Total** | **Stem** | **Branch** | **Leaves** | **Twigs** | **Total** |
| 5-10 | 7.50 (39.44) | 5.77 (30.34) | 3.87 (20.37) | 1.87 (9.85) | 19.01 (10.02) | 3.48 (38.67) | 2.50 (27.85) | 2.05 (22.79) | 0.96 (10.69) | 8.99 (10.66) |
| 10-15 | 26.46 (36.27) | 19.48 (26.71) | 16.14 (22.13) | 10.86 (14.89) | 72.94 (38.47) | 21.69 (45.36) | 12.45 (26.03) | 7.44 (15.56) | 6.24 (13.06) | 47.82 (26.47) |
| 15-20 | 59.32 (41.79) | 37.57 (26.47) | 33.15 (23.36) | 11.89 (8.38) | 141.93 (74.85) | 33.11 (39.11) | 23.27 (27.49) | 19.21 (22.69) | 9.05 (10.69) | 84.65 (56.31) |
| >20 | 90.27 (47.6) | 45.88 (24.19) | 35.88 (18.92) | 17.59 (9.28) | 189.62 | 53.87 (41.69) | 39.68 (30.7) | 25.32 (19.59) | 10.36 (8.01) | 129.23 |

Figure in parentheses are per cent contribution towards total biomass

The maximum per cent contribution towards green biomass by stem, branch, leaves and twigs was 47.60(>20cm), 30.34(5-10cm), 23.36(15-20cm) and 14.89(10-15cm) respectively in *P. roxburghii*. Same trend was observed for dry biomass, maximum per cent contribution by stem followed by branch, leaves and twigs and valued 45.36(10-15cm), 30.70(>20cm), 22.79(5-10cm) and 13.06(10-15cm) respectively as shown in table 8.

In *E. tereticornis* the maximum values of green biomass of stem, branch, leaves and twigs were 98.99Kg, 62.16, 33.60 and 28.97Kg in >20cm diameter class, similarly, in dry biomass of stem, branch, leaves and twigs the maximum values were 79.71Kg, 34.80Kg, 20.80Kg and 19.66Kg respectively in same diameter class.

The maximum per cent contribution towards green biomass by stem, branch, leaves and twigs in case of *E. tereticornis* was 51.13(15-20cm), 27.78(>20cm), 24.12(5-10cm) and 12.95(>20cm) respectively as shown in table 9. Similarly in case of dry biomass maximum per cent contribution by stem, branch, leaves and twigs was 51.44(>20cm), 26.02(10-15cm), 20.74(10-15cm) and 12.69(>20cm) respectively.

**Table 9. Diameter wise biomass partitioning (green and dry) in *Eucalyptus tereticornis***

| | Green biomass (Kg/tree) | | | | | Dry biomass (Kg/tree) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Dia. Class (cm)** | **Stem** | **Branch** | **Leaves** | **Twigs** | **Total** | **Stem** | **Branch** | **Leaves** | **Twigs** | **Total** |
| 5-10 | 10.23 (40.59) | 5.86 (23.24) | 6.08 (24.12) | 3.03 (12.04) | 25.20 (11.26) | 8.18 (49.51) | 3.57 (21.62) | 3.06 (18.49) | 1.08 (6.57) | 16.52 (10.66) |
| 10-15 | 30.18 (41.5) | 16.43 (22.6) | 17.16 (23.59) | 8.94 (12.29) | 72.72 (32.50) | 18.26 (44.52) | 10.67 (26.02) | 8.51 (20.74) | 3.57 (8.71) | 41.02 (26.47) |
| 15-20 | 69.42 (51.13) | 24.29 (17.89) | 25.33 (18.66) | 16.72 (12.32) | 135.76 (60.68) | 44.75 (51.28) | 14.97 (17.15) | 17.56 (20.12) | 9.99 (11.44) | 87.27 (56.31) |
| >20 | 98.99 (44.25) | 62.16 (27.78) | 33.60 (15.02) | 28.97 (12.95) | 223.73 | 79.71 (51.44) | 34.80 (22.46) | 20.80 (13.42) | 19.66 (12.69) | 154.97 |

Figure in parentheses are per cent contribution towards total biomass

In *M. azedarach* the maximum values of green biomass of stem, branch, leaves and twigs were 106.86Kg, 91.32, 47.18 and 29.15Kg respectively in >20cm diameter class. Similar trend was observed in dry biomass of stem, branch, leaves and twigs and maximum values were 76.59Kg, 62.54, 36.18 and 16.34Kg in same diameter class.

**Table 10. Diameter wise biomass partitioning (green and dry) in *Melia azedarach***

| | Green biomass (Kg/tree) | | | | | Dry biomass (Kg/tree) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Dia. Class (cm)** | **Stem** | **Branch** | **Leaves** | **Twigs** | **Total** | **Stem** | **Branch** | **Leaves** | **Twigs** | **Total** |
| 5-10 | 17.71 (47.32) | 10.08 (26.93) | 5.72 (15.28) | 3.92 (10.47) | 37.43 (13.63) | 9.04 (41.06) | 7.10 (32.25) | 3.26 (14.78) | 2.62 (11.91) | 22.03 (11.49) |
| 10-15 | 47.78 (51.18) | 20.65 (22.11) | 15.09 (16.16) | 9.84 (10.54) | 93.36 (34.01) | 20.15 (38.61) | 13.54 (25.96) | 9.81 (18.79) | 8.68 (16.63) | 52.18 (27.23) |
| 15-20 | 78.89 (50.41) | 34.31 (21.92) | 28.39 (18.14) | 14.90 (9.52) | 156.48 (57.00) | 50.33 (51.17) | 24.38 (24.79) | 12.79 (13) | 10.85 (11.03) | 98.34 (51.31) |
| >20 | 106.86 (38.93) | 91.32 (33.27) | 47.18 (17.19) | 29.15 (10.62) | 274.51 | 76.59 (39.96) | 62.54 (32.63) | 36.18 (18.88) | 16.34 (8.52) | 191.64 |

Figure in parentheses are per cent contribution towards total biomass

The maximum per cent contribution towards green biomass by stem, branch, leaves and twigs was 51.18(10-15cm), 33.27(>20cm), 18.14(15-20cm) and 10.62(>20cm) respectively in *M. azedarach*. Similarly in case of dry biomass maximum per cent contribution by stem, branch, leaves and twigs was 51.17(15-20cm), 32.63(>20cm), 18.18(>20cm) and 16.63(10-15cm) respectively as shown in table 10.

In *U. villosa* the maximum values of green biomass of stem, branch, leaves and twigs was 103.84Kg, 80.39, 44.75 and 36.50Kg respectively in >20cm diameter class whereas the value of dry biomass of stem, branch, leaves and twigs were 81.83Kg, 58.17Kg, 22.36Kg and 19.39Kg respectively in the same diameter class.

**Table 11. Diameter wise biomass partitioning (green and dry) in *Ulmus villosa***

| | Green biomass (Kg/tree) | | | | | Dry biomass (Kg/tree) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Dia. Class (cm)** | **Stem** | **Branch** | **Leaves** | **Twigs** | **Total** | **Stem** | **Branch** | **Leaves** | **Twigs** | **Total** |
| 5-10 | 11.34 (43.46) | 8.18 (31.35) | 4.16 (15.94) | 2.41 (9.25) | 26.09 (9.83) | 7.89 (50.47) | 3.79 (24.26) | 2.26 (14.43) | 1.69 (10.84) | 15.63 (8.60) |
| 10-15 | 39.71 (61.43) | 12.72 (19.68) | 7.60 (11.76) | 4.61 (7.13) | 64.64 (24.35) | 14.94 (49.17) | 9.20 (30.28) | 3.87 (12.74) | 2.37 (7.81) | 30.38 (16.71) |
| 15-20 | 77.89 (46.39) | 45.58 (27.14) | 25.24 (15.04) | 19.19 (11.43) | 167.90 (63.24) | 44.57 (47.85) | 25.06 (26.9) | 13.24 (14.22) | 10.27 (11.03) | 93.14 (51.25) |
| >20 | 103.84 (39.11) | 80.39 (30.28) | 44.75 (16.86) | 36.50 (13.75) | 265.48 | 81.83 (45.02) | 58.17 (32) | 22.36 (12.3) | 19.39 (10.67) | 181.75 |

Figure in parentheses are per cent contribution towards total biomass

The maximum per cent contribution towards green biomass per tree by stem, branch, leaves and twigs in case of *U. villosa* was 61.43(10-15cm), 31.35(5-10cm), 16.86(>20cm) and 13.75(>20cm) respectively as shown in table 11. Similarly in case of dry biomass maximum per cent contribution by stem, branch, leaves and twigs was 50.47(5-10cm), 32.00(>20cm), 14.43(5-10cm) and 11.03(15-20cm) respectively.

### 4.1.2 Crown characteristics and diameter classes

The data recorded on randomly selected trees for all the species arranged in four diameter classes with 5cm class interval and analysed for various crown characteristics i.e. crown area, crown height, crown width and crown length were showing statistically significant variation among four diameter classes for all the species. The mean values for these crown characteristics have been presented in table 12.

Crown area increased with increase in diameter class in case of *P. roxburghii* (13.53$m^2$), *E. tereticornis* (8.51$m^2$), *M. azedarach* (23.50$m^2$) and *U. villosa* (31.85$m^2$) however, in case of *Q. leucotrichophora* the maximum value (10.87$m^2$) was observed in 15-20cm diameter class but in >20cm diameter class it was significantly low (8.24$m^2$).

Crown height also increased with increase in diameter in *Q. leucotrichophora* (5.23m), *P. roxburghii* (5.02m), *E. tereticornis* (7.96m) and *U. villosa* (7.20m) however, in case of *M. azedarach* the maximum value (7.47m) was observed in 15-20cm diameter class but in >20cm it was significantly low (6.62m).

In case of crown width maximum values for different species viz. *P. roxburghii* (3.95m), *E. tereticornis* (4.06m), *M. azedarach* (5.15m) and *U. villosa* (6.37m) increases with increase in diameter whereas, for *Q. leucotrichophora* the maximum value (3.68m) was observed in 15-20cm diameter class but it was significantly low in >20cm (3.19m).

Crown length also increased with increase in diameter in *Q. leucotrichophora* (4.81m), *P. roxburghii* (4.31m), *E. tereticornis* (6.96m), *M. azedarach* (7.47m) and *U. villosa* (9.45m) and the maximum values were obtained in >20cm diameter class.

## 4.2 VARIABILITY ANALYSIS AND EVALUATION OF FACTORS RESPONSIBLE FOR BIOMASS PRODUCTION

### 4.2.1 Variation among different growth characters

The data were collected on randomly selected trees for various growth parameters viz., diameter at breast height (DBH), collar diameter (CD), height (H), crown area (CA), crown width (CW), crown length (CL), crown height (CH).

## Table 12. Diameter class wise crown characteristics of different species

| Diameter class (cm) | Crown area ($m^2$) | | | | | Mean | Crown height (m) | | | | | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | |
| 5-10 | 2.89 | 2.61 | 2.46 | 3.66 | 2.46 | 2.82 | 2.27 | 2.66 | 3.82 | 3.60 | 2.37 | 2.95 |
| 10-15 | 5.22 | 5.82 | 4.39 | 8.54 | 18.94 | 8.58 | 3.86 | 3.31 | 4.42 | 5.10 | 4.67 | 4.27 |
| 15-20 | 10.87 | 9.48 | 5.70 | 15.40 | 24.55 | 13.20 | 4.40 | 4.15 | 5.49 | 7.47 | 6.07 | 5.16 |
| >20 | 8.24 | 13.53 | 8.51 | 23.50 | 31.85 | 24.78 | 5.23 | 5.02 | 7.96 | 6.62 | 7.20 | 6.41 |
| **Mean** | 6.81 | 7.86 | 5.26 | 12.77 | 19.45 | **12.34** | 3.94 | 3.79 | 5.42 | 5.70 | 5.08 | **4.79** |
| | CD (D) = 0.52<br>CD (S) = 0.65<br>CD (DXS) = 1.28 | | | | | | CD (D) = 0.52<br>CD (S) = 0.58<br>CD (DXS) = 1.16 | | | | | |
| **Diameter class (cm)** | **Crown width (m)** | | | | | **Mean** | **Crown length (m)** | | | | | **Mean** |
| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | |
| 5-10 | 1.78 | 1.62 | 1.71 | 2.05 | 1.72 | 1.78 | 2.63 | 2.24 | 2.38 | 4.30 | 3.30 | 2.97 |
| 10-15 | 2.51 | 2.64 | 2.32 | 3.17 | 4.35 | 3.00 | 3.47 | 3.23 | 3.33 | 5.47 | 6.02 | 4.30 |
| 15-20 | 3.68 | 3.34 | 2.59 | 4.35 | 5.02 | 3.80 | 4.24 | 4.09 | 4.10 | 6.10 | 6.40 | 4.99 |
| >20 | 3.19 | 3.95 | 4.06 | 5.15 | 6.37 | 4.95 | 4.81 | 4.31 | 6.96 | 7.47 | 9.45 | 6.60 |
| **Mean** | 2.79 | 2.89 | 2.67 | 3.68 | 4.36 | **3.38** | 3.79 | 3.47 | 4.19 | 5.84 | 6.29 | **4.71** |
| | CD (D) = 0.56<br>CD (S) = 0.62<br>CD (DXS) = 1.25 | | | | | | CD (D) = 0.48<br>CD (S) = 0.53<br>CD (DXS) = 1.07 | | | | | |

$S_1$ = *Quercus leucotrichophora*
$S_2$ = *Pinus roxburghii*
$S_3$ = *Eucalyptus tereticornis*
$S_4$ = *Melia azedarach*
$S_5$ = *Ulmus villosa*

## Table 13. Species wise variability analysis for different growth characteristics

| Tree characteristics | *Q. leucotrichophora* ($n_1$=40) | | | *P. roxburghii* ($n_2$=40) | | | *E. tereticornis* ($n_3$=40) | | | *M. azedarach* ($n_4$=40) | | | *U. villosa* ($n_5$=40) | | | $\chi^2$ (UC) | CF | $\chi^2$ (C) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Mean** | **SD** | **CV (%)** | **Mean** | **SD** | **CV (%)** | **Mean** | **SD** | **CV (%)** | **Mean** | **SD** | **CV (%)** | **Mean** | **SD** | **CV (%)** | | | |
| Diameter (cm) | 14.94 | 4.86 | 32.56 | 15.96 | 5.74 | 35.95 | 15.18 | 5.93 | 39.08 | 15.6 | 6.36 | 40.74 | 14.95 | 5.54 | 37.03 | 2.8 | 1.01 | 2.77 |
| Collar diameter (cm) | 18.43 | 5.1 | 27.67 | 18.67 | 6.36 | 34.04 | 19.76 | 7.56 | 38.29 | 19.53 | 6.59 | 33.77 | 19.33 | 6.72 | 34.75 | 6.4 | 1.01 | 6.34 |
| Tree height (m) | 7.74 | 2.08 | 26.92 | 7.22 | 2.27 | 31.38 | 9.71 | 3.76 | 39 | 11.54 | 3.19 | 27.69 | 11.37 | 4.78 | 42.07 | 37.39 | 1.01 | 37.02** |
| Crown height (m) | 3.97 | 1.32 | 33.37 | 3.76 | 1.4 | 37.31 | 5.42 | 2.04 | 37.58 | 5.7 | 2.29 | 40.24 | 5.08 | 2.18 | 42.87 | 20.11 | 1.01 | 19.91** |
| Crown width (m) | 2.79 | 1.93 | 33.44 | 2.89 | 1.28 | 44.44 | 2.67 | 1.08 | 40.41 | 3.68 | 1.65 | 44.83 | 4.36 | 3.41 | 70.12 | 69.66 | 1.01 | 68.97** |
| Crown length (m) | 3.79 | 1.01 | 26.75 | 3.47 | 1.17 | 33.14 | 4.19 | 1.86 | 44.37 | 5.84 | 1.9 | 32.58 | 6.21 | 2.74 | 40.29 | 49.37 | 1.01 | 48.88** |
| Stem volume ($m^3$/tree) | 0.07 | 0.06 | 82.03 | 0.09 | 0.09 | 104.93 | 0.117 | 0.13 | 108.24 | 0.15 | 0.14 | 91.82 | 0.149 | 0.14 | 96.74 | 40.66 | 1.01 | 40.26** |
| Crown area ($m^2$/tree) | 6.81 | 4.01 | 58.33 | 7.86 | 6.25 | 79.46 | 5.26 | 5.45 | 83.57 | 12.77 | 11.57 | 90.65 | 19.45 | 16.53 | 31.59 | 71.32 | 1.01 | 68.63** |
| Stem basal area ($cm^2$/tree) | 193.7 | 117.09 | 60.45 | 225.8 | 154.98 | 68.64 | 208.45 | 153.23 | 73.51 | 222.75 | 166.82 | 74.89 | 205.86 | 140.34 | 68.03 | 73.75 | 1.01 | 73.02** |
| Crown height/ tree height | 0.5 | 0.08 | 15.64 | 0.52 | 0.09 | 17.77 | 0.56 | 0.07 | 13.38 | 0.48 | 0.11 | 23.29 | 0.45 | 0.05 | 11.04 | 25.43 | 1.01 | 25.18** |

** Significant at probability level of significance $\alpha = 0.01$

$n_1$, $n_2$, $n_3$, $n_4$ and $n_5$ = number of trees in each species

Bartlett's $\chi^2$ test was applied to compare variation and average performance of various characters among different species. The data were analysed for mean, standard deviation and coefficient of variation and shown in table 13 for *Quercus leucotrichophora*, *Pinus roxburghii*, *Eucalyptus tereticornis*, *Melia azedarach* and *Ulmus villosa* respectively.

*U. villosa* showed maximum mean values for crown area (19.45$m^2$), crown width (4.36m) and crown length (6.21m) whereas crown height was maximum for *M. azedarach* (5.70m).

The computed values through Bartlett's $\chi^2$ test when compared at 1 per cent level of significance revealed that there was no significant variation among tree characters such as diameter and collar diameter whereas all the other tree characters such as tree height, crown height, crown width, crown length, stem volume/tree, crown area and crown height/tree height showed statistically significant variation.

The highest coefficient of variation was shown by stem volume for all the species and maximum value was shown by *U. villosa* (96.74). However highest standard deviation is shown by stem basal area for all the species.

### 4.2.2 Correlation and regression analysis

**Correlation study**

Karl Pearson's coefficient of correlation between stem volume and different tree growth parameters (dbh, height, crown diameter, crown width, crown length, crown area and crown height) were worked out on data collected from the field and presented in a matrix for *Q. leucotrichophora*, *P. roxburghii*, *E. tereticornis*, *M. azedarach* and *U. villosa* in table 14 15, 16, 17 and table 18 respectively.

It is evident from the table 14 that stem volume was positively correlated with all tree growth parameters. Among stem growth parameters, the highest correlation coefficient was 0.94 between dbh and stem volume followed by dbh and tree height (0.90) and dbh and crown length (0.81), whereas, minimum correlation was 0.52 between crown area and volume.

**Table 14. Simple correlation coefficient (r) between stem volume and tree growth parameters for *Quercus leucotrichophora***

| Parameters | Dbh | Tree Height | Crown area | Crown diameter | Crown length | Crown height | Volume |
|---|---|---|---|---|---|---|---|
| Dbh | 1.00 | | | | | | |
| Tree height | 0.90** | 1.00 | | | | | |
| Crown area | 0.60** | 0.63** | 1.00 | | | | |
| Crown diameter | 0.65** | 0.69** | 0.97** | 1.00 | | | |
| Crown length | 0.81** | 0.79** | 0.77** | 0.80** | 1.00 | | |
| Crown height | 0.80** | 0.90** | 0.49** | 0.54** | 0.58** | 1.00 | |
| Volume | 0.94** | 0.86** | 0.52** | 0.55** | 0.73** | 0.75** | 1.00 |

** Significant at 1% level of significance.

It is evident from the table 15 that stem volume was positively correlated with all tree growth parameters. Among stem growth parameters, the highest correlation coefficient was 0.91 between crown length and crown diameter. Crown height indicated a highly significant relationship with tree height (0.90), followed by crown length and crown area (0.88) etc., while minimum correlation was 0.48 between crown height and crown diameter.

**Table 15: Simple correlation coefficient (r) between stem volume and tree growth parameters for *Pinus roxburghii***

| Parameters | Dbh | Tree height | Crown area | Crown diameter | Crown length | Crown height | Volume |
|---|---|---|---|---|---|---|---|
| Dbh | 1.00 | | | | | | |
| Tree height | 0.73** | 1.00 | | | | | |
| Crown area | 0.63** | 0.76** | 1.00 | | | | |
| Crown diameter | 0.63** | 0.77** | 0.98** | 1.00 | | | |
| Crown length | 0.65** | 0.85** | 0.88** | 0.91** | 1.00 | | |
| Crown height | 0.65** | 0.90** | 0.49** | 0.48** | 0.54** | 1.00 | |
| Volume | 0.73** | 0.85** | 0.61** | 0.61** | 0.67** | 0.82** | 1.00 |

** Significant at 1% level of significance.

**Table 16: Simple correlation coefficient (r) between stem volume and tree growth parameters for *Eucalyptus tereticornis***

| Parameters | Dbh | Tree height | Crown area | Crown diameter | Crown length | Crown height | Volume |
|---|---|---|---|---|---|---|---|
| Dbh | 1.00 | | | | | | |
| Tree height | 0.89** | 1.00 | | | | | |
| Crown area | 0.76** | 0.68** | 1.00 | | | | |
| Crown diameter | 0.89** | 0.69** | 0.98** | 1.00 | | | |
| Crown length | 0.91** | 0.93** | 0.80** | 0.81** | 1.00 | | |
| Crown height | 0.80** | 0.94** | 0.51** | 0.51** | 0.78** | 1.00 | |
| Volume | 0.92** | 0.92** | 0.79** | 0.78** | 0.91** | 0.79** | 1.00 |

** Significant at 1% level of significance.

It is evident from the table 16 that stem volume was positively correlated with all tree growth parameters. Among stem growth parameters, the highest correlation coefficient was 0.94 between crown height and tree height followed by crown length and tree height (0.93). Stem volume indicated a highly significant relationship with diameter (0.92) and tree height (0.92), followed by crown length and diameter (0.91) and crown length and volume (0.91) etc., while minimum correlation was 0.51 between crown height and crown diameter and crown height and crown area.

**Table 17: Simple correlation coefficient (r) between stem volume and tree growth parameters for *Melia azedarach***

| Parameters | Dbh | Tree height | Crown area | Crown diameter | Crown length | Crown height | Volume |
|---|---|---|---|---|---|---|---|
| Dbh | 1.00 | | | | | | |
| Tree height | 0.76** | 1.00 | | | | | |
| Crown area | 0.65** | 0.54** | 1.00 | | | | |
| Crown diameter | 0.71** | 0.62** | 0.97** | 1.00 | | | |
| Crown length | 0.57** | 0.70** | 0.27 | 0.35 | 1.00 | | |
| Crown height | 0.58** | 0.81** | 0.53** | 0.58** | 0.15 | 1.00 | |
| Volume | 0.93** | 0.78** | 0.67** | 0.69** | 0.61** | 0.58** | 1.00 |

** Significant at 1% level of significance.

It is evident from the table 17 that stem volume was positively correlated with most of the tree growth parameters. Among stem growth parameters, the highest correlation coefficient was 0.93 between stem volume and diameter, crown height indicated a highly significant relationship with tree height (0.81), stem volume also indicated a highly significant relationship with total height (0.78) and crown diameter (0.69), followed by total height and diameter (0.76) and crown diameter and diameter (0.71) etc., while minimum correlation was 0.53 between crown height and crown area. Crown length showed no effect on crown area and crown diameter.

It is evident from the table 18 that stem volume was positively correlated with most of the tree growth parameters. Among stem growth parameters, the highest correlation coefficient was obtained between crown length and tree height (0.98) followed by stem volume and diameter (0.91), crown length indicated a highly significant relationship with crown height (0.89) and volume (0.89) followed by total height and crown diameter (0.88) and volume (0.88) etc., while minimum correlation was 0.60 between crown area and diameter.

**Table 18: Simple correlation coefficient (r) between stem volume and tree growth parameters for *Ulmus villosa***

| Parameters | Dbh | Tree height | Crown area | Crown diameter | Crown length | Crown height | Volume |
|---|---|---|---|---|---|---|---|
| Dbh | 1.00 | | | | | | |
| Tree height | 0.83** | 1.00 | | | | | |
| Crown area | 0.60** | 0.83** | 1.00 | | | | |
| Crown diameter | 0.69** | 0.88** | 0.98** | 1.00 | | | |
| Crown length | 0.80** | 0.98** | 0.82** | 0.85** | 1.00 | | |
| Crown height | 0.81** | 0.96** | 0.80** | 0.86** | 0.89** | 1.00 | |
| Volume | 0.91** | 0.88** | 0.77** | 0.81** | 0.89** | 0.82** | 1.00 |

** Significant at 1% level of significance.

### 4.2.2.2 Regression study

**Linear and non linear functions**

Various linear and non-linear functions have been tried on primary and secondary data by taking volume as the dependent variable and other different tree characteristics as independent variates i.e., diameter breast height (D), height (H), form factor (F). The fitted equations for volume, with standard error of estimates and adjusted $\bar{R}^2$ have been presented for *Q. leucotrichophora*, *P. roxburghii*, *E. tereticornis*, *M. azedarach* and *U. villosa* in table 19, 20, 21, 22 and 23 respectively. The data were also subjected to multiple regression analysis to understand the simultaneous effect of various characters viz., diameter breast height (D), height (H), crown width (CW), crown length (CL), crown height (CH) on volume.

Table 19 is showing various linear and non linear relationships to find out volume with different tree characters for *Q. leucotrichophora*. The relationship between volume with diameter at breast height, volume with tree height and volume with form factor is shown through different functions simultaneously, where power function showed highest adjusted $\bar{R}^2$ (0.97) for volume with

**Table 19. Linear and non-linear functions for volume with diameter at breast height, tree height and form factor for *Quercus leucotrichophora***

| **Volume** | **Adj $\bar{R}^2$** | **SE of b,c** |
|---|---|---|
| $V= -0.102+0.012D$ | 0.89 | 0.001 |
| $V= -0.35+ 0.16LnD$ | 0.82 | 0.012 |
| $V= 0.002e^{0.21D}$ | 0.94 | 0.01 |
| $V= 0.03-0.01D+0.001D^2$ | 0.93 | 0,0.004 |
| $V= 0.00002D^{2.96}$ | 0.97 | 0.08 |
| **Volume** | | |
| $V= -0.12+0.025H$ | 0.73 | 0.002 |
| $V = -0.27+ 0.171LnH$ | 0.67 | 0.02 |
| $V = 0.001e^{0.47H}$ | 0.89 | 0.03 |
| $V = 0.03-0.02H+0.003H^2$ | 0.76 | 0.02, 0.001 |
| $V = 0.00005H^{3.38}$ | 0.91 | 0.17 |
| **Volume** | | |
| $V= -0.15+ 0.54F$ | 0.30 | 0.13 |
| $V = -0.27+0.22LnF$ | 0.28 | 0.05 |
| $V = 0.001e^{8.9F}$ | 0.28 | 2.21 |
| $V = 0.30-1.61F+2.48F^2$ | 0.33 | 1.36, 1.57 |
| $V = 1.38F^{3.78}$ | 0.28 | 0.94 |

V = Stem volume ($m^3$) F = Form factor
H = Height (m) D = Diameter at breast height (cm)

diameter at breast height, whereas, less variability was observed in different types of relationships (linear and non linear) for individual tree character. Similarly power function showed highest adjusted $\bar{R}^2$ (0.91) for volume with tree height followed by polynomial of second degree which showed highest adjusted $\bar{R}^2$ (0.33) for volume with form factor. Since in this case all the values were very less so they showed a poor relationship in all types of equations for the estimation of volume with form factor.

Table 20 is showing various linear and non linear functions to find out volume with different tree characters for *P. roxburghii*. The relationship between volume with diameter at breast height, volume with tree height and volume with form factor is shown through different functions simultaneously. The highest value of adjusted $\bar{R}^2$ was 0.65 for volume with diameter at breast height, shown by power function followed by exponential which showed highest adjusted $\bar{R}^2$ (0.52) for volume with tree height. The exponential function shows highest adjusted $\bar{R}^2$ (0.34) for volume with form factor. The overall calculated values

**Table 20. Linear and non-linear functions for volume with diameter at breast height, tree height and form factor for *Pinus roxburghii***

| Volume | Adj $\bar{R}^2$ | SE of b,c |
|---|---|---|
| $V= -0.07+0.01D$ | 0.27 | 0.003 |
| $V= -0.27+0.14LnD$ | 0.19 | 0.04 |
| $V= 0.004e^{0.2D}$ | 0.64 | 0.02 |
| $V= 0.16-0.02 D+0.001 D^2$ | 0.33 | 0.01,0 |
| $V= 0.00008D^{2.43}$ | 0.65 | 0.29 |
| **Volume** | | |
| $V = -0.09+0.03H$ | 0.29 | 0.01 |
| $V = -0.23+0.17LnH$ | 0.20 | 0.05 |
| $V = 0.004e^{0.37H}$ | 0.52 | 0.06 |
| $V =0.43-0.12H+0.01H^2$ | 0.50 | 0.04, 0.002 |
| $V =0.0H^{2.68}$ | 0.50 | 0.42 |
| **Volume** | | |
| $V= -0.19+0.69F$ | 0.16 | 0.23 |
| $V = 0.33-0.26LnF$ | 0.13 | 0.1 |
| $V = 0.001e^{9.92F}$ | 0.34 | 2.14 |
| $V = 0.73-3.75F+5.19F^2$ | 0.23 | 2.1, 2.44 |
| $V = 1.92F^{4.04}$ | 0.33 | 0.89 |

V = Stem volume ($m^3$) F = Form factor
H = Height (m) D = Diameter at breast height (cm)

adjusted $\bar{R}^2$ were very low indicating the comparatively poor relationship between different parameters for the estimation of volume in *P. roxburghii* as compared to *Q. leucotrichophora*.

Table 21 is showing various linear and non linear relationships to find out volume with different tree characters for *E. tereticornis*. The relationship between volume with diameter at breast height, volume with tree height and volume with form factor is shown through different functions simultaneously, where both power function and polynomial showed highest and equal value of adjusted $\bar{R}^2$ (0.96) for volume with diameter at breast height. Similar trend was observed for volume with tree height where both power and exponential function showed highest and equal value of adjusted $\bar{R}^2$ (0.86). For different types of relationships (linear and non linear) less variability was observed for individual tree character. Volume with form factor showed highest adjusted $\bar{R}^2$ (0.42) with exponential function but the relationship was not very effective.

**Table 21. Linear and non-linear functions for volume with diameter at breast height, tree height and form factor for *Eucalyptus tereticornis***

| **Volume** | **Adj $\bar{R}^2$** | **SE of b,c** |
|---|---|---|
| $V= -0.18+0.02D$ | 0.85 | 0.001 |
| $V= -0.57+0.26LnD$ | 0.71 | 0.03 |
| $V= 0.003e^{0.21D}$ | 0.94 | 0.01 |
| $V= 0.1-0.02 D+0.001 D^2$ | 0.96 | 0.004,0 |
| $V= 0.00002D^{2.99}$ | 0.96 | 0.09 |
| **Volume** | | |
| $V = -0.19+0.03H$ | 0.85 | 0.002 |
| $V = -0.55+0.30LnH$ | 0.77 | 0.03 |
| $V = 0.003e^{0.3H}$ | 0.81 | 0.02 |
| $V = -0.05+0.003H+0.001H^2$ | 0.86 | 0.01, 0.001 |
| $V = 0.00006H^{3.14}$ | 0.86 | 0.20 |
| **Volume** | | |
| $V = -0.36+1.12F$ | 0.25 | 0.29 |
| $V = 0.49+0.43LnF$ | 0.23 | 0.12 |
| $V = 0.00001e^{14.1F}$ | 0.42 | 2.59 |
| $V = 0.95-5.33F+7.78F^2$ | 0.31 | 3.07, 3.69 |
| $V = 8.11F^{5.68}$ | 0.41 | 1.05 |

V = Stem volume ($m^3$)  F = Form factor
H = Height (m)  D = Diameter at breast height (cm)

Table 22 is showing various linear and non linear relationships to find out volume with different tree characters for *M. azedarach*. The relationship between volume with diameter at breast height, volume with tree height and volume with form factor is shown through different functions simultaneously, where power function showed highest value of adjusted $\bar{R}^2$ as 0.95 for volume with diameter at breast height Similarly, for volume with tree height power function showed highest adjusted $\bar{R}^2$ (0.77). For different types of relationships (linear and non linear) less variability was observed for individual tree characters. The exponential function showed highest adjusted $\bar{R}^2$ (0.33) for volume with form factor but the relationship was poor.

**Table 22. Linear and non-linear functions for volume with diameter at breast height, tree height and form factor for *Melia azedarach***

| Volume | Adj $\bar{R}^2$ | SE of b,c |
|---|---|---|
| $V = -0.16+0.02D$ | 0.87 | 0.001 |
| $V = -0.54+0.26LnD$ | 0.73 | 0.02 |
| $V = 0.005e^{0.18D}$ | 0.88 | 0.01 |
| $V = -0.002-0.003D+0.001D^2$ | 0.91 | 0.005,0 |
| $V = 0.00007D^{2.67}$ | 0.95 | 0.09 |
| **Volume** | | |
| $V = -0.2+0.03H$ | 0.49 | 0.005 |
| $V = -0.59+0.31LnH$ | 0.46 | 0.05 |
| $V = 0.002e^{0.34H}$ | 0.74 | 0.032 |
| $V = -0.05+0.001H+0.001H^2$ | 0.48 | 0.04, 0.002 |
| $V = 0.00002H^{3.57}$ | 0.77 | 0.31 |
| **Volume** | | |
| $V = -0.4+1.14F$ | 0.22 | 0.33 |
| $V = 0.52+0.5LnF$ | 0.20 | 0.15 |
| $V = 0.00001e^{12.41F}$ | 0.33 | 2.75 |
| $V = 1.53-7.42F+9.3F^2$ | 0.26 | 4.96, 5.38 |
| $V = 4.94F^{5.54}$ | 0.32 | 1.26 |

V = Stem volume ($m^3$) F = Form factor
H = Height (m) D = Diameter at breast height (cm)

Table 23 is showing various linear and non linear functions to find out volume with different tree characters for *U. villosa*. The relationship between volume with diameter at breast height, volume with tree height and volume with form factor is shown through different functions simultaneously. For volume with diameter at breast height, power function showed highest adjusted $\bar{R}^2$ (0.95). Similarly for volume with tree height and volume with form factor, power function showed highest adjusted values of $\bar{R}^2$ as 0.90 and 0.41 respectively. In all the cases more variability was observed for all tree parameters.

**Table 23. Linear and non-linear functions for volume with diameter at breast height, tree height and form factor for *Ulmus villosa***

| Volume | Adj $\bar{R}^2$ | SE of b,c |
|---|---|---|
| $V = -0.2+0.02D$ | 0.82 | 0.002 |
| $V = -0.64+0.3LnD$ | 0.71 | 0.03 |
| $V = 0.002e^{0.23D}$ | 0.89 | 0.01 |
| $V = 0.02-0.01D+0.001D^2$ | 0.87 | 0.01,0 |
| $V = 0.00001D^{3.27}$ | 0.95 | 0.12 |
| **Volume** | | |
| $V = -0.15+0.03H$ | 0.78 | 0.002 |
| $V = -0.47+0.27LnH$ | 0.68 | 0.03 |
| $V = 0.004e^{0.25H}$ | 0.80 | 0.02 |
| $V = -0.04+0.005H+0.001H^2$ | 0.79 | 0.01, 0 |
| $V = 0.00009H^{2.87}$ | 0.90 | 0.16 |
| **Volume** | | |
| $V = -0.12+0.55F$ | 0.12 | 0.22 |
| $V = 0.39+0.35LnF$ | 0.18 | 0.11 |
| $V = 0.002e^{7.37F}$ | 0.26 | 1.9 |
| $V = -0.95+3.52F-2.54F^2$ | 0.32 | 0.72, 0.86 |
| $V = 2.19F^{4.7}$ | 0.41 | 0.89 |

V = Stem volume ($m^3$) F = Form factor
H = Height (m) D = Diameter at breast height (cm)

Likewise in case of branch green biomass and branch dry biomass using branch diameter and branch length as independent variable, various linear and non linear relationships have been tried on primary and secondary data collected from field and the fitted equations for branch green biomass and branch dry biomass with standard error of estimates and adjusted $\bar{R}^2$ have been presented in the following tables (24-28).

In table 24, polynomial of second degree showed highest adjusted $\bar{R}^2$ (0.62) and (0.60) for branch diameter with branch green biomass and branch diameter with branch dry biomass respectively. Similarly, polynomial function showed highest adjusted $\bar{R}^2$ (0.68) and (0.65) for branch length with branch green biomass and branch length with branch dry biomass respectively in case of *Q. leucotrichophora.*

**Table 24. Linear and non-linear functions for branch green biomass ($B_g$) and branch dry biomass ($B_d$) with branch diameter ($D_b$) and branch length ($L_b$) for *Quercus leucotrichophora***

| **Branch green biomass** | **Adj $\bar{R}^2$** | **SE of b,c** |
|---|---|---|
| $B_g = -1656.43+853.44D_b$ | 0.55 | 158.06 |
| $B_g = -1560.53+2259.85LnD_b$ | 0.49 | 467.07 |
| $B_g = 27.11e^{1.09Db}$ | 0.54 | 0.20 |
| $B_g = 2528.68-2147.2D_b+521.97D_b^2$ | 0.62 | 1320.01, 228.23 |
| $B_g = 28.93D_b^{2.94}$ | 0.51 | 0.59 |
| **Branch dry biomass** | | |
| $B_d = -956.26+486.15D_b$ | 0.49 | 102.14 |
| $B_d = -888.403+1274.14LnD_b$ | 0.43 | 300.58 |
| $B_d = 16.75e^{1.04Db}$ | 0.47 | 0.22 |
| $B_d = 2077.18-1688.80\ D_b+378.33\ D_b^2$ | 0.60 | 825.12, 142.66 |
| $B_d = 18.13D_b^{2.79}$ | 0.44 | 0.64 |
| **Branch green biomass** | | |
| $B_g = -830.12+1038.38L_b$ | 0.59 | 179.07 |
| $B_g = 322.55+1111.11LnL_b$ | 0.40 | 274.06 |
| $B_g = 77.13e^{1.33Lb}$ | 0.58 | 0.23 |
| $B_g = 465.27-789.96\ L_b+598.23\ L_b^2$ | 0.68 | 694.39, 221.26 |
| $B_g = 314.45L_b^{1.58}$ | 0.50 | 0.32 |
| **Branch dry biomass** | | |
| $B_d = -490.58+594.87L_b$ | 0.52 | 116.05 |
| $B_d = 173.41+626.16LnL_b$ | 0.34 | 173.24 |
| $B_d = 45.21e^{1.27\ Lb}$ | 0.51 | 0.25 |
| $B_d = 430.22-668.06L_b+413.23\ L_b^2$ | 0.65 | 439.26,139.96 |
| $B_d = 176.32L_b^{1.51}$ | 0.44 | 0.35 |

In table 25 exponential function showed highest adjusted $\bar{R}^2$ (0.44) and (0.37) for branch diameter with branch green biomass and branch diameter with branch dry biomass respectively. Similarly, polynomial function showed highest adjusted $\bar{R}^2$ (0.44) and (0.39) for branch length with branch green biomass and branch length with branch dry biomass respectively in case of *P. roxburghii*.

**Table 25. Linear and non-linear functions for branch green biomass ($B_g$) and branch dry biomass ($B_d$) with branch diameter ($D_b$) and branch length ($L_b$) for *Pinus roxburghii***

| **Branch green biomass** | **Adj $\bar{R}^2$** | **SE of b,c** |
|---|---|---|
| $B_g = -1291.09+775.25D_b$ | 0.30 | 236.73 |
| $B_g = -1377.88+2212.36LnD_b$ | 0.32 | 640.09 |
| $B_g = 27.74e^{1.17Db}$ | 0.40 | 0.29 |
| $B_g= -9849.73+7000.55D_b-1113.04D_b^2$ | 0.38 | 3129.29, 558.08 |
| $B_g = 24.04D_b^{3.36}$ | 0.44 | 0.77 |
| **Branch dry biomass** | | |
| $B_d = -475.32+294.15D_b$ | 0.26 | 98.04 |
| $B_d = -505.55+836.71LnD_b$ | 0.28 | 266.29 |
| $B_d = 13.10e^{1.11Db}$ | 0.34 | 0.31 |
| $B_d= -3454.65+2461.23D_b-387.46D_b^2$ | 0.31 | 1331.62, 237.48 |
| $B_d = 11.65D_b^{3.16}$ | 0.37 | 0.83 |
| **Branch green biomass** | | |
| $B_g = -501.89+685.67\ L_b$ | 0.32 | 198.07 |
| $B_g = -38.91+1354.73LnL_b$ | 0.32 | 392.75 |
| $B_g = 95.41e^{1.02Lb}$ | 0.42 | 0.24 |
| $B_g = -569.62+754.86\ L_b-16.88\ L_b^2$ | 0.29 | 1933.07, 483.72 |
| $B_g = 183.65L_b^{2.06}$ | 0.44 | 0.47 |
| **Branch dry biomass** | | |
| $B_d = -159.74+251.80\ L_b$ | 0.26 | 83.46 |
| $B_d = 9.927+498.06LnL_b$ | 0.26 | 165.37 |
| $B_d = 40.58e^{0.98\ Lb}$ | 0.37 | 0.26 |
| $B_d = -208.67+301.79L_b-12.19\ L_b^2$ | 0.22 | 839.79, 203.82 |
| $B_d = 76.14L_b^{\ 1.99}$ | 0.39 | 0.49 |

In *E. tereticornis* both linear and polynomial functions showed highest adjusted $\bar{R}^2$ (0.83) for branch diameter with branch green biomass whereas linear function showed highest adjusted $\bar{R}^2$ (0.82) for branch diameter with branch dry biomass respectively. Similarly, polynomial and linear function showed highest adjusted $\bar{R}^2$ (0.75) and (0.77) for branch length with branch green biomass and branch length with branch dry biomass respectively as shown in table 26.

**Table 26. Linear and non-linear functions for branch green biomass ($B_g$) and branch dry biomass ($B_d$) with branch diameter ($D_b$) and branch length ($L_b$) for *Eucalyptus tereticornis***

| Branch green biomass | Adj$\bar{R}^2$ | SE of b,c |
|---|---|---|
| $B_g = -1541.75+907.63D_b$ | 0.83 | 84.91 |
| $B_g = -1490.96+2514.47LnD_b$ | 0.75 | 301.49 |
| $B_g = 58.24e^{0.88Db}$ | 0.70 | 0.12 |
| $B_g= -924.88+485.69D_b+65.57D_b^2$ | 0.83 | 492.07, 75.30 |
| $B_g = 53.67D_b^{2.59}$ | 0.71 | 0.34 |
| **Branch dry biomass** | | |
| $B_d = -850.13+500.51D_b$ | 0.82 | 48.47 |
| $B_d = -825.21+1389.92LnD_b$ | 0.74 | 168.98 |
| $B_d = 31.86e^{0.88Db}$ | 0.70 | 0.12 |
| $B_d= -561.35+302.99D_b+30.69D_b^2$ | 0.81 | 282.56,43.24 |
| $B_d = 29.21D_b^{2.6}$ | 0.71 | 0.34 |
| **Branch green biomass** | | |
| $B_g = -1035.30+763.02L_b$ | 0.75 | 90.53 |
| $B_g = -778.84+1925.51LnL_b$ | 0.68 | 270.94 |
| $B_g = 87.10e^{0.78Lb}$ | 0.70 | 0.1 |
| $B_g = -340.27+221.61L_b+93.30 L_b^2$ | 0.75 | 548.77, 93.27 |
| $B_g = 108.96L_b^{2.01}$ | 0.67 | 0.29 |
| **Branch dry biomass** | | |
| $B_d = -588.22+427.77L_b$ | 0.77 | 48.41 |
| $B_d = -442.11+1076.76LnL_b$ | 0.69 | 147.39 |
| $B_d = 46.82e^{0.79\ Lb}$ | 0.71 | 0.1 |
| $B_d = -135.27+74.94L_b+60.80L_b^2$ | 0.77 | 290.07, 49.3 |
| $B_d = 58.71L_b^{\ 2.03}$ | 0.68 | 0.29 |

In table 27 exponential function showed highest adjusted $\bar{R}^2$ (0.79) for branch diameter with branch green biomass whereas for branch diameter with branch dry biomass exponential function showed highest adjusted $\bar{R}^2$ (0.77). Power function showed highest adjusted $\bar{R}^2$ (0.89) and (0.89) for branch length with branch green biomass and branch length with branch dry biomass respectively in *M. azedarach*.

**Table 27. Linear and non-linear functions for branch green biomass ($B_g$) and branch dry biomass ($B_d$) with branch diameter ($D_b$) and branch length ($L_b$) for *Melia azedarach***

| **Branch green biomass** | **Adj $\bar{R}^2$** | **SE of b,c** |
|---|---|---|
| $B_g = -365.07+311.79D_b$ | 0.65 | 46.86 |
| $B_g = -84.63+585.66LnD_b$ | 0.53 | 113.18 |
| $B_g = 25.26e^{0.96Db}$ | 0.79 | 0.1 |
| $B_g= 400.92-450.58D_b+162.15D_b^2$ | 0.78 | 207.54, 43.43 |
| $B_g = 53.18D_b^{1.95}$ | 0.77 | 0.22 |
| **Branch dry biomass** | | |
| $B_d = -235.75+177.03D_b$ | 0.56 | 32.4 |
| $B_d = -68.73+327.50LnD_b$ | 0.43 | 75.82 |
| $B_d = 8.21e^{1.08Db}$ | 0.77 | 0.12 |
| $B_d= 278.42-330.72D_b+107.99D_b^2$ | 0.71 | 146.92, 30.74 |
| $B_d = 19.31D_b^{2.17}$ | 0.73 | 0.27 |
| **Branch green biomass** | | |
| $B_g = -207.19+401.74L_b$ | 0.82 | 39.29 |
| $B_g = 274.67+467.86LnL_b$ | 0.65 | 71.16 |
| $B_g = 46.02e^{1.15Lb}$ | 0.86 | 0.09 |
| $B_g = 56.57-17.04L_b+126.24L_b^2$ | 0.87 | 13.53, 39.62 |
| $B_g = 177.49L_b^{1.52}$ | 0.89 | 0.11 |
| **Branch dry biomass** | | |
| $B_d = -130.89+209.21L_b$ | 0.72 | 26.69 |
| $B_d = 121.46+235.54LnL_b$ | 0.53 | 45.23 |
| $B_d = 16.44e^{1.25\ Lb}$ | 0.86 | 0.11 |
| $B_d = 86.81-136.43L_b+104.19L_b^2$ | 0.85 | 80.75, 23.61 |
| $B_d = 71.57L_b^{\ 1.65}$ | 0.89 | 0.13 |

In *U. villosa* both exponential and power function showed highest adjusted $\bar{R}^2$ (0.38) for branch diameter with branch green biomass. Similarly for branch diameter with branch dry biomass exponential and power function showed highest adjusted $\bar{R}^2$ (0.41). Polynomial function showed highest adjusted $\bar{R}^2$ (0.47) and (0.53) for branch length with branch green biomass and branch length with branch dry biomass respectively as shown in table 28.

**Table 28. Linear and non-linear functions for branch green biomass ($B_g$) and branch dry biomass ($B_d$) with branch diameter ($D_b$) and branch length ($L_b$) for *Ulmus villosa***

| Branch green biomass | Adj $\bar{R}^2$ | SE of b,c |
|---|---|---|
| $B_g = 14.02+114.33D_b$ | 0.33 | 32.29 |
| $B_g = 136.20+173.29LnD_b$ | 0.30 | 52.08 |
| $B_g = 59.06e^{0.59Db}$ | 0.38 | 0.15 |
| $B_g= 109.90-18.79D_b+36.7D_b^2$ | 0.32 | 202.08, 54.97 |
| $B_g = 110.11D_b^{0.93}$ | 0.38 | 0.24 |
| **Branch dry biomass** | | |
| $B_d = -3.33+59.66D_b$ | 0.37 | 15.67 |
| $B_d = 60.39+90.50LnD_b$ | 0.34 | 25.35 |
| $B_d = 25.13e^{0.63Db}$ | 0.41 | 0.15 |
| $B_d= 55.54-22.09D_b+22.54D_b^2$ | 0.36 | 97.46, 26.51 |
| $B_d = 48.82D_b^{1.01}$ | 0.41 | 0.24 |
| **Branch green biomass** | | |
| $B_g = -128.62+189.74L_b$ | 0.43 | 44.36 |
| $B_g = 49.05+298.34LnL_b$ | 0.36 | 79.92 |
| $B_g = 29.38e^{0.96Lb}$ | 0.46 | 0.21 |
| $B_g = 201.87-199.84L_b+104.68L_b^2$ | 0.47 | 236.81, 62.59 |
| $B_g = 68.23L_b^{1.63}$ | 0.46 | 0.36 |
| **Branch dry biomass** | | |
| $B_d = -75.58+97.70L_b$ | 0.46 | 21.52 |
| $B_d = 16.59+152.12LnL_b$ | 0.38 | 39.31 |
| $B_d = 12.30e^{1.01Lb}$ | 0.47 | 0.22 |
| $B_d = 121.58-134.71L_b+62.45L_b^2$ | 0.53 | 110.92, 29.32 |
| $B_d = 29.86L_b^{1.70}$ | 0.47 | 0.37 |

**4.2.2.2.2 Multilinear functions**

Multilinear analysis were done so as to study the overall contribution of different tree parameters viz. diameter at breast height, tree height, crown width, crown height and crown length for stem volume of different species. Thus for volume of different species multilinear equations developed are presented in table 29.

The maximum value of adjusted $\bar{R}^2$ was obtained in *E. tereticornis* with value 0.93 followed by *U. villosa*, *Q. leucotrichophora*, *M. azedarach* and *P. roxburghii* with values 0.90, 0.88, 0.87 and 0.85 respectively.

**Table 29. Multilinear function for volume with different tree characteristics in different species**

| Species | Equations | Adj $\bar{R}^2$ |
|---|---|---|
| *Q. leucotrichophora* | V= −0.099+0.012D+0.005H*−0.007CW*−0.004CH*−0.003CL*<br>(0.002) (0.006 ) (0.006) (0.006) (0.008) | 0.88 |
| *P. roxburghii* | V= −0.178 +0.007D+0.026H*+0.003CW*+0.003CH*−0.016CL*<br>(0.001) (0.035) (0.011) (0.036) (0.034) | 0.85 |
| *E. tereticornis* | V= −0.182 +0.001D*+0.088H+0.023CW−0.074CH−0.057CL<br>(0.003) (0.016) (0.010) (0.016) (0.016) | 0.93 |
| *M. azedarach* | V= −0.211 +0.016D+0.003H*+0.005CW*+0.002CH*+0.008CL*<br>(0.002) (0.036) (0.007) (0.036) (0.036) | 0.87 |
| *U. villosa* | V= −0.189 +0.016D+0.011CW−0.016CH*+0.021CL<br>(0.002) (0.005) (0.009) (0.007) | 0.90 |

(* Significant at 5% level of significance)

| | | | | | |
|---|---|---|---|---|---|
| V | = | Volume | D | = | Diameter |
| H | = | Height | CH | = | Crown height |
| CW | = | Crown width | CL | = | Crown length |

### 4.2.3 Other studies - soil, solar flux and LAI

The study was conducted for soil, solar flux and LAI for all the five species viz. *Q. leucotrichophora*, *P. roxburghii*, *E. tereticornis*, *M. azedarach* and *U. villosa*.

#### 1. Soil studies

Soil analysis was done for pH, bulk density, particle density, organic carbon, available nitrogen, phosphorus, potassium, calcium and magnesium and the mean values have been presented in table 30. The data shows higher range of soil pH under *Q. leucotrichophora* at both the depths i.e. 0-15cm (6.23) and 15-30cm (6.16). However, there is no statistically significant effect of tree species on soil pH. The mean response is presented in table 30.

Organic carbon per cent was higher under both the depths in *E. tereticornis* (1.38 and 1.41 at 0-15cm and 15-30cm respectively). There is statistically significant effect of different tree species on organic carbon per cent however it was absent under various depths. The mean values are 1.18, 1.26, 1.23 and 1.19 for *Q. leucotrichophora*, *P. roxburghii*, *M. azedarach* and *U. villosa* respectively.

Similarly bulk density was also higher under *E. tereticornis* (1.45 g/cm$^3$ and 1.44 g/cm$^3$ at 0-15cm and 15-30cm respectively). The effect of different tree species is statistically significant on bulk density but it is absent in case of various depths. The mean values are 1.40, 1.39, 1.39 and 1.39 for *P. roxburghii*, *Q. leucotrichophora*, *M. azedarach* and *U. villosa.*

Particle density showed similar maximum values for both *Q. leucotrichophora* and *P. roxburghii* at both the depths (2.66 g/cm$^3$ and 2.60 g/cm$^3$ at 0-15cm and 15-30cm respectively). There is statistically no significant effect of different tree species on particle density under various depths. The mean values are shown in table 30.

Available nitrogen was quite higher at 0-15cm (403.50 kg/ha) under *M. azedarach* whereas it was higher at 15-30cm depth (371.09 kg/ha) for *Q. leucotrichophora*. There is statistically significant effect of different tree species on available nitrogen however it was absent under various depths. The mean values are 384.70, 350.70, 190.10 and 183.88 for *M. azedarach*, *P. roxburghii*, *E. tereticornis* and *U. villosa* respectively.

Available phosphorus was higher under *P. roxburghii* for both the depths (37.64 Kg/ha and 28.80 Kg/ha at 0-15cm and 15-30cm respectively). There is statistically no significant effect of different tree species on available phosphorus under various depths. The mean values are shown in table 30.

Under *Q. leucotrichophora* available potassium was higher (232.40 Kg/ha) at 0-15cm depth whereas it was higher under *P. roxburghii* (234.00 Kg/ha) for 15-30cm depth. There is statistically no significant effect of different tree species on available potassium under various depths. The mean values are shown in table 30.

Exchangeable calcium was higher under *U. villosa* plantation (1670.00 mg/Kg and 1288.00 mg/Kg at 0-15cm and 15-30cm respectively). There is statistically significant effect of different tree species on available calcium under various depths as shown in table 30. However, in case of interaction among species and various depths it was non significant. The mean values are 1184, 1165, 1002 and 970.8 for *M. azedarach*, *P. roxburghii*, *E. tereticornis* and *Q. leucotrichophora*, respectively.

In case of exchangeable magnesium, it was higher under *E. tereticornis* (423.54 mg/Kg and 371.65 mg/Kg at 0-15cm and 15-30cm respectively).There is statistically no significant effect of different tree species on available magnesium under various depths. The mean values are shown in table 30.

**Table 30. Effect of different species on different soil parameters**

| Soil pH | | | | | | |
|---|---|---|---|---|---|---|
| **Depth (cm)** | **$S_1$** | **$S_2$** | **$S_3$** | **$S_4$** | **$S_5$** | **Mean** |
| 0-15 | 6.23 | 6.12 | 6.05 | 6.15 | 6.18 | 6.15 |
| 15-30 | 6.16 | 6.10 | 6.12 | 6.12 | 6.14 | 6.08 |
| **Mean** | 6.19 | 6.11 | 6.08 | 6.13 | 6.16 | **6.13** |
| CD (D) = NS<br>CD (S) = NS<br>CD (DXS) = NS | | | | | | |

| Organic C (%) | | | | | | |
|---|---|---|---|---|---|---|
| **Depth (cm)** | **$S_1$** | **$S_2$** | **$S_3$** | **$S_4$** | **$S_5$** | **Mean** |
| 0-15 | 1.19 | 1.23 | 1.38 | 1.25 | 1.18 | 1.25 |
| 15-30 | 1.16 | 1.29 | 1.41 | 1.21 | 1.20 | 1.25 |
| **Mean** | 1.18 | 1.26 | 1.39 | 1.23 | 1.19 | **1.25** |
| CD (D) = NS<br>CD (S) = 0.12<br>CD (DXS) = NS | | | | | | |

| Bulk density (g/cm$^3$) | | | | | | |
|---|---|---|---|---|---|---|
| **Depth (cm)** | **$S_1$** | **$S_2$** | **$S_3$** | **$S_4$** | **$S_5$** | **Mean** |
| 0-15 | 1.39 | 1.40 | 1.45 | 1.40 | 1.36 | 1.40 |
| 15-30 | 1.39 | 1.40 | 1.44 | 1.39 | 1.42 | 1.41 |
| **Mean** | 1.39 | 1.40 | 1.45 | 1.39 | 1.39 | **1.40** |
| CD (D) = NS<br>CD (S) = 0.03<br>CD (DXS) = NS | | | | | | |

| Particle density (g/cm$^3$) | | | | | | |
|---|---|---|---|---|---|---|
| **Depth (cm)** | **$S_1$** | **$S_2$** | **$S_3$** | **$S_4$** | **$S_5$** | **Mean** |
| 0-15 | 2.66 | 2.66 | 2.62 | 2.62 | 2.52 | 2.61 |
| 15-30 | 2.60 | 2.60 | 2.60 | 2.51 | 2.45 | 2.55 |
| **Mean** | 2.63 | 2.63 | 2.61 | 2.56 | 2.48 | **2.58** |
| CD (D) = NS<br>CD (S) = NS<br>CD (DXS) = NS | | | | | | |

| Available Nitrogen (Kg/ha) | | | | | | |
|---|---|---|---|---|---|---|
| **Depth (cm)** | **$S_1$** | **$S_2$** | **$S_3$** | **$S_4$** | **$S_5$** | **Mean** |
| 0-15 | 401.40 | 380.50 | 189.20 | 403.50 | 180.80 | 311.1 |
| 15-30 | 371.10 | 320.90 | 190.94 | 365.90 | 186.96 | 287.16 |
| **Mean** | 386.30 | 350.70 | 190.10 | 384.70 | 183.88 | **221.88** |
| CD (D) = NS<br>CD (S) = 0.01<br>CD (DXS) = NS | | | | | | |

| Available Phosphorus (Kg/ha) | | | | | | |
|---|---|---|---|---|---|---|
| **Depth (cm)** | **$S_1$** | **$S_2$** | **$S_3$** | **$S_4$** | **$S_5$** | **Mean** |
| 0-15 | 27.40 | 37.64 | 33.34 | 36.18 | 33.86 | 33.69 |
| 15-30 | 22.22 | 28.80 | 24.13 | 27.99 | 27.05 | 26.04 |
| **Mean** | 24.81 | 33.22 | 28.73 | 32.09 | 30.45 | **29.86** |
| CD (D) = NS<br>CD (S) = NS<br>CD (DXS) = NS | | | | | | |

| Available Potassium (Kg/ha) | | | | | | |
|---|---|---|---|---|---|---|
| **Depth (cm)** | **$S_1$** | **$S_2$** | **$S_3$** | **$S_4$** | **$S_5$** | **Mean** |
| 0-15 | 232.40 | 181.50 | 225.90 | 217.20 | 204.50 | 212.30 |
| 15-30 | 216.50 | 234.00 | 228.70 | 204.80 | 191.30 | 215.10 |
| **Mean** | 229.40 | 207.70 | 227.30 | 211.00 | 197.90 | **213.70** |
| CD (D) = NS<br>CD (S) = NS<br>CD (DXS) = NS | | | | | | |

| Exchangeable Calcium (mg/Kg) | | | | | | |
|---|---|---|---|---|---|---|
| **Depth (cm)** | **$S_1$** | **$S_2$** | **$S_3$** | **$S_4$** | **$S_5$** | **Mean** |
| 0-15 | 1095 | 1250 | 1197 | 1383 | 1670 | 1319 |
| 15-30 | 846.7 | 1080 | 806.7 | 984.3 | 1288 | 1001 |
| **Mean** | 970.8 | 1165 | 1002 | 1184 | 1479 | **1160** |
| CD (D) =0.004<br>CD (S) = 0.002<br>CD (DXS) =NS | | | | | | |

| Exchangeable Magnesium (mg/Kg) | | | | | | |
|---|---|---|---|---|---|---|
| **Depth (cm)** | **$S_1$** | **$S_2$** | **$S_3$** | **$S_4$** | **$S_5$** | **Mean** |
| 0-15 | 347.5 | 372 | 423.5 | 376.1 | 397.1 | 383.2 |
| 15-30 | 299.7 | 347 | 371.6 | 332 | 351.6 | 342 |
| **Mean** | 323.6 | 359.5 | 397.6 | 354.1 | 378.3 | **362.6** |
| CD (D) = NS<br>CD (S) = NS<br>CD (DXS) = NS | | | | | | |

$S_1$ = *Quercus leucotrichophora*, $S_2$ = *Pinus roxburghii*, $S_3$ = *Eucalyptus tereticornis*, $S_4$ = *Melia azedarach*, $S_5$ = *Ulmus villosa*

## 2. Solar flux

In table 31 the studies regarding the solar interception below the canopy under different diameter classes were shown. In *Q. leucotrichophora* maximum value (57.24) was under 15-20cm diameter class while minimum value (34.31) was under 5-10cm and >20cm.

Maximum value (25.23) was obtained in 10-15cm diameter class whereas minimum value (11.91) was under 15-20cm in *P. roxburghii*. Both *E. tereticornis* (29.54) and *U. villosa* (6.88) showed least values in >20cm diameter class whereas maximum value for *E. tereticornis* (62.18) and *U. villosa* (47.07) was observed in 5-10cm and 10-15cm diameter class. In *M. azedarach* highest value (55.42) was under 10-15cm diameter class whereas least value (20.36) was under 15-20cm diameter class. The maximum value (62.18) was obtained in *E. tereticornis* under 5-10cm whereas minimum value (6.88) was obtained in >20cm in *U. villosa* among all the species.

**Table 31. Solar flux in different species**

| Diameter classes | Solar interception (%) | | | | |
|---|---|---|---|---|---|
| | ***Q. leucotrichophora*** | ***P. roxburghii*** | ***E. tereticornis*** | ***M. azedarach*** | ***U. villosa*** |
| **5-10** | 34.31 | 14.98 | 62.18 | 40.61 | 33.39 |
| **10-15** | 43.56 | 25.23 | 61.60 | 55.42 | 47.07 |
| **15-20** | 57.24 | 11.91 | 60.42 | 20.36 | 11.58 |
| **>20** | 34.31 | 15.57 | 29.54 | 21.42 | 6.88 |

## 3. LAI

For leaf area index, all the sites were showing increasing trend as shown in table 32. In *Q. leucotrichophora* lowest value (23.20) was obtained in 5-10cm diameter class, while highest in >20cm diameter class (44.73). In *P. roxburghii* lowest value (0.81) was obtained in 5-10cm diameter class, while highest in >20cm diameter class (1.22). *E. tereticornis* showed lowest value (23.58) under 5-10cm diameter class whereas highest value was obtained under >20cm diameter class (37.46).Similarly *M. azedarach* and *U. villosa* showed lowest values (3.12, 5.89) under 5-10cm diameter class, while highest values (7.79, 11.93) were obtained under >20cm diameter class respectively. The maximum value (44.73) was obtained in *Q. leucotrichophora* under >20cm whereas minimum value (0.81) was obtained under 5-10cm in *P. roxburghii* among all five species.

**Table 32. Leaf Area Index under different species**

| **Diameter classes** | **Leaf Area Index** | | | | |
|---|---|---|---|---|---|
| | ***Q. leucotrichophora*** | ***P. roxburghii*** | ***E. tereticornis*** | ***M. azedarach*** | ***U. villosa*** |
| **5-10** | 23.30 | 0.81 | 23.58 | 3.12 | 5.89 |
| **10-15** | 30.44 | 1.02 | 25.39 | 3.96 | 8.46 |
| **15-20** | 38.14 | 1.11 | 30.11 | 5.39 | 9.48 |
| **>20** | 44.73 | 1.22 | 37.46 | 7.79 | 11.93 |

Overall crop height and crop diameter of all the species was studied and it was found that crop height followed the trend in increasing order and was maximum in *M. azedarach* (11.66m) followed by *U. villosa* (11.45m), *E. tereticornis* (9.79m), *Q. leucotrichophora* (7.79m)and *P. roxburghii* (7.26m). Whereas for crop diameter value was obtained in *P. roxburghii* (16.96 cm) followed by *M. azedarach* (16.82cm), *E. tereticornis* (16.29cm), *U. villosa* (16.19cm)and *Q. leucotrichophora* (15.7cm).

**Table 33. Crop height and crop diameter in different species**

| **Species** | **Crop height (m)** | **Crop diameter (cm)** |
|---|---|---|
| ***Q. leucotrichophora*** | 7.79 | 15.7 |
| ***P. roxburghii*** | 7.26 | 16.96 |
| ***E. tereticornis*** | 9.79 | 16.29 |
| ***M. azedarach*** | 11.66 | 16.82 |
| ***U. villosa*** | 11.45 | 16.19 |

# *Chapter-5*

# DISCUSSION

The results obtained in the present study entitled "Studies on biomass partitioning and soil enrichment in plantations of different tree species under mid hill conditions of Himachal Pradesh" have been discussed in this chapter with suitable and reasonable explanation in the light of available literature under the following heads:

## 5.1 Growth behaviour

For the present study data were recorded for 40 randomly selected trees by grouping 10 trees in four diameter classes with 5cm interval and different tree parameters viz. diameter at breast height, tree height, form factor, collar diameter, basal area, volume, crop height, crop diameter, specific gravity, volume/ha and number of trees/ha were studied for different species viz. *Q. leucotrichophora*, *P. roxburghii*, *E. tereticornis*, *M. azedarach* and *U. villosa* (Table 2-6). All the growth parameters in general increased with the increase in diameter class which is in accordance with the studies conducted under different agro-forestry systems in Kuthar and Arla region of Himachal Pradesh by Singh (2002) in *Acacia catechu*.

In *Q. leucotrichophora*, *P. roxburghii* and *U. villosa* maximum proportion of trees were found in 10-15cm diameter class whereas in *E. tereticornis* and *M. azedarach*, the maximum tree proportion was found in >20cm diameter class, due to the variable light requirement of different species at various stages of growth period (Luna, 1995).

The maximum values of collar diameter for all the species were found in >20cm diameter class which may be due to the growth accumulation in variable thickness from base to the upper part of the stem as in most of the species with the increase in age and diameter buttressing effect is prominent. The results are in accordance with the findings of Woodcock *et al*. (2000) in tropical tree species.

Tree height also showed an increasing trend with increase in diameter class/age for all the five species. Similar results were observed by Kozlowski (1979) for different temperate species. In case of *P. roxburghii* increase in height with increase in diameter is less as compared to other species since its life span is larger, due to this reason its rotation period is quite high (Parkash and Khanna, 1979). Similar results have been reported by Cannell (1987) for angiosperms and conifers.

The form factor in general showed an increase from lowest diameter to highest diameter class in all five species. The maximum value of form factor in all the diameter classes among all the species was 0.54 in >20cm diameter class for *U. villosa* indicating less taper (Gray, 1956) whereas minimum value (0.36) was obtained in 5-10cm diameter class in *P. roxburghii*. The increase in form factor from lower diameter class to higher diameter class is in accordance with the studies conducted by Singh (2004) for Deodar and Shephard *et al*. (1991) for black spruce.

Average basal area increased from lower to upper diameter class in all the species. The maximum value was obtained in >20cm diameter class in *M. azedarach* (0.047$m^2$). This is attributed to the effect of diameter increase since basal area is calculated by squaring the (linear value) diameter (Chaturvedi and Khanna, 1982).

The tree characters and their growth behaviour among different diameter classes revealed that stem volume followed an increasing trend with increase in diameter. The similar trend was well documented in literature by several authors such as Kramer and Kozlowski (1979) in conifers, Kishor (1991) in *Ulmus levigata*, Jain *et al*. (1998) in *Azadirachta indica*, Negi *et al*. (1998) in *Prosopis juliflora*, Kumar (1998) in *Acacia mollissima*, Shephard *et al*. (1991) in black spruce and Ashwani (2004) in *Toona ciliata*.

Specific gravity of wood varied from minimum 0.45 in *P. roxburghii* (5-10cm) to maximum 0.72 in *Q. leucotrichophora* (>20cm diameter class). The variation in specific gravity may be due to the place of wood in trees, stand location, climate etc. which is well supported on the basis of the reports by Troup (1921), Shukla and Rajput (1981) Shukla *et al.* (1991) and Mishra *et al.* (1992).

The maximum values of volume/ha was observed in >20cm diameter class for *P. roxburghii*, *E. tereticornis*, *M. azedarach* and *U. villosa* since the trees were bigger in size. Whereas, for *Q. leucotrichophora* it was maximum in 10-15cm diameter class which was due to the presence of comparatively more number of trees.

It was observed that crop height was higher in *M. azedarach* (11.66m). Crop diameter was higher in *P. roxburghii* (16.96cm) among all five species (Table 33). Similar trend was reported by Hamilton and Christie (1971) and Schober (1975) that trunk thickness was greater in conifers than deciduous tree species. Increased diameter growth may also be attributed to greater plant spacing, cultural operations and additional nutrients applied.

Biomass contribution (Table 7-11) by branch, leaves and twigs, on the basis of percentage was more in lower diameter classes whereas stem biomass was more in higher diameter class in all the species except *U. villosa* where stem contribution was maximum (61.45%), due to the impact of higher branch growth of the species. Whereas, in case of *P. roxburghii*, *E. tereticornis* and *M. azedarach* contribution of stem, branch, leaves and twigs towards total biomass increased with diameter class and age as number of trees per hectare were more in higher diameter classes as these are light demanding species as indicated by Luna (1995).

The increase in average tree biomass is attributed to the fact that the trees at lower density were having more diameter and number of branches per plant. The total biomass (Kg/tree) also exhibited the same trend. These results are in line to the findings of Saralch (1994) and Temeche (1999) in *Eucalyptus tereticornis* plantation. However, total biomass and biomass allocation were unrelated to tree height as reported by Osada *et al*. (2002) in *Elateriospermum tapos*, a tropical species.

Mean per tree above ground biomass and volume was considerably variable among the species (Table 7-11). Maximum mean tree green biomass (140.44Kg) and mean tree dry biomass (91.05Kg) was produced in *M. azedarach* due to maximum crop height (11.66m) and second highest crop diameter when compared with other species. The results are in agreement with those of Hu *et al.* (1980), Van *et al.* (1982), George (1984), Relwani *et al.* (1984), Mishra *et al.* (1996), Pathak *et al.* (1987), Mishra *et al.* (1992) and Nayak (1996) which indicates that the variation could be due to the fact that biomass and volume are merely the reflection of locality, age, density, diameter and height growth. The branch moisture per cent varied from 37.24 (>20cm) to 61.01 (5-10cm) in *Q. leucotrichophora* and *P. roxburghii* respectively, whereas, twig moisture per cent varied from 41.36 (5-10cm) to 80.72 (5-10cm) in *E. tereticornis* and *M. azedarach* respectively. In leaves, the moisture per cent varied from 39.37 (10-15cm) to 78.51 (>20cm) in *Q. leucotrichophora* and *M. azedarach* respectively, however, the individual mean of moisture percent in different diameter classes showed erratic behavior which has made impact on dry biomass of individual tree in different diameter classes of all the species. This may be due to the variation in growth conditions such as aspect, slope and/or soil. These results are contradictory to the findings of Kumar (1996) and Sharma (1997) for eucalypts and black locust.

Diameter at breast height alone is a strong predictor of biomass, but better biomass estimates were obtained when height and crown projection ratios were added to the model as reported by Canadell and Roda (1991). A very strong linear relationship existed between dbh and total biomass production as studied by Hussain and Sheikh (1986). Individual tree biomass increased with increase in age in all the species. Similar results are observed by Liu (2011) for *Pinus tarbulaeformis*.

The growth of trees is influenced by biotic potential, photosynthesis activity, absorption of nutrients, constructive metabolism, competition, limiting resources, stress, respiration and aging factors (Kozlowski, 1971).

## 5.2 Crown characteristics

All crown characters viz. crown area, crown height, crown width and crown length showed an increasing trend with increasing diameter (Table 12). Crown area increased with increase in diameter class and maximum values are obtained in >20cm diameter class in *P. roxburghii*, *E. tereticornis*, *M. azedarach* and *U. villosa* whereas, in *Q. leucotrichophora* these parameters showed maximum value in 15-20cm diameter class. This variation was due to the effect of lopping of trees falling under >20cm diameter class.

Crown height was maximum in *Q. leucotrichophora* (5.23m), *P. roxburghii* (5.02m), *E. tereticornis* (7.96m) and *U. villosa* (7.20m) in >20cm diameter class but in *M. azedarach* (7.47m) it was maximum in 15-20cm diameter class.

In case of crown width the maximum values were obtained in >20cm diameter class in *P. roxburghii*, *E. tereticornis*, *M. azedarach* and *U. villosa* whereas, in *Q. leucotrichophora* it showed slight decrease in same diameter class, this might be due to the effect of lopping. Crown width was maximum in lowest tree density under *U. villosa* and the results are in accordance with the study conducted by Khan and Choudhry (2007) in poplar.

Crown length increased with increase in diameter class for all the five species and the maximum value was obtained in case of *U. villosa* in >20cm diameter class. The similar results were obtained when a study on crown characters was conducted by Kajihara (1976) by measuring 24 stands of Sugi (*Cryptomeria japonica*) to find out the changes in crown morphology with tree height, crown length, diameter and slenderness ratio (length/diam.) where crown length and diameter showed a gradual linear increase with increasing height.

## 5.3 Variation among different growth characters.

The data on tree growth parameters of randomly selected sample trees (Table 13) depicts that tree height (m), crown area ($m^2$), crown width (m), crown length (m), crown height (m), stem volume/tree ($m^3$), stem basal area ($cm^2$) and crown height/tree height were having statistically significant variation between different species. However, diameter at breast height and collar diameter were having statistically non-significant variation for all the species. The maximum values for diameter (15.96cm) and stem basal area (225.8cm$^2$) was observed in *P. roxburghii*, whereas, collar diameter was maximum in *E. tereticornis* (19.76cm). Tree height (11.54m), crown height (5.7m) and stem volume/tree (0.15m$^3$) was maximum in *M. azedarach*. In *U. villosa*, the maximum values for crown width (4.36m), crown length (6.21m) and crown area (19.45m$^2$) was observed.

## 5.4 Correlation and regression

**Correlation**

The results of correlation study (Table 14-18) revealed that stem volume was positively and highly correlated with all the stem growth parameters and crown characteristics in all the species. Similar results were obtained in *Toona ciliata* (Ashwani, 2004), *Populus* hybrid (Huogen and Minren, 1991), *Pinus roxburghii* (Sharma, 1999), *Acacia mollissima* (Kumar, 1998) and sub-alpine forest tree species (Kaufmann and Trondle, 1981).

Diameter at breast height was significantly correlated with tree height for all the species and the results are in accordance with the findings of Liu (2011) for *Pinus tarbulaeformis*.

**Regression**

Various linear and non-linear functions have been employed to study the relationship between stem volume (Table 19-23) with different tree growth parameters. The power fittings ($V = a*D^b$) were best with reasonable accuracy for relationship of volume (V) with diameter (D) and the maximum adjusted $\bar{R}^2$ (0.97) value was obtained in case of *Q. leucotrichophora* and it indicated that increase in one unit of diameter will bring 0.00002 unit increase in volume. Power, polynomial and exponential ($V = a*e^x$) functions showed mixed responses of maximum coefficient of determination for both volume with height (H) and volume with form factor (F) and in case of *Q. leucotrichophora* (0.91) and *E. tereticornis* (0.42) the maximum adjusted $\bar{R}^2$values were obtained in exponential functions. However, Canadell and Roda (1991) have reported logarithmic equation with dbh as independent variable as best fit for volume estimation of *Quercus ilex*.

Similarly, various linear and non-linear functions have been employed to study the relationship between branch green biomass and branch dry biomass with branch diameter and branch length (Table 24 to 28). The linear and polynomial functions showed highest and equal value of adjusted $\bar{R}^2$ (0.83) for the relationship of branch green biomass ($B_{gb}$) with branch diameter ($D_b$) in *E. tereticornis*. The power function showed the maximum value of adjusted $\bar{R}^2$ (0.89) for branch green biomass with branch length in *M. azedarach*. The linear equation was best fitted for branch dry biomass ($B_{db}$) estimation using regression method with its relationship with branch diameter ($D_b$) and showed maximum value of adjusted $\bar{R}^2$ (0.82) in *E. tereticornis*, whereas, for relationship between branch dry biomass ($B_{db}$) and branch length ($L_b$) power equations were best fit and maximum value of adjusted $\bar{R}^2$ (0.89) was recorded in *M. azedarach*.

The use of diameter at breast height remained the best independent variable for estimating volume of standing trees of all the five species in this study on all the sites thus making diameter as most reliable and effective estimator, since the calculation for volume as well as biomass is largely based on the size of tree stem, which is estimated easily, being most accurately measurable parameter. Diameter at breast height is the best predictive variable for stem volume estimation in the study is well supported by earlier findings of Mittal *et al*., (1991) in *Acacia auriculiformis*, Negi *et al*., (1998) in *Prosopis juliflora*, Pant, (2001) in *Pinus caribea* and Ashwani, (2004) in *Toona ciliata*. Wan *et al.* (1989), Pant (2001), Dogra and Sharma (2003) and Ashwani (2004) have reported logarithmic function as best fit in *Acacia mangium*, *Pinus caribea*, *Eulyptus* hybrid, *Toona ciliata* respectively. On the other hand parabolic function in teak (Chakarbarti and Gaharwar, 1995) and polynomial in *Pinus caribae* (Allen, 1991) and linear in *Terminalia paniculata* and *Xylia xylocarpa* (Swamy *et al*., 1991) were found to be best fit. Tree height has often been used as an additional predictor variable for allometric modeling of aboveground tree biomass (Vallet *et al*. 2006) because it is an indicator of site quality and when combined with dbh it becomes an indicator of tree taper.

## 5.5 Other studies (soil, solar flux and LAI)

The physico-chemical studies of soil (Table 30) showed higher range of soil pH, available nitrogen (15-30cm) and available potassium (0-15cm) under *Q. leucotrichophora*. Bulk density, organic carbon and available magnesium were higher under *E. tereticornis* at both the depths. Particle density, available phosphorus and available potassium (15-30cm) were higher under *P. roxburghii*. Available calcium was higher under *U. villosa* plantation at both the depths. These results are in accordance with the findings of Kumar (1998) where he indicated that different trends of soil enrichment could be attributed to the differences in species-site interaction, quantum of litter produced, decomposition and mineralization as well as differential nutrient uptake and cycling under *Acacia mollissima*. Prasad *et al.* (1985), Saralch (1994), Bhola (1995) and Nayak (1996) have also reported differential changes in soil properties owing to differences in nutrient biocycling.

The pH level in all the sites and both the depths ranged between 6.05 to 6.23 may be due to decomposition of organic matter and release of organic acids during the decomposition of litter resulting in moderately acidic soils and results are also reported by Yadav (1963) in Chakrata Forest Division, Saralch (1994) for eucalypts, Bhola (1995) in nitrogen fixing trees and Nayak (1996) under high density plantations.

The level of soil nitrogen varied from 180.80 to 403.50 Kg/ha in all the sites and both the depths and the differences in nitrogen enrichment between the sites could be due to differential nodulation behaviour, availability of water and nutrient status of the site. Such results have also been reported by Russel (1975) and Mishra *et al.* (1994).

Organic carbon under the plantations in all the sites and depths ranged between 1.16 to 1.41 per cent, slightly higher may be due to higher density and excessive contribution of leaves and twigs of different species and other understorey vegetation. Similar findings have also been reported by Hazra and Tripathi (1986), Hussain *et al.* (1987), Sharma and Gupta (1989), Singh (1989), Bhola (1995) and Nayak (1996).

Further more, higher organic carbon accumulation in surface soil than sub-surface layers could be attributed to higher amount of litter accumulation on surface. These results are in accordance with the findings of Benerjee and Badola (1980), Gupta *et al.* (1991), Kaushal (1992), Saralch (1994), Bhola (1995) and Nayak (1996).

The concentration of available phosphorus increased with increase in soil depth and varied from 22.22 to 37.64 Kg/ha under different tree species. The concentration of available potassium followed the same trend and the minimum and maximum values varied between 181.50 to 234.00 Kg/ha under different species. Similar findings have been reported by Baravaraja *et al.* (2010), Rhoades *et al.* (1994) and Noureen *et al.* (2008).

Exchangeable calcium decreased with increase in soil depth for all the species and the minimum and maximum values ranged between 806.7 to 1670 mg/Kg in all sites and both the depths. Similar trend was observed in case of exchangeable magnesium where the maximum and minimum values varied between 299.7 to 423.5 mg/Kg for all species and both the depths. The results are in accordance with the findings of Chirino *et al*. (2010).

Gradual decline in the availability towards lower soil layers could be due to more accumulation and mineralization and reduced root biomass in deeper soil layers. The other reason may be photo cycling of nutrients i.e. deep tap root system may be extracting elements from lower layers and deposited in surface soils. These results are also well supported by the findings of Malik (1992) for chir pine forests of Solan district in Himachal Pradesh, Benerjee and Nath (1991) for soils of Kinnaur, Kaushal (1992) for deodar forests soils, Saralch (1994) for soil under Eucalyptus plantation, Bhola (1995) and Nayak (1996) for high density plantations.

The solar intensity below the canopy under the trees of different diameter classes showed (Table 31) overall decreasing trend in all five sites from 62.18 in *E. tereticornis* to 6.88 in *U. villosa* in lowest (5-10cm) and highest (>20cm) diameter class respectively. The highest value under lowest diameter class might be due to the impact of the bigger size trees intermingled in the plantation. These results are in accordance with the study carried out in the community of sun flower plants by Hiroi and Monsi (1963) in which they reported that leaf area index is the indicator of optimal plant growth which depends upon the light intensity, where the optimum LAI was 7 under full sun, 5 under 60 per cent and only 1.5 under 23 per cent of full sun. Hazara and Tripathi (1986) reported that biomass production is a function of the photosynthetically active radiation on leaves. As optimal leaf mass increase, biomass production would substantially decrease. Shading results in higher relative biomass allocation to the stem and foliage under high or full light conditions as studied by Curt *et al*. (2005).

The leaf area index for all five species showed (Table 32) increasing trend with increase in diameter of trees, however it was overall higher in *Q. leucotrichophora.* The lowest value (0.81) was obtained in *P. roxburghii* at lowest diameter (5-10cm) class while the highest value (44.73) was obtained in >20cm diameter class in *Q. leucotrichophora*. This variation in LAI between different species might be due to the difference in the size of tree crowns and foliage. Similar range was also observed by Dutt (1999) in Chir pine, whereas Sehgal (1999) reported less range of LAI for deciduous trees. Yamada *et al*. (2000) reported that leaf size increase with increase in tree height before branching, but decreased after branches were produced in three *Scaphium* spp.

# *Chapter-6*

# SUMMARY AND CONCLUSION

The present investigation entitled "Studies on biomass partitioning and soil enrichment under plantations of different tree species under mid hill conditions of Himachal Pradesh" was carried out at five sites under five different species, selected and raised at the main campus of Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni (Solan), H.P. The study was conducted in pure plantations of *Quercus leucotrichophora, Pinus roxburghii, Eucalyptus tereticornis, Melia azedarach* and *Ulmus villosa*. The sample of 30 per cent trees out of total population in all five species were studied to record the observations for different growth parameters namely diameter at breast height, collar diameter, tree height, form factor, basal area, volume, crown area, crown length, crown width, crown height, specific gravity and number of branches per plant on diameter class basis. Total above ground biomass, allocated by different tree components (leaf, branch+twig and stem wood) was estimated using non-destructive method of sampling. Actual data on above ground biomass (dry and green) and volume, dbh, total height and other variables were used in construction of various linear and non-linear functions. Physico-chemical studies on soil were carried out by taking composite samples at two depths i.e., 0-15cm and 15-30cm in all the sites. These samples were analysed for estimation of pH, per cent organic carbon, bulk density, particle density, available nitrogen, phosphorus, potassium, exchangeable calcium and magnesium. Other important information was also collected about growth factors which include LAI and solar interception.

## 5.1 Growth behaviour

The data was recorded for 40 randomly selected trees by grouping 10 trees in four diameter classes with 5cm interval and different growth parameters for different species viz. *Q. leucotrichophora, P. roxburghii, E. tereticornis, M. azedarach* and *U. villosa* (Table 2-6). In *Q. leucotrichophora, P. roxburghii* and

*U. villosa* maximum proportion of trees were found in 10-15cm diameter class whereas in *E. tereticornis* and *M. azedarach*, the maximum tree proportion was found in >20cm diameter class.

The maximum values of collar diameter for all the species were found in >20cm diameter class. Tree height also showed an increasing trend with increase in diameter class/age for all the five species. In case of *P. roxburghii* increase in height with increase in diameter was less as compared to other species. The form factor in general showed an increase from lowest diameter to highest diameter class in all five species. The maximum value of form factor in all the diameter classes among all the species was 0.54 (>20cm) in *U. villosa*, whereas, minimum value (0.36) was obtained (5-10cm) in *P. roxburghii*.

Average basal area increased from lower to upper diameter class in all the species. The maximum value was obtained in >20cm diameter class in *M. azedarach* (0.047$m^2$). This is attributed to the effect of diameter increase. The tree characters and their growth behaviour among different diameter classes revealed that stem volume followed an increasing trend with increase in diameter. Specific gravity of wood varied from 0.45 in *P. roxburghii* (5-10cm) to 0.72 in *Q. leucotrichophora* (>20cm diameter class). The maximum values of volume/ha was observed in >20cm diameter class for *P. roxburghii*, *E. tereticornis*, *M. azedarach* and *U. villosa*, whereas, for *Q. leucotrichophora* it was maximum in 10-15cm diameter class. It was observed that crop height was higher in *M. azedarach* (11.66m), crop diameter was higher in *P. roxburghii* (16.96cm) among all the species (Table 33).

Biomass contribution (on the basis of percentage) by branch, leaves and twigs was more in lower diameter classes whereas stem biomass was more in higher diameter class in all the species except *U. villosa* where stem contribution was maximum (61.45%), whereas, in case of *P. roxburghii*, *E. tereticornis* and *M. azedarach* contribution of stem, branch, leaves and twigs towards total biomass increased with diameter class (Table 7-11). The increase in average tree biomass may be attributed to the fact that the trees at lower density were having more diameter and number of branches per plant. The total biomass (Kg/tree) also exhibited the same trend. Mean per tree above ground biomass and volume was considerably variable among the species (Table 7-11). Maximum mean tree green biomass (140.44Kg) and mean tree dry biomass (91.05Kg) was produced in *M. azedarach* as compared to other species. The branch moisture per cent varied from 37.24 (>20cm) to 61.01 (5-10cm) in *Q. leucotrichophora* and *P. roxburghii* respectively, whereas, twig moisture per cent varied from 41.36 (5-10cm) to 80.72 (5-10cm) in *E. tereticornis* and *M. azedarach* respectively. In leaves, the moisture per cent varied from 39.37 (10-15cm) to 78.51 (>20cm) in *Q. leucotrichophora* and *M. azedarach* respectively.

## 5.2 Crown characteristics

All crown characters viz. crown area, crown height, crown width and crown length increased with increase in diameter (Table 12). The maximum values for crown area was obtained in >20cm diameter class in *P. roxburghii*, *E. tereticornis*, *M. azedarach* and *U. villosa*, whereas, in *Q. leucotrichophora* these parameters showed maximum value in 15-20cm diameter class. Crown height was maximum in *Q. leucotrichophora* (5.23m), *P. roxburghii* (5.02m), *E. tereticornis* (7.96m) and *U. villosa* (7.20m) in >20cm diameter class but in *M. azedarach* it was maximum (7.47m) in 15-20cm diameter class. In case of crown width the maximum values were obtained in >20cm diameter class in *P. roxburghii*, *E. tereticornis*, *M. azedarach* and *U. villosa* whereas, in *Q. leucotrichophora* it showed slight decrease in same diameter class. Crown width was maximum in lowest tree density under *U. villosa*. Crown length increased with increase in diameter class for all the five species and the maximum value was obtained in case of *U. villosa* in >20cm diameter class.

## 5.3 Variation among different growth characters.

The data on tree growth parameters of randomly selected sample trees (Table 13) depicts that tree height (m), crown area ($m^2$), crown width (m), crown length (m), crown height (m), stem volume/tree ($m^3$), stem basal area ($cm^2$) and crown height/tree height were having statistically significant variation between different species. However, diameter at breast height and collar diameter were having statistically non-significant variation for all the species.

## 5.4 Correlation and regression

**Correlation**

The results of correlation study (Table 14-18) revealed that stem volume was positively and highly correlated with all the stem growth parameters and crown characteristics in all the species. Diameter at breast height was significantly correlated with tree height for all the species.

**Regression**

Various linear and non-linear functions have been employed to study the relationship between stem volume (Table 19-23) with different tree growth parameters. The power fittings ($V = a*D^b$) were best with reasonable accuracy for relationship of volume (V) with diameter (D) and the maximum adjusted $\bar{R}^2$ (0.97) value was obtained in case of *Q. leucotrichophora* and it indicated that increase in one unit of diameter will bring 0.00002 unit increase in volume. Power, polynomial and exponential ($V = a*e^x$) functions showed mixed responses of maximum coefficient of determination for both volume with height (H) and volume with form factor (F) and in case of *Q. leucotrichophora* (0.91) and *E. tereticornis* (0.42) the maximum adjusted $\bar{R}^2$ values were obtained in exponential functions respectively. Similarly, various linear and non-linear functions have been employed to study the relationship between branch green biomass and branch dry biomass with branch diameter and branch length (Table 24 to 28). The linear and polynomial functions showed highest and equal value of adjusted $\bar{R}^2$ (0.83) for the relationship of branch green biomass ($B_{gb}$) with branch diameter ($D_b$) in *E. tereticornis*. The power function showed the maximum value of adjusted $\bar{R}^2$ (0.89) for branch green biomass with branch length in *M. azedarach*. The linear equation was best fitted for branch dry biomass ($B_{db}$) estimation using regression method with its relationship with branch diameter ($D_b$) and showed maximum value of adjusted $\bar{R}^2$ (0.82) in *E. tereticornis*, whereas, for relationship between branch dry biomass ($B_{db}$) and branch length ($L_b$) power equations were best fit and maximum value of adjusted $\bar{R}^2$ (0.89) was recorded in *M. azedarach*.

## 5.5 Other studies (soil, solar flux and LAI)

The physico-chemical studies of soil (Table 30) showed higher range of soil pH, available nitrogen (15-30cm) and available potassium (0-15cm) under *Q. leucotrichophora*. Bulk density, organic carbon and available magnesium were higher under *E. tereticornis* at both the depths. Particle density, available phosphorus and available potassium (15-30cm) were higher under *P. roxburghii*. Available calcium was higher under *U. villosa* plantation at both the depths.

The pH level in all the sites and both the depths ranged between minimum 6.05 to maximum 6.23 values under *E. tereticornis* and *Q. leucotrichophora*, respectively. Bulk density in all the sites and both the depths ranged between 1.36 to 1.45 g/cm$^3$, whereas, particle density ranged between 2.45 to 2.66 g/cm$^3$ in all the species. Organic carbon under the plantations in all the sites and depths ranged between 1.16 to 1.41 per cent. The level of soil nitrogen varied from 180.80 to 403.50 Kg/ha in all the sites and both the depths. The concentration of available phosphorus increased with increase in soil depth and vary from 22.22 to 37.64 Kg/ha under different tree species. The concentration of available potassium followed the same trend and the minimum and maximum values varied between 181.50 to 234.00 Kg/ha under different species. Exchangeable calcium decreased with increase in soil depth for all the species and the minimum and maximum values ranged between 806.7 to 1670 mg/Kg in all sites and both the depths. Similar trend was observed in case of exchangeable magnesium where the maximum and minimum values varied between 299.7 to 423.5 mg/Kg for all species and both the depths.

The solar intensity below the canopy under the trees of different diameter classes showed (Table 31) overall decreasing trend in all five sites from 62.18% in *E. tereticornis* to 6.88% in *U. villosa* in lowest (5-10cm) and highest (>20cm) diameter class respectively. The leaf area index for all five species showed (Table 32) increasing trend with increase in diameter of trees, however it was overall higher in *Q. leucotrichophora.* The lowest value (0.81) was obtained in *P. roxburghii* at lowest diameter (5-10cm) class while the highest value (44.73) was obtained in >20cm diameter class in *Q. leucotrichophora*.

## CONCLUSION

- Stem volume along with all other tree parameters including specific gravity increased with increase in diameter at breast height.

- Green biomass contribution followed the trend in decreasing order of stem>branch >leaves>twigs in *M. azedarach* however, contribution of leaves to total biomass is maximum of *P. roxburghii* as compared to other species.

- Dry biomass partitioning indicated maximum contribution from stem followed by branches, leaves and twigs in decreasing order.

- Crown height, crown width, crown length and crown area increased with increase in diameter at breast height and showed significant variation among diameter classes.

- All growth parameters were found to have significant correlation among themselves, however, stem volume was positively correlated with all the tree parameters in all the species.

- Statistically significant variation was observed between all the tree growth variables except diameter at breast height and collar diameter.

- Diameter at breast height (dbh) remained the best predictor of stem volume while, stem volume was the best predictor of biomass followed by diameter at breast height and for volume estimation, power function was best fitted for all the species.

- LAI showed increasing trend with increase in diameter and the maximum value was observed in *Q. leucotrichophora* and minimum in *P. roxburghii* whereas solar flux showed erratic trend in all diameter classes in all the five species.

- Soil pH and available calcium were higher at both depths in *Q. leucotrichophora*, whereas, organic carbon, bulk density and available magnesium were higher at both the depths under *E. tereticornis.*

- Particle density was higher in *Q. leucotrichophora* and *P. roxburghii* at both the depths.

- Available N was higher under *M. azedarach* at 0-15cm whereas *Q. leucotrichophora* showed highest value for 15-30cm and available P was higher under *P. roxburghii*, whereas, available K was higher under *Q. leucotrichophora* at 0-15cm. At 15-30cm it was higher in *P. roxburghii.*

# *Chapter-7*

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## ABSTRACT

The present investigation entitled, "Studies on biomass partitioning and soil enrichment in plantations of different tree species under mid hill conditions of Himachal Pradesh" was carried out during the year 2011-2012 at five sites under five species viz. *Quercus leucotrichophora*, *Pinus roxburghii*, *Eucalyptus tereticornis*, *Melia azedarach* and *Ulmus villosa* with 5cm interval in four diameter classes (5 to10cm to >20cm), raised by the department of Silviculture and Agroforestry, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni(Solan), Himachal Pradesh. The various observations regarding different growth parameters, standing volume, green and dry biomass were taken from the randomly selected trees (30% of the total population). The different tree growth parameters increased with increase in diameter in all the species. The data on various growth parameters were used for variability analysis and correlation study. Among crown characters, crown area, crown width, crown height and crown length showed significant differences within four diameter classes in all the species. All the tree parameters showed statistically significant variation except diameter at breast height and collar diameter for all the species. Stem volume of sample trees increased with increase in diameter. Stem volume was significantly correlated with all the tree growth parameters and high correlation coefficient was observed between all the tree growth parameters. For estimation of volume, diameter as independent variable remained best estimator using power function while form factor and tree height showed mixed results with power, exponential and polynomial functions. Similar results were obtained in case of estimation of branch (green and dry) biomass with branch length and branch diameter where power, exponential and polynomial functions gave the maximum value of adjusted $R^2$. Studies on biomass partitioning were also done to find out contribution of different plant parts (stem, branch+twig, leaves) towards total biomass and their per cent contribution was also calculated. *Melia azedarach* was having maximum green as well as dry biomass. Soil parameters generally showed decreasing trend with increase in depth except exchangeable calcium and magnesium. The solar flux and LAI varied with age and species.

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# APPENDIX-I

## ANOVA for relationship of Diameter classes with diameter at breast height (dbh), Collar diameter, Tree height, Crown height, Crown width, Crown length, Volume, Crown area, Basal area and Crown height/tree height

| Diameter at breast height (cm) | | | Collar diameter (cm) | | | Tree height (m) | | |
|---|---|---|---|---|---|---|---|---|
| **Source of variation** | **Degree of freedom** | **Mean Square** | **Source of variation** | **Degree of freedom** | **Mean Square** | **Source of variation** | **Degree of freedom** | **Mean Square** |
| Diameter classes (A) | 3 | 2006.80 | Diameter classes (A) | 3 | 2347.10 | Diameter classes (A) | 3 | 458.86 |
| Number of species (B) | 4 | 7.90 | Number of species (B) | 4 | 12.84 | Number of species (B) | 4 | 160.16 |
| Characters (C) | 9 | 2.70 | Characters (C) | 9 | 9.31 | Characters (C) | 9 | 6.49 |
| A*B | 12 | 4.41 | A*B | 12 | 20.91 | A*B | 12 | 18.37 |
| Error | 171 | 2.43 | Error | 171 | 6.52 | Error | 171 | 3.63 |
| Total | 199 | | Total | 199 | | Total | 199 | |
| | | | | | | | | |
| **Crown height (m)** | | | **Crown width (m)** | | | **Crown length (m)** | | |
| **Source of variation** | **Degree of freedom** | **Mean Square** | **Source of variation** | **Degree of freedom** | **Mean Square** | **Source of variation** | **Degree of freedom** | **Mean Square** |
| Diameter classes (A) | 3 | 113.52 | Diameter classes (A) | 3 | 89.00 | Diameter classes (A) | 3 | 114.18 |
| Number of species (B) | 4 | 30.40 | Number of species (B) | 4 | 33.91 | Number of species (B) | 4 | 64.48 |
| Characters (C) | 9 | 2.61 | Characters (C) | 9 | 2.33 | Characters (C) | 9 | 1.75 |
| A*B | 12 | 4.57 | A*B | 12 | 7.78 | A*B | 12 | 5.89 |
| Error | 171 | 1.73 | Error | 171 | 1.99 | Error | 171 | 1.47 |
| Total | 199 | | Total | 199 | | Total | 199 | |

| Volume ($m^3$) | | | Crown area ($m^2$) | | | Basal area ($m^2$) | | | Crown height/Tree height | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Source of variation** | **Degree of freedom** | **Mean Square** | **Source of variation** | **Degree of freedom** | **Mean Square** | **Source of variation** | **Degree of freedom** | **Mean Square** | **Source of variation** | **Degree of freedom** | **Mean Square** |
| Diameter classes (A) | 3 | 0.669 | Diameter classes (A) | 3 | 4338.10 | Diameter classes (A) | 3 | 0.01263 | Diameter classes (A) | 3 | 0.007 |
| Number of species (B) | 4 | 0.049 | Number of species (B) | 4 | 3226.50 | Number of species (B) | 4 | 0.00007 | Number of species (B) | 4 | 0.075 |
| Characters (C) | 9 | 0.003 | Characters (C) | 9 | 288.24 | Characters (C) | 9 | 0.00002 | Characters (C) | 9 | 0.007 |
| A*B | 12 | 0.016 | A*B | 12 | 1015.30 | A*B | 12 | 0.00005 | A*B | 12 | 0.01 |
| Error | 171 | 0.003 | Error | 171 | 200.78 | Error | 171 | 0.00003 | Error | 171 | 0.007 |
| Total | 199 | | Total | 199 | | Total | 199 | | Total | 199 | |

# APPENDIX-II

## Moisture per cent of different plant parts for different tree species

| Diameter Classes (cm) | Branch moisture percent | | | | | Twigs moisture per cent | | | | | Leaves moisture per cent | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ |
| 5-10 | 47.39 | 61.01 | 40.60 | 46.27 | 45.70 | 42.30 | 61.72 | 41.36 | 80.72 | 77.97 | 51.6 | 65.07 | 49.37 | 73.25 | 69.28 |
| 10-15 | 43.95 | 58.76 | 38.10 | 47.76 | 51.35 | 49.13 | 54.77 | 46.23 | 80.56 | 67.21 | 39.37 | 61.87 | 47.73 | 72.88 | 66.50 |
| 15-20 | 38.88 | 61.35 | 39.14 | 50.79 | 49.74 | 63.93 | 54.95 | 43.23 | 80.35 | 62.54 | 44.10 | 65.19 | 48.37 | 71.55 | 72.98 |
| >20 | 37.24 | 57.45 | 44.04 | 44.37 | 53.05 | 60.40 | 55.41 | 45.83 | 80.52 | 63.69 | 48.37 | 59.35 | 47.43 | 78.51 | 74.55 |

$S_1$ = *Quercus leucotrichophora*
$S_2$ = *Pinus roxburghii*
$S_3$ = *Eucalyptus tereticornis*
$S_4$ = *Melia azedarach*
$S_5$ = *Ulmus villosa*

## APPENDIX-III

### ANOVA for relationship of different species with different soil parameters viz. Soil pH, Organic carbon, Bulk density, Particle density, Available Nitrogen, Available Phosphorus, Available Potassium, Available Calcium and Available Magnesium

| Soil Ph | | | Organic carbon | | | Bulk density | | | Particle density | | | Available Nitrogen | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Source of variation** | **Degree of freedom** | **Mean Square** | **Source of variation** | **Degree of freedom** | **Mean Square** | **Source of variation** | **Degree of freedom** | **Mean Square** | **Source of variation** | **Degree of freedom** | **Mean Square** | **Source of variation** | **Degree of freedom** | **Mean Square** |
| Species (A) | 4 | 0.01 | Species (A) | 4 | 0.0602 | Species (A) | 4 | 0.0053 | Species (A) | 4 | 0.0009 | Species (A) | 4 | 1329.9 |
| Depth (B) | 1 | 0.05 | Depth (B) | 1 | 0.0004 | Depth (B) | 1 | 0.0006 | Depth (B) | 1 | 0.0009 | Depth (B) | 1 | 3154.4 |
| Replications (C) | 3 | 0.08 | Replications (C) | 3 | 0.0057 | Replications (C) | 3 | 0.0018 | Replications (C) | 3 | 0.0008 | Replications (C) | 3 | 2510.1 |
| A*B | 4 | 0.05 | A*B | 4 | 0.0034 | A*B | 4 | 0.0017 | A*B | 4 | 0.0009 | A*B | 4 | 8771.9 |
| Error | 27 | 0.02 | Error | 27 | 0.0130 | Error | 27 | 0.0009 | Error | 27 | 0.0009 | Error | 27 | 1023.0 |
| Total | 39 | | Total | 39 | | Total | 39 | | Total | 39 | | Total | 39 | |

| Available Phosphorus | | | Available Potassium | | | Exchangeable Calcium | | | Exchangeable Magnesium | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Source of variation** | **Degree of freedom** | **Mean Square** | **Source of variation** | **Degree of freedom** | **Mean Square** | **Source of variation** | **Degree of freedom** | **Mean Square** | **Source of variation** | **Degree of freedom** | **Mean Square** |
| Species (A) | 4 | 2035.6 | Species (A) | 4 | 912.18 | Species (A) | 4 | 4321.6 | Species (A) | 4 | 4447.0 |
| Depth (B) | 1 | 5934.4 | Depth (B) | 1 | 914.96 | Depth (B) | 1 | 7440.8 | Depth (B) | 1 | 5665.0 |
| Replications (C) | 3 | 2566.7 | Replication (C) | 3 | 1248.4 | Replication (C) | 3 | 1749.9 | Replications (C) | 3 | 1167.9 |
| A*B | 4 | 2592.6 | A*B | 4 | 1481.7 | A*B | 4 | 5742.7 | A*B | 4 | 1289.2 |
| Error | 27 | 2799.5 | Error | 27 | 2783.9 | Error | 27 | 7571.8 | Error | 27 | 1656.9 |
| Total | 39 | | Total | 39 | | Total | 39 | | Total | 39 | |

# APPENDIX IV

## Effect of diameter classes on crown characteristics

| Spp. | Dia. Class (cm) | Crown % | CFR | CPR | CQ |
|---|---|---|---|---|---|
| **$S_1$** *(Q. leucotrichophora)* | **$D_1$** (5-10cm) | 53.55 | 0.67 | 0.20 | 0.04 |
| | **$D_2$** (10-15cm) | 47.73 | 0.72 | 0.20 | 0.04 |
| | **$D_3$** (15-20cm) | 49.06 | 0.87 | 0.22 | 0.05 |
| | **$D_4$** (>20cm) | 48.65 | 0.67 | 0.15 | 0.02 |
| **$S_2$** *(P. roxburghii)* | **$D_1$** (5-10cm) | 45.39 | 0.72 | 0.18 | 0.04 |
| | **$D_2$** (10-15cm) | 49.87 | 0.83 | 0.19 | 0.04 |
| | **$D_3$** (15-20cm) | 50.7 | 0.81 | 0.19 | 0.04 |
| | **$D_4$** (>20cm) | 46.42 | 0.90 | 0.17 | 0.03 |
| **$S_3$** *(E. tereticornis)* | **$D_1$** (5-10cm) | 39.41 | 0.73 | 0.21 | 0.05 |
| | **$D_2$** (10-15cm) | 43.87 | 0.71 | 0.19 | 0.04 |
| | **$D_3$**(15-20cm) | 43.47 | 0.65 | 0.16 | 0.03 |
| | **$D_4$** (>20cm) | 45.56 | 0.59 | 0.17 | 0.03 |
| **$S_4$** *(M. azedarach)* | **$D_1$** (5-10cm) | 56.29 | 0.48 | 0.27 | 0.08 |
| | **$D_2$** (10-15cm) | 51.33 | 0.65 | 0.25 | 0.07 |
| | **$D_3$**(15-20cm) | 45.50 | 0.72 | 0.25 | 0.06 |
| | **$D_4$** (>20cm) | 52.90 | 0.78 | 0.21 | 0.05 |
| **$S_5$** *(U. villosa)* | **$D_1$** (5-10cm) | 57.61 | 0.54 | 0.22 | 0.05. |
| | **$D_2$** (10-15cm) | 55.99 | 0.73 | 0.33 | 0.13 |
| | **$D_3$**(15-20cm) | 51.43 | 0.79 | 0.31 | 0.11 |
| | **$D_4$** (>20cm) | 56.45 | 0.85 | 0.37 | 0.17 |

# CURRICULUM VITAE

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**(Sanyam)**