“BIOMASS AND NUTRIENT ACCUMULATION IN 18 YEARS OLD MULTIPURPOSE TREES (MPTs) ON RED LATERITIC SOIL (ENTISOLS)”

M. Sc. (Forestry) THESIS

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CERTIFICATE – I

This is to certify that the thesis entitled **“BIOMASS AND NUTRIENT ACCUMULATION IN 18 YEARS OLD MULTIPURPOSE TREES (MPTs) ON RED LATERITIC SOIL (ENTISOLS)”**, submitted in partial fulfillment of the requirement for the degree of “**MASTER OF SCIENCE IN FORESTRY”** of the Indira Gandhi Agricultural University, Raipur, is a record of the bonafide research work carried out by **Mr. SATISH CHAND MEENA** under my guidance and supervision. The subject of the thesis has been approved by the Student’s Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma (certificate awarded etc.) or has been published/ published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by him.

(M. N. NAUGRAIYA)
Date: Chairman Advisory Committee

THESIS APPROVED BY THE STUDENT’S ADVISORY COMMITTEE

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CERTIFICATE – II

This is to certify that the thesis entitled **“BIOMASS AND NUTRIENT ACCUMULATION IN 18 YEARS OLD MULTIPURPOSE TREES (MPTs) ON RED LATERITIC SOIL (ENTISOLS)”**, submitted by **Mr. SATISH CHAND MEENA** to the Indira Gandhi Agricultural University, Raipur (C.G.) in partial fulfillment of the requirement for the degree of **“MASTER OF SCIENCE IN FORESTRY”,** in the **DEPARTMENT OF FORESTRY** has been approved by the Student’s Advisory Committee after an oral examination in collaboration with the external examiner.

Date: **EXTERNAL EXAMINAR**

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DIRECTOR OF INSTRUCTIONS **………………………………**

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LIST OF ABBREVIATIONS

Abbreviation	Description
&	And
AG	Above- ground
AGB	Above- ground biomass
BG	Below- ground
BGB	Below- ground biomass
C.G.	Chhattisgarh
Ca	Calcium
cm	centimeter
CD	Collar diameter
C.D.	Critical difference
CEC	Cation Exchange Capacity
DBH	Diameter at breast height
DM	Dry matter
^{0}C	degree centigrade
Viz;	For example
F. wt. tree-1	Fresh weight per tree
g tree^{-1}	gram per tree
Ht.	Height
kg ha^{-1} yr^{-1}	kilogram per hectare per year
kg tree^{-1}	kilogram per tree
<	Less than
>	More than
m	meter
Mg	Magnesium
mm day^{-1}	millimeter per day
MPTs	Multipurpose tree species
MSL	Mean sea level
N	Nitrogen

Abbreviation	Description
NS	Non-significant
%	Per cent
P	Phosphorus
K	Potassium
Na	Sodium
±	Standard deviation
SEm ±	Standard error of mean
SEd ±	Standard error of difference
t ha^{-1}	ton per hectare
t ha^{-1} yr^{-1}	ton per hectare per year
WHC	Water Holding Capacity

CHAPTER- I

INTRODUCTION

The human beings and animals both are directly or indirectly depend on the natural resources for their daily requirement of bio-chemical energy. The plants are useful to mankind and offer both tangible (food, fuelwood, timber and fodder etc.) and intangible (carbon sequestration, soil amelioration and hydrological balance etc.) benefits.

Shortage of wood for fuel, household use and raw material for paper industries have been increasing in the globe specially in the tropical countries like India. The population increase has put enormous pressure on the forest, resulting the reduction in forest cover less than to minimum requirement. Forestlands are either converted in agricultural land or left as unproductive barren land after elicit felling of trees. This situation should be checked as preventive measures by growing of trees in the wastelands and unproductive marginal land, for obtaining required biomass, to meet out the demands of both industries and individuals (Rao *et al*., 2000).

The importance of tree plantations are known for their ability to restore soil fertility and for amelioration of microclimatic conditions (Singh *et al.,* 2002). The ecological basis for the use of plantations for rehabilitation of damaged tropical lands has been described by Lugo, 1992; Lugo *et al*., 1993; and Parrota, 1992.

Fast growing MPTs are of great importance not only to meet out the various needs of community but also to produce good biomass and leaf litter for banking and recycling the nutrients in soil. Though several advantages have been documented due to tree culture, (Sreemannarayana *et al*., 1994; Singh and Roy, 1994) information on nutrient pools drawn by the trees and on usefulness of lands for future cropping, which are made unproductive by nutrient withdrawal is lacking. Such experiences do exist, wherever trees are grown on less productive sites and also with highly exhaustive species. Therefore, such situation warrants studies on "unit nutrient losses" as a result of using various kinds tree culture on degraded lands (Rao *et al.,* 2000).

Out of the India's total 329 million hectare geographical area, 187.7 m ha (57%) land suffers from various kinds of degradation problems (Paroda, 1998). Ravine, shallow gravely red soils and rocky areas of semi-arid region, hot desert and sand dunes, cold desert and wet lands etc., comes under wastelands. Red lateritic soil in plains of Chhattisgarh State (India), popularly known as Bhata lands (Entisols), is very common feature and estimated to be around 20% area fall under this category (Naugraiya *et al.,* 2005). The distribution of Bhata soil in every village as upland, is a common topographic phenomenon. These lands have gentle slopes and undulating topography (Pofali and Bhattacharjee, 1970) with gravel's and sub-soil layers forming hard and compact lateritic pans at places (Singh and Totey, 1985). Rehabilitation of such type of degraded lands can be done by revegetation with multipurpose trees/woody species/perennial plants (Naugraiya and Puri, 1997). The choice of woody species plays a key role in such degraded land, hence, suitable species can be grown not only to produce biomass for community uses but also improve the soil health.

Neem, botanically known as *Azadirachta indica* A. Juss. belongs to the family Meliaceae and is an indigenous tree to Indian sub continent. It is a multipurpose tree, widely used for obtaining fatty oil, fodder, gum and for making mosquito repellents, organic fertilizers, contraceptives, cosmetics, etc. It has recently received much global attention for its use as an environmentally safe, biodegradable and broad-spectrum biopesticide. Now it is extensively planted for rehabilitation of arid and semi-arid regions, degraded ecosystems and wastelands. Neem is highly efficient in restoring soil productivity and improving environment (Tiwari, 1992).

Aonla (*Emblica officinalis* Gaertn.) an important indigenous fruit crop of India belongs to the family Euphorbiaceae, sub-family Phyllanthoideae. Its fruit is not only rich and cheapest source of Vitamin 'C' but also the fair source of minerals, carbohydrates, carotene, thiamin and riboflavin (Pillay and Mahadeva, 1958). Owing to hardy nature, suitability to various wastelands, high productivity/unit area (15-20 t ha^{-1}), nutritive and therapeutic value, Aonla have become an important fruit. Since aonla is a hardy plant, it can be successfully grown in variable soil conditions. The deep root system, reduced foliage, dormancy of fertilized fruitlets makes aonla an ideal plant for arid and semi-arid conditions.

Eucalyptus tereticornis, popularly known as Mysore gum, belongs to family Myrtaceae, is a fast growing and promising MPTs of Australian continent.

Its wood is used for a variety of purposes such as roofing material, packing cases, plywood manufacture, paper making and furniture for ordinary use (Dogra and Sharma, 2005). Since it is suitable for short rotation plantation forestry to get fast returns as well as to fulfill the requirement of local community and industrial sector of the country. Therefore it is being cultivated throughout India in pure stands as well as under different agro forestry system. (Dogra and Sharma, 2003). *Eucalyptus* has been found very successful for roadside, canal banks, field bunds and energy plantations in village/community lands under social agroforestry programme (Dhyani *et al.*, 1996). The species is often planted in degraded lands.

Hardwickia binata Roxb. belongs to family Leguminosae, subfamily Caesalpinioideae is considered to be a valuable indigenous multipurpose tree species in India. This tree grows in dry teak forests, dries savanna and in degraded dry deciduous forests. It yields an extremely hard, very heavy and durable timber known in the trade as Anjan, which is used locally for tool handles, posts and beams, mine props, tent pegs, bridges, wells and a variety of agricultural tools. It is also good as fuel wood and used for making charcoal. The leaves are good fodder, with 8.9% crude protein, 30.4% crude fibre, 49.7% nitrogen-free extract, 2.3% calcium and 0.13% phosphorus (Singh, 1988). MacDicken (1994) reports that the leaves are also a good green manure. Since is a fast growing MPTs and more suitable for degraded wasteland, therefore it has been introduced in agroforestry system as tree component in 1970’s (Singh, 1988; Hegde, 1990; Madiwalar and Hanamshetti, 1990; Bisaria *et al.*, 1997; Roy, 1996).

Arjun (*Terminalia arjuna* Bedd.) member of Combretaceae family is a large, handsome, evergreen tree with generally buttressed and drooping branches. It is moderately fast growing and shade bearing MPTs. The timber is used for agricultural implements and mine props. The wood has high calorific value, and known for quality charcoal and excellent firewood. The bark is acrid and sweet, cooling and heating; alexiteric, styptic, tonic, antidysenteric; useful in fractures, ulcers, blood diseases, intoxications, urinary discharges, "kapha", biliousness, strangury, diseases of heart, anemia, excessive perspiration, asthma, tumours, leucoderma and false presentations of the fetus; allays thirst and relieves fatigue (Ayurveda). The juice of the fresh leaves is a remedy for earache. The National Forest Policies of our country advocated for needs of short rotation farm forestry and agroforestry management on marginal wastelands to meet out the country requirement.

India has 18 per cent of the world's forest and facing the great task to meet out the requirement of 16 per cent of the world's human and 15 percent cattle population. Rai and Chakarbarti, 2001 worked out the deficit of fuel and small timber wood in the country and they advocated to increase the production area by using the degraded lands for tree crop. Therefore, it is an urgent issue to take care to manage Eco-resources for conserving biodiversity, environment and natural resource cycling and there is need to study the management of fast growing multipurpose tree species on degraded forest/wasteland to provide average 10 to 20 t ha^{-1} yr^{-1} of dry matter to full fill the demand of local community.

The present studies were focused to explore the potentiality of the Five multipurpose tree species *viz; Azadirachta indica, Emblica officinalis, Eucalyptus tereticornis, Hardwickia binata* and *Terminalia arjuna* on red lateritic soils (Bhata lands).

The present research study entitled **"Biomass and nutrient accumulation in 18 years old multipurpose trees (MPTs) on red lateritic soil (Entisols)"** was carried out with the following objectives:

1. To study the morphological stand characteristics of 18-year-old MPTs.
2. To find out the biomass and nutrient accumulation in MPTs.
3. To examine the changes in soil properties under MPTs after 18 years.

CHAPTER- II

REVIEW OF LITERATURE

In this chapter an attempt is made to review the work done on "Biomass and nutrient accumulation in 18 years old multipurpose trees (MPTs) on red lateritic soil (Entisols)". Emphasis is given to review the available literature on stand characteristics, biomass and nutrients in plants and soil. The literature is broadly reviewed under following aspects.

2.1 Growth and biomass accumulation of multipurpose tree species under different types of degraded lands.

2.2 Nutrient allocation pattern in tree components.

2.3 Changes in soil properties under plantation of MPTs.

2.1 Growth and biomass accumulation of multipurpose tree species under different types of degraded lands

The growth and biomass production of MPTs depend on the genetic potential of species, site characteristics and management practices adopted. Choice of species plays a key role in influencing both the growth rate and biomass production.

Pandey *et al.* (1996) reported that the distribution of biomass in various tree components and productivity in an age series plantations of *Eucalyptus* and *Acacia auriculiformis*. The total shoot biomass increased more than three times from 3 years (6.54 kg tree $^{-1}$) to 7 years (19.37 kg tree $^{-1}$) of age in *Eucalyptus* and nearly five times from 3 years (4.55 kg tree $^{-1}$) to 7 years (19.83 kg tree $^{-1}$) of age in *A. auriculiformis*. The utilizable biomass recorded for *Eucalyptus* was higher than *A. auriculiformis* for comparable age of trees.

Pal and Raturi (1989) raised *Acacia nilotica* as short rotation energy plantation at density of 6170 trees ha^{-1} and harvested 48.25 t ha^{-1} biomass after 3-years, where the bole and branches alone contributed about 44.1 and 30.2 per cent biomass, respectively as major produce, while contribution of root, bole-bark and leaf were 14.2, 9.8 and 1.6 per cent, respectively.

Goirola (1990) studied the biomass production in one-year-old plantation of ten multipurpose tree species *viz; Acacia catechu, Albizia lebbeck, Bauhinia purpurea, Bauhinia racemosa, Bauhinia retusa, B. variegata, Celtis australis, Grewia optiva, Ougeinia dalbergioides* and *Sapindus mukorossi.* The highest above-ground biomass (30.6 t ha^{-1}) and wood production (17.6 t ha^{-1}) were recorded by *Sapindus mukorossi*, while *Acacia catechu* accumulated least biomass (2.79 t ha^{-1}). Maximum (13.02 t ha^{-1}) leaf biomass was observed in *Sapindus mukorossi* and minimum (1.46 t ha^{-1}) in *Acacia catechu.*

Negi *et al.* (1990) estimated the biomass production in 20 year old teak (*Tectona grandis*) and khamar (*Gmelina arborea*) plantations at Tripura. The tree density, diameter, height and mean annual increment were recorded as 444 stems ha^{-1}, 21.1 cm, 20.4 m and 7.913 m^3 for teak, while corresponding values of the same were 452 stems ha^{-1}, 25.4 cm, 20.9 m and 10.48 m^3, respectively for khamar.

Singh and Puri (1990) studied the biomass in 9 years-old *Populous deltoides* stands planted at three different spacing in semi-arid region of Haryana.

They recorded maximum above-ground biomass (206 t ha^{-1}) and net primary productivity (33.3 t ha^{-1} yr^{-1}) at 2 x 2 m spacing, which further reduced to the 88 t ha^{-1} and 14.2 t ha^{-1} yr^{-1}, respectively and lowest was at 6 x 6 m spacing 41 t ha^{-1} and 6.6 t ha^{-1} yr^{-1}, respectively.

Roy and Gill (1991) studied the growth of five MPTs (*Casuarina equisetifolia, Emblica officinalis, Eucalyptus tereticornis, Leucaena leucocephala* and *Dalbergia sissoo*) under Agrisilviculture system and as a sole plantation. They observed better growth (height and collar diameter) of MPTs in the Agrisilviculture system than sole tree planting.

Halendra (1993) estimated the biomass production in six year old *Gmelina arborea* plantations established at Sarawak, Malaysia, where total mean above-ground biomass was estimated as 92.1 t ha^{-1}. For this biomass, 68.5 per cent was contributed by stem wood, 8.8 per cent by stem bark, 12.3 per cent by branches, 5.1 per cent by dead branches, 3 per cent by foliage and 2.3 per cent by twigs.

Toky and Bisht (1993) estimated above-ground and below-ground biomass and its allocation pattern in 6-years-old nine tree species *viz; Acacia catechu, Acacia nilotica, Albizia lebbeck, Azadirachta indica, Dalbergia sissoo, Melia azadirach, Morus alba, Prosopis cineraria, Ziziphus mauritiana* etc. grown in arid north-western India. The above-ground biomass (kg $tree^{-1}$) varied from 11.6 in *Ziziphus mauritiana* to 37.5 in *Melia azadirach*. Maximum biomass (39.65 %) was allocated to the boles and minimum to the branches (22 – 40 %) and roots (29 %). Root biomass (kg $tree^{-1}$) ranged from 2.2 in *Acacia catechu* to

8.7 in *Albizia lebbeck*. Net primary productivity was 0.98 to 9.33 kg tree^{-1} year^{-1} across the species.

Nwoboshi (1994) reported the growth and biomass accumulation of *Gmelina arborea* in Ghana, Africa. The mean height of trees increased from 16.6 m to 19.6 m between 4 to 7 years. Similarly, increased the tree volume and dry matter contents from 200-to 274 m^3 ha^{-1} and 68 to 119 t ha^{-1}, respectively.

Adu-Annig *et al.* (1995) observed above-ground biomass accumulation in 34 year-old *Anogeissus leiocarpus,* 16 year-old *Tectona grandis* and 10 year-old *Azadirachta indica* grown in the Sudan, Savanna of Ghana. The mean tree biomass was 29.0, 8.6 and 7.7 kg with share of 1, 5 and 8 per cent leaf component and 99, 95 and 92 per cent woody component in *A. leiocarpus, T. grandis* and *A. indica,* respectively.

Dhyani *et al*. (1996) studied the biomass production of *Eucalyptus tereticornis* planted in two apparently different sites of Doon valley, one was deep soil, and the other was relatively poor riverbed bouldery land. As per their results, above-ground biomass were 23.30 t ha^{-1} on the deep soils and 20.83 t ha^{-1} on the riverbed lands.

Naugraiya and Puri (1997) worked out growth and mid term biomass production under the pruning management of branches for four MPTs *viz; Dalbergia sissoo, Eucalyptus tereticornis, Gmelina arborea* and *Leucaena leucocephala* grown as high density plantation in red lateritic soil (Entisols) of Chhattisgarh plain. The biomass varied from 0.95 to 2.13 t ha^{-1} for branches, 0.46 to 0.91 t ha^{-1} for foliage and 0.01 to 0.035 t ha^{-1} for fruit components. The maximum biomass in branches was recorded in *L. leucocephala* followed by *G. arborea, E. tereticornis* and *D. sissoo*.

Bisht *et al.* (1989) studied the 18 year old *Eucalyptus* hybrid plantation raised in foot hills of Nainital and reported that the total above-ground parts of trees accumulated 110.0 t ha^{-1} biomass, of which the maximum biomass was produced by bole accounting 70.6 to 81.9 per cent, while other tree components produced more or less similar biomass.

Pacholi and Pandey (1998) studied the biomass production of *Dalbergia sissoo* planted at four different spacing (1 x 1 m, 1.5 x 1.5 m, 2 x 2 m and 3 x 3 m). They reported that above-ground biomass and mean annual biomass increment were affected by plantation density. Above-ground biomass was found maximum (104.6-t ha^{-1}) in 2 x 2 m spacing, while it decreased with an increase in tree density.

Prasad *et al*. (1998) reported the result of provenance trial of *Eucalyptus* raised on lateritic soil, where the consistently better performance was shown by *E. tereticornis* followed by *E. camandulensis,* while *E. camandulensis* produced more organic matter than those of *E. tereticornis.*

Roy *et al*. (1998) studied the eight year old *Acacia tortilis, Albizia amara* and *Hardwickia binata* based silvipastoral system, for estimation of fodder and fire wood productivity and reported that production from tree component was obtained maximum in *Albizia amara* (5.89 t ha^{-1}) followed by *Acacia tortilis* (52.1 t ha^{-1}) and *Hardwickia binata* (52.21 t ha^{-1}) after eight years of growth. Over all, total productivity of different tree under silvipastoral system, were also worked out and it was in order of *Albizia amara* (7.95 t ha^{-1}) > *Acacia tortilis* (7.60 t ha^{-1}) > *Hardwickia binata* (3.32 t ha^{-1}). Lowest productivity of *Hardwickia binata* was on account of slow growth of the tree.

Singh and Singh (1998) studied the performance of eight forest tree species, *viz; Albizia lebbeck, A. procera, Cassia siamea, Casuarina equisetifolia, Dalbergia sissoo, Emblica officinalis, Gmelina arborea* and *Hardwickia binata* on Bhata wastelands of Chhattisgarh plains. Mean annual biomass production at the age of 2.5 and 4.5 years were maximum 1274 and 4423.7 g plant $^{-1}$, respectively in *G. arborea* followed by *E. officinalis* (797.9 and 2896.4 g plant $^{-1}$) and *A. lebbeck* (561 and 2259 g plant $^{-1}$). They also observed statistically significant positive correlation of Ca with N, P and K and significant negative correlation of N with Mg.

Singh *et al*. (1998) evaluated the growth performance of fifteen MPTs in an experiment conducted at ICAR Research Complex, Manipal for identifying the trees which yielded higher fuel wood, fodder, pole, timber, etc. The maximum height (9.46 m), girth (89.67 cm) and numbers of branches (19) were recorded in *Grewia optiva* followed by *Ficus hispida, Celtis australis* and *Ailanthus excelsa*. Minimum canopy (42.44 m^3) was observed in *Ficus hispida*, while crown height (6.69 m) in *Grewia optiva*. The highest fodder yield (95.5 kg $tree^{-1}$) was recorded in *Grewia optiva*, whereas, total dry matter production (50.3 kg $tree^{-1}$) in *Ficus hispida.*

Devaranavadgi *et al.* (1999) evaluated the performance of MPTs under dryland conditions in a semiarid tract at Bijapur in Karnataka, India. After 8 years, *Leucaena leucocephala* had the highest height (8.51 m), DBH (7.06 cm) and crown spread (N-S, 2.16 m and E–W, 2.28 m) followed by *Acacia auriculiformis*, *Hardwickia binata* and *Albizia lebbeck*. The growth was lowest in *Pongamia pinnata* (height 2.96 m, DBH 3.87 cm, crown spread N-S 2.69 m and E-W 2.24 m). The species with intermediate performance were *Azadirachta indica*, *Acacia nilotica*, *Casuarina equisetifolia*, *Cassia siamea*, *Dalbergia sissoo*, *Inga dulce* and *Samanea saman*. However, considering the economic importance of multiple products, *Leucaena leucocephala* and *Azadirachta indica* could the best choice for planting in dryland conditions.

Gabhane *et al*. (1999) studied the relative performance in terms of growth, biomass production and soil nutrient status, in 8 yr. old stands of 12 MPTs on a moderately deep black soil in the semiarid region of Nagpur in Maharashtara, India. The trees were planted at three spacing (2 x 2 m, 3 x 3 m and 4 x 4 m) *Madhuca latifolia* and *Syzygium cumini* failed to survive under the rainfed and partially waterlogged conditions. *Acacia nilotica* was significantly superior in performance, followed by *Leucaena leucocephala, Dalbergia sissoo* and *Albizia lebbeck*. The remaining species (*Eucalyptus tereticornis, Tectona grandis, Hardwickia binata, Acacia catechu, Azadirachta indica, Dendrocalamus strictus*) performed less well. However, all the tree species, which survived, contributed to the nutrient enrichment of the soil.

Pal *et al.* (1999) evaluated the growth performance of thirteen (13) species in Jhargram district in the red lateritic tract of West Bengal, India. Among different species, *Eucalyptus tereticornis, Acacia auriculiformis, Leucaena* *leucocephala* and *Gmelina arborea* were found as fast growing species, while *Albizia lebbeck, Sapinadus muskorossi* and *Holarrhena antidysentrica* as slow growing species.

Singh (1999) studied the morphological growth in five year old plantation of *Ceiba pentandra*, planted at three spacing *viz;* 4 x 4 m, 4 x 6 m and 4 x 8 m and found that growth parameters such as tree height, clean bole height, diameter at breast height, crown width and crown length decreased numerically from the lower tree density to higher density.

Bhardwaj and Andarge *et al.* (2000) studied above-ground biomass production in high density plantation of *Eucalyptus tereticornis* after 12 years of plantation. Total above-ground biomass were 320.92 t ha^{-1}, 224.83 t ha^{-1} and 145.25 t ha^{-1} at 60 x 60 cm, 90 x 90 cm and 120 x 120 cm spacing, respectively. Maximum total above-ground biomass (320.92 t ha^{-1}) was found in the closest spacing. Height (9.46 m) and diameter (7.63 cm) were maximum in wider spacing (120 x 120 cm) with minimum total above-ground biomass (145.25 t ha^{-1}) after 12 years of plantation.

Gopikumar (2000) reported the growth behaviour, biomass production and rate of decomposition of leaf biomass in four MPTs, *viz; Artocarpus integrifolia, Erythrina indica, Albizia falcataria* and *Artocarpus hirsuta.* Total and monthly mean height and girth increments were maximum in *Albizia falcataria* followed by *Erythrina indica*. Most of the species recorded better growth from June to December, while growth was poor during dry periods. *A. falcataria* recorded the highest biomass production during the entire course of study.

Kanmegne *et al.* (2000) evaluated the growth performance of eighteen (18) agroforestry species in aluminum toxic soils of humid tropics at Nkoemvone, Sourthen Cameroon. Excellent growth in height and stem diameter was observed in *Indigofera zollingeriana, Inga edulis, Grewia mollis* and *Pterocarpus santalinoides* after 20 months of planting. The height ranged from 6 to 19 m and diameter between 8 to 10 cm.

Rai *et al*. (2000) evaluated the growth and biomass production of 12 multipurpose tree species *viz; Albizia procera*, *A. amara*, *Azadirachta indica*, *Anogeissus acuminata*, *Dalbergia sissoo*, *Dichrostachys cinerea*, *Emblica officinalis*, *Eucalyptus tereticornis*, *Hardwickia binata*, *Leucaena leucocephala*, *Melia azadirach* and *Terminalia arjuna* in natural grassland under semi arid condition in Uttar Pradesh, India. They were found significant differences among MPTs for tree height, CD, DBH, and canopy diameter. Tree height, DBH and canopy diameter were maximum in *D. sissoo.* Minimum plant height was recorded in *Anogeissus acuminata*. Canopy diameter was maximum in *Albizia procera.* Total biomass production was maximum in *D. sissoo* while *A. procera* had maximum values for dry leaf and branch production. It was concluded that *D. sissoo* was most suitable tree species for introduction in natural grasslands followed by *A. procera*, *L. leucocephala*, *E. officinalis*, *Dichrostachys cinerea* and *A. amara.*

Rao *et al.* (2000) evaluated the growth and biomass production of some important multipurpose tree species on rainfed sandy loam soils in Andhra Pradesh, (India). After 9 years, *Dalbergia sissoo, Leucaena leucocephala, Acacia* *auriculiformis* and *Eucalyptus camandulensis* were fast growing and suitable for this Southern Telengana Zone of Andhra Pradesh. Data on biomass production showed that *D. sissoo* yielded maximum biomass (214.6 t ha^{-1}) followed by *L. leucocephala* (187.8 t ha^{-1}) and *A. auriculiformis* (162.4 t ha^{-1}). Maximum mean annual biomass production (MABP) was also most for *D. sissoo* (23.8 t ha^{-1}) followed by *L. leucocephala* (20.9 t ha^{-1}) and *A. auriculiformis* (18.0 t ha^{-1}). Foliage yield was maximum in *L. leucocephala* (16.8 t ha^{-1}) followed by *A. auriculiformis* (12.0 t ha^{-1}) and *E. camandulensis* (9.9 t ha^{-1}).

Ajit *et al.* (2001) studied the effect of tree densities (800, 400 and 200 trees/ha) on the growth of *Hardwickia binata* and yield of intercrop *Brassica campestris*. Results found that higher densities of *Hardwickia binata* (800 and 400 trees ha^{-1}) increased the height of trees at a faster rate as compared to lower density (200 trees ha^{-1}). On the other hand, DBH (diameter at breast height) increased at a rapid rate in lower density in contrast to higher densities. Growth in height was maximum during the summer season, while the DBH in winter season.

Gill *et al.* (2001) conducted a study to investigate the effect of pruning (up to 50% height) and spacing (2 x 4m, 2 x 6m, and 2 x 10 m) on MPTs. He found that the maximum plant height was recorded in close plant spacing, while insignificant difference was observed in CD, plant canopy and DBH. Highest fresh foliage yield was observed in *Leucaena leucocephala* but no definite trend was observed in terms of plant biomass production, though among the MPTs studied, *L. leucocephala, A. lebbeck* and *E. tereticornis* were superior over *M. indica.*

Naugraiya and Puri (2001) studied the performance of multipurpose tree species (7.5 year–old plantation) grown for fodder, fuel and timber in the wastelands of Chhattisgarh plains. They found that growth and dry matter production were in the order of *Leucaena leucocephala* > *Eucalyptus tereticornis* > *Albizia procera* > *Dalbergia sissoo* > *Azadirachta indica* > *Hardwickia binata* > *Terminalia arjuna*, where total dry wood biomass production ranged between 1.5 to 35.1 kg tree^{-1}. The dry matter production of under storey pasture (grass + stylo) was also worked out with maximum pasture yield (35.5q ha^{-1}) under *H. binata* and minimum (9.54q ha^{-1}) under *T. arjuna*.

Rana *et al.* (2002) evaluated the growth performance of 13 multipurpose tree species, namely *Eucalyptus hybrid, Sesbania grandiflora*, *Leucaena leucocephala, Tectona grandis, Casuarina equisetifolia, Dalbergia sissoo, Butea frondosa*, *Acacia nilotica, Moringa pterygosperma*, *Azadirachta indica, Shorea robusta*, *Terminalia arjuna,* and *Bambusa sp.*, raised on sodic land. Among 13 species studied, *C. equisetifolia*, *E. hybrid*, *D. sissoo,* and *L. leucocephala* reflected conceivably better growth and total tree biomass at 8 years age, it was in the order of *L. leucocephala* (199.6 t ha^{-1}) > *C. equisetifolia* (197.3 t ha^{-1}) > *E. hybrid* (136.t ha^{-1}) > *D. sissoo* (62.2 t ha^{-1}).

Swamy *et al.* (2003) estimated the above-ground and below-ground biomass production in a 4 year old *Gmelina arborea* planted at a spacing of 2 x 2 m, 2 x 3 m, 2 x 4 m and 2 x 5 m under agrisilviculture system. The total biomass varied from 10.89-t ha^{-1} to 3.68 t ha^{-1} depending on the tree density. It was highest in 2 x 2 m spacing and lowest in 2 x 5 m spacing.

Singh *et al*. (2004) studied the effect of tree spacing on growth and biomass allocation in *Acacia tortilis,* which was planted at 3 x 4 m, 3 x 5 m, 4 x 4 m, 4 x 5 m, 5 x 5 m and 5 x 6 m spacing. Plant height, crown diameter and collar diameter were measured annually, while biomass after 4 years of growth. They determined that per cent increment in height, crown diameter and collar diameter was high ($p < 0.05$) at initial stage, but decreased with time. Dry biomass of individual plants ranged from 5.48 kg plant^{-1} at 3 x 4 m spacing to 12.67 kg plant^{-1} at 5 x 6 m spacing. However, biomass production ha^{-1} was high at 3 x 5 m followed by 3 x 4 m spacing.

Chand *et al.* (2005) studied the growth and biomass production of some fuelwood species under short rotation high-density plantation in Palampur, H.P. After 3 years the highest vertical growth rate was recorded in *Grevillea robusta* followed by *Jacaranda acutifolia* and *Eucalyptus tereticornis*. Significantly highest radial growth was exhibited by *Bauhunia variegata* followed by *Eucalyptus* and *Grevillea*. Significantly highest fresh and dry biomass per plant was produced by *Eucalyptus* followed by *G. robusta* and *Melia azederach*.

Singh *et al.* (2005) estimated the biomass and productivity in seven seed sources of *Eucalyptus tereticornis* grown for three years under short rotation in sub-humid dry tropical environment of India. Above-ground biomass ranged between 9.99 t ha^{-1} to 21.69 t ha^{-1}, where the production of above-ground biomass was allocated maximum to bole (60.4-63.3 %) followed by branch (including twigs) (12.0-14.5 %) and foliage (4.1-4.8 %). The below-ground biomass in different seed sources of *Eucalyptus* varied from 2.6 t ha^{-1} to 5.3 t ha^{-1} with highest in Raipur and lowest in Australian seed sources.

Naugraiya *et al.* (2005) reported growth and nutrient use efficiency in four MPTs *viz; D. sissoo, E. tereticornis, G. arborea* and *L. leucocephala,* which were planted at 1x1 m spacing as high density plantation on one hectare red lateritic soil in central India during 1992. The results showed non-significant differences in DBH but significant for height growth. Wood contribution trend in above-ground biomass for all the MPTs was in the order: stem > branch > twigs. Maximum dry matter in bole was recorded by *L. leucocephala* (27.60 kg $tree^{-1}$) and minimum was recorded by *E. tereticornis* (10.30 kg $tree^{-1}$).

Nandeshwar *et al.* (2006) evaluated the performance of 12 multipurpose tree species in degraded land of Satpura region of Madhya Pradesh. The survival percentage at the end of the fourth year was found to be maximum in *Gmelina arborea* (94%), followed by *Azadirachta indica* (92%). Higher height growth was noted for *Gmelina arborea* (610.0 cm) and *Dalbergia sissoo* (602.8 cm), while collar diameter (6.9 cm) and canopy spread (2.9 cm) were higher in *Bauhinia variegata. Pongamia pinnata, Azadirachta indica* and *Emblica officinalis* showed moderate height and diameter growth.

2.2 Nutrient allocation pattern in tree components

Biomass is the product of natural photosynthesis process and is available in wide varieties of forms including wood, foliage, root, agricultural and forest residues and being a renewable organic matter a product of biological conversion of solar energy, is likely to play a strategic role in the future in view of the particular attention being given to plantation as a dependable renewable source (Sharma and Prasad, 1989). Use of renewable source of energy should be safer and environmentally more desirable for energy supply in the long run. One of the alternative renewable sources of energy is biomass, the vegetative material produced by plant life of which the most common and abundant form is forest trees and woody shrubs.

Bargali *et al.* (1992) narrated the findings of nutrient dynamics in 2 year old plantation of *Eucalyptus tereticornis*. The nutrient concentrations in different components decreased with plantation age. The nutrient content increased in trees and shrubs and decreased in herbs with an increase in plantation age. In tree components, total N, P and K were increased from 12.8 to 246.2 kg N ha^{-1}, 0.9 to 21.0 kg P ha^{-1} and 12.9 to 275.9 kg K ha^{-1}, respectively.

Halendra (1993) reported in a study on biomass production and nutrient distribution in *Gmelina arborea* plantations that upper storey biomass contained 394 kg ha^{-1} of K, 236 kg ha^{-1} of Ca, 70 kg ha^{-1} of Mg and 17 kg ha^{-1} of P. The large proportion of these nutrients were immobilized in the stem wood and bark, while remaining nutrients were immobilized in twigs and branches (14.5 to 25.8 per cent), foliage (8.6 to 20.5 per cent) and dead branches (1.7 to 4.7 per cent).

Rawat and Tandon (1993) reported the biomass production and mineral cycling in *Pinus roxburghii* at Kangra valley of Himachal Pradesh, where the substantial amount of nutrient would be drained off as a result of whole tree harvesting. A total of 2401, 3067, 3211 and 4999 kg ha^{-1} of litter was produced annually at age of 6, 10, 14, 16 and 18 years, respectively. The total amount of nutrients accumulated in the above-ground biomass ranged from 120.1 to 298.5 kg ha^{-1} of N, 2.8 to 7.3 kg ha^{-1} of P, 91.4 to 234.4 kg ha^{-1} of K, 77.4 to 188.3 kg ha^{-1} of Ca and 36.1 to 98.5 kg ha^{-1} of Mg.

Singh (1994) studied the biomass and nutrient accumulation in different age stands (7 to 40 years) of *Cryptomeria japonica* grown at Darjeeling, where above-ground biomass varied from 5.5 to 158 t ha^{-1} with maximum nutrient concentrations of Ca (2.9 per cent) and N (2.3 per cent), and minimum level of P (0.022 per cent). Nutrient accumulation and biomass were increased with an increasing in age of the stand but their proportions in aerial components showed in reverse trend.

Negi and Tandon (1997) estimated biomass and nutrient contents at 3, 5, 7 and 9 years age sequence of *Populus deltoides* plantations. The total standing biomass increased from 14.2 t ha^{-1} to 14.5 t ha^{-1} between 3 to 9 years. The component wise nutrient distribution revealed that maximum amount of N, P, K and Mg were accumulated in bole, whereas Ca in bark at 9 years age of plantation.

Kumar *et al*. (1998) studied the biomass production and nutrient use efficiency of MPTs grown as wood lot and in silvipastoral system. The rate of biomass and nutrient accumulation were higher for *Acacia auriculiformis* and least for *Leucaena leucocephala*. The nutrient concentration decreased in the order: foliage > branch > roots > bole. *A. auriculiformis* showed highest N (1539 kg ha^{-1}), P (113 kg ha^{-1}) and K (478 kg ha^{-1}) accumulation at 7 year age, when grown in silvipastoral system.

Pacholi and Pandey (1998) worked out the nutrient content of *Dalbergia sissoo* planted at four spacing *viz*; 1 x 1 m, 1.5 x 1.5 m, 2 x 2 m and 3 x 3 m. They stated that the total nutrients content were influenced with plantation density. The level of nutrients *viz*; N, P, K, Ca and Mg were found maximum in 2 x 2 m spacing, and these decreased with increasing in the planting density.

Singh and Singh (1998) studied the growth and production of eight forest tree species *viz; Dalbergia sissoo, Hardwickia binata, Albizia lebbeck, A. procera, Gmelina arborea, Emblica officinalis, C. equisetifolia* and *Cassia siamea* in Bhata wastelands of Chhattisgarh plain. After 2.5 and 4.5 years of growth, the maximum N was found in leaves (1.18 to 2.02 per cent) of all the species, followed by twigs (0.54 to 0.80 per cent), roots (0.28 to 0.57 per cent) and stems (0.32 to 0.5 per cent).

Bhardwaj *et al*. (2001) studied the nutrient dynamics of *Populus deltoides* under high density plantations and observed that both accumulation of nutrients and its uptake showed increasing trends for macronutrients (N P and K kg ha^{-1}), with increase in plant population. Total amount of nitrogen retained in branch and bole was highest (1005.6 kg ha^{-1}) at 60 x 60 cm and thus (765.4 kg ha^{-1}) at 120 x 120 cm plantation spacing respectively, while P and K was in tune of 18.47 kg ha^{-1} and 895.7 kg ha^{-1} at closest spacing and 13.5 kg ha^{-1} and 011.9 kg ha^{-1} at wider spacing, respectively. They also observed that the total above-ground uptake (retained + retained through litter fall) was highest at narrow spacing and least at wider spacing. While N, P and K retention in branch, bole and above-ground biomass showed decreasing trend with an increase in spacing.

Kushwaha (2001) carried out a study to evaluate the performance of *Gmelina arborea* for growth as well as nutrients accumulation on Bhata soil of Chhattisgarh plains. Result of six year old plantation showed that stand attained 14.1 cm DBH, 9.3 m total height and produced 57.38 t ha^{-1} total biomass. The contribution of stem, branch, root and leaf were 56.2, 18.7, 18.4 and 6.8 per cent, respectively for the total biomass. In case of N, P, K elements, foliage contributed 30.0, 23.3 and 12 per cent, respectively, while these were 43.0, 45.3 and 54.3 per cent in stem. Roots had 13.3, 16.6 and 18.2 per cent of N, P and K, respectively.

Bertalot *et al.* (2002) evaluated the growth, biomass production, nutrient recycling and regeneration performance of *Leucaena leucocephala*, *L. diversifolia*, *Acacia melanoxylon* and *Mimosa scabrella* in degraded land, distrophic red yellow soil (Oxisol). *A. melanoxylon* and *L. diversifolia* were the tallest species (5.25 and 4.97 m, respectively) and *A. melanoxylon* and *M. scabrella* had the largest diameters at 20 cm from tree base. *Mimosa scabrella* and *A. melanoxylon* had the highest dry matter production and quantity of nutrients in the above-ground biomass. In all species, the highest nutrient contents were found in the leaves, followed by branches and stems. From all species, the highest nutrient utilization efficiency indexes were obtained for sulfur, phosphorus, and magnesium. *L. diversifolia* had the highest utilization of nitrogen, potassium, calcium, sulfur, and manganese, while *A. melanoxylon* for phosphorus, magnesium, boron, iron, and zinc.

2.3 Changes in soil properties under plantation of MPTs

One of the major issues of global concern today is declining productivity of land in tropics. Faulty land management practices, increased deforestation, traditional agriculture practices, injudicious use of chemical fertilizer, pesticides and fungicides are greatly responsible for land degradation. Several studies demonstrated that multipurpose trees on crop lands or wastelands improved both nutrient cycling and carbon storage (Datta and Dhiman, 2001; Kaur *et al.,* 2002 and Georage and Kumar, 1999).

Therefore, the plantations of MPTs on degraded lands not only check the soil erosion but also improve the productivity of land. Trees are known to maintain soil organic matter and nutrient cycling through the addition of litter and root residues into the soil.

Sreemannarayana *et al.* (1994) evaluated nine MPTs *viz; Dalbergia sissoo, Leucaena leucocephala, Albizia lebbeck, Acacia auriculiformis, A. albida, A. tortilis, Azadirachta indica, Eucalyptus camandulensis* and *Dendrocalamus strictus* on a red sandy loam soil of Andhra Pradesh for their growth performance. Evaluation of tree species after five years of plantation revealed that fast growing *Eucalyptus* and *Leucaena* were found suitable in Southern Telangana of Andhra Pradesh. They also added in their observations that *A. lebbeck* and *L. leucocephala* added comparatively more organic carbon, available P_2O_5 and available K_2O in the soil than the other species studied.

Chavan *et al.* (1995) studied the effect of multipurpose trees on physico-chemical properties of red lateritic soils. Soil pH was slightly decreased by trees.

It was 5.6 in controlled plot, while it reduced up to 5.2, 5.4 and 5.3 under *Gmelina arborea, Acacia auriculiformis* and *Pongamia pinnata,* respectively. *G. arborea* and *Tectona grandis* recorded higher organic carbon in the surface layer with mean values of 20.2, 20.0 and 18.7 g kg^{-1} soil, respectively as compared to *Casuarina, Eucalyptus, A. auriculiformis* and *P. pinnata.* Organic carbon in soil decreased with soil depth. *T. grandis* and *G. arborea* recorded highest N, while P and K were highest in soil under *Eucalyptus* species and *G. arborea*.

Subrahmanyam *et al.* (1996) studied the organic carbon and available nitrogen in *Dalbergia sissoo* based Agroforestry system at Hyderabad, India. The organic carbon and nitrogen were highest under sole *Dalbergia sissoo* plantation followed by agrisilviculture system and lowest in open area (without tree). The organic carbon was 0.36%, 1.10% and 1.05%, while N was 107.8 kg ha^{-1}, 382.5 kg ha^{-1} and 332.8 kg ha^{-1} in open field, agrisilviculture and sole *Dalbergia* plantations, respectively.

Tomar *et al.* (1998) conducted a study in 5-yr-old woodlots of 6 MPTs *viz; Albizia lebbeck, Alnus nepalensis, Boehmeria rugulosa, Dalbergia sissoo, Ficus glomerata* and *Grewia optiva* in Chamoli District, Uttar Pradesh, India. Soils at 2 depths (0-15 and 15-30 cm) close to tree stems and at 2 m distance from tree, and for control (site without trees) were analyzed for percentage water content, water holding capacity and pH. Significant differences were observed for percentage water content and water holding capacity, the presence of tree and its distance as well as soil depth did not exhibit any significant response. Soil pH values tended to be slightly lower under tree.

Pandey *et al.* (2000) reported the effect of different canopy positions *viz;* mid canopy, canopy edge and canopy gap (open) of *Acacia nilotica* on soil nutrient status under traditional agroforestry system in Chhattisgarh. Soil organic carbon, total N, total P, mineral N and P were found to be maximum under mid canopy positions as compared to canopy edges and canopy gaps. Soil organic carbon and N pool sizes were higher in 0-10 cm and declined with soil depth.

Ponnabalam *et al.* (2001) studied the reclamation of limestone mine dump through plantation of *Acacia auriculiformis, A. holoseriecea, A. mellifera, Azadirachta indica, Delonix regia* and *Eucalyptus tereticornis* at Coimbatore. *A. auriculiformis* and *A. holoseriecea* improved soil fertility appreciably as compared to other species. Though the maximum stem and leaf weight were observed in *D. regia* and *E. tereticornis*, respectively. Thus nitrogen-fixing trees performed better in terms of soil development as well as biomass production. They also reported that performance of *A. indica* was very poor.

Rothe *et al.* (2002) studied the soil carbon and nitrogen changes under pure Douglas-fir (*Pseudotsuga menziesii*) and mixed red alder (*Alnus rubra*) stands. They reported that red alder/Douglas-fir, plots with 25% red alder, the soil N pool to a 45 cm depth increased significantly (p 0.05) by 190 g N m^{-2}, corresponding 10 g N m^{-2} yr^{-1} accretion, while N accretion in soil was 8.7 g m^{-2} yr^{-1}, while in pure Douglas-fir, the soil N pool remained nearly constant.

Singh *et al*. (2004) studied the associated changes in soil properties in *Acacia tortilis* plantation in relation to stand density in Indian arid zone Jodhpur, Rajasthan. Seedlings were planted in 1996 at 3 x 4 m, 3 x 5 m, 4 x 4 m, 4 x 5 m, 5 x 5 m and 5 x 6 m spacing. After four years (2000), they observed an increase in soil pH ($p < 0.01$), organic carbon ($p < 0.05$) and NH_4-N ($p < 0.01$) and decrease ($p < 0.01$) in NO_3-N, Mg, K, Cu and Mn compared to their initial data of September 1996. Availability of PO_4-P, Ca and Fe did not differ ($p > 0.05$) with the initial values.

CHAPTER-III

MATERIAL AND METHODS

The present study was conducted on "Biomass and nutrient accumulation in 18 years old multipurpose trees (MPTs) on red lateritic soil (Entisols)" at "Baronda Research Farm", Raipur in Chhattisgarh, during 2005-06. The study deals with the different aspect *viz;* stand characteristics, biomass accumulation, nutrient allocation pattern and changes in soil properties under plantation of five MPTs *viz; Azadirachta indica, Emblica officinalis, Eucalyptus tereticornis, Hardwickia binata* and *Terminalia arjuna.* The observations were made, when plantation attained 18 year of growth.

The details of study site, climatic conditions, weather, geology, physiographic features, soil properties and experimental procedures followed and techniques adopted under each objective are described in this chapter.

3.1 Experimental site

The study was conducted in marginal wasteland area at "Baronda Research Farm," IGAU, Raipur, Chhattisgarh situated at 27 km away from Raipur on Raipur- Balodabajar state highway and has 10 km aerial distance from main campus of IGAU, Raipur. The "Baronda Research Farm" is located at $17^0$41' to $24^0$45' North latitudes and at $79^0$30' to $84^0$15 East longitudes with an altitude of 295 m above the mean sea level (MSL). Chhattisgarh state has been divided into three agro-climatic zones *viz;* central Chhattisgarh plains, southern

Baster plateau and Northern hills. The study site falls under the central region of Chhattisgarh plains agro-climatic zone.

3.2 Climate and weather

The climate of study site is dry humid sub-tropical with an average annual rainfall of 1250 mm. About 80 percent of the annual rainfall is received from south- west monsoon during June to mid August. The highest amount of rainfall occurs in July. Number of rainy days varies from 65 to 79 days. The mean monthly maximum temperature varies from 13.2^0C in December to 28.3^0C in May. The maximum temperature goes beyond 45^0C in May and minimum below 10^0C in December. The relative humidity lies between 70-90 per cent from mid June to March end. Sunshine period in a day prolong more than 9 hours in summer and less than 7 hours in winter. Evaporation remains higher during April to June (10-13 mm day $^{-1}$) and lower during July to February (2.4-5.0 mm day $^{-1}$).

The mean annual weather data recorded at meteorological observation, IGAU, Raipur (C.G.) is presented in table 3.1.

Table 3.1. Mean annual meteorological data of study area

Year	Maximum Temp. (^{0}C)	Minimum Temp. (^{0}C)	Total rainfall Annual (mm)	Relative Humidity (%)
1994	31.1	18.4	1688.2	71.76
1995	32.2	19.7	1188.7	81.66
1996	33.2	19.6	1122.8	69.66
1997	32.2	19.6	1208.4	79.90
1998	32.3	20.6	1080.0	83.41
1999	32.5	19.0	0858.8	79.40
2000	32.9	19.2	0789.1	79.42
2001	32.9	20.1	1033.2	79.01
2002	33.4	20.2	0767.2	77.83
2003	34.2	19.2	1511.0	79.38
2004	34.4	20.3	985.5	78.4
2005	34.6	20.1	1180.5	80.46

3.3 Geology

Raipur has three distinct geological formations *viz;* Bijapur, Cuddapahas, Dharwar and Archean. Lithologically the area is divided into seven groups namely Raipur shale and lime stone, Gunderdehi shale, Khairagarh sand stone, Cuddapahas, Charmur like limestone, Chandrapur sand stone grit, Dharwar rocks, Granite and genesis.

3.4 Physiography

In agro-climatic zone of Chhattisgarh plain, there are ten districts *viz;* Raipur, Bilaspur, Drug, Rajnandgaon, Kawardha, Mahasamund, Dhamtari, Janjgir, Korba and Raigarh.This agro-climatic zone is also known as upper Mahanadi basin, which is saucer shaped, the larger part of this basin is undulating flat, terrain, gently slopes from west to east. The general geological features of the region comprises of laterites alluvium capping over horizontally bedded sequence of sedimentary rocks of limestone and dolomite on the top followed by limestone, quartzite, sandstone, granite, geneisis and meta sediments of old age. These formations have very limited primary porosity and permeability to water.

3.4.1 Soils

Soil of Chhattisgarh plains varies from lateritic/ entisols (20 %), sandy loam inceptisols (45 %), clay loam/ alfisols (10 %) and clayey/ vertisols (25 %). The soil depth varies from 20 cm in entisols to 100 cm vertisols with light undulation and general slopes of 2 per cent. The specific features of soil distribution in every village show a toposequence, which ranges from entisols to inceptisols, alfisols and vertisols with slope and this heterogeneous status of soil system always drains into river. Thus, a typical semi-arid condition of soil appears just after the rainy season due to shallow soil depth and high rate of percolation.

3.4.2 Characteristics of Entisols

The study site was marginal wasteland of entisols soil, which is reddish to dark reddish brown in colour and very shallow in depth. Entisols is classified as coarse, loamy, mixed hypothermic and typical undulating soil. It is locally known as Bhata and have ferruginous gravels. Low pH (acidic highly), low nitrogen, high potassium and low phosphorus with low organic matter are the basic characteristics of entisols. The soil characteristics of study site are presented in table 3.2.

3.4.3 Physico-chemical features of the soil

The study was conducted on entisols locally known as Bhata land. It is also known as red lateritic soil. As land use classification pattern point of view, it comes under marginal wasteland. These lands have long gentle slopes with undulating topography (Pofali and Bhattacharjee, 1970). The soil having high percentages of gravels and sub soil layers are hard and compact, forming even lateritic pans at places (Singh and Totey, 1985). In red lateritic soil, the content of organic matter was found in fewer amounts, which is responsible for causing moisture and thermal stress, which affect microbial activity and the availability of nutrients and subsequently affect the growth of plant (Gupta and Agrawal, 1988).

Table 3.2. Physico-chemical properties of Entisols (Bhata soil)

S.No.	Soil features		Status
1.	Slope		Undulating rolling
2.	Colour		Reddish to dark reddish brown
3.	Texture		Gravelly, Course loamy to sandy
4.	Consistency		Non-sticky and non plastic
5.	Cracks		Absent
6.	Depth		Very shallow
7.	Internal drainage		Rapid
8.	Mechanical composition (per cent)		
		(a) Sand	60-80
		(b) Silt	15-22
		(c) Clay	9-20
9	Infiltration rate (cm hr^{-1})		5.0-7.0
10	Field capacity (cm)		5.50
11	Wilting point (cm)		3.30
12	Available water (cm)		2.15
13	Porosity (per cent)		45.0
14	pH		5.6-6.5
15	% Organic carbon		0.28-0.50
16	CEC (C mol (+) kg^{-1})		7.0-10.6
17	Available nitrogen (per cent)		0.06
18	Exchangeable cations	Ca^{++}	3.5-6.2
	(C mol (p+)(kg^{-1})	Mg^{++}	1.7-3.4
		Na^{+}	0.3-0.4
		K^{+}	0.1-0.3

3.5 Experimental details

Tree crops	-*Azadirachta indica, Emblica officinalis, Eucalyptus tereticornis, Hardwickia binata* and *Terminalia arjuna.*
Year of planting	-July, 1987
Soil types	-Red lateritic soil (Entisols) or Bhata land
Replications	-Four
Design	-Randomized Block Design.

3.6 Plantation of MPTs

The seedling of MPTs *viz; Azadirachta indica, Emblica officinalis, Eucalyptus tereticornis, Hardwickia binata* and *Terminalia arjuna* were planted at 3 x 3 m spacing in July 1987.

3.7 Selection of trees for biomass study

Selection of trees were done on the basis of height, collar diameter (CD) and diameter at breast height (DBH) which recorded for each tree species and mean values was worked out to select the representative stands of tree for felling. Thus selected trees represented the average heights, CD and DBH of their group for the study.

3.8 Measurement of stand characteristics

The stand characteristics (Height, CD, DBH, Crown Diameter, Crown Length and Number of Branches) were measured with the standard methods (Chaturvedi and Khanna, 1982).

3.8.1 Measurement of Tree Height

The total height of standing trees was measured with the help of a standard graduated bamboo pole, meter scale and 30 m long tape. The height was recorded from the base to the tip of the tree.

3.8.2 Bole Height

Bole height was measured from the ground level to the crown point, which is the position of first crown forming with the help of tape.

3.8.3 Clear Bole Height

Clear bole height was measured from the base to the point of first green branch forming on the tree with the help of tape.

3.8.4 Measurement of CD and DBH

The collar diameter (CD) and diameter at breast height (DBH) of standing trees were recorded with the help of vernier calliper at 10 cm and 1.37 m, respectively from the ground level. Two measurements of diameter was taken at two directions (N-S & E-W) with making right angles to each other and the average value of two measurements was taken under consideration.

3.8.5 Measurement of Crown Diameter and Crown Length

Crown diameter was measured from the trunk to the drip line (which is the outer edge of the canopy) on two opposite sides of the tree and the measurement are taken on a North-South and East-West axis with the help of tape and standard graduated bamboo pole.

Crown length was measured vertically from the tip to the point half way between the lowest green branches forming green crown all round and the lowest green branch on the bole. Measurement was done with the help of tape.

The number of major branches (> 5 cm diameter) per plant were also counted

3.9 Felling of Trees

3.9.1 Study of Biomass Production

The selected four (4) trees of each treatment were felled one by one with the help of hand saw. The felling was done at 10 cm above the ground level. After felling, trees were measured for total tree height, bole height, clear bole height and dbh. Biomass accumulated in different components *viz;* bole wood, bole bark, branches, twigs, foliage and roots were also measured. These components were further analyzed for nutrients (N, P, and K) and ash content. The felled tree was separated into different components *viz;* bole wood, bole bark, branches, twigs, foliage and roots by using hand saw, secateurs and hand. Main stem was again divided into clean bole and rest stem. After the separation, total number of major branches was counted. For biomass estimation fresh weight of each component was recorded with the help of field and top pan balance. Immediately sub samples of each component were made for determination of dry biomass and nutrient analysis in the laboratory. In case of bole wood, disks were cut out from basal, middle and top portion of bole of each felled tree. Sub sample of each components were weighed for fresh weight (sample taken 1 kg for bole wood, bole barks, branches, twigs, foliage and roots) and dried at 80^0 C in hot air oven for 24 hrs then weight of samples were taken. The fresh weight: dry weight ratios were worked out for different components. These ratios were used for estimation of dry biomass of respective components. The foliage, twigs, branch, bole bark, bole wood and roots biomass were added to get total biomass of each tree (Naugraiya *et al.,* 2005).

3.9.2 Dry Matter Estimation

Dry matter of individual components was worked out by using given formula

$$\text{Dry matter} = \frac{\text{Dry weight of sample}}{\text{Fresh weight of sample}} \; X \; \text{Total fresh weight of component}$$

3.10 Analysis of Physical and Chemical Characteristics of Soil and Plant

Standard methods were used to determine the water holding capacity (WHC), pH, organic carbon, available nitrogen, available phosphorus and available potassium in soil and total nitrogen, phosphorus, potassium and ash content in plants.

3.10.1 Physico-chemical Analysis of Soil

Soil samples were collected from each replication under all the tree species and from adjacent open field (control/ area without tree) at the depth of 0-15 cm, 15-30 cm, 30-60 cm and 60-100 cm with the help of soil agar. Bulk samples of each soil depth of each treatment i.e. tree and control were used for analysis.

These soil samples so collected were dried in hot air oven at 105^0 C, pounded and sieved using 2 mm sieve and were analyzed for studying the depth wise distribution of N, P, K, organic carbon and soil pH. The chemical analysis was done as per the standard methods:

WHC - Determined by perforated soil box method

Soil pH - Measured by using1: 2.5 soil- water suspension method, (Jackson, 1967)

Org. C - Determined by ammonium ferrous sulphate and potassium dichromate method, (Walkley and Black, 1934)

Available N - Determined by Micro-kjeldhal method

Available P - Determined by ammonium molybdate stannous chloride method, (Jackson, 1958)

Available K - Measured by flame photometer, (AOAC, 1975)

3.10.2 Determination of Nutrient and Ash content in Plants

Oven dried samples were used for subsequent nutrient analysis. Each biomass components *viz;* bole wood, bole bark, branch, twigs, foliage and roots were powdered in a willey mill and passed through 2 mm sized sieve to obtain fine powder. The powdered plant materials of different components were analyzed for total nitrogen, phosphorus, potassium and ash content as per the standard methods:

Total N - Determined by Kjeltec nitrogen distillation method, (AOAC, 1975)

Total P - Measured by vandomolybdo- phosphoric acid yellow colour method, (Jackson, 1967)

Total K - Determined by flame photometer, (AOAC, 1975)

Ash - Estimated by muffle furnace combustion methods

3.11 Data Analysis

The entire data generated from the present investigations was subjected to statistical analysis in accordance with procedures outlined by Gomez and Gomez (1984). The spreadsheet based software MS Excel and Lotus- 123 were used for all the calculations.

3.12 Photography

Colour photographic descriptions were also recorded for evidence of research work by using SLR Cannon AE-1 Programme with 30-70 mm zoom camera.

CHAPTER- VI

RESULTS AND DISCUSSION

The research results and discussion on morphological stand characteristics, biomass and nutrients accumulation in MPTs grown in red lateritic soil after the growth of 18 years are presented in this chapter. The results of physico-chemical properties of soil at four soil-depths *viz;* 0-15 cm, 15-30 cm, 30-60 cm and 60-100 cm are also presented for soil under each tree species, as well as for adjacent open field. The data are presented in appropriate tables and graphics format after statistical analysis.

4.1 Morphological stand characteristics of tree:

The morphological growth performance of five MPTs *viz; A. indica, E. officinalis, E. tereticornis, H. binata* and *T. arjuna* in Bhata soil with regard to various growth parameters were found as follows:

4.1.1 Total tree height:

The total height of eighteen (18) years old trees are presented in Table 4.1, revealed that total height was found statistically significant, where the maximum average total height was attained by *E. tereticornis* (12.24 m) followed by *H. binata* (10.51 m), while minimum was attained by *T. arjuna* (5.75 m). However, statistically insignificant differences were found between *E. officinalis* (8.13 m) and *A. indica* (7.43 m).

4.1.2 Bole height:

The bole height was maximum in *E. tereticornis* (7.25 m) followed by *H. binata* (6.26 m), *E. officinalis* (5 m) and *A. indica* (4.24 m) sequentially. While minimum was recorded in *T. arjuna* (2.98 m). Over all, the results were significant statistically but insignificant relation was seen between two corresponding steps of data (Table 4.1).

4.1.3 Clear bole height:

Tree height up to clean bole among the MPTs showed statistically significant result. The growth performance of clean bole height was found maximum in *E. tereticornis* (4.43 m) followed by *H. binata* (4.1 m). However, statistically non- significant differences were found among rest three species, *viz; E. officinalis* (2.24 m), *A. indica* (2.01 m) and *T. arjuna* (1.81 m), respectively.

4.1.4 Crown length:

The crown length was found high in *E. tereticornis* (7.83 m) followed by *H. binata* (6.43 m) and minimum was found in *T. arjuna* (3.94 m) with significant variation. While the intermediate results of crown length in *E. officinalis* (5.89 m) and *A. indica* (5.41 m). Over all, results were found statistically significant (Table 4.1).

4.1.5 Crown diameter:

It is evident from the Table 4.1 that crown diameter showed statistically non-significant relationship among the five MPTs. The performance of five important species for crown diameter growth was in order of *A. indica* (3.89m) > *T. arjuna* (3.87m) > *E. officinalis* (3.65m) > *H. binata* (3.39m) > *E. tereticornis* (3m). All the trees have moderate to large crown spread when they grow either as sole tree or as wider spacing plantation, but when grown at 5 x 5 m spacing for longer 18 years are supposed to restrict crown diameter due to close proximity of crown and resulted insignificant variation. In the present study minimum canopy diameter was observed in *E. tereticornis*, which is similar to the findings of Rai *et al.* (2000), where they were observed that out of 12 MPTs, *E. tereticornis* showed minimum diameter than other species.

4.1.6 Collar diameter:

The Collar diameter (CD) was recorded, maximum in *E. tereticornis* (21.49 cm), which was statistically significant to rest of the species in order of *H. binata*, *A. indica*, *E. officinalis* and *T. arjuna* having insignificant variations (17.28, 16.75, 16.23 and 14.46 cm, respectively).

4.1.7 Diameter at Breast Height:

The tree growth in diameter at breast height was found statistically significant in 18 years plantations of five MPTs and presented in Table 4.1. Perusal of table showed that diameter at breast height was considerably varied from species to species, where *E. tereticornis* attained average DBH of 17.28 cm ranking first followed by *H. binata* (14.76 cm) and *A. indica* (13.75 cm). However, insignificant relationship found between *E. officinalis* (10.48 cm) and *T. arjuna* (9.48 cm).

4.1.8 Number of Branches:

The branching pattern among all the tree species did not show significant results. It was recorded maximum in *A. indica* (8.5) followed by *T. arjuna* (8), *E. officinalis* (6) and *H. binata* (6) with minimum in *E. tereticornis* (5.75). This is further evident that crown spread is corresponding to branching of any tree species. The results of branching pattern was found insignificant and similar to crown spread which further exhibited due to closing of tree canopy over 18 years growth.

The morphological growth characteristics of MPTs were recorded for total tree height, bole height, clear bole height, crown length, crown diameter, collar diameter, diameter at breast height and number of branches, where crown diameter and number of branches were found statistically insignificant. Similarly, Rai *et al.* (2000) observed significant differences among 12 MPTs for tree height, collar diameter and diameter at breast height. Sreemannarayana *et al.* (1994) revealed that critical perusal of growth performance in the trees are influenced by their genetic potentialities as well as adaptabilities to the edaphic and climatic conditions. In present study over all, the growth performances were found better in *E. tereticornis* and *H. binata,* because *E. tereticornis* and *H. binata* reported comparatively fast growing species than *A. indica, E. officinalis* and *T. arjuna* (Drake Hocking, 1993). Naugraiya and Puri (2001), also reported similar trend when trees were harvested at the age of 7.5 years, thus *E. tereticornis* and *H. binata* both are found suitable for red lateritic soil, as they have been consistently performing better. Raizada and Padmach (1993) also reported that growth of height, collar diameter and diameter at breast height in a tree, displayed the potential of species for adoptability in particular environment and soil, therefore many authors claimed that indigenous species were more adoptive to their natural habitats (Toky *et al.,* 1989; Naugraiya and Puri, 1994), but in the present study better growth performances were observed in exotic species as compared to indigenous due to its straight and fast growing altitude in the humid tropical environment of Chhattisgarh. Gill and Ajit (2004) also reported that out of 12 MPTs experimented under semi-arid conditions, where the growth performance of *E. tereticornis* in respect of height and CD, was outstanding than other species after 5 years of growth. Similar results have been recorded in the present study with five MPTs, where *E. tereticornis* attained maximum height and CD after 18 years of growth. Rai *et al.* (2000) worked out with 12 MPTs (including 5 species of current study) in sandy loam soil, where height growth performance of *T. arjuna* was significantly lowest than other species after 10 years of growth. In current study *T. arjuna* also showed minimum height growth among 5 MPTs after 18 years of growth.

4.2 Biomass accumulation of trees:

Selected trees of each species were harvested for accumulation of biomass in different components *viz;* foliage, twigs, branches, bole bark, bole wood and root. Fresh and dry weight of the biomass components were statistically analyzed and presented in following heads (Table 4.2 and 4.3):

4.2.1 Bole wood:

The fresh bole wood biomass in different tree species as found statistically significant (Table 4.2), where *E. tereticornis* gained highest bole biomass (128.06 kg F. wt. tree^{-1}) followed by *H. binata* (69.74 kg F. wt. tree^{-1}), *E. officinalis* (66.96 kg F. wt. tree^{-1}) and *A. indica (*45.46 kg F. wt. tree^{-1}), respectively. The minimum fresh bole biomass was recorded in *T. arjuna* (20.08 kg F. wt. tree^{-1}).

The dry matter accumulated in bole wood was also found statistically significant (Table 4.3) and followed the trend of fresh weight. *E. tereticornis* possessed maximum dry matter (82.32 kg tree^{-1}) followed by *H. binata* (41.41 kg tree^{-1}), *E. officinalis* (39.69 kg tree^{-1}) and *A. indica* (28.86 kg tree^{-1}), respectively. The minimum dry matter was found in *T. arjuna* (12.15 kg tree^{-1}).

4.2.2 Bole barks:

The fresh bole bark biomass production in the tree was found statistically significant (Table 4.2). It is revealed from the data that the maximum fresh weight production for bole bark was obtained by *E. tereticornis* and minimum by *T. arjuna*. This was at the tune of 43.45, 20.01, 12.05, 9.26 and 6.35 kg F. wt. tree^{-1} for *E. tereticornis, H. binata, E. officinalis, A. indica* and *T. arjuna*, respectively.

The bole bark dry matter production also showed significant variation among the MPTs (Table 4.3) with similar trend as in case of fresh bole bark weight. Whereas, the dry matter production of bole bark in five MPTs was found in decreasing order: *E. tereticornis* (21.64 kg tree^{-1}) > *H. binata* (11.49 kg tree^{-1})

> *E. officinalis* (6.3 kg tree^{-1}) > *A. indica* (4.34 kg tree^{-1}) > *T. arjuna* (2.8 kg tree^{-1}), respectively.

4.2.3 Branches:

Branches of tree played major role in the formation of tree canopy and provide physical strength to the tree. The fresh biomass of branches was found statistically significant (Table 4.2), where it was found highest in *E. tereticornis* (53.19 kg F. wt. tree^{-1}) followed by *E. officinalis* (37.13 kg F. wt. tree-1), *A. indica* (36.5 kg F. wt. tree^{-1}) and *H. binata* (23.83 kg F. wt. tree^{-1}), respectively. The lowest fresh biomass was given by *T. arjuna* (12.35 kg F. wt. tree^{-1}).

The dry matter production by branches was also found statistically significant (Table 4.3), where the maximum was found in *E. tereticornis* (27.75 kg tree^{-1}) followed by *A. indica* (22.7 kg tree^{-1}), *E. officinalis* (19.52 kg tree^{-1}) and *H. binata* (12.92 kg tree^{-1}). *T. arjuna* attained minimum dry matter (7.77 kg tree^{-1}).

4.2.4 Twigs:

The fresh biomass of twigs recorded after 18 years of trees growth was found statistically significant (Table 4.3), where the *E. tereticornis* stored highest fresh weight (10.28 kg F. wt. tree^{-1}) followed by *H. binata* (9.02 kg F. wt. tree^{-1}). However, statistically insignificant differences were found between *E. officinalis*

(7.66 kg F. wt. tree^{-1}) and *A. indica* (7.56 kg F. wt. tree^{-1}). The minimum was found in *T. arjuna* (4.35 kg F. wt. tree^{-1}).

The dry matter production pattern in twigs was also found to be statistically significant (Table 4.3) and the trend of dry matter in twigs was similar to that of fresh biomass of twigs. The mean dry matter production of twigs was recorded maximum for *E. tereticornis* (5.7 kg tree^{-1}) followed by *H. binata* (4.06 kg tree^{-1}). However, insignificant variation was found between *E. officinalis* (3.22 kg tree^{-1}) and *A. indica* (2.87 kg tree^{-1}). The minimum dry matter in twigs was recorded for *T. arjuna* (1.96 kg tree^{-1}).

4.2.5 Foliage:

The formation and shedding of foliage varied from species to species and it is also governed by climatic and edaphic conditions of the site. At the time of harvesting of trees, the maximum fresh weight in foliage was recorded in *E. tereticornis* (11.69 kg F. wt. tree^{-1}) followed by *H. binata* (10.31 kg F. wt. tree^{-1}), *A. indica* (8.69 kg F. wt. tree^{-1}) and *E. officinalis* (8.18 kg F. wt. tree^{-1}), respectively. While the minimum was recorded in *T. arjuna* (6.6 kg F. wt. tree^{-1}).

The significant difference was obtained in foliage dry matter of different MPTs (Table 4.3), where *H. binata* recorded highest dry matter production of foliage (6.19 kg tree^{-1}) followed by *E. tereticornis* (6.02 kg tree^{-1}) with insignificant differences. However, insignificant variation was found between *E. officinalis* (3.4 kg tree^{-1}) and *A. indica* (3.31 kg tree^{-1}). The minimum was recorded in *T. arjuna* (2.74 kg tree^{-1}).

4.2.6 Above-ground biomass:

The results of above-ground (AG) fresh biomass in different tree species after 18 years of growth are presented in Table 4.2. It is evident from the data that the highest above-ground fresh biomass was obtained in *E. tereticornis* (246.68 kg F.wt. tree^{-1}) and lowest was obtained in *T. arjuna* (52.9 kg F. wt. tree^{-1}). However, insignificant differences were found between *H. binata* (134.9 kg F. wt. tree^{-1}) and *E. officinalis* (131.96 kg F. wt. tree^{-1}).

The dry matter of above-ground (AG) is presented in Table 4.3. It is revealed from the data that the maximum above-ground dry matter was obtained by *E. tereticornis* (143.44 kg tree^{-1}) and minimum was obtained by *T. arjuna* (11.93 kg tree^{-1}). There was statistically insignificant variation among rest of the three species *viz; H. binata* (76.07 kg tree^{-1}), *E. officinalis* (72.12 kg tree^{-1}) and *A. indica* (62.07 kg tree^{-1}), respectively.

4.2.7 Below-ground biomass:

The below-ground biomass production showed statistically significant results (Table 4.2). The total fresh root biomass production was recorded maximum for *H. binata* (49.0 kg F. wt tree^{-1}) and minimum for *T. arjuna* (22.63 kg F. wt tree^{-1}). However, rest three species showed insignificant variation for their fresh root biomass *viz; E. tereticornis* (47.0 kg F. wt tree^{-1}), *A. indica* (40.83 kg F. wt tree^{-1}) and *E. officinalis* (39.05 kg F. wt tree^{-1}), respectively.

The below-ground dry matter production also showed statistically significant variation (Table 4.3), where root biomass of five MPTs was registered maximum in *H. binata* (25.97 kg tree^{-1}) followed by *E. tereticornis* (22.56 kg tree^{-1}) with insignificant variation and minimum was registered in *T. arjuna* (12.45 kg tree^{-1}). However, non- significant variations were showed in *E. officinalis* (19.14 kg tree^{-1}) and *A. indica* (18.78 kg tree^{-1}).

4.2.8 Total tree biomass:

The data on total biomass production of MPTs grown in red lateritic soil are presented in Table 4.2. Perusal of table revealed that highest total fresh biomass (above- ground and below- ground) was obtained by *E. tereticornis* (293.68 kg F. wt tree^{-1}) followed by *H. binata* (183.91 kg F. wt tree^{-1}) with insignificant to *E. officinalis* (171.01 kg F. wt tree^{-1}). The lowest total biomass was obtained by *T. arjuna* (75.53 kg F. wt tree^{-1}). While, *A. indica* obtained similar total fresh biomass to *E. officinalis* (148.29 kg F. wt tree^{-1}).

The total dry matter production of five MPTs showed significant variation (Table 4.3). The highest total dry matter production was recorded in *E. tereticornis* (166 kg tree^{-1}), as it was leading tree species for having higher dry weight accumulation in all the components *viz;* bole wood, bole barks, branches, twigs and above- ground among the other tree species. In case of foliage and below- ground biomass, the highest dry matter was recorded by *H. binata*. The minimum total dry matter was found in *T. arjuna* (39.85 kg tree^{-1}), which remained lowest for biomass accumulation in all other components. Thus over all, production of total tree biomass at the age of 18 years was in the merit of *E. tereticornis* > *H. binata* > *E. officinalis* > *A. indica* > *T. arjuna.*

4.3 Dry matter contribution in different parts of MPTs:

The component-wise above-ground and below-ground dry matter contribution (%) against total tree biomass is presented in Fig. 4.1 and perusal of figure showed that the maximum dry matter was accumulated in bole wood for all the tree species except *T. arjuna,* where it was contributed maximum in roots, because *T. arjuna* is comparatively slow growing species and also prefer moist site. The minimum dry matter was contributed in twigs for all the MPTs. The dry matter contribution in bole wood was highest in *E. tereticornis* (50.5%) followed by *E. officinalis* (43.49%), *H. binata* (40.58%), *A. indica* (35.69%) and *T. arjuna* (30.47%). In case of branches, it was maximum in *A. indica* (28.07%) as compared to other species, while in case of twigs and foliage, *T. arjuna* shared maximum dry matter (4.92 and 6.87%) and minimum was contributed in *E. tereticornis.* In case of roots, the maximum dry matter was accumulated also in *T. arjuna* (31.23%) followed by *H. binata* (25.45%) and minimum was recorded in *E. tereticornis* (13.84%). The highest dry matter was contributed in above-ground parts as compared to below- ground parts. Over all, the dry matter distributed in the order of bole wood > branch > root > bole bark > foliage > twigs.

The results on dry matter production by five MPTs, revealed that above-ground and below-ground biomass along with their different components varied significantly from species to species. *E. tereticornis* produced more bole wood, bole bark, branch and twigs biomass followed by *H. binata*, other species showed less or more. This may be attributed to comparatively fast growing nature of *E.*

tereticornis and *H. binata.* Rai *et al.* (2000) also reported similar results, where out of 12 MPTs, *E. tereticornis* attained maximum bole wood biomass followed by *H. binata,* as these species have comparatively fast and straight growth rate with less forking. Rana *et al.* (2002) also evaluated growth performance of 13 MPTs in saline-sodic soil in U.P., where in poor saline soil, leguminous species performed better than non-leguminous species, because they develop capacity to tolerate stress with the help of symbiotic relationship to rhizobium for mobilizing NPK. In present study the poor status of entisols, also create a stress in the tree to develop root system and foliage density for utilizing the deep soil moisture and nutrient resources, which ultimately reflected in case of leading fast growing species *i.e. H. binata* and *E. tereticornis.* Least amount of dry matter was recorded for *T. arjuna* in all the components as it was comparatively a slow growing species.

The dry matter production after 18 years of growth was in the merit of *E. tereticornis* > *H. binata* > *E. officinalis* > *A. indica* > *T. arjuna.* In the tree, biomass was shared by different components in the order of bole wood > branch > root > bole bark > foliage > twigs at the age of 18 years. Singh *et al.* (2005) reported the similar trend of biomass distribution even at early age of tree during their study on biomass and productivity of seven seed sources of *E. tereticornis* grown in three years old short rotation in sub-humid dry tropical environment. They also reported that distribution of biomass in different components was in the order of bole > branch > foliage > twigs. Naugraiya *et al.* (2005) also noticed similar trend in case of non-leguminous species at the age of 10.5 years, where maximum biomass was shared by bole wood and minimum by twigs. This might be ascribed that an uniform trend of biomass distribution in different tree components was maintained right from early age (3-years) to harvesting age of trees (18-years). Results obtained in present study, showed close proximity with findings of Bishat *et al.* (1989), they worked on 18 years-old *Eucalyptus* plantation raised in foot hills of Nainital and reported that maximum biomass was produced by bole, while rest of the tree components produced more or less similar biomass.

4.4 Nutritive status of MPTs:

Major nutrients *viz;* N, P, K and other parameter *viz;* ash available in different part of trees are presented here in following heads:

4.4.1 Nutrients:

The nutrients available in different components of trees are presented in Table 4.4. It is evident from the data that level of nutrients was ranged from 1.13 to 0.17%, 0.22 to 0.033% and 7.75 to 1.03% for N, P and K, respectively in different components of five MPTs.

The level of nitrogen was found maximum in foliage (1.13 to 0.67%) followed by twigs (0.9 to 0.57%), branches (0.83 to 0.43%), bole barks (0.72 to 0.35%), roots (0.71 to 0.48%) and bole wood (0.37 to 0.17%), respectively. Where *H. binata* showed higher level of N, while *E. tereticornis* showed lowest availability of N in all the components (Table 4.4).

The availability of phosphorus as macro-nutrient ranged between 0.22 to 0.033% in all the MPTs. The highest P was recorded in twigs of *T. arjuna* (0.22%) and lowest was recorded in roots of *H. binata* (0.033%).

Potassium, the source of ion- exchange play important role in movement of water and food material in the plant, was detected maximum in foliage followed by twigs in all the cases. In case of foliage it was maximum in *H. binata* (7.75%) and minimum in *E. tereticornis* (4.06%), but over all, it was minimum in the bole barks of *E. tereticornis* (1.03%). The availability of K was in order of *H. binata* > *E. officinalis* > *T. arjuna* > *A. indica* > *E. tereticornis*.

4.4.2 Ash content:

The ash available after combustions in muffle furnace in different parts of MPTs is presented in Table 4.4. Perusal of table showed that overall maximum ash content was recorded in bole barks (17.74 to 11.33%) in all the cases except *A. indica*, where it was found maximum in foliage. The minimum ash content was found in bole wood (2.05 to 1.12%) in all the cases. The maximum ash was found in bole barks of *E. officinalis* (17.74%), while the minimum was found in bole wood of *T. arjuna* (1.12%). Ash received from burning of branch and roots was more or less ranged 7.03 to 4.21 per cent, while it was in range of 13.57 to 5.03 per cent in case of green soft twigs and leaves.

The results on nutrient accumulation in different parts of the MPTs showed that maximum concentration of nutrients (N and K) were found in foliage of *H. binata* (1.13% N and 7.75% K). Similar trend was observed by Singh and Gupta (1993). Rao *et al.* (2000) worked out the biomass and nutrient accumulation behaviour in MPTs with similar results that highest nutrient concentration always remained in foliage as compared to woody parts of trees. Though over all, share of nutrients in foliage always less as compare to woody part because they defoliated according genetic and climatic conditions of species and site, respectively. But reverse trend was found in case of P concentration, which was found maximum in twigs of *T. arjuna* (0.22%). Similar trend was worked out by Rajiv (2004), where maximum P was in twigs of *T. arjuna*. In the present study, minimum N and K was found in bole wood and bole barks of *E. tereticornis* (0.17% N and 1.03% K), which is similar to the findings of Sisodya (2003) for same species (*E. tereticornis*).

Zobel and Talbert (1984) justified in their study, the residue of ash always depends on the molecular constituents of stored organic substance in different tissues of a plant, which behave according to genetic and climatic adaptability. Bhatt and Todaria (1992) and Kataki and Konwer (2001) also noticed in their studies that heat energy of combusting material found to be decreased with increase in ash quantity. In case of current study, bole bark produced more ash because the deposition of non- volatile molecules are more in the bark layer, as the bark function is to protect the soft tissues of stem, this further strengthen the results of Rajiv (2004). Shanavas and Kumar (2003) also reported that maximum ash content was found in bole bark than that of sapwood and heartwood. Similar results were observed in present study with the combustion of five tree species.

4.5 Harvesting of nutrients from MPTs:

Removals or harvesting of trees are directly and indirectly responsible for exporting the major part of nutrients from soil where they were grown. Export of N, P and K through harvest of *A. indica, E. officinalis. E. tereticornis, H. binata* and *T. arjuna* after 18 years of growth are presented in Table 4.5 to 4.7. It is revealed that the data showed significant variation in accumulation of N, P and K in different parts of tree, which partly removed from plantation site and partly gets deposited on the site by falling and decomposition foliages of concern tree species.

4.5.1 Nitrogen:

The nitrogen removed from tree components was directly related to the inherent growth performance of tree species and its biomass production along with mineral utilization behaviour. The total amount of N in a tree was removed maximum by *H. binata* (634.06 g tree^{-1}) followed by *E. tereticornis* (526.3 g tree^{-1}). However, insignificant differences were found between two species *viz; E. officinalis* (382.72 g tree^{-1}) and *A. indica* (361.05 g tree^{-1}). While minimum amount of N was removed by *T. arjuna* (188.92 g tree^{-1}). There was insignificant variation between *A. indica* and *E. officinalis* for bole wood, bole barks, branches, twigs, foliage, above- ground, below-ground and total tree. In case of branches, twigs and above-ground, all the species showed insignificant variation except *T. arjuna.* Whereas the statistical analysis of data showed significant results for all the components (Table 4.5).

4.5.2 Phosphorus:

The harvesting of trees after 18 years growth showed that phosphorus accumulated in different tree components, removed from plantation area was varied from species to species (Table 4.6) with statistically significant results. Among the different components of five MPTs, the highest quantity of P content was harvested through bole wood component at the tune of 41.84, 32.93, 28.58, 22.78 and 20.65 g tree^{-1} by *A. indica*, *E. tereticornis*, *E. officinalis*, *H. binata* and *T. arjuna*, respectively, while the minimum was from foliage in order of *H. binata*, *A. indica*, *E. tereticornis*, *E. officinalis* and *T. arjuna* at the tune of 5.32, 4.99, 3.37, 3.16 and 2.11 g tree^{-1}, respectively. The overall phosphorus among different MPTs were removed in the sequence of *E. tereticornis* (95.57 g tree^{-1}) > *A. indica* (87.09 g tree^{-1}) > *E. officinalis* (64.17 g tree^{-1}) > *H. binata* (49.53 g tree^{-1}) > *T. arjuna* (46.06 g tree^{-1}).

4.5.3 Potassium:

It is exhibited in the Table 4.7 that K content varied from 3036.05 to 1448.61 g tree^{-1} among five MPTs, whereas the variation among different components in the tree ranged from 740.1 to 48.99 g tree^{-1} for *A. indica*, 708.57 to 68.64 g tree^{-1} for *E. officinalis*, 1300.64 to 181.42 g tree^{-1} for *E. tereticornis*, 712.25 to 234.29 g tree^{-1} for *H. binata* and 514.82 to 34.97 g tree^{-1} for *T. arjuna*, respectively. The highest amount of K was obtained in *E. tereticornis* (1300.64 g tree^{-1}) for bole wood and lowest was obtained in *T. arjuna* (34.97 g tree^{-1}) for bole barks. In case of twigs and foliage, it was found maximum in *H. binata* (274.63 and 479.54 g tree^{-1}) and minimum in *T. arjuna* twigs (109.23 g tree^{-1})

and foliage of *A. indica* (176.49 g tree^{-1}). In case of branches, K was removed highest in *A. indica* (740.1 g tree^{-1}) followed by *E. officinalis* (708.57 g tree^{-1}) and *E. tereticornis* (574.48 g tree^{-1}) with insignificant variation. The lowest quantity of K was harvested in *T. arjuna* (514.82 g tree^{-1}), respectively and *H. binata* (378.63 g tree^{-1}) with non-significant difference. In case of roots, maximum amount of K was accumulated in *H. binata* (786.97 g tree^{-1}) which was at par to *E. officinalis* (723.30 g tree^{-1}) but significant to *A. indica* (559.60 g tree^{-1}) and *E. tereticornis* (512.11 g tree^{-1}). The minimum K was recorded in *T. arjuna* (385.8 g tree^{-1}). Over all, the results were found statistically significant (Table 4.7).

4.6 Distribution of nutrients in different parts of MPTs:

The distribution of N accumulated in tree was varied among the different components in different species grown in Bhata lands (Fig. 4.2). It is very clear from the figure that maximum N was shared by branches of *A. indica* and *E. officinalis* (33.95 and 31.11%), respectively and bole wood of *E. tereticornis* (26.59%), while in case of *T. arjuna* and *H. binata,* it was shared (35.67 and 29.08%) for roots, respectively. Twigs in all the tree species showed the minimum N share, where least was found in *E. officinalis* (4.79%).

The distribution of phosphorus in different components of five MPTs is depicted in Fig. 4.3. The maximum distribution of phosphorus was observed in bole wood at the tune of 48, 45.99, 44.82, 44.53 and 34.46 per cent for *A. indica*, *H. binata, T. arjuna, E. officinalis* and *E. tereticornis,* respectively. The minimum distribution of phosphorus was recorded in twigs of *A. indica* and *H. binata* (3.56

and 5.65%), respectively, while in case of *E. officinalis*, *E. tereticornis* and *T. arjuna*, it was minimum in foliage with 4.92, 3.53 and 4.58%, respectively. The share of roots for P accumulation was in the order of *E. tereticornis* (16.13%) > *A. indica* and *E. officinalis* (12.46%) > *T. arjuna* (10.46%) > *H. binata* (8.73%).

In case of potassium, the maximum distribution was found in branch of *A. indica* and *T. arjuna* (36.36 and 35.54%), respectively and bole wood of *E. tereticornis* (42.84%), while it was shared maximum in the roots of *E. officinalis* (28.34%) and *H. binata* (27.46%), respectively. The minimum K was distributed in bole barks of each tree species which was further in order of *H. binata* (8.17%) > *E. officinalis* (2.69%) > *A. indica* and *T. arjuna* (2.41%), except *E. tereticornis*, where it was found in twigs (5.98%). Over all, distribution of K in upper parts of the MPTs was in order of *E. tereticornis* (83.13%) > *T. arjuna* (73.37%) > *A. indica* and *H. binata* (72.5%) > *E. officinalis* (71.66%). Over all roots shared minimum quantity of K in the range of 28.34 to 16.87 per cent, respectively.

In the present study, maximum N was exported from *H. binata* than other tree species as it belongs to Leguminosae hence, it store more N and other nutrients subject to the nature of organic substances because the root system of species had two to six times higher N, which might be attributed to association of rhizobium lead higher mobilization of N compound required for initiations and growth of nodules in leguminous (Singh and Singh, 1998). Brewbaker *et al.* (1990) also reported the positive role of nodulation in growth and production of *H. binata* along with development of soil fertility status.

Phosphorus always available more in growing tissues, is involved in the synthesis of nucleoprotein and gets deposited in least concentration in all the plant tissues as compared to nitrogen. In case of five MPTs studied, amount of total P varied significantly from species to species, where it was removed maximum by *E. tereticornis* (95.57 g tree^{-1}) and minimum by *T. arjuna* (46.06 g tree^{-1}). This might be due to fast growth habits of *E. tereticornis,* thus required sufficient amount of phosphorus for maintaining its sustainable growth and production performance particularly when grown as short rotation cycle through coppice. Rajiv (2004) also found in the silvipastoral studies that maximum P was recruited by fast growing *D. sissoo*, and minimum by *T. arjuna*, a slow growing species. In high-density short rotation crops of MPTs Sisodya (2003) also reported similar results for fast growing leguminous and non-leguminous *L. leucocephala, D. sissoo, E. tereticornis* and *G. arborea.*

Potassium is the only monovalent cation essential for plant growth and it does not take part in the composition of important organic compounds in plants. It maintained the ionic concentration, cellular organization, permeability and hydration in tissues. The availability of potassium in studied MPTs showed statistically significant variation. The results were found similar to phosphorus, hence removal of potassium from the site by different tree components was maximum in *E. tereticornis* (3036.05 g tree^{-1}) followed by *H. binata* (2866.3 g tree^{-1}) and minimum in *T. arjuna* (1448.61 g tree^{-1}). Rajiv (2004), also found minimum K in *T. arjuna*.

It was commonly observed that the concentration of the nutrients in different components of the same tree species differed to a certain extent, depending on the site quality and growth behaviour, while in case of different tree species, it depend on interaction of genetic and climatic conditions for utilizing the available resources to produce qualitative and quantitative structures of the trees. The similar variability was observed in the studied MPTs as they belong to different families as leguminosae and non-leguminosae. *A. indica, E. officinalis, H. binata* and *T. arjuna* comes under indigenous species, while *E. tereticornis* as exotics, which exert profound influence on the nutrients content of the trees (Rodin and Bazilevich, 1967). In the current study, the maximum K was removed by *E. tereticornis*, which has high requirement of potassium and minimum stored in *T. arjuna*, which has low requirement of potassium.

4.7 Physico-chemical changes in soil:

Soil of any plantation site gets changed over a period according to utilization and deposition of nutrients by the tree species. The utilization of nutrient depends on the resource availability. Similarly deposition of nutrient in the soil depends on falling of litters as well as on the decomposition rate, which further governed by microclimate of the plantation site. In the present study, the soil under the five tree species *viz; A. indica, E. officinalis, E. tereticornis, H. binata* and *T. arjuna,* were compared with the soil of adjacent open field, where no plantation was raised. The status of nutrients were detected at four soil depth *viz;* 0-15, 15-30, 30-60, and 60-100 cm. The results of plantation treatments, soil depths and their interactions were presented in Table 4.8 to 4.10 for important soil properties.

4.7.1 Water Holding Capacity (WHC):

Water holding capacity was tested in the laboratory as per standard methods and results revealed the availability of hydrophillic organic material in the soil to bind the water molecules.

Treatment (Tree crop):

Water holding capacity was found maximum under plantation (49.5 to 45.5%) and minimum under control plot (41.78%) with sharp significant status. But among the tree species, it was maximum in *H. binata* (49.53%). The insignificant results were found among *T. arjuna* (47.44%), *A. indica* (47.18%), and *E. officinalis* (47%).

Soil depth:

The role of soil depth was found statistically significant for WHC and it was maximum at upper layer of soil (38.06%) and increased with increasing the soil depth i.e. 54.93% at 60-100 cm depth (Table 4.9).

Interaction of treatment x soil depth:

The results of water holding capacity under plantation treatment and different soil depths interaction are presented in Table 4.10. Over all, maximum water holding capacity was found under *H. binata* (57.28%) at 60-100 cm depth, while the minimum in control plot (32.5%) at 0-15 cm depth. The results were found statistically significant. The insignificant variation was observed at 60 - 100 cm soil depth for plantation site of all the tree species, while at 30 -60 cm soil depth, it was insignificant for *A. indica*, *H. binata and T. arjuna.*

4.7.2 Soil pH:

The concentration of H^+ ions in the soil media decides the nature of soil whether it is acidic, or alkaline or neutral in nature, which directly/indirectly responsible for ultimate growth and performance of any plant grown.

Treatment (Tree crop):

The level of pH under treatments are presented in Table 4.8. It is revealed from the data that there was not found much variation in pH status among treatments. The maximum pH was recorded under *A. indica* (6.1) and *H. binata* (6.06) followed by *E. tereticornis* and control (5.96) and minimum was recorded under *E. officinalis* (5.89).

Soil depth:

The pH recorded at different depths *viz;* 0-15, 15-30, 30-60 and 60-100 cm are depicted in Table 4.9. It is evident from the data that highest pH value (6.35) was observed at surface layer (0-15 cm) followed by next soil depth (6.04) and this further decreased with increasing the soil depth up to 60-100 cm depth (5.72).

Interaction of treatment x soil depth:

The behaviour of soil in relation of pH values under tree and soil depths considerably varied in plantation species as well as different soil layers and it was found acidic in nature under trees and control plot (Table 4.10). The maximum pH value was found in *A. indica* at 0-15 cm soil depth (6.61) and minimum was found in control plot at 60-100 cm soil depth (5.55). The pH values decreased sharply with the increasing soil depth (from 0-15 cm to 60-100 cm) under *A. indica, E. officinalis, H. binata, T. arjuna* and in control plot (5.83 to 5.55). But this unique trend was not found in case of *E. tereticornis,* where it was lowest at 30-60 cm soil depth (5.67). The highest pH value was recorded at upper layer (0-15 cm) under all treatments (6.61 to 6.07) followed by 15-30 cm soil depth (6.21 to 5.93).

4.7.3 Organic carbon:

Organic carbon is considered as a basic parameter for determining the soil quality. The availability of organic substances in its bio- degradable forms is found to be responsible to built a rich humus soil. The growth performance of plants depends on the availability of organic matter in which organic carbon along with essential minerals are necessary. The results of organic carbon in different plantation crop treatment, soil depth and their interaction were found statistically significant and presented in Table 4.8 to 4.10.

Treatment (Tree crop):

Organic carbon was found highest in the soil under *H. binata* (0.83%) followed by *A. indica* (0.8%) and *E. tereticornis* (0.79%), while lowest was found in control plot (0.51%). Where insignificant differences were found between *A. indica* (0.80%) and *E. tereticornis* (0.79%). The effect of plantation treatment was found statistically significant (Table 4.8).

Soil depth:

The effect of soil depth was found statistically significant and there was sharp variation in availability of organic carbon at different soil depth (Table 4.9). It was maximum at surface layer (1.01%) followed by 15-30 cm soil depth (0.75%). The availability of organic carbon decreased with increasing the soil depth and it was 0.49% at 60-100 cm depth.

Interaction of treatment x soil depth:

Organic carbon data depicted in Table 4.10, showed statistically significant variation with treatment and soil depth interaction. Organic carbon was found gradually decreasing from top layer to the deep layer of soil under all the tree crop treatments and it was recorded maximum at 0-15 cm top layer under *H. binata* (1.26%) and *E. tereticornis* (1.25%) with minimum at 60-100 cm depth of soil under *E. officinalis* (0.37%) and control plot (0.36%), respectively.

4.7.4 Available nutrients:

The data of available macro-nutrients i.e. N, P and K in the soil is given in Table 4.8 to 4.10 for plantation crop treatment, soil depth and their interaction (treatment x soil depth). It is evident from the data that the results were found statistically significant for N, P and K availability in different parameters and their interactions.

Treatment (Tree crop):

The highest amount of nitrogen (244.35 kg N ha^{-1}) and potassium (259.03 kg K ha^{-1}) were recorded under *H. binata* and maximum phosphorus was found under *T. arjuna* (21.67 kg P ha^{-1}). While lowest amount of these macronutrients were recorded in the control plot (144.78 kg N ha^{-1}, 6.79 kg P ha^{-1} and 118.8 kg K ha^{-1}). However, minimum amount of NPK nutrients under tree species were at the tune of 153.92 kg N ha^{-1} in *E. tereticornis* and 18.45 kg P ha^{-1} and 130.32 kg K ha^{-1} in *A. indica* (Table 4.8).

Soil depth:

The soil depth significantly influenced the amount of available macro-nutrients. These macro-nutrients were recorded maximum at top layer of soil and gradually decreased as the soil depth increased. It was ranged 231.19 to 156.63 kg ha^{-1} for N and 23.26 to 13.01 kg ha^{-1} for P. In case of potash it was varied from 231.12 to 120.43 kg ha^{-1}. The trend of decreasing the level of nutrients was more or less similar (Table 4.9).

Interaction of treatment x soil depth:

The combined effect of tree crop plantation (treatment) and soil depth was found statistically significant on the availability of soil nutrients (Table 4.10). The level of N was decreased gradually with increasing the soil depth in all the cases. The maximum variation of N was observed under *H. binata* from upper layer (304.19 kg N ha^{-1}) to deep layer (175.61 kg N ha^{-1}). While, minimum variation was found in the control plot (171.44 to 122.39 kg N ha^{-1}), which at par to *E. tereticornis*. In case of *A. indica*, *E. officinalis* and *T. arjuna,* the availability of N between upper layer (0-15 cm) and deep layer (60-100 cm) was varied by 73.95, 56.45 and 89.31 kg N ha^{-1}, respectively.

Phosphorus varied significantly between different treatment and soil depth interaction, where it was maximum at top layer under *T. arjuna* (29.75 kg P ha^{-1}) and minimum at 30-60 cm depth in control plot (5.38 kg P ha^{-1}). *T. arjuna*, *E. officinalis* and *A. indica* showed highest level of P (29.75, 27.49 and 23.53 kg P ha^{-1}), respectively at upper layer of soil and it decreased with increasing soil depth, where lowest was at deeper layer of soil (13.82, 14.02 and 13.29 kg P ha^{-1}), respectively. In case of *E. tereticornis* and control plot, maximum values of P was found at 0-15 cm soil depth (27.47 and 9.13 kg P ha^{-1}), respectively and minimum at 30-60 cm soil depth (16.39 and 5.38 kg P ah^{-1}), respectively. In *H. binata*, the highest value of P was recorded at 15-30 cm soil depth (23.85 kg P ha^{-1}) and lowest at 60-100 cm soil depth (11.68 kg P ha^{-1}).

Amount of available K was significantly affected by treatment x soil depth interaction. The level of K appeared at surface layer was maximum under *H. binata* (376.62 kg K ha^{-1}) followed by *E. officinalis* (311.06 kg K ha^{-1}) with minimum of 132.76 kg K ha^{-1} in open plot. While over all, minimum amount of K was obtained in control plot (92.14 kg K ha^{-1}) at 60-100 cm soil depth. Among the treatment maximum K was found under *H. binata* (376.62 to 152.17 kg K ha^{-1}) followed by *E. officinalis* (311.06 to 131.52 kg K ha^{-1}), *E. tereticornis* (241.92

to 140.19 kg K ha^{-1}), *A. indica* (170.01 to 96.28 kg K ha^{-1}), *T. arjuna* (154.33 to 110.20 kg K ha^{-1}) with minimum in open field (132.76 to 92.14 kg K ha^{-1}).

The physico-chemical characteristics of the soil under plantation of MPTs and adjacent open field (area without trees) showed that WHC was increased significantly with increasing soil depth. pH of the soil was decreased with increase in soil depth, where it was found maximum under *A. indica* at 0-15 cm soil depth and minimum at 60-100 cm soil depth in open field. It was found to be influenced by tree canopy but in a limited range. Organic carbon also decreased as increasing soil depth. These results are in conformity with the findings of Bisht *et al.* (1989); Soni (1991); Sharma and Singh (1991); Sharma (1991); Jha and Chhimwal (1993) and Saralch (1994).

The decrease in available macro-nutrients with increase in soil depth is common feature in degraded soil. The level of nutrients was found comparatively more under tree crop as compare to control (without tree). This can be attributed to deep-rooted nature of trees. These results are on line with the findings of Banerjee and Nath (1991) for forest soils of Sikkim, Sharma and Singh (1991) for soils of Kinnaur, Malik (1992) for pine forests of Solan district and Kaushal (1992) for deodar forest soils of Kinnaur. There was a decreasing trend in available nitrogen content with increase in soil depth, which is similar to the findings of Sisodya, (2003). It was found maximum under *H. binata* at 0-15 cm soil depth and minimum in control plot at 60-100 cm depth.

In general, there was an increase of available phosphorus in the soils when soil surface has litter, this can be attributed to solubilizing behavior of organic acids, which ever released into soil during organic matter decomposition (Rao *et al.,* 2000). In all the cases, it was observed that phosphorus status of soil decreased with increase in soil depth, this can be attributed to deep rooted nature of tree, which exerted on nutrient absorption from deep layer of soil (Bhardwaj *et al.,* 2001). Similar trend was also seen under high density plantation of MPTs Sisodya (2003), where the significant variation was seen under different tree species at both the layers of soil *i.e.* surface and lower depths of soil.

Like phosphorus, the available potassium of soils under different trees decreased with increase in soil depth because nutrient absorbed by roots from various soil depths and mobilize to different tree components and liter of which get deposited on surface, where they decomposed. Thus quantity of NPK increased on the surface of the soil. Similar results were also recorded by Shankaranarayanan (1984). Kapoor and Singh (1992) justified the views for increasing the nutrients on surface layer of soil in their studies that tree plantations for long period prevented leaching down the nutrients from the surface profile during rainy season, thereby showing higher values at the surface of the soil than at lower soil depths.

CHAPTER-V

SUMMARY, CONCLUSION AND SUGGESTIONS FOR FUTURE RESEARCH WORK

The study on "Biomass and nutrient accumulation in 18 years old multipurpose trees (MPTs) on red lateritic soil (Entisols)" was carried out at "Baronda Research Farm" IGAU, Raipur, (C.G.) during 2005-2006. Climate of study site is sub-humid dry tropical. The mean annual rainfall is 1250 mm. Five tree species *viz; Azadirachta indica, Emblica officinalis, Eucalyptus tereticornis, Hardwickia binata* and *Terminalia arjuna* were planted in July 1987.

The highlights of the finding are here with:

1 Average height of five MPTs was found maximum in *E. tereticornis* (12.24 m) followed by *H. binata* (10.51 m), *E. officinalis* (8.13 m), *A. indica* (7.43 m) and *T. arjuna* (5.75 m).

2 The performance of five MPTs for attaining the bole height was in the order of *E. tereticornis* (7.25 m) > *H. binata* (6.26 m) > *E. officinalis* (5 m) > *A. indica* (4.24 m) > *T. arjuna* (2.98 m).

3 Clean bole growth of different multipurpose tree species showed statistically significant variation with maximum average clean bole growth in *E. tereticornis* (4.43 m) followed by *H. binata* (4.1 m), *E. officinalis* (2.24 m), *A. indica* (2.01 m) and *T. arjuna* (1.81 m).

4 The highest average crown length was recorded in *E. tereticornis* (7.83 m) followed by *H. binata* (6.43 m), *E. officinalis* (5.89 m), *A. indica* (5.41 m) and *T. arjuna* (3.94 m).

5 The mean crown diameter of MPTs varied from 3.9 m to 3 m for *A. indica* and *E. tereticornis*, respectively. It was found statistically insignificant.

6 Average collar diameter of five MPTs was found maximum in *E. tereticornis* (21.49 cm) followed by *H. binata* (17.23 cm), *A. indica* (16.75 cm), *E. officinalis* (16.23 cm) and *T. arjuna* (14.46 cm).

7 The average diameter at breast height was observed highest in *E. tereticornis* (17.28 cm) followed by *H. binata* (14.76 cm), *A. indica* (13.75 cm), *E. officinalis* (10.48 cm) and *T. arjuna* (9.48 cm).

8 The branching pattern did not show the significant variations for their number of branches per tree. It was recorded maximum in *A. indica* (8.5tree^{-1}) and minimum in *E. tereticornis* (5.75tree^{-1}).

9 *E. tereticornis* stored the maximum dry matter (82.32 kg tree^{-1}) in bole wood, while *T. arjuna* stored minimum (12.15 kg tree^{-1}) with significant variation to other species.

10 The bole bark dry matter production showed significant variation in the order of *E. tereticornis* (21.64 kg tree^{-1}) > *H. binata* (11.49 kg tree^{-1}) > *E. officinalis* (6.3 kg tree^{-1}) > *A. indica* (4.34 kg tree^{-1}) > *T. arjuna* (2.8 kg tree^{-1}).

11 The maximum dry matter in branch was recorded in *E. tereticornis* (27.75 kg tree^{-1}) followed by *A. indica* (22.7 kg tree^{-1}) with insignificant difference. Where the minimum was recorded in *T. arjuna* (7.77 kg tree^{-1}).

12 In case of twigs, the highest dry matter was also found in *E. tereticornis* (5.71 kg tree^{-1}) and lowest in *T. arjuna* (1.96 kg tree^{-1}).

13 The foliage dry matter production showed significant variation in the order of *H. binata* (6.19 kg tree^{-1}) > *E. tereticornis* (6.02 kg tree^{-1}) > *E. officinalis* (3.4 kg tree^{-1}) > *A. indica* (3.31 kg tree^{-1}) > *T. arjuna* (2.74 kg tree^{-1}).

14 The maximum and minimum above-ground dry matter production were registered by *E. tereticornis* (143.44 kg tree^{-1}) and *T. arjuna* (27.41 kg tree^{-1}), respectively.

15 Dry matter production in root followed similar trend as of foliage with significant results.

16 The total dry matter production in 18 years old MPTs was in the order of *E. tereticornis* (166 kg tree^{-1}) > *H. binata* (102.04 kg tree^{-1}) > *E. officinalis* (91.26 kg tree^{-1}) > *A. indica* (80.85 kg tree^{-1}) > *T. arjuna* (39.85 kg tree^{-1}). Similar trend was observed for all the tree components except foliage and roots.

17 Concentration of NPK nutrients was maximum in foliage of *H. binata* (1.13%) and minimum in bole wood of *E. tereticornis* (0.17%) for nitrogen. In case of P, it was distributed 0.22 to 0.03% in twigs of *T. arjuna* and roots of *H. binata.* While 7.75% K was distributed in foliage of *H. binata* and 1.03% in bole barks of *E. tereticornis.*

18 The residue of ash was found maximum in bole barks of *E. officinalis* (17.74%) and minimum in bole wood of *T. arjuna* (1.12%). The overall, results were showed that highest ash was received in bole

barks of all the species except *A. indica*, where it was in foliage. The lowest ash residue was received in bole wood of all the species.

19 At harvest, highest amount of N exported from both MPTs *viz; H. binata* (634.06 g tree^{-1}) and *E. tereticornis* (526.3 g tree^{-1}), while the lowest from *T. arjuna* (188.92 g tree^{-1}).

20 The overall, P deposited in five MPTs was found in the merit of *E. tereticornis* (95.57 g tree^{-1}) > *A. indica* (87.09 g tree^{-1}) > *E. officinalis* (64.17 g tree^{-1}) > *H. binata* (49.53 g tree^{-1}) > *T. arjuna* (46.06 g tree^{-1}) with statistically significant results.

21 MPTs were showed statistically significant variation for potassium deposition in their components, where maximum amount of K was accumulated in *E. tereticornis* (3036.05 g tree^{-1}) followed by *H. binata* (2866.3 g tree^{-1}), while the minimum was in *T. arjuna* (1448.61 g tree^{-1}).

22 WHC was recorded highest under *H. binata* (49.32%) followed by *T. arjuna* (47.44%), *A. indica* (47.18%) and *E. officinalis* (47%). The lowest was recorded in control plot (41.78%). It was lowest at upper layer (38.06%) and increased with increasing soil depth with statistically significant variation.

23 pH was recorded maximum at top layer and minimum at deep layer of soil, where over all the maximum and minimum pH were found under *A. indica* at 0-15 cm soil depth (6.61) and in control plot at 60-100 cm soil depth (5.55), respectively.

24 Organic carbon in soil was found to be decreased as soil depth increased from 0-15 to 60-100 cm depth, while it was analyzed higher under *H. binata* at 0-15 cm depth (1.26%) and lower in control plot at 60-100 cm depth (0.36%) with significant differences.

25 The highest amount of N, P and K were observed under *H. binata* (244.35 Kg N ha^{-1}), *T. arjuna* (21.67 Kg P ha^{-1}) and also *H. binata* (259.03Kg K ha^{-1}), while lowest amount were observed in the control plot, 144.78 N, 6.79 P and 118.8 K kg ha^{-1}, respectively, with statistically significant variation.

26 The highest difference of N was recorded under *H. binata* x soil depth interaction from top layer to deep layer, while the lowest difference was recorded in the control plot from 0-15 to 60-100 cm depth layers. The level of N was decreased with increasing the soil depth in all treatments.

27 The highest amount of P was recorded at upper layer of soil (0-15 cm) in *T. arjuna* (29.75 kg P ha^{-1}) followed by *E. officinalis* (27.49 kg P ha^{-1}), *E. tereticornis* (27.47 kg P ha^{-1}) and least in *H. binata* (22.2 kg P ha^{-1}), except in case of *H. binata*, it was at 15-30 cm depth (23.85). The over all, lowest amount of P was recorded in control plot (5.38 kg P ha^{-1}) at 30-60 cm soil depth.

28 The maximum level of K was observed under *H. binata* at upper layer (376.62 kg K ha^{-1}). Where the minimum amount of K was recorded in control plot (92.14 kg K ha^{-1}) at 60-100 cm soil depth. The increasing

the soil depth decreased the quantity of K in all the cases with statistically significant variation.

Conclusion:

The study conducted on "Biomass and nutrient accumulation in 18 years old multipurpose trees (MPTs) on red lateritic soil (Entisols)" was indicated that *Eucalyptus tereticornis* and *Hardwickia binata* based Farm forestry plantation was found comparatively more suitable for development and utilization of red lateritic wasteland. These species attained maximum growth, biomass production and nutrient accumulation along with improvement in physico- chemical properties of Bhata land. However, *Emblica officinalis* and *Azadirachta indica*, both the species showed more or less similar growth and biomass production. *T. arjuna* tree species is not suitable for such Bhata land.

Suggestions for future research work:

It is seen from the study that plantation of *Eucalyptus tereticornis* and *Hardwickia binata* are comparatively more suitable to utilize red lateritic wasteland not only to full fill the requirement of timber, fuel wood and fodder/medicinal substances of local community and industries but also help to make eco-friendly environment in terms of improving soil properties and micro-climate conditions significantly.

Economics of these MPTs further needed to be worked out as farm forestry and agroforestry in the wastelands.

Changes in micro-climate conditions in and around the plantation of MPTs in need to be studied.

The upland red lateritic wastelands suffers from soil-water and nutrient loss due to soil erroson and runoff of water, the mono plantation of each species is also needed to be studied to prevent soil-water & nutrient loss.

“BIOMASS AND NUTRIENT ACCUMULATION IN 18- YEARS OLD MULTIPURPOSE TREES (MPTs) ON RED LATERITIC SOIL (ENTISOLS)”

By

SATISH CHAND MEENA

ABSTRACT

The study entitled “Biomass and nutrient accumulation in 18-years old multipurpose trees (MPTs) on red lateritic soil (Entisols)” was conducted at Baronda Research Farm, Indira Gandhi Agricultural University (IGAU), Raipur (C.G.) during 2005- 2006. The study was carried out with five multipurpose tree species *viz; Azadirachta indica, Emblica officinalis, Eucalyptus tereticornis, Hardwickia binata* and *Terminalia arjuna,* which were planted on Bhata land in July 1987. The observations were carried out in randomized block design with four replications.

All trees of each species were measured for their height and DBH, to get mean height and DBH values of each species, thus the representative trees of each species were selected for felling and excavation of roots. The felled trees were also measured for biomass production and nutrients (NPK) accumulation along with ash available in different components of MPTs. The soil properties (physical and chemical) under plantation of MPTs in comparison to adjacent open barren field were also studied at four level of soil depth *viz;* 0-15, 15-30, 30-60 and 60-100 cm.

Collar diameter, diameter at breast height and tree height of 18- years old stand was ranged from 21.49 to 14.46 cm, 17.28 to 9.48 cm and 12.24 to 5.75 m for *E. tereticornis* as maximum and for *T. arjuna* as minimum, respectively with statistically significant results ($p < 0.05$). The crown diameter and branching pattern did not show significant results.

The maximum dry matter production for bole wood, bole bark, branch and twigs were found in *E. tereticornis* by 82.32, 21.64, 27.75 and 5.71 kg tree^{-1} and minimum in *T. arjuna* by 12.15, 2.8, 7.77 and 1.96 kg tree^{-1}, respectively. The maximum foliage and root dry matter was recorded in *H. binata* (6.19 and

25.97 kg tree^{-1}), while minimum was recorded in *T. arjuna* (2.74 and 12.45 kg tree^{-1}). Over all, the maximum total dry matter production was found statistically significant in *E. tereticornis* (166 kg tree^{-1}) and minimum in *T. arjuna* (39.85 kg tree^{-1}). The trend of biomass production for all the MPTs was at the order of bole wood > branch > root > bole bark > foliage > twigs.

All the MPTs showed significant variation for accumulation and harvesting of major nutrients (NPK) in their different components ($p < 0.05$). Large amount of these nutrients are exported from the field as material removed. The highest amount of nitrogen was removed by *H. binata* (634.06 g tree^{-1}) and lowest by *T. arjuna* (188.92 g tree^{-1}). Phosphorus is the second important nutrient found in trees at the tune of 95.57, 87.09, 64.17, 49.53 and 46.06 g tree^{-1} with *E. tereticornis, A. indica, E. officinalis, H. binata* and *T. arjuna.* Potassium content was varied significantly from 3036.05 to 1498.61 g tree^{-1} with *E. tereticornis* and *T. arjuna,* respectively. The maximum ash content was found in bark of *E. officinalis* (17.74%) and minimum in bole of *T. arjuna* (1.12%).

The maximum pH value was recorded at upper layer (0-15 cm) under all treatments with control plot. Water holding capacity (WHC) was highest under *H. binata* (49.32 per cent) and lowest under *E. tereticornis* (45.55 per cent). Organic carbon was found maximum under *H. binata* (0.83 per cent) and minimum under *E. officinalis* (0.64 per cent). The maximum amount of nitrogen, phosphorus and potassium were recorded under *H. binata* (244.35 kg ha^{-1}), *T. arjuna* (21.67 kg ha^{-1}) and *H. binata* (259.03 kg ha^{-1}), respectively. While minimum amount of same nutrient at the tune of 153.92, 18.45 and 130.32 kg ha^{-1} under *E. tereticornis, A. indica* and also *A. indica,* respectively. Hence, in comparison to adjacent open barren field the improvement in soil quality was found under plantation field in respect to *H. binata* > *A. indica* > *T. arjuna* > *E. tereticornis* > *E. officinalis.*

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Table 4.2: **Fresh biomass accumulation in plantations of MPTs after 18 years of growth**

Table 4.5: Export of Nitrogen (g tree^{-1}) from harvesting tree after 18 years of growth

Species	Fresh weight kg/tree							
	Bole wood	**Bole barks**	**Branches**	**Twigs**	**Foliage**	**AGB**	**BGB**	**Total**
Azadirachta indica	45.46	9.26	36.5	7.56	8.69	107.47	40.83	148.29
	± 4.61	± 0.94	± 4.80	± 1.84	± 1.85	± 11.41	± 4.88	± 14.83
Emblica officinalis	66.96	12.05	37.13	7.66	8.18	131.96	39.05	171.01
	± 5.84	± 1.04	± 8.05	± 1.45	± 0.87	± 12.85	± 4.89	± 1.71
Eucalyptus tereticornis	128.06	43.45	53.19	10.28	11.69	246.68	47.00	293.68
	± 6.86	± 2.47	± 11.99	± 1.64	± 2.86	± 21.83	± 9.64)	± 30.12
Hardwickia binata	69.74	22.01	23.83	9.02	10.31	134.91	49.00	183.91
	± 4.00	± 1.26	± 5.74	± 1.79	± 3.22	± 9.37	± 2.68	± 7.45
Terminalia arjuna	20.08	6.35	15.53	4.35	6.60	52.90	22.63	75.53
	± 4.14	± 1.34	± 3.29	± 0.78	± 1.71	± 8.85	± 3.35	± 11.46
SEm ±	2.87	0.80	4.01	0.82	1.02	7.23	2.82	9.47
SEd ±	4.06	1.13	5.67	1.16	1.45	10.22	3.99	13.39
C.D. at (5%)	8.84	2.47	12.35	2.53	3.16	22.29	8.69	29.19

Species	Bole wood	Bole barks	Branches	Twigs	Foliage	AG	BG	Total
Azadirachta indica	83.68	19.07	122.59	18.67	23.14	267.15	93.90	361.05
	±8.48	±1.93	±16.11	±4.54	±4.94	±23.33	±11.13	±30.64
Emblica officinalis	83.35	24.56	119.07	18.32	30.26	275.56	107.16	382.72
	±7.26	±2.14	±25.81	±3.53	±3.64	±31.91	±13.43	±43.44
Eucalyptus tereticornis	139.95	75.74	124.89	37.08	40.35	418.01	108.29	526.30
	±7.5	±4.3	±28.15	±5.91	±9.85	±46.95	±22.2	±65.93
Hardwickia binata	153.22	82.69	107.26	36.56	69.92	449.65	184.41	634.06
	±8.78	±4.76	±25.9	±7.26	±21.81	±44.95	±10.09	±37.74
Terminalia arjuna	32.79	15.39	33.39	13.12	26.85	121.54	67.38	188.92
	±6.76	±3.23	±7.07	±2.35	±6.97	±20.14	±10.26	±28.04
SEm ±	4.27	1.83	11.90	2.60	5.14	17.50	7.08	21.85
SEd ±	6.04	2.59	16.82	3.68	7.27	24.74	10.01	30.89
C.D. at (5%)	13.17	5.64	36.67	8.01	15.84	53.94	21.82	67.34

Table 4.6: Export of Phosphorus (g $tree^{-1}$) from harvesting tree after 18 years of growth

Species	Bole wood	Bole barks	Branches	Twigs	Foliage	AG	BG	Total
Azadirachta indica	41.84	3.43	21.34	3.10	4.99	74.70	12.46	87.09
	±4.24	±0.35	±2.80	±0.75	±1.06	±6.77	±1.48	±7.62
Emblica officinalis	28.58	5.73	10.15	4.12	3.16	51.74	12.44	64.17
	±2.49	±0.50	±2.20	±0.78	±0.38	±4.55	±1.56	±5.94
Eucalyptus tereticornis	32.93	14.93	23.59	4.62	3.37	79.45	16.13	95.57
	±1.76	±0.85	±5.32	±0.73	±0.82	±8.08	±3.17	±10.56
Hardwickia binata	22.78	5.51	4.39	2.80	5.32	40.81	8.73	49.53
	±1.30	±0.32	±1.06	±0.56	±1.66	±3.30	±0.75	±2.72
Terminalia arjuna	20.65	2.60	5.90	4.35	2.11	35.61	10.46	46.06
	±4.26	±0.55	±1.25	±0.78	±0.55	±6.00	±1.55	±6.99
SEm ±	1.64	0.29	1.55	0.37	0.51	3.11	0.92	3.78
SEd ±	2.31	0.41	2.20	0.53	0.72	4.40	1.31	5.34
C.D. at (5%)	5.05	0.90	4.79	1.15	1.57	9.60	2.85	11.65

Table 4.7: Export of Potash (g tree^{-1}) from harvesting tree after 18 years of growth

Species	Bole wood	Bole barks	Branches	Twigs	Foliage	AG	BG	Total
Azadirachta indica	383.77	48.99	740.10	126.39	176.49	1475.74	559.64	2035.38
	±38.89	±4.97	±97.24	±30.75	±37.68	±123.68	±66.91	±167.19
Emblica officinalis	638.97	68.64	708.57	185.65	227.12	1828.95	723.30	2552.25
	±55.69	±5.98	±153.61	±35.46	±27.33	±201.82	±90.65	±167.19
Eucalyptus tereticornis	1300.64	222.89	574.48	181.42	244.51	2523.94	512.11	3036.05
	±69.68	±12.64	±129.49	±28.90	±59.68	±252.87	±104.98	±345.63
Hardwickia binata	712.25	234.29	378.63	274.63	479.54	2079.33	786.97	2866.30
	±40.80	±13.48	±91.44	±54.50	±149.59	±255.41	±43.05	±219.12
Terminalia arjuna	221.04	34.97	514.82	109.23	182.76	1062.81	385.80	1448.61
	±45.53	±7.34	±109.01	±19.54	±47.46	±164.67	±57.12	±215.24
SEm ±	28.12	5.05	63.4	18.69	35.55	103.54	36.81	127.54
SEd ±	39.76	7.13	89.65	26.43	50.27	146.40	52.04	180.33
C.D. at (5%)	86.68	15.55	195.43	57.62	109.58	319.15	113.45	393.13

Table 4.4: Nutrient status in tree components of MPTs

Species	% Nutrient						
		Bole wood	**B. barks**	**Branches**	**Twigs**	**Foliage**	**Roots**
A. indica	**N**	0.29	0.44	0.54	0.65	0.70	0.50
	P	0.145	0.089	0.094	0.108	0.151	0.066
	K	1.33	1.13	3.26	4.40	5.34	2.98
	Ash	1.56	11.33	6.93	9.73	13.57	7.03
E. officinalis	**N**	0.21	0.39	0.61	0.57	0.89	0.56
	P	0.072	0.091	0.052	0.128	0.093	0.065
	K	1.61	1.09	3.63	5.77	6.68	3.78
	Ash	1.82	17.74	6.80	8.60	5.03	6.40
E. tereticornis	**N**	0.17	0.35	0.45	0.65	0.67	0.48
	P	0.04	0.069	0.085	0.081	0.056	0.071
	K	1.58	1.03	2.07	3.18	4.06	2.27
	Ash	1.39	15.40	4.21	7.97	8.37	5.77
H. binata	**N**	0.37	0.72	0.83	0.90	1.13	0.71
	P	0.056	0.048	0.034	0.069	0.086	0.033
	K	1.72	2.04	2.93	6.76	7.75	3.03
	Ash	2.05	13.4	5.37	7.80	6.17	4.77
T. arjuna	**N**	0.27	0.55	0.43	0.67	0.98	0.54
	P	0.171	0.093	0.076	0.222	0.077	0.084
	K	1.82	1.25	6.63	5.58	6.67	3.10
	Ash	1.12	16.38	6.43	9.37	9.00	5.81

Table 4.8: Properties of soil under different MPTs

Tree species	pH	WHC %	Org. C %	Available nutrient (kg ha^{-1})		
				N	P	K
Azadirachta indica	6.10	47.18	0.80	233.32	18.45	130.32
Emblica officinalis	5.89	47.00	0.64	188.94	19.89	212.01
Eucalyptus tereticornis	5.95	45.55	0.79	153.92	21.64	178.81
Hardwickia binata	6.06	49.32	0.83	244.35	19.22	259.03
Terminalia arjuna	5.93	47.44	0.74	214.03	21.67	141.78
Control	5.95	41.78	0.51	144.78	6.79	118.80
SEm ±		0.31	0.01	2.24	0.16	2.37
SEd ±		0.44	0.01	3.17	0.22	3.35
C.D. at (5%)		0.88	0.02	6.36	0.45	6.72

Table 4.9: Properties of soil at different depth under plantation of MPTs

Soil depth	pH	WHC %	Org. C %	Available nutrient (kg ha^{-1})		
				N	P	K
0-15 cm	6.35	38.06	1.01	231.19	23.26	231.12
15-30 cm	6.04	43.24	0.75	216.04	20.40	190.65
30-60 cm	5.76	49.28	0.63	182.38	15.09	151.62
60-100	5.72	54.93	0.49	156.63	13.01	120.43
SEm ±		0.25	0.01	1.83	0.13	1.94
SEd ±		0.36	0.01	2.59	0.18	2.74
C.D. at (5%)		0.72	0.02	5.20	0.37	5.49

Table 4.10: Effect of interaction of tree species x soil depth on soil properties under plantation of MPTs

Tree x Soil depth	pH	WHC %	Org. C %	Available nutrient (kg ha^{-1})		
				N	P	K
Azadirachta indica						
0-15 cm	6.61	38.36	1.02	262.38	23.53	170.01
15-30 cm	6.10	43.80	0.86	256.11	21.37	131.30
30-60 cm	5.85	51.50	0.73	226.64	15.60	123.68
60-100	5.82	55.07	0.60	188.16	13.29	96.28
Emblica officinalis						
0-15 cm	6.30	40.36	0.86	215.34	27.49	311.06
15-30 cm	5.97	42.15	0.73	209.07	21.13	228.96
30-60 cm	5.69	49.20	0.62	172.48	16.92	176.48
60-100	5.58	56.30	0.37	158.89	14.02	131.52
Eucalyptus tereticornis						
0-15 cm	6.11	37.30	1.25	178.75	27.47	241.92
15-30 cm	5.93	43.59	0.87	160.98	23.64	190.21
30-60 cm	5.67	47.31	0.60	147.39	16.39	142.91
60-100	5.83	53.98	0.44	128.58	19.05	140.19
Hardwickia binata						
0-15 cm	6.59	41.20	1.26	304.19	22.2	376.62
15-30 cm	6.21	46.57	0.75	274.92	23.85	298.55
30-60 cm	5.73	52.22	0.63	222.66	19.17	208.77
60-100	5.71	57.28	0.70	175.61	11.68	152.17
Terminalia arjuna						
0-15 cm	6.07	38.63	1.04	255.06	29.75	154.33
15-30 cm	5.96	44.65	0.73	242.52	25.98	177.97
30-60 cm	5.86	51.00	0.72	192.34	17.12	124.54
60-100	5.83	55.47	0.47	166.21	13.82	110.28
Control						
0-15 cm	6.45	32.5	0.64	171.44	9.13	132.76
15-30 cm	6.05	38.7	0.59	152.62	6.42	116.93
30-60 cm	5.74	44.45	0.46	132.76	5.38	133.35
60-100	5.55	51.46	0.36	122.30	6.22	92.14
SEm ±	-	0.62	0.02	4.49	0.32	4.74
SEd ±	-	0.88	0.02	6.34	0.45	6.70
C.D. at (5%)	**-**	1.76	0.04	12.73	0.90	13.45

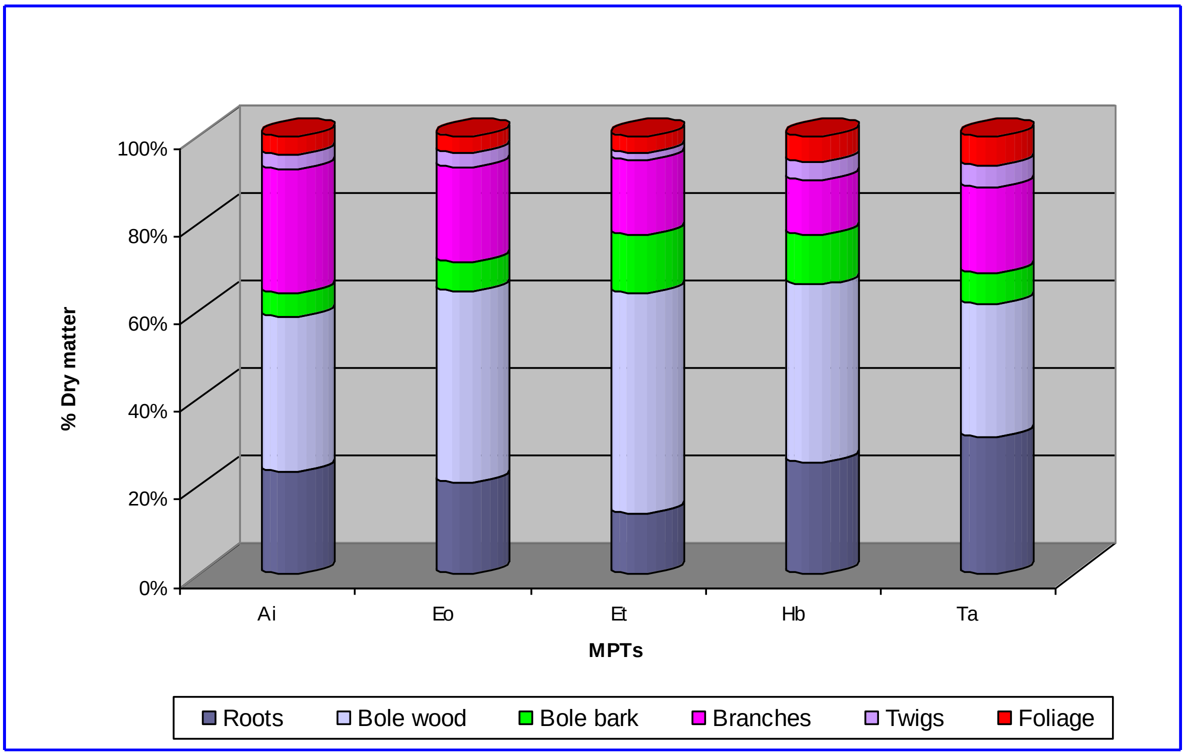

Fig. 4.1: Dry matter contribution in different parts of MPTs

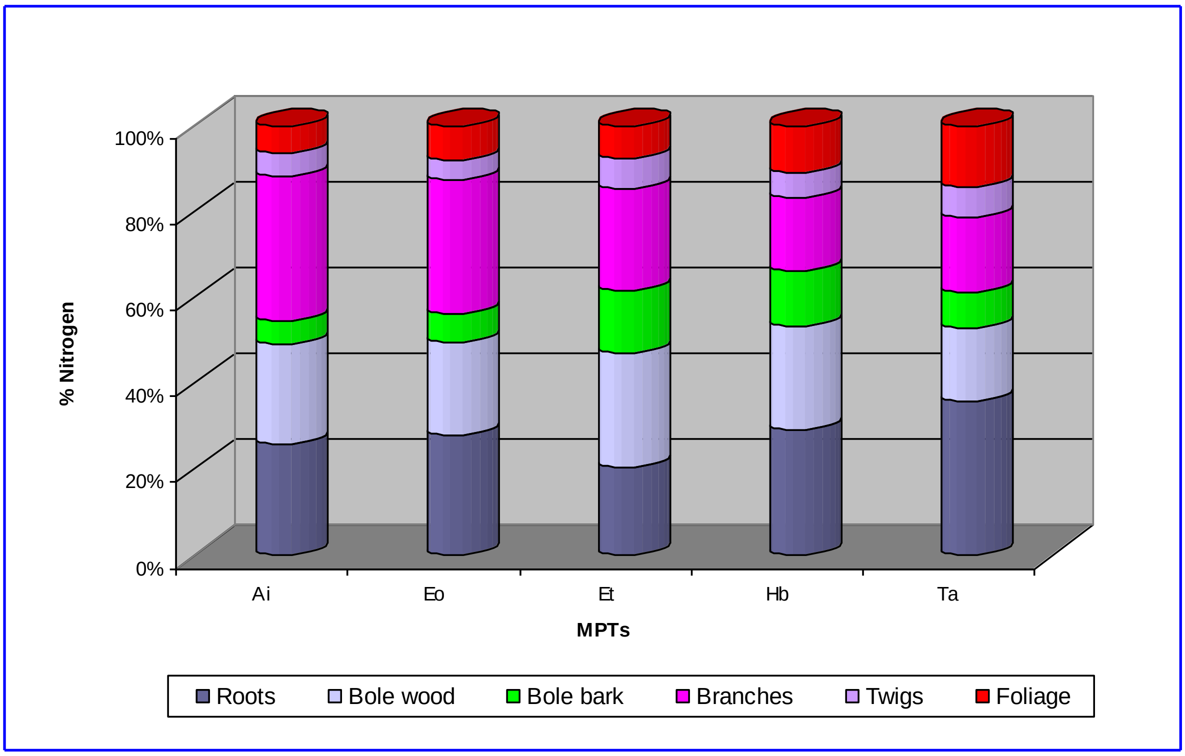

Fig. 4.2 : % Nitrogen stored in different parts of MPTs after 18 years of growth

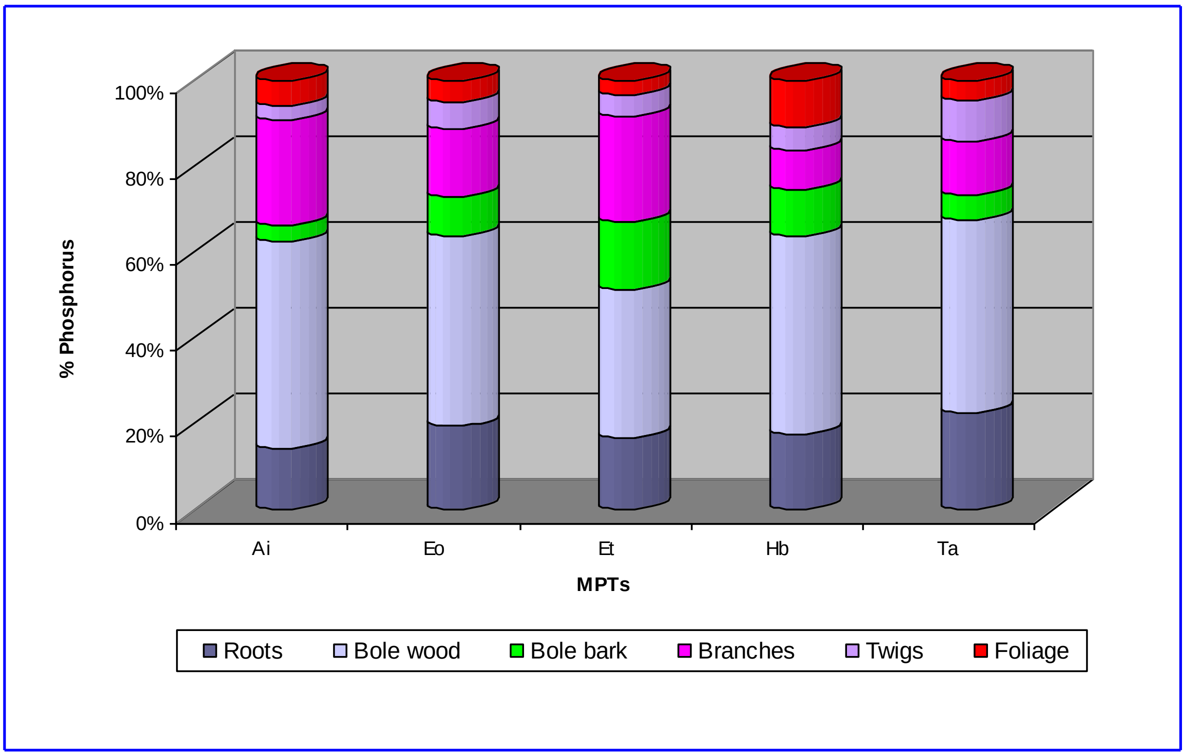

Fig. 4.3 : % Phosphorus stored in different parts of MPTs after 18 years of growth

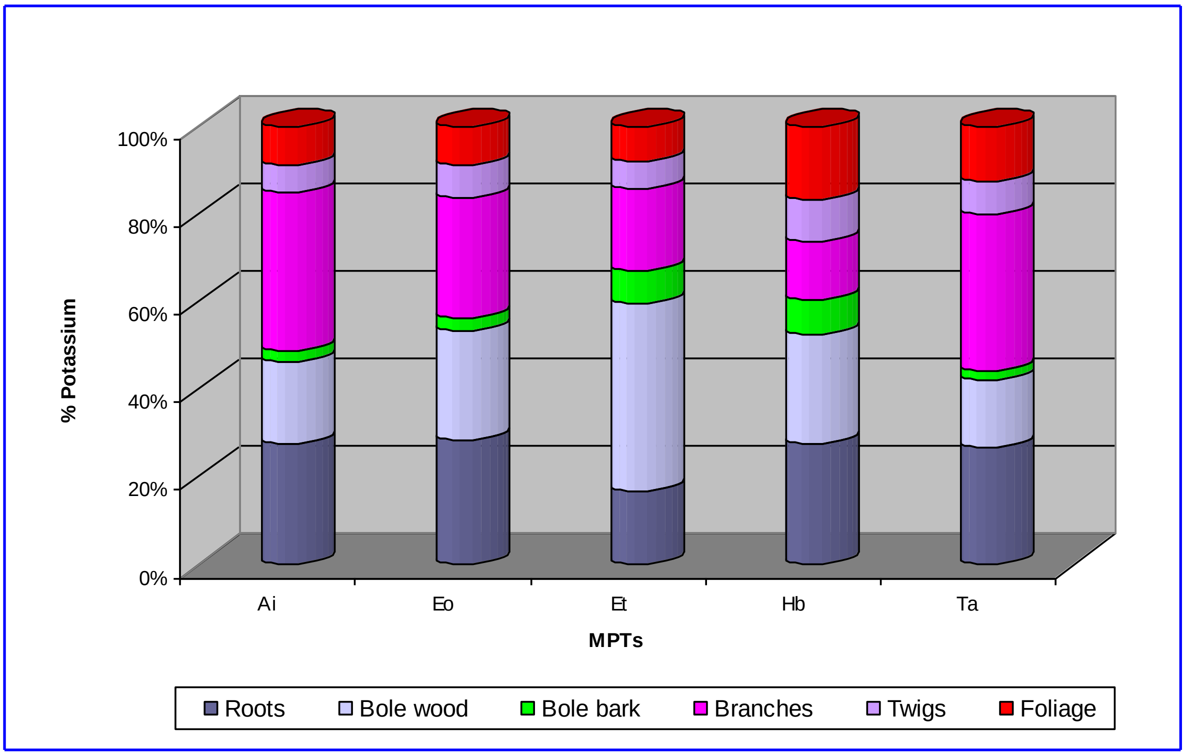

Fig. 4.4 : % Potassium stored in different parts of MPTs after 18 years of growth

A. indica

E. officinalis

T. arjuna

E. tereticornis

H. binata

Plate 1: Growth of MPTs on Bhata land

A. indica

E. officinalis

T. arjuna

E. tereticornis

H. binata

Plate 2: Boles of different MPTs

A. indica

E. officinalis

T. arjuna

E. tereticornis

H. binata

Plate 3: Root growth in different MPTs on Bhata land