Studies on physical, anatomical and chemical characteristics of *Eucalyptus* hybrid wood from two agro-climatic zones of Odisha.

By

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Adm.No.-01 FPU/16

DEPARTMENT OF FOREST PRODUCTS&UTILISATION

COLLEGE OF FORESTRY

ORISSA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY

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A

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CERTIFICATE- I

This is to certify that the thesis entitled **"Studies on physical, anatomical and chemical characteristics of *Eucalyptus* hybrid wood from two agro-climatic zones of Odisha."** submitted in partial fulfillment of the requirements for the award of the degree of **MASTER OF SCIENCE IN FORESTRY (FOREST PRODUCTS & UTILISATION)** to the Orissa University of Agriculture and Technology,Bhubaneswar is a faithful record of *bonafide* and original research work carried out by **Rajesh Kumar Sahoo** under my supervision and guidance. No part of this thesis has been submitted for any other degree or diploma.

It is further certified that the assistance and help received by him from various sources during the course of these studies have been duly acknowledged.

(SRI. SASWAT NAYAK)
CHAIRMAN
ADVISORY COMMITTEE

CERTIFICATE- II

This is to certify that the thesis entitled **"Studies on physical, anatomical and chemical characteristics of *Eucalyptus* hybrid wood from two agro-climatic zones of Odisha."** submitted by **Rajesh Kumar Sahoo, Adm No. 01 FPU/16** to the Orissa University of Agriculture and Technology, Bhubaneswar in partial fulfillment of the requirements for the award of the degree of **MASTER OF SCIENCE IN FORESTRY (FOREST PRODUCTS & UTILISATION)** has been approved by the Student's Advisory Committee after an oral examination on the same in collaboration with an External Examiner.

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Bhubaneswar **(Rajesh Kumar Sahoo)**
Date-

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABBREVIATIONS

^{0}C- Degree celcius

%- Percentage

No.- Number

Hrs- Hours

Fig- Figure

pH- Potential of hydrogen

nm- Nano meter

mm- Milli meter

cm- Centimeter

m- Meter

mm^2 – Milli meter square

mm^3 – Millimeter cube

wt.- Weight

g- Gram

Kg- Kilo gram

Kg/ha- Kilo gram per hectare

ha^{-1}- Per hectare

ml- Milli liter

1^{st} , I- First

2^{nd} , II- Secound

3^{rd} ,III- Third

4^{th} ,IV- Fourth

5^{th} ,V- Fifth

ABSTRACT

The present investigation entitled, **"**Studies on physical, anatomical and chemical characteristics of *Eucalyptus* hybrid wood from two agro-climatic zones of Odisha**"** was carried out in the laboratory of College of Forestry, Orissa University of Agriculture and Technology, Bhubaneswar, Odisha during the period 2017-2018 with objectives to study variability in physical, anatomical and chemical properties of *Eucalyptus* hybrid wood.

In the first experiment, trees are harvested at stump height and wood discs of 2cm height are cut *Eucalyptus* from the basal portion of the tree from which five sections representing five year growth approximately and labelled as 1st year growth ring (Section- I), 2nd year growth ring (Section- II), 3rd year growth ring (Section- III), 4th year growth ring (Section- V) and 5th year growth ring (Section- V) respectively. From each section , one cuboid is prepared and taken for estimation of density and specific gravity for each growth ring . For estimation of chemical properties like cellulose content, hemicellulose content and lignin content, saw dust of 2gm is taken from each growth ring and then analysed . The mean cellulose content (36 %) , hemicellulose content (17.40 %) and lignin content (33.20 %) is more in Titlagarh in comparison to cellulose content (36 %) , hemicellulose content (16.60 %) and lignin content (31.80 %) of Bissamcuttack . Similarly, the mean density (33.20 %) and specific gravity (0.95) is more in Titlagarh in comparison to density (31.80 %) and specific gravity (0.89) of Bissamcuttack.

In the second experiment, for estimation of anatomical features, wood blocks were to be macerated with distilled water and glycerine for 7 days from which transversal and tangential micro-sections were obtained using microtome and slides were prepared. Images were then captured using digital microscope connected to a personal computer and a digital camera. The mean vessel number per unit area is more in Bissamcuttack (18.26) in comparison to Titlagarh(16.99) whereas the mean vessel diameter (0.19mm ,0.30mm) and vessel length (0.17 mm ,0.25 mm) was found more in Titlagarh in comparison to Bissamcuttack. The mean numbers of horizontal parenchyma is more in Titlagarh (18.26/mm^2) in comparison to Bissamcuttack (16.93/mm^2) and the mean horizontal parenchyma length is more in Bissamcuttack (0.23 mm) in comparison to Titlagarh (0.19 mm).

In the third experiment, samples comprising of the surface (0-15cm) and subsurface (15-30) layers from plantation sites of Bissamcuttack and Titlagarh under Rayagada and Bolangir district were collected to study their physico-chemical soil characteristics. The average surface soil pH of the *Eucalyptus* hybrid plantation site at Raygada found to be maximum (5.59) whereas the pH of sub-surface soil for Raygada was found to be 5.01. The surface soil organic carbon concentration of plantation site of *Eucalyptus* hybrid at Rayagada to be 0.50% (medium) and whereas sub-surface organic carbon found to be 0.27%. The available nitrogen content of the surface soil of the plantation site of *Eucalyptus* hybrid found maximum for Titlagarh (133 kg/ha) whereas the available nitrogen content of sub-surface to be 114.56 kg/ha. The available phosphorus content (P_2O_5) of the surface soil of the plantation site of *Eucalyptus* hybrid at Rayagada found to be maximum (22.79 kg/ha) whereas the available phosphorus content of sub-surface soil was recorded to be 18.68 kg/ha .The available potassium content (K_2O) of the surface soil of the plantation site of *Eucalyptus* hybrid at Titlagarh found to be maximum (251.18kg/ha) whereas the available potassium content of sub-surface soil for Titlagarh to be 265.65 kg/ha.

INTRODUCTION

Eucalyptus is a diverse genus of flowering trees and shrubs in the myrtle family, Myrtaceae. The generic name is derived from the Greek words '*eu*' and '*kalypto'* which means "well" and "to cover" respectively, referring to the operculum on the calyx that initially conceals the flower. Many species, though by no means all, are known as gum trees because they exude copious 'kino' from any break in the bark. Eucalyptus is a fast growing, medium- sized to tall tree attaining 20- 50m in height and up to 2m in diameter and strongly coppicing tree possessing a wide range of soil and climatic adaptability. It is known for its drought hardiness, although annual rainfall of 800 mm is preferred. The species grows under a wide range of climatic/soil conditions from warm to hot, sub humid to humid and from good to degraded soil.

The oil extracted from its leaves used for treatment of respiratory illnesses like Coughs, colds, sore throats, asthma and congestion, curing burns, cuts, insect bites, muscle and joint pains. Interest in Eucalyptus research, in India from the point of view of utilization, dates back to Tippu sultan's period when seeds of different species were planted in Nandi Hills, and then successfully introduced to the Nilgiri hills in southern India. For the subsequent large-scale plantations the seed source from Nandi Hills became the center point for wide spread distribution in the afforestation programmes (Kaikini 1961). Eucalyptus plantations were also raised under State and centrally sponsored schemes to meet the demands of local people in respect of the requirement of firewood, small timber, poles etc. Eucalypt was also accepted as a good farm forestry species for planting on field bunds, canal sides and in marginal agricultural lands. In most States, the Forest Departments had schemes providing free supply of seedlings of various species, including eucalypt. The success of Eucalyptus, both for regenerating degraded forest and waste lands, made it one of the main species under Social Forestry Projects. Most requirements of wood based industries were met from government owned forests. The State Governments had entered into long term agreements with the industries to supply raw material. The new National Forest Policy (1988) completely reversed this arrangement. Now, industries have to meet their requirements from farm forestry areas.

The Government forests are to be managed for ecological purposes and to meet requirements of the local communities. With this change in policy, *Eucalyptus*, which has established itself as a good farm forestry species, has a high potent. According to one estimate (Tewari 1992) Eucalyptus plantations were raised to the tune of 4.28 lakh hectares primarily to meet the requirement of fuel wood and paper and pulp industries. The potential productivity is around 5 tons of biomass/ha/yr on an average, but the average production is some 2.5 ton/ha/yr. Some eucalyptus species have attracted attention because of desirable traits such as being fast-growing sources of wood, producing oil that can be used for cleaning and as a natural insecticide, or an ability to be used to drain swamps and thereby reduce the risk of malaria. In India, *Eucalyptus grandis, E. tereticornis, E. globulus, E. camaldulensis, E. citriodora* and some other species are planted to meet the fuel wood, pulp wood and solid wood requirements of the Industry (Sreevani and Rao, 2014).

Natural Eucalyptus hybrids have been developed from the above species like *E. grandis x E. camaldulensis, E. grandis x E. tereticornis, E. camaldulensis x E. tereticornis* etc which are also widely planted and clones of different species and their hybrids have also been developed by various paper industry and govt. organizations. Some studies were made on assessment of wood quality of different Eucalyptus species belonging to different localities of ordinary seed source and clones in India (Miranda and Pereira, 2002). The state of Odisha lies in the tropical zone between latitudes of 17^{o} 47^{o} N – 22^{o} 34^{o} N and longitudes 82^{o} 22^{0}E – 87^{o} 29^{o} with 10 agro climatic zones. The physico-chemical properties of wood depends on the presence, distribution, size, density of the anatomical structures of wood which vary with different localities. Eucalyptus trunks can present large spatial variation in terms of wood quality due to environmental and genetic factors (Raymond 2002). Numerous studies have reported similar patterns of radial (Chafe 1986; Oliveira and Silva, 2003) or longitudinal variation for wood density (Quilho´and Pereira 2001; Alzate *et al*. 2005), wood stiffness (Cruz *et al.* 2003) and micro fibril angle (Evans *et al.* 2000; Lima *et al.* 2004; Hein and Brancheriau, 2011) in the genus Eucalyptus. It has also been studied that the morpho-physiological variations exists between plants of *E. camaldulensis* from locations under different water deficit conditions (Gibson *et al.*, 1994) and even some work has been carried out correlating the anatomy of this species to the different provenances in relation to the climatic and hydric conditions. (James & Bell,

1995).Taking into considerations of such studies the present work has been taken up to assess the variation in anatomical structures and physiochemical properties of wood of Eucalyptus hybrid clones in agroclimatic zone-5 and agroclimatic zone-9 of odisha .

(B) Objective of the study:

(i) To study variability in physical and chemical properties of Eucalyptus hybrid wood.

(ii) To assay the anatomical variations of Eucalyptus hybrid wood grown under different site conditions of Odisha.

REVIEW OF LITERATURE

In this chapter an attempt has been made to review the work done on physical, anatomical and chemical characteristics of Eucalyptus hybrid wood.

The relevant literature pertaining to the present study on "Studies on physical, anatomical and chemical characteristics of Eucalyptus hybrid wood from two agro-climatic zones of Odisha" is reviewed under the following heads:

1. Physical characteristics of wood of Eucalyptus and other tree species
2. Chemical characteristics of wood of Eucalyptus and other tree species
3. Anatomical characteristics of wood of Eucalyptus and other tree species.
4. Soil chemical characteristics

2.1 Physical characteristics of wood Eucalyptus Hybrid

The literature pertaining to the studies on Physical characteristics of wood of Eucalyptus have been reviewed below.

Specific gravity is an important parameter to determine wood quality, pulp yield and strength of paper (Elliott, 1970; Panshin and DeZeeuw, 1970 and Horn, 1974). Spacing did not show any significant effect on specific gravity in *Eucalyptus tereticornis* (Chauhan *et al.* 1983). Taylor (1973). In his studies on *Eucalyptus grand*is observed that specific gravity of stem wood decreased between 5 and 15 ft. above ground and increased with increasing height above 15 ft. Skolmen (1972) studied specific gravity variation in *Eucalyptus robusta* grown in Hawaii at different tree heights along the stem of the tree. The author reported significant variability in specific gravity values along the tree stem.

Olufemi and Malami (2011) concluded that *E. camaldulensis* had an average density of 977.58 kg m^{-3} and static bending strength of 133.33 N mm^{-2}. *E. camaldulensis* collected from three geographical locations were significantly different for both the density and bending strength. Also the modulus of elasticity (stiffness) was 15219.89 N mm^{-2}.

Miranda *et al.* (2009) investigated heartwood and sapwood development in 18 year old *Eucalyptus globulus* trees and reported that the trees possessed a large proportion of heartwood, on average 60% of the wood cross-sectional surface. Spacing was a statistically significant source of variation in heartwood area, which ranged between 99 and 206 cm^2 for the closer (3 × 2) and wider (4 × 5) spacings, respectively. A positive and high statistical significant correlation between heartwood diameter and tree diameter, and larger trees contained more heartwood regardless of spacing. Heartwood proportion in cross- section remained practically constant between spacings but increased with tree diameter class. The sapwood width did not depend on tree diameter growth and remained practically constant at an average of 18 mm (range 15-21 mm), but sapwood area showed a good linear regression with tree diameter.

Wimmer *et al.* (2002) reported that lower density was formed early in the growing season and higher wood density later in six year old *Eucalyptus nitens*. While, Sharma and Sharma (2003) studied wood characteristics of *Eucalyptus tereticornis* Smith under high density and found maximum wood percentage and minimum bark percentage at sixty percent of total tree height. They also found that moisture content and wood density decreased with sampling height

Miranda and Pereira (2001) studied the differences in basic wood density, fibre morphology, chemical composition and pulp yield were studied among 4 provenances of *Eucalyptus globulus* planted in trials at three sites. Sampling was carried out at the age of 9 years. Provenance and site were significant sources of variation for fibre length, cell wall thickness and lumen diameter. At the worst growth quality site, fibres were shorter, with thicker cell walls and smaller lumen diameter. In relation to chemical composition, only extractives showed within tree variation and significant provenance and sites effects.

Quilho and Pereira (2001) sampled *Eucalyptus globulus* trees, 15 years old, at different heights from commercial pulpwood plantations in two sites in Portugal. Tree mean wood basic density averaged 600 kg /m3 and 568 kg /m3 for best and worst site, respectively, and was not correlated with tree growth. Wood density increased from base to top of the tree. Between-tree variation was low with coefficients of variation of site mean below 10%. Bark density (374 kg /m3 and 454 kg /m3 for best and worst site, respectively) did not show significant within tree variation.

Evans *et al.* (2000) worked15 year old *Eucalyptus nitens* trees and reported that after an initial decrease near ground level, density increased with height in the stem. In the radial direction, density first decreased for a few years, then increased towards the bark.

Barrichelo and Brito (1984) studied basic density in longitudinal and radial directions at different heights in *Eucalyptus grandis*. Density was high at the base, decreased up to breast height and then increased to the top.

Bhat and Bhat (1984) examined *Eucalyptus tereticornis* for wood properties like weight, diameter, wood density, bark percentage and moisture content soon after the first year growth. Density at stem height was 2.6 per cent greater than whole tree density reported in 8-9 year old trees. Bark percent by weight was 23.91 per cent, which is smaller to that for other young hardwoods.

Similar types of work on physical properties of wood carried out on other tree species are also reviewed as

Montes *et al.* (2007) studied 1225 trees at 39 months in a provenance/progeny test of *Calycophyllum spruceanum* (Benth.) Hook.f. ex Shum established in three planting zones located in one watershed in the Peruvian Amazon. They reported that density increased significantly from pith to bark in all planting zones. The difference in density between the pith and bark was larger in the zones where trees grew more rapidly, and for trees with faster growth. Phenotypic correlations also suggested that selecting faster growing trees would result in less homogeneous wood density.

Varghese *et al.* (2000) studied growth and wood traits of teak in peninsular India and found that very moist population (Nilambur, Kerala) had best growth and form but comparatively lower wood density on par with the slightly moist natural stand (Nasik) and the dry teak population (Pandarkawda, Maharashtra).Sapwood content was negatively correlated with growth rate with significantly lower values for very moist and moist populations (Nilambur, Top slip and Konni).Wood density and sapwood content showed significant negative and positive trends respectively with latitude.

Matyas and Peszlen (1997) studied wood quality traits of poplar clones and found that age had significant effect on wood quality traits. They observed significant

differences between clonal means for specific gravity. Within tree specific gravity wasgenerally high near the pith, but each clone exhibited different radial patterns.

Butterfield *et al.* (1993) studied two Central American hardwood species: *Hyeronima alchorneoides* and *Vochysia guatemalensis* in the Atlantic lowlands of Costa Rica. They reported that Specific gravity increased radially from pith to bark for both species; ranging from 0.23 to 0.70 (natural) and 0.23 to 0.50 (plantation) for Hyeronima; and from 0.27 to 0.51 (natural) and 0.26 to 0.38 (plantation) for Vochysia. Natural grown trees of both species had significant tree-to-tree variation in specific gravity ($p>0.001$). Neither species had a clearly defined juvenile wood zone.

2.2 Chemical characteristics of wood of Eucalyptus and other tree species

The literature pertaining to the studies on chemical characteristics of wood of Eucalyptus have been reviewed below:

Sartori *et al.* (2016) studied the chemical composition of six commercial hybrids clones of *E. urophylla*×*E. grandis, E. urophylla*×*E. Camaldulensis*, and undisclosed *E. urophylla* hybrids. The hybrids had similar composition, on average (data based on oven dry bark): 16% extractives, mainly corresponding to polar compounds that are soluble in ethanol and water, 19% lignin, 47% polysaccharides, 1% suberin, and 2% ash. The polysaccharides consists mainly of cellulose as indicated by 84% of total neutral monosaccharides in the acid hydrolysate and 10% xylose.

Kasmani *et al.* (2011) reported that by increasing tree age, the amount of cellulose, extractives and lignin increased but the amount of hemicelluloses and ash decreased in *Eucalyptus camaldulensis*. Mohammadi *et al.* (2011) also observed same results for the same species.

Arantes *et al.* (2011) worked on a clone of *Eucalyptus grandis* W. Hill ex Maiden x *Eucalyptus urophylla* S. T. Blake at an age of six years. They reported that, overall, concentrations of extractives and total lignin in the wood tended to decrease with increasing distance from the pith and tended to increase in portions closer to the tree base. While, Dutt and Tyagi (2011) compared 11 eucalypt species for their morphological and chemical characteristics and found satisfactory levels of holocellulose

(except *Eucalyptus camaldulensis*) and Klason lignin content of less than 30 per cent (except *Eucalyptus camaldulensis* and E-348 hybrid).

Kasmani *et al.* (2011) reported that by increasing tree age, the amount of cellulose, extractives and lignin increased but the amount of hemicelluloses and ash decreased in *Eucalyptus camaldulensis*. Mohammadi et al. (2011) also observed same results for the same species.

Sharma and Sharma (2003) found that the lignin content decreased, while holocellulose content increased from ground level to top of the tree of *Eucalyptus tereticornis* Smith.

Unkalker *et al.* (1975) studied lignin content in *Eucalyptus* hybrid. The lignin content decreased from 25 to 23 percent from the base to the top of the tree. They have also reported that the water solubility (cold and hot water) and alcohol-benzene solubility decreased rapidly from bottom to top in 9-10 year trees of Eucalyptus hybrid. Within tree variation for extractives and cellulose content in *Eucalyptus globulus* was noticed by Pereira (1988). The content of hot water percent decreased and alcohol-benzene percentage extractive increased with height in *Eucalyptus robusta* (Chawla and Shanker, 1974).

Similar types of work on chemical properties of wood carried out on other tree species are also reviewed as-

Samariha and Kiaei (2011) studied *Ailanthus altissima* wood of trunks and branches and reported that in trunk wood amount of cellulose, lignin, extractive alcohol-benzene and ash were 47.18, 25.19, 3.5 and 1.25 per cent respectively, whereas, for branch wood the corresponding values were 44.12, 23.86, 3.2 and 1.75 per cent respectively. The amount of cellulose and lignin in the trunk wood and branch wood when compared with other types of wood suggested that relatively high pulp yield can be obtained from them.

Via *et al.* (2007) investigated longleaf pine *(Pinus palustris*) trees and observed that Klason lignin and extractives were strongly influenced by ring age from pith while extractives exhibited more of a height effect than lignin. Lekha and Sharma (2008) reported a decrease in alcohol-benzene soluble extractives with increase in height of the trees of *Acacia catechu* Willd. They also found that lignin content was maximum (24.01

percent) at ground level and minimum at 80 percent of total tree height whereas, holocellulose percentage showed increasing trend with increase in sampling height.

Bodirlau *et al.* (2007) studied oak wood and found that the cellulose content increased with tree's radial growth. The extractives content both in hot water and percent sodium hydroxide solution increased with tree's height, while the cellulose content decreased. Li *et al.* (2007) examined one, three and five year old culms of *Phyllostachys pubescen*s grown in south-eastern USA and reported small but significant increase in holocellulose and α-cellulose contents from the base to the top of the culm at all three ages. In contrast, no significant differences in Klason lignin and ash were detected.

Sharma and Sharma (2005) found that holocellulose content increased and lignin content decreased from ground level to top of the trees of *Robinia pseudoacacia* Linn. They also observed decrease in extractives from base to top of the tree and increase in levels of these extractives with increase in spacing. While, Kumar and Sharma (2005) observed significant negative correlation between hot water extractives of sapwood and alcohol-benzene extractives of sapwood with a correlation coefficient of -0.4590. They also found significant negative correlation between lignin percentage of sapwood and alcohol-benzene soluble extractives of sapwood with a correlation coefficient of -0.2985.

Gierlinger *et al.* (2004) studied larch heartwood from different species and origin (*Larix decidua* var. decidua, *L. decidua* var. sudetica, *L. kaempferi*, *L. eurolepis*). They reported that the hot water soluble extractives were very variable (from5.66 per cent to 20.50 percent of dry weight), but there was no significant variation between the investigated species and origins. In contrast, acetone extractives, the total amount of phenolic and lignin showed significant differences. The concentration of phenolics and lignin was significantly higher in *L. kaempferi* and in *L.urolepis* than in L. decidua

Sheng-Zuo and Wen-Zhong (2003) reported significant variation in cellulose content among poplar clones. There was significant difference in cellulose content among the growth rings, which had an increasing tendency along the direction from pith to bark. Whereas, Sykes *et al.* (2008) reported that there was more variability from ring to ring than at different heights going up the stem in the lignin content of Populus species. The extractives and lignin content did not change with thinning in *Pinus nigra* Arnold trees (Uner *et al.* 2009).

Thakur *et al.* (1999) studied some shrubs of Himachal Pradesh and observed significant variation among the species and diameter classes within a species for lignin and holocellulose contents of wood. The lignin content varied from 20.90 to 29.62 percent. While holocellulose content ranged from 63.54 to 69.84 percent, irrespective of species, zone and diameter class within species.

Stinger and Olson (1987) revealed that total extractive contents did not vary significantly among sampling heights. However, ethyl alcohol-benzene and hot water extractive content exhibited an inverse relationship to height with mean value of 3.7 percent at ground level decreasing to 2.7 percent at 80 percent of the total height of tree. Hot water extractives varied positively with height.

Mullins and Mcknight (1981) worked on aspen (*Populus tremuloides*) and reported the following chemical profile: cellulose 53 per cent, hemicelluloses 31 per cent and lignin 16 per cent, on extractive free wood basis. The amount of extractives was reported at 2.1 per cent (hot water as solvent).

2.3 Anatomical characteristics of wood of Eucalyptus and other tree species.

The literature pertaining to the studies on Anatomical characteristics of wood of Eucalyptus have been reviewed below:

Carrillo *et al.* (2015) studied six 15-year-old *Eucalyptus globulus* trees, ranging in wood density from 474 to 575 kg.m-3, were sampled at breast height for anatomical study and fiber measurement. Vessel and fiber dimensions showed an increase from pith to bark, while vessel frequency decreased. Cell wall thickness, fiber length, runkel ratio and coarseness were significantly superior in the high-density genotypes (group A) in almost each section along the radius analyzed. Lumen width was significantly different among the groups, being higher in group B, but no significant differences were found for vessel features

Sreevani and Rao (2014) studied the basic density, anatomical properties of certain clones of *Eucalyptus tereticornis* developed by ITC Bhadrachalam were reported. The five clones represented by four trees each of four and half years old, were from Sarapaka, Andhra Pradesh. There was clone-to-clone variation for all the properties studied except for vessel length, fibre diameter and fibre percentage. The girth was

positively correlated with ray and parenchyma percentage and negatively with vessel percentage.

Ohshima *et al.* (2014), the relationship between fibre length and vessel element length was examined by their within-tree variations for breeding quality plantation pulpwood from the viewpoints of pulp properties, that is, shorter vessel element and longer fibre are preferable. Because the genetic difference between trees may express the different ratio of fibre length to vessel element length. Within-tree variations in the trunk of fibre length and vessel element length were studied in *Eucalyptus camaldulensis* and E. *globulus* trees grown at the same site. The relationships between fibre length and vessel element length were significant in all trees although the rate of fibre length to vessel element length was significantly different both between individuals in each species and between species.

Rao *et al*. (2002) investigated that within tree variation in anatomical properties of four and half year old grown *Eucalyptus tereticornis* Sm. clones and correlated with specific gravity. Vessel frequency, vessel diameter and fiber length were found to vary significantly from bottom to top with no definite trend. However, highly significant differences have been found between clones among four cell types except fibers. Specific gravity is positively correlated with ray percentage, fiber percentage – vessel percentage ratio and negatively correlated with vessel percentage, while all other anatomical parameters including height and girth have no effect.

Souza *et al.* (1999) studied shoots of *E. camaldulensis* seedlings from three distinct provenances were submitted to three different levels of in vitro water deficit induced by the addition of sorbitol in the growth media. Transversal sections from the leaf blades and stems were anatomically analysed using the historesin inclusion technique. Shoots from the different provenances presented distinct responses to the treatments. The Gilbert River provenance was the most sensible. The basic alterations found on the anatomical structure in response to the water deficit were: cell collapse, late tissue differentiation, vascular bundle and epidermis disorganization, and alterations on the mesophyll and epidermis thickness.

Skene and Balodis (1968) laid experiment on *Eucaluptus obliqua* and found that the proportion of vessel which extend right through a section of tree trunk increases as

the length of the specimen is decreased. A statistical formula is developed to calculate the frequency distribution of vessels from observations of the number of vessels which pass through sections. In *Eucaluptus obliqua* most of the vessels were found to be less than 20 cm long, even though the longest vessels extends up to 4 m in length.

Similar types of work on anatomical properties of wood carried out on other tree species are also reviewed as-

Jing and Tyree (2014) said that scientists have been measuring the vessel length of plants for more than 50 years. The method involves infusing stem or segments with a visible substance that completely fills vessels cut open at the infusion surface. The number of infused vessels is then quantified versus distance from the infusion surface. A theoretical model is then used to convert the counts of infused vessels to a vessel length distribution. Over the years the methods and theory have changed greatly. The purpose of this review is to give the reader an understanding of why vessel length is important and to provide a theoretical basis for selection of the best method and theory to arrive at vessel length data.

Olson and Rosell (2013) found that variation in angiosperm vessel diameter is of major functional significance. They assembled a comparative dataset including vessel and stem diameter measurements from 237 species from over 40 angiosperm orders across a wide range of habits and habitats. Stem diameter predicted vessel diameter across self-supporting plants. Predictable relationships between vessel diameter and stem diameter mirrored predictable relationships between stem length and diameter across self-supporting species. That vessels are proportional to stem diameter and stem diameter is proportional to stem length suggests that taper in relation to conductive path length gives rise to the vessel diameter-stem diameter relationship. In turn, plant size is related to climate, leading indirectly to the vessel-climate relationship: vessels are likely narrower in drier communities because dryland plants are on average smaller, not because they have narrow vessels for their stem sizes.

Fisher *et. al* (2007) tested the hypothesis that trees growing at high elevations with occasional freezing temperatures have smaller diameter xylem vessels than trees of the same species growing at lower and warmer elevations. The young branch wood of the wide- ranging Hawaiian tree species *Metrosideros polymorpha* (Myrtaceae) was examined in three natural field populations (high, middle, and low elevations: 2469,

1280, and 107 m m.s.l., respectively) and contrasted with seedlings from these populations that were grown in a common garden at middle elevation (1190 m). Previous studies showed that these populations have some genetic differences and have distinctive leaf structure and eco-physiological traits. Vessel diameter was significantly smaller in the high elevation field and common garden plants than in middle elevation plants. However, high elevation vessels were wider in common garden plants compared to field plants, indicating that vessel diameter is determined both by genotype (parental populations) and environment (growing conditions different from those of parents). Reduced vessel diameter has implications for resistance to cavitation induced by freezing and/or drought in plants growing near tree line in Hawaii.

Voulgaridis *et al.* (2000) worked on a kenaf plantation (*Hibiscus cannabinus* L.) established in North Greece and reported that the bark consisted of thick and long (2,330 μm) fibres. Vessel diameters decreased from base to top, while vessel member lengths remained constant from base to middle but decreased at the top of the stem.

Chauhan *et al.* (1999) examined anatomical parameters of wood quality such as fi bre characteristics, vessel frequency and diameter and proportion of tissues in 8 year old trees of six *Populus deltoides* clones growing in plantations. The analysis indicated significant clonal variation in specific gravity, fibre length vessel length, fibre diameter, lumen diameter, vessel frequency and vessel diameter. The specific gravity, fibre length and vessel length also show an increase with age. A relative correlation was also observed between vessel area and specific gravity.

Ismail *et al.* (1995) carried out his study and sampled six plantation grown Kelempayan trees [*Neolamarckia cadamba* (Roxb.) Bosser, syn. *Anthocephalus chinensis* (Lamk.) A. Rich. exWalp., Rubiaceae] along their radii and at five different height levels to evaluate variations of wood anatomical properties. Analysis of variance indicates that between tree differences in all anatomical properties measured were significant. Vessel proportion increases while ray proportion decreases with height, while both fibre diameter and fibre lumen diameter decrease with height. No significant trend was found for fibre length vertically. Cell wall substance and vessel and ray proportion increase from pith to bark, while fibre proportion decreases. Fibre length and fibre wall thickness increase from pith to bark, while fibre diameter and fibre lumen

diameter first increase and then decrease. Within-tree variations are more consistent radially than vertically.

Zimmermann and Potter (1982) found that every part of the tree contains a range of vessel lengths, and always a much larger percentage of short than long vessels. Vessel diameter and longest vessel length increase from twigs to branches, down along the stem, to the long, rope-like roots. The percentage of vessels in the shortest length class decreases in the same direction. Although red maple is considered a diffuse-porous species, vessels in latewood are narrower and shorter than in the early-wood in any given part of the tree.

2.4 Soil chemical characteristics

Review of literature on fertility status of soil concerning the present study with respect to soil reaction, organic carbon, available nitrogen, available phosphorus and available potassium are discussed in the following section.

Kotiyal *et al.* (2017) said that the capacity of soils to be productive depends on plant nutrients. The physical, biological, and chemical characteristics of soil influence its fertility. Long term nitrogen fertilization can influence important soil properties such as soil structure and density, soil pH, soil quality and quantity and distribution of soil organic matter and nutrient cycling within. pH of the soils under eucalyptus plantation is varying from 6.1 to 6.6. This shows acidic nature of the soils but the pH of the soils under poplar plantation ranged from 6.9 to 7.7. This means soils are neutral to alkaline in nature. Organic carbon under poplar plantation is varying from 0.7% to 1.2%, whereas, in eucalyptus plantations the organic carbon % varies from 0.3 to 1.3. Organic Matter (OM) % in poplar plantations ranged from 1.2 to 2.1 and in eucalyptus plantations it is 0.6% to 1.6%. Potassium (K) under poplar plantations ranged from 42.56 /ha to 136.64 /ha, whereas in eucalyptus grown area K varies from 44.80 /ha to 154.56 /ha. Results of this study show that nitrogen (N) is higher in concentration under plantations in Haryana soils as it varies from 371.3 /ha to 423.99 /ha under poplar and 371.3 /ha to 381.34 /ha under eucalyptus. Phosphorus (P) under poplar plantations ranges from 40.29 /ha to 59.91 /ha and in eucalyptus plantation the P varies from 49.18 /ha to 115.51 /ha.

Zhang et al. (2012) studied the effect of *Eucalyptus grandis* on soil physicochemical and microbiological properties. The soils were acidic (pH < 5.7) throughout the soil profile at all of the study sites. Neither stand age nor soil layer had any significant effect on soil pH. The soil organic matter content decreased significantly with the soil depth. The soil organic matter content in each layer increased significantly with stand age.

Alemie (2009) conducted study at the Koga Watershed in the Western Amhara region of Ethiopia. The main objective of the study was to observe if the Eucalyptus plantation is harmful for the ecosystem. The study through key informants' interview proved that almost all local farmers perceive that Eucalyptus trees are exhausting the once productive land because of its fast growth. Water points dried up, too. Despite this, the growers insist on planting Eucalyptus because of its fast biomass production to sell it after relative short time for cash income and use in construction. A triplicate experiment was established to understand the effect of Eucalyptus on soil properties, crop production and water bodies. There were no pronounced changes in soil bulk density, organic matter, texture, pH, exchangeable potassium and available water capacity due to Eucalyptus hedgerows along maize farmland. Eucalyptus trees significantly affect available phosphorus (avail. P), exchangeable calcium (exch. Ca), total nitrogen (TN), moisture content (MC), soil hydrophobicity, light intensity and the density of the undergrowth.

Similar types of work on Soil chemical characteristics of wood carried out on other tree species are also reviewed as-

Mishra *et al.* (2014) studied the soils of different blocks of Dhenkanal district in Odisha. They studied soils of Dhenkanal sadar and found pH, E.C and organic carbon to be 5.25, 0.117 dSm-1 and 0.640 % respectively. They found that soils of Kankadahad had pH, EC, organic carbon 4.88, 0.082 dSm-1 and 0.837 %, soils of Bhuban had pH, EC, organic carbon 5.24, 0.088 dSm1 and 0.685 % , soils of Kamakhya nagar had pH, EC, organic carbon 5.26, 0.080 dSm-1 and 0.724 % , soils of Parjang had pH, EC, organic carbon 5.38, 0.098 dSm1 and 0.751% respectively. They also found pH, EC and organic carbon of soil of Odapada to be 5.66, 0.182 dSm1 and 0.822%, soils of Hindol to

be 5.85, 0.094 dSm1 and 0.707%, soils of Gondia to be 5.14, 0.09 dSm1 and 0.756% respectively.

Mishra and Saren (2014) studied the soils of Kankadahada block of Dhenkanal district in Odisha and found the available Sulphur content to be 16.33 mg/kg, the soils of Hindol to be 14.40 mg/Kg , the soils of Gandia block to be 16.35 mg/Kg . Dhenkanal sadar block to be 12.96 mg/ha; Soils of Bhuban block to be 12.38 Mg/ha; Soils of Kamakhya Nagar block to be 14.46 mg/ha. Soils of Parjang to be 17.80 mg/ha. Soils of Odapada block to be 15.70 mg/ha respectively. The mean available sulphur content of the cultivated surface soils of different blocks of Dhenkanal district was found to be in the medium range.

Mishra *et al*.(2013) studied soils of different blocks of Khordha district of Odisha Bolagarh and found pH, EC, organic carbon to be 5.63, 0.043 dSm1 and 0.322 % respectively,

Mishra *et al.* (2013) studied the soil of Jatni block in khordha district in Odisha and found the content of available Nitrogen to be 131.21 Kg/ha. They studied the soils of Chilika and found the content of available Nitrogen to be 143.42Kg/ha, the soils of Begunia contained available Nitrogen of 148.41 Kg/ha, the soils of Bolagarh had available Nitrogen 131.58 Kg/ha. The soils of Tangi had available Nitrogen 146.96 Kg/ha the soils of Balipatna were found to contain available Nitrogen of 155.77 Kg/ha, the soils of Bhubaneswar block contained available Nitrogen of 121.58 kg/ha, the soils of Banpurhad available Nitrogen 147.14 kg/ha, the soils of Khurda contained available Nitrogen to be 148.99 kg/ha, the soils of Balianta had available Nitrogen of 168.60 Kg/ha respectively.

Rahman *et al.* (2012) has studied on some physical soil properties like moisture content, particle density, organic matter, bulk density and porosity between planted and deforested sites at surface (0-10cm) and sub surface (10-30cm) soil of North eastern Bangladesh. They found that moisture content at all the soil depths was higher in planted sites than deforested site. The organic matter on both the plantations and deforested site decreased with the increase of soil depth. Deforested site contained lower soil organic matter than plantation site.

Foth and Ellis (1997)said that descriptive terms commonly associated with certain ranges in pH are extremely acidic (pH < 4.5), very strongly acidic (pH – 4.5 to 5.0), strongly acidic (pH – 5.1 to 5.5), moderately acidic (pH – 5.6 to 6.0), slightly acidic (pH – 6.1 to 6.5), neutral (pH – 6.6 to 7.3), slightly alkaline (pH – 7.4 to 7.8), moderately alkaline (pH – 7.9 to 8.4), strongly alkaline (pH – 8.5 to 9.0) and very strongly alkaline (pH > 9.1).

MATERIALS AND METHODS

The present investigation was conducted during the 2017-2018 in laboratory located at the college of Forestry, OUAT, Bhubaneswar. The details of materials used, techniques adopted and observation noted during the course of this study are presented in this chapter.

3.1 GEOGRAPHICAL LOCATION OF THE EXPERMINTAL SITE

The wood samples were collected from the plantation sites at Bissamcuttack (19º 50'North and 83º 50'East, altitude 342 m above m.s.l) and Titlagarh (20º 28'East and 83º 14'North, altitude 215 m above m.s.l) of Rayagada and Bolangir district respectively. The analysis was carried out in laboratory of College of Forestry, OUAT, Bhubaneswar, which is situated in the campus of the College in Odisha at 20 º 15' North and 85 º 52' East and at altitude of 25.9 m above m.s.l.

3.2 CLIMATE

Bissamcuttack is located on the north eastern ghat agroclimatic zone of Odisha . The summer months from March to May are hot and dry, and temperatures often shoot past 37.65° C in May. It receive average rainfall over 195.08 mm a month. Titlagarh is located on western central table land agroclimatic zones of Odisha . The summer months from March to May are hot and dry, and temperatures often shoot past 43.5° C in May. It receives average rainfall over 115.34 mm a month. College of Forestry OUAT, Bhubaneswar is located on the coastal plains of Odisha, south-west of the river Mahanadi. It experiences typical tropical weather conditions. The summer months from March to May are hot and humid, and temperatures often shoot past 40° C in May. The south west monsoon lashes Odisha and in June to August receive the maximum rainfall, which may average over 220 mm a month.

3.3 EXPERIMENTAL DETAIL

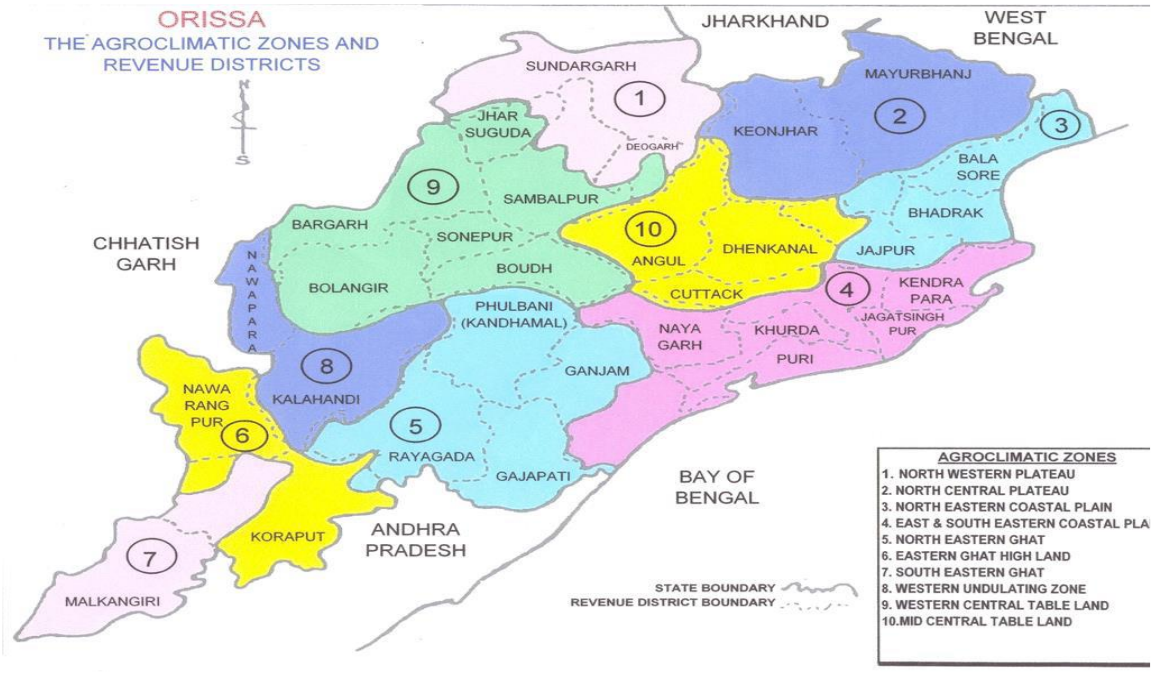
The details of experiments are given below:

3.4. Morphometric characters of sample trees of *Eucalyptus* Hybrid

3.4.1 Selection of sample Trees of *Eucalyptus* Hybrid

Selection of sample trees was done from each five year old plantation of *Eucalyptus* hybrid (*Eucalyptus camaldulensis x Eucalyptus tereticornis*) clone JK-2 at Bissamcuttack and Titlagarh of Raygada and Bolangir district of Odisha respectively under agroclimatic zone 5 and 9. During sampling process, three healthy trees were

considered on the basis of straightness of bole, less branching, devoid of insect pest infestation and diameter at breast height .



The passport detail of the sample Trees are given below :

Sample Tree No.	**Place of collection**	**Block**	**District**	**Agro climatic zone**
R -1	Bissamcuttack	Bissamcuttack	Raygada	5
R -2	Bissamcuttack	Bissamcuttack	Raygada	5
R-3	Bissamcuttack	Bissamcuttack	Raygada	5
B -1	Titlagarh	Titlagarh	Bolangir	9
B -2	Titlagarh	Titlagarh	Bolangir	9
B -3	Titlagarh	Titlagarh	Bolangir	9

3.4.1 Observations recorded

Each sample tree is felled using power saw and then cut into logs of size of 3m length. Observations like mid diameter (cm) of each log by using tree calliper, green biomass (kg), oven dry biomass (kg) and Heart wood - Sap wood proportion is recorded.

Volume Estimation

Volume of each log of 3 m length is calculated and then summed up to find out the tree volume .Volume of log on mid diameter and length basis was calculated by using following formula:

$V = \pi d^2 l / 4$

Where ,

V = Volume of log

d= mid diameter of log

l = length of the log

Tree bole Biomass Estimation

Each converted log is weighed and recorded for each tree after felling. Three samples from each converted green log of about 1kg is taken and recoded and then kept in oven at $102^oC \pm 1^oC$ till constant weight is achieved. After drying, the oven dry weight of sample is recorded and proportionately converted with respect to green weight for each log. Oven dry weight of each log is then added to get the oven dry biomass of the felled tree.

Sapwood - Heart wood Proportion

Trees are harvested at stump height and wood discs of 3-4cm height are cut from the basal portion of the tree. Sapwood and heart wood identified by comparatively darker portion in part of heart wood than sapwood. It is calculated by

Sapwood - Heart wood Proportion = $\pi (R^2 - r^2) / \pi r^2$

Where ,

R = Average radius of wood disc
r = Average radius of heart wood portion of disc

3.4.2 Morphometric Observations

Table -1 Morphometric Observations of sample trees of *Eucalyptus* Hybrid

Place of Sample Collection	Sample trees	Tree height (in m)	DBH (in cm)	Tree Volume (in m^3)	Tree Biomass (Kg)	Heart wood : Sapwood
Bissamcuttack	R-1	18.18	39	1.53	1484.10	5.06 :1.00
	R-2	16.6	35	1.13	1084.80	8.82:1.00
	R-3	12.12	32	0.66	627.00	7.65:1.00
	Mean	**15.63**	**35.33**	**1.11**	**1065.30**	**7.17 :1.00**
Titlagarh	B-1	12.12	40	1.11	987.90	6.98:1.00
	B-2	24.54	43	2.21	2011.10	4.50:1.00
	B-3	12.72	41	1.19	1071.00	7.20:1.00
	Mean	**16.46**	**41.33**	**1.50**	**1356.67**	**6.22:1.00**

3.5 EXPERIMENT 1

To study the Physico-chemical properties of wood samples of *Eucalyptus* hybrid

3.5.1 Lay out experiment

Treatment : 1. Site (2)
2. Wood growth ring (5)
Treatment combinations : 10
Replication : 3(No. of trees per site)

3.5.2 Preparation of sample from wood discs

Sample Trees (Table-1) are harvested at stump height and wood discs of 2cm height are cut from the basal portion of the tree. The disc are dried in oven till achieve constant weight. Then from each disc a strip of 2cm (breadth) to be taken along the radius from pith to bark. Each strip is then divided into five sections representing five year growth approximately and labelled as 1^{st} yr growth ring (Section- I) , 2^{nd} yr growth ring (Section- II) , 3^{rd} yr growth ring (Section- III), 4^{th} yr growth ring (Section- IV) and 5^{th}

yr growth ring (Section- V) respectively. From each section, one cuboid (Dimension- length of growth ring in 2cm x 2cm breadth x 2cm height) is prepared and taken for estimation of density and specific gravity for each growth ring.

For estimation of chemical properties like cellulose content, hemicellulose content and lignin content, saw dust of 2gm is taken from each growth ring and then analysed.

3.5.3 Observations recorded

In case of physical properties, for estimation of density, length (cm), breadth (cm), height (cm) and weight (g) of cuboid derived from each disc is recorded. For determining specific gravity, weight (g) of wood cuboid and weight of water displaced by it is recorded.

In case of chemical properties, cellulose content, hemicellulose content and lignin content are estimated

3.5.4 Estimation

3.5.4.1 Density of wood sample

Density of wood cuboid sample is calculated by

Density = W/ L xBx H

Where ,
W = Oven dry weight of wood cuboid
L = Length of wood cuboid
B= Breadth of wood cuboid
H= Height of wood cuboid

3.5.4.2 Specific gravity of wood sample

Specific gravity of wood sample is determined by the formula

Specific Gravity = Wt. of the wood sample / Wt. of equal volume of water displaced by the wood sample at $4^{o}C$.

3.5.4.3 Cellulose, Hemicellulose and Lignin content of Wood sample

Cellulose, Hemicellulose and Lignin content of Wood sample is done by as per the method followed by Direct method of cellulose, hemicelluloses and Lignin extraction (Moubasher *et al.*, 1982).

2g of fibre was boiled in 2:1 ethanol-toluene solvent for 4 hours using Soxhlet extraction and washed thoroughly and kept in oven for dry weight at 40^{o}C overnight, then divided into two parts in which one part is considered as A fraction.

Second part of residue was treated with 24% KOH for 4hrs at 25^{o}C, washed thoroughly with distilled water dried at 80^{o}C over night and the dry weight taken as B fraction. The same samples again treated with 72% H_2SO_4 for 3hrs to hydrolyze the cellulose and the refluxed with 5% H_2SO_4 for 2hrs.

H_2SO_4 was removed completely by washing it with distilled water, dried at 80^{o}C in oven for overnight and dry weight taken as C fraction.

Cellulose = B-C

Hemicellulose = A-B

Lignin = C

3.5.5 Statistical Analysis

The data regarding the variation in the Physico-Chemical properties of wood were subjected to simple analysis of variance (ANOVA) as described by Snedecor and Cochran (1980) 2nd. Edition. The data were analyzed in statistical package MStatC. Coefficient of variance (CV%) and linear correlation coefficients among studied parameters were also calculated.

3.6 EXPERIMENT 2

To study anatomical properties of wood samples of *Eucalyptus* hybrid

3.6.1 Lay out experiment

Treatment	:	1. Site (2)
		2. Wood growth ring (5)
Treatment combinations	:	10
Replication	:	3(No. of trees per site)

3.6.2 Preparation of sample from wood discs

Wood samples collected from felled sample trees (Table-1) and then wood blocks are prepared from the wood discs as per the methodology adopted in experiment-1. For estimation of width of growth rings, it is identified by using hand lens and measured by using Vernier calliper. For estimation of anatomical features, wood blocks were to be macerated with distilled water and glycerine for 7 days. From each block, transversal and tangential micro-sections were obtained using microtome. It is dehydrated with 50% ethanol .Samples were stained with Safranin for 1 minute , then washed with 50% ethanol and again stained with fast green for 30 second,after that it is placed in distilled water to remove excess fast green stain. The sample is then assembled in a slide using glycerol.

Images were captured using digital microscope connected to a personal computer and a digital camera.

3.6.3 Observations recorded

In case of anatomical features, observations were recorded for width of growth ring (cm), vessels diameter (mm), vessel length (mm), vessel no. /mm2 area, horizontal parenchyma length (mm) and horizontal parenchyma width (mm).

Vessels diameter (mm) and vessel no./mm^2 area were measured using digital microscope using lens 10X from transverse section of wood and vessel length ,

horizontal parenchyma length (mm) and horizontal parenchyma width (mm) measured using lens 10X from tangential section.

3.6.4 Statistical Analysis

The data regarding the variation in the anatomical properties of wood were subjected to Analysis of variance (ANOVA) as described by Snedecor and Cochran (1980) 2nd. Edition. The data were analyzed in statistical package MStatC.

3.7 EXPERIMENT 3

To study the Soil Chemical propertiesof the plantation sites of *Eucalyptus* hybrid

3.7.1 Collection of samples and their processing

Samples (12 No.) comprising of the surface(0-15cm) and subsurface(15-30) layers from plantation sites of Bissamcuttack and Titlagarh under Rayagada and Bolangir district were collected to study their physico-chemical soil characteristics. These soil samples were dried under shed, grinded in wooden hammer,passed through 2mm sieve and preserved in polyethylene bags for laboratory study.

3.7.2 Methods of soil analysis

3.7.2.1 Soil reaction (pH)

The pH of the soil sample was determined in 1:2.5 soil-water suspension after equilibration for half an hour with intermittent stirring using the Systronics pH meter (Model M K VI).

3.7.2.2Organic carbon

One gram of processed soil sample was taken in a dry glass500ml conical flask and added 10 ml of 1N $K_2Cr_2O_7$ and swirl a little. The flask was kept on asbestos sheet. Then added 20 ml of concentrated H_2SO_4 and swirl again two or three times. The flask was allowed to stand for 30 minutes preferably in darkness. Added 200 ml of distilled water, 10 ml of ferroin indicator the contents was titrated against fresh (0.5N) ferrous ammonium sulphate solution till the colour changes to wine red. Simultaneously, a blank was run without soil.

The soils having organic carbon content (%) 0.50% is rated as low, 0.5% to 0.75% as medium and >0.75 % as high.

3.7.2.3 Available Nitrogen

Available nitrogen in soil was determined by using alkaline $KMnO_4$ method (Subbiah & Asija, 1956). One hundred (100 ml) of 0.32% $KMnO_4$ solution was added to 5gm of soil sample in 200ml Kjeldahl flask followed by 25 ml of 2.5% NaOH solution and distilled water. Distillation was continued and the distillate was collected at receiver end in the 250 ml conical flask containing 20 ml boric acid (2%) mixed indicator. The distillate was titrated against 0.02 N H_2SO_4 taken in burette to a pink colour end point. From the amount of H_2SO_4 consumed the amount of available Nitrogen was calculated.

Based on the rating chart, <250 kg N ha^{-1} as low, 250-500 kg N ha^{-1} as medium and > 500 kg ha^{-1} as high, different soils were ratted.

3.7.2.4Available Phosphorus

Available Phosphorus in the surface soil sample were determined by Bray's-1method. Three gram soil was extracted with 21 ml of Bra's-1 solution (0.03 NH_4F and 0.025 N HCl) and was shaken for one minute by mechanical shaker and filtered through Whatman no.42 filter paper. Five ml aliquot was transferred into 25 ml volumetric flask. Then 5ml chloromolybdate solution was added, followed by distilled water to make up the volume up to 20 ml and then 1 ml of diluted $SnCl_2$ (0.5 ml diluted to 66ml) was added and the volume was made up to 25 ml mark. The P concentration was analysed by the help of spectrophotometer (Model: Systronics 166) at 660 nm. The P concentration was calculated from the standard graph prepared by taking different known P concentrations.

Soils containing <32 kg P_2O_5 ha^{-1} were rated as low, 32 to 92 kg P_2O_5 ha^{-1} as medium and >92 kg P_2O_5 ha^{-1} as high.

3.7.2.5Available Potassium

Available potassium in soil was determined by taking 5 g soil sample in 100 ml conical flask and 25 ml of 1N NH_4OAc solution was added to it. Then it was shaken with the

help of mechanical shaker for five minutes, then filtered and the K concentration in the filtrate was analyzed with the help of a Flame photometer (Model: Systronics 128).

Based on the ratting criterion, K_2O<141 kg ha^{-1} as low, K_2O 141-336 kg ha^{-1} as medium and K_2O >336 kg ha^{-1} as high, different soil were ratted.

3.7.3 Climatic data's of sites of *Eucalyptus* hybrid

Climatic data's of the plantation sites of Bissamcuttack and Titlagarh under Rayagada and Bolangir district were collected from world weather onlineand presented in annexure –I

3.7.4 Statistical methods

Correlation between different soil parameters, Physico-Chemical and anatomical properties were found at using suitable statistical methods as outlined by Snedecor and Cochran (1980) 2nd Edition.

EXPERIMENTAL RESULTS

The results obtained during the present course of investigation "Studies on physical, anatomical and chemical characteristics of *Eucalyptus* hybrid wood from two agro-climatic zones of Odisha" are presented in this chapter under

4.1 Studies on Variation in Physico-Chemical properties of wood samples of *Eucalyptus* Hybrid

In this investigation the study was carried out to study the anatomical variations of 5 year old *Eucalyptus* hybrid clones wood grown at Bissamcuttack and Titlagarh of Rayagada and Bolangir district under agroclimatic zone 5 and 9 respectively. The observations were recorded for wood samples under each growth ring for density, specific gravity, cellulose content, hemicelluloses content, holocellulose content and lignin content.

4.1.1 Variation in density of wood samples in growth rings of *Eucalyptus* hybrid.

The studies on variation in density of wood samples in growth rings *Eucalyptus* hybrid collected from Bissamcuttack and Titlagarh of Rayagada and Bolangir district respectively were found significant.

The density of wood sample collected from Titlagarh varies from 952 kg/m^3-986 kg/m^3. The maximum density (986 kg/m^3) was recorded in the section-I whereas the minimum density (952 kg/m^3) was recorded in section-III of the wood disc (Table-2). Similarly, the density of wood sample collected from Bissamcuttack varies from 886 kg/m^3-950 kg/m^3. The maximum density (950 kg/m^3) was recorded in the section-III whereas the minimum density (886 kg/m^3) was recorded in section-II of the wood disc. Among Bissamcuttack and Titlagarh, the mean density is more in Titlagarh (972.4 kg/m^3) in comparison to Bissamcuttack (911.8 kg/m^3).

Table 2 : Variation in Oven dry Density of wood samples of *Eucalyptus H*ybrid

Place of Sample collection	Oven dry Density(Kg/m^3)					Mean
	I	II	III	IV	V	
Bissamcuttack	913 a	886 b	950 d	916 a	894 b	**911.80**
Titlagarh	986 c	974	952 d	968	982 c	**972.40**
Mean	**949.5 eg**	**930.0**	**951. e**	**942.0 fg**	**938.0 f**	

CD value

Factor A(Site)	4.400
Factor B (Growth ring)	7.795
Factor(A X B)	11.367

Table 3 : Variation in Oven dry Specific Gravityof wood samples of *Eucalyptus* Hybrid

Place of Sample collection	Oven dry Specific Gravity					Mean
	I	II	III	IV	V	
Bissamcuttack	0.89 ef	0.86 a	0.92 bdf	0.90 bd	0.88 ae	**0.89**
Titlagarh	0.97 c	0.95 b	0.93 b	0.95 bc	0.97 c	**0.95**
Mean	**0.93 h**	**0.90 g**	**0.92 gh**	**0.92 gh**	**0.92 gh**	

CD value

Factor A(Site)	0.01
Factor B (Growth ring)	0.02
Factor(A X B)	0.03

4.1.2 Variation in Specific gravity of wood samples in growth rings of *Eucalyptus* hybrid.

The studies on variation in Specific gravity of wood samples in growth rings *Eucalyptus* hybrid collected from Bissamcuttack and Titlagarh of Rayagada and Bolangir district respectively were found significant.

The Specific gravity of wood sample collected from Titlagarh varies from 0.93-0.97. The maximum Specific gravity (0.97) was recorded in the section-I and section-V whereas the minimum Specific gravity (0.93) was recorded in section-III of the wood disc (Table-3). Similarly, the Specific gravity of wood sample collected from Bissamcuttack varies from 0.86 – 0.92. The maximum Specific gravity (0.92) was recorded in the section-III whereas the minimum Specific gravity (0.86) was recorded in section-II of the wood disc. Among Bissamcuttack and Titlagarh, the mean Specific gravity is more in Titlagarh (0.95) in comparison to Bissamcuttack (0.89).

4.1.3 Variation in cellulose content of wood samples in growth rings of *Eucalyptus* hybrid.

The studies on variation in cellulose content of wood samples in growth rings *Eucalyptus* hybrid collected from Bissamcuttack and Titlagarh of Rayagada and Bolangir district respectively were found significant.

The cellulose content of wood sample collected from Bissamcuttack varies from 30 % - 35 %. The maximum cellulose content (35 %) was recorded in the section-II, IV and V whereas the minimum cellulose content (30 %) was recorded in section-III of the wood disc. Similarly, the cellulose content of wood sample collected from Titlagarh varies from 30 % - 44 %. The maximum cellulose content (44 %) was recorded in the section-I whereas the minimum cellulose content (30 %) was recorded in section-III of the wood disc (Table-4). Among Bissamcuttack and Titlagarh, the mean cellulose content is more in Titlagarh (36 %) in comparison to Bissamcuttack (33 %).

Table 4 : Variation in Cellulose content of wood samples of *Eucalyptus H*ybrid

Place of Sample collection	Cellulose content (%)					Mean
	I	II	III	IV	V	
Bissamcuttack	32 b	35 c	30 a	35 c	35 c	**33.4**
Titlagarh	44	31 ab	30 a	36	39	**36.0**
Mean	**38.0 d**	**33.0**	**30.0**	**35.5**	**37.0 d**	

CD value

Factor A(Site)	0.70
Factor B (Growth ring)	1.34
Factor(A X B)	1.95

Table 5 : Variation in Hemicellulose content of wood samples of *Eucalyptus* Hybrid

Place of Sample collection	Hemicellulose content (%)					Mean
	I	II	III	IV	V	
Bissamcuttack	18	19 a	19 a	17 b	20	**16.6**
Titlagarh	13	19 a	22	16	17 b	**17.4**
Mean	**15.5**	**19.0**	**20.5**	**16.5**	**18.5**	

CD value

Factor A(Site)	0.35
Factor B (Growth ring)	0.66
Factor(A X B)	0.98

4.1.4 Variation in Hemi cellulose content of wood samples in growth rings of *Eucalyptus* hybrid.

The studies on variation in Hemi cellulose content of wood samples in growth rings *Eucalyptus* hybrid collected from Bissamcuttack and Titlagarh of Rayagada and Bolangir district respectively were found significant.

The Hemi cellulose content of wood sample collected from Bissamcuttack varies from 17 % - 20 %. The maximum Hemi cellulose content (20 %) was recorded in the section-V whereas the minimum Hemi cellulose content (17 %) was recorded in section-IV of the wood disc. Similarly, the Hemi cellulose content of wood sample collected from Titlagarh varies from 13 % - 22 %. The maximum Hemi cellulose content (22 %) was recorded in the section-III whereas the minimum Hemi cellulose content (13 %) was recorded in section-I of the wood disc (Table-5). Among Bissamcuttack and Titlagarh, the mean Hemi cellulose content is more in Bissamcuttack (18 %) in comparison to Titlagarh (17 %).

4.1.5 Variation in Holocellulose content of wood samples in growth rings of *Eucalyptus* hybrid.

The studies on variation in Holocellulose content of wood samples in growth rings *Eucalyptus* hybrid collected from Bissamcuttack and Titlagarh of Rayagada and Bolangir district respectively were found significant.

The Holocellulose content of wood sample collected from Bissamcuttack varies from 49 % - 55 %. The maximum holocellulose content (55 %) was recorded in the section-V whereas the minimum holocellulose content (49 %) was recorded in section-III of the wood disc. Similarly, the holocellulose content of wood sample collected from Titlagarh varies from 51 % -56 %. The maximum holocellulose content (56 %) was recorded in the section-I whereas the minimum holocellulose content (51 %) was recorded in section-II and section-IV of the wood disc (Table-6) .Both Bissamcuttack and Titlagarh has equal amount of mean holocellulose content (52 %).

Table 6 : Variation in Holocellulose content of wood samples of *Eucalyptus H*ybrid

Place of Sample collection	Holocellulosecontent (%)					Mean
	I	II	III	IV	V	
Bissamcuttack	50 a	54	49 a	52 b	55	**52.0**
Titlagarh	57 c	50 a	52 b	52 b	56 c	**53.4**
Mean	**53.5 e**	**52.0 de**	**50.5 d**	**52.0 de**	**55.5**	

CD value

Factor A(Site)	0.7
Factor B (Growth ring)	1.3
Factor(A X B)	1.8

Table 7 : Variation in Lignin content of wood samples of *Eucalyptus* Hybrid

Place of Sample collection	Lignin content (%)					Mean
	I	II	III	IV	V	
Bissamcuttack	33 f	29 e	34 cf	31 ab	32 b	**31.8**
Titlagarh	30 ae	36 d	35 cd	35 cd	30 ae	**33.2**
Mean	**31.5 gh**	**32.5 hi**	**34.5 j**	**33.0 ij**	**31.0 g**	

CD value

Factor A(Site)	0.58
Factor B (Growth ring)	1.01
Factor(A X B)	1.32

4.1.6 Variation in lignin content of wood samples in growth rings of *Eucalyptus* hybrid.

The studies on variation in lignin content of wood samples in growth rings *Eucalyptus* hybrid collected from Bissamcuttack and Titlagarh of Rayagada and Bolangir district respectively were found significant.

The lignin content of wood sample collected from Bissamcuttack varies from 29 % -34 %. The maximum lignin content (34 %) was recorded in the section-III whereas the minimum lignin content (29 %) was recorded in section-II of the wood disc (Table-7). Similarly, the lignin content of wood sample collected from Titlagarh varies from 30 % - 36 %. The maximum lignin content (36 %) was recorded in the section-II whereas the minimum lignin content (30 %) was recorded in section-I and section-V of the wood disc. Among Bissamcuttack and Titlagarh, the mean lignin content is more in Titlagarh (33 %) in comparison to Bissamcuttack (32 %).

4.2 Studies on anatomical variations of *Eucalyptus* hybrid wood grown under different site conditions of Odisha.

In this investigation the study was carried out to study the anatomical variations of 5 year old Eucalyptus hybrid clones wood grown at Bissamcuttack and Titlagarh of Rayagada and Bolangir district respectively. The observations were recorded under each growth ring for width of growth ring, vessels lumen size, length, number per mm^2 area, horizontal parenchyma length, thickness and width.

4.2.1 Variation in Growth ring width of *Eucalyptus* hybrid.

The studies on variation in the growth ring width of *Eucalyptus* hybrid collected from Bissamcuttack and Titlagarh of Rayagada and Bolangir district respectively were found significant.

The width of growth rings of wood sample collected from Bissamcuttack varies from 0.75cm-1.00cm. The maximum width of growth ring (1.00 cm) was recorded in the section-III whereas the minimum width of growth ring (0.75 cm) was recorded in section-V of the wood disc. Similarly, the width of growth rings of wood sample collected from Titlagarh

Table 8 : Variation in Growth Rings of wood samples of *Eucalyptus* Hybrid

Place of Sample collection	Growth Rings (cm)					Mean
	I	II	III	IV	V	
Bissamcuttack	0.90 b	0.85 a	1.00 c	0.90	0.75	**0.88**
Titlagarh	0.85 a	0.90 b	1.10 d	1.10 d	1.00 c	**0.99**
Mean	**0.87 e**	**0.87 e**	**1.05 f**	**1.00 f**	**0.87 e**	

CD value

Factor A(Site)	0.03
Factor B (Growth ring)	0.05
Factor(A X B)	0.07

Table 9 : Variation in Vessel numbers of wood samples of *Eucalyptus H*ybrid

Place of Sample collection	Vessel numbers (No./mm^2)					Mean
	I	II	III	IV	V	
Bissamcuttack	20.67 f	20.33 f	18.33 e	16.00 bc	16.00 bc	**18.26**
Titlagarh	18.33 e	17.33 d	17.33 d	15.33 ab	16.67 cd	**16.99**
Mean	**19.5**	**18.83**	**17.83**	**15.66**	**16.38**	

CD value

Factor A(Site)	0.30
Factor B (Growth ring)	0.56
Factor(A X B)	0.81

varies from 0.85cm-1.10cm (Table-8). The maximum width of growth ring (1.10 cm) was recorded in the section-III and section-IV whereas the minimum width of growth ring (0.75 cm) was recorded in section-V of the wood disc. Among Bissamcuttack and Titlagarh, the mean width of the growth ring is more in Titlagarh (0.99cm) in comparison to Bissamcuttack (0.88cm).

4.2.2 Variation in Vessels per unit area of *Eucalyptus* hybrid.

The studies on variation in the vessel number per unit area of *Eucalyptus* hybrid collected from Bissamcuttack and Titlagarh of Rayagada and Bolangir district respectively were found significant.

The vessel number per unit area of wood sample collected from Bissamcuttack varies from 16.00-20.67cm. The maximum vessel number per unit area (20.67) was recorded in the section-I whereas the minimum vessel number per unit area (16.00) was recorded in section-IV and V of the wood disc. Similarly, the vessel number per unit area of wood sample collected from Titlagarh varies from 15.33-18.33. The maximum vessel number per unit area (18.33) was recorded in the section-I whereas the minimum vessel number per unit area (15.33) was recorded in section-IV of the wood disc (Table-9). Among Bissamcuttack and Titlagarh, the mean vessel number per unit area is more in Bissamcuttack (18.26) in comparison to Titlagarh (16.99).

4.2.3 Variation in Vessel diameter of *Eucalyptus* hybrid.

The studies on variation in the vessel diameter of *Eucalyptus* hybrid collected from Bissamcuttack and Titlagarh of Rayagada and Bolangir district respectively were found significant.

The vessel diameterof wood sample collected from Bissamcuttack varies from 0.16 mm-0.19 mm. The maximum vessel diameter (0.19 mm) was recorded in the section-V whereas the minimum vessel diameter (0.16 mm) was recorded in section-III of the wood disc. Similarly, the vessel diameter of wood sample collected from Titlagarh varies from 0.15mm-0.21mm. The maximum vessel diameter (0.21mm) was recorded in the section-I whereas the minimum vessel diameter (0.15 mm) was recorded in section-II of the wood disc (Table-10). Among

Table 10 : Variation in Vessel diameter of wood samples of *Eucalyptus* Hybrid

Place of Sample collection	Vessel diameter(mm)										Mean
	I		II		III		IV		V		
Bissamcuttack	0.18	bcd	0.17	abc	0.16	ab	0.17	ab	0.19	cde	**0.17**
Titlagarh	0.21	e	0.15	a	0.19	cd	0.21	e	0.20	de	**0.19**
Mean	**0.19**	**g**	**0.16**	**f**	**0.17**	**f**	**0.19**	**g**	**0.19**	**g**	

CD value

Factor A(Site)	0.01
Factor B (Growth ring)	0.01
Factor(A X B)	0.02

Table 11 : Variation in Vessel length of wood samples of *Eucalyptus H*ybrid

Place of Sample collection	Vessel length (mm)										Mean
	I		II		III		IV		V		
Bissamcuttack	0.27	bc	0.24	ab	0.25	ab	0.25	ab	0.27	bc	**0.25**
Titlagarh	0.33	e	0.23	a	0.29	cd	0.33	e	0.32	de	**0.30**
Mean	**0.30**		**0.23**		**0.27**		**0.29**	**f**	**0.29**	**f**	

CD value

Factor A(Site)	0.01
Factor B (Growth ring)	0.02
Factor(A X B)	0.03

Bissamcuttack and Titlagarh, the mean vessel diameter is more in Titlagarh (0.19mm) in comparison to Bissamcuttack (0.17 mm).

4.2.4 Variation in Vessel length of *Eucalyptus* hybrid.

The studies on variation in the vessel length of *Eucalyptus* hybrid collected from Bissamcuttack and Titlagarh of Rayagada and Bolangir district respectively were found significant.

The vessel length of wood sample collected from Bissamcuttack varies from 0.24 mm-0.27 mm. The maximum vessel length (0.27 mm) was recorded in the section-I and V, whereas, the minimum vessel length (0.24 mm) was recorded in section-II of the wood disc (Table-11). Similarly, the vessel length of wood sample collected from Titlagarh varies from 0.23mm-0.33mm. The maximum vessel length (0.33mm) was recorded in the section-I and IV, whereas, the minimum vessel length (0.23 mm) was recorded in section-II of the wood disc. Among Bissamcuttack and Titlagarh, the mean vessel length is more in Titlagarh (0.30mm) in comparison to Bissamcuttack (0.25 mm) .

4.2.5 Variation in number of Horizontal Parenchyma of *Eucalyptus* hybrid.

The studies on variation in the numbers of horizontal parenchyma of *Eucalyptus* hybrid collected from Bissamcuttack and Titlagarh of Rayagada and Bolangir district respectively were found significant.

The numbers of horizontal parenchymaof wood sample collected from Bissamcuttack varies from 15.33/mm^2-18.67/mm^2. The maximum numbers of horizontal parenchyma (18.67 / mm^2) was recorded in the section-V, whereas, the minimum numbers of horizontal parenchyma (15.33/mm^2) was recorded in section-III of the wood disc (Table-12). Similarly, the numbers of horizontal parenchyma of wood sample collected from Titlagarh varies from 17.33/mm^2-19.67/mm^2. The maximum numbers of horizontal parenchyma (19.67/mm^2) was recorded in the section-I, whereas, the minimum numbers of horizontal parenchyma (17.33/mm^2) was recorded in section-IV of the wood disc. Among Bissamcuttack and Titlagarh, the mean numbers of horizontal parenchyma is more in Titlagarh (18.26/mm^2) in comparison to Bissamcuttack (16.93/mm^2).

Table 12 : Variation in Horizontal Parenchyma numbers of wood samples of *Eucalyptus* Hybrid

Place of Sample collection	Horizontal Parenchyma (No. / mm^2)					Mean
	I	II	III	IV	V	
Bissamcuttack	16.33 a	16.33 a	15.33	18.67	18.00 c	**16.93**
Titlagarh	19.67	18.67	17.67 b	17.33 b	18.00 c	**18.26**
Mean	**18.00**	**17.50**	**16.50**	**18.00 d**	**18.00 d**	

CD value

Factor A(Site)	0.24
Factor B (Growth ring)	0.40
Factor(A X B)	0.53

Table 13 : Variation in Horizontal Parenchyma Length of wood samples of *Eucalyptus Hybrid*

Place of Sample collection	Horizontal Parenchyma Length (mm)					Mean
	I	II	III	IV	V	
Bissamcuttack	0.23 cde	0.26 e	0.25 d	0.21 abcd	0.21 abcd	**0.23**
Titlagarh	0.16 a	0.18 ab	0.18 ab	0.20 abc	0.25 cde	**0.19**
Mean	**0.19 f**	**0.22 g**	**0.21 fg**	**0.20 f**	**0.23 g**	

CD value

Factor A(Site)	0.01
Factor B (Growth ring)	0.02
Factor(A X B)	0.03

4.2.6 Variation in Horizontal Parenchyma length of *Eucalyptus* hybrid.

The studies on variation in the horizontal parenchyma length of *Eucalyptus* hybrid collected from Bissamcuttack and Titlagarh of Rayagada and Bolangir district respectively were found significant.

The horizontal parenchyma length of wood sample collected from Bissamcuttack varies from 0.21mm-0.26mm. The maximum horizontal parenchyma length (0.26mm) was recorded in the section-II, whereas, the minimum horizontal parenchyma length (0.21mm) was recorded in section-IV and V of the wood disc. Similarly, the horizontal parenchyma length of wood sample collected from Titlagarh varies from 0.16mm-0.25mm. The maximum horizontal parenchyma length (0.25mm) was recorded in the section-V, whereas, the minimum horizontal parenchyma length (0.16mm) was recorded in section-I of the wood disc (Table-13). Among Bissamcuttack and Titlagarh, the mean horizontal parenchyma length is more in Bissamcuttack (0.23 mm) in comparison Titlagarh to (0.19 mm).

4.2.7 Variation in Horizontal Parenchyma width of *Eucalyptus* hybrid.

The studies on variation in the horizontal parenchyma width of *Eucalyptus* hybrid collected from Bissamcuttack and Titlagarh of Rayagada and Bolangir district respectively were found non-significant.

The horizontal parenchyma width of all wood samples collected from Bissamcuttack and parenchyma found to be 0.02 mm. There is no variation in parenchyma width in the wood samples from the two places.

4.3 Soil Chemical Properties

4.3.1 Soil reaction (pH 1:2.5)

The negative logarithm of hydrogen ion activity in soil is called as soil pH. Itcontrols most of the soil chemical reactions **(**Foth and Ellis, 1997). It is the mostimportant and fundamental character of soil. pH of the horizon soils were determinedby pH meter and presented in table- 4. The average surface soil pH of the Eucalyptus hybrid plantation site at Raygada found to be 5.59 where as the pH of sub-surface soil was found to be 5.01.

Similarly, the soil pH for surface soil of the plantation site of Eucalyptus hybrid at Titlagarh was recorded to be 4.69

Table 14 : Variation in Horizontal Parenchyma Width of wood samples of *Eucalyptus* Hybrid

Place of Sample collection	Horizontal Parenchyma Width (mm)					Mean
	I	II	III	IV	V	
Bissamcuttack	0.02 a	0.02 a	0.02 a	0.02 a	0.02 a	**0.02 c**
Titlagarh	0.02 a	0.02 a	0.02 a	0.02 a	0.02 a	**0.02 c**
Mean	**0.02 b**	**0.02 b**	**0.02 b**	**0.02 b**	**0.02 b**	

CD value

Factor A(Site)	0.01
Factor B (Growth ring)	0.02
Factor(A X B)	0.03

Table -15 Physico-Chemical parameters of plantation sites of *Eucalyptus* Hybrid

Place of Sample Collection	Soil Layer	Soil pH	Organic Carbon (%)	N (Kg/ha)	P_2O_5 (Kg/ha)	K_2O (Kg/ha)
Bissamcuttack	0-15 cm	5.59	0.50	119.75	22.79	196.12
	15-30 cm	5.01	0.27	101.43	18.68	201.45
Titlagarh	0-15 cm	4.69	0.24	133.00	18.35	251.18
	15-30 cm	4.26	0.19	114.56	14.36	265.65

whereas the pH of the sub-surface soil was found to be 4.26. The soil pH value was maximum in surface soil and decreased in sub-surface soil.

4.3.2 Soil Organic Carbon

Soil organic carbon (SOC) is one of the most important indicator of soil health. In sub-tropical climatic condition, the soil health is good if organic carbonsequestration is more. The data were presented in Table-14. It wasrevealed that surface soil organic carbon concentration of plantation site of Eucalyptus hybrid at Rayagada to be 0.50% where as sub-surface organic carbon concentration found to be 0.27%. Similarly, surface soil organic carbon concentration of plantation site of Eucalyptus hybrid at Titlagarh found to be 0.24% where as sub-surface organic carbon concentration found to be 0.19%. The values was maximum in surface soil and decreased downwards in sub-surface soil layer.

4.3.3 Available Nitrogen

The available nitrogen content of the soils of the study area ispresented in the Table No.14. The available nitrogen content of the surface soil of the plantation site of Eucalyptus hybrid at Rayagada found to be 119.75 kg/ha where as the available nitrogen content of sub-surface soil was recorded to be 101.43 kg/ha . Similarly, the available nitrogen content of the surface soil of the plantation site of *Eucalyptus* hybrid at Titlagarh found to be 133 kg/ha where as for sub soil it was recorded to be 114.56 kg/ha .The available nitrogen content was maximum in surface soil and decreased downwards in sub-surface soil layer.

4.3.4 Available Phosphorus

The available phosphoruscontent of the soils of the study area is presented in the Table No.14. The available phosphorus content of the surface soil of the plantation site of Eucalyptus hybrid at Rayagada found to be 22.79 kg/ha whereas the available phosphorus content of sub-surface soil was recorded to be 18.68kg/ha. Similarly, the available phosphorus content of the surface soil of the plantation site of Eucalyptus hybrid at Titlagarh found to be 18.35 kg/ha whereas for sub soil it was recorded to be 14.36 kg/ha. The available phosphoruscontent was maximum in surface soil and decreased downwards in sub-surface soil layer.

4.3.5 Available Potassium

The available potassium content of the surface soil of the plantation site of Eucalyptus hybrid at Rayagada found to be 196.12kg/ha where as the available potassium content of sub-surface soil was recorded to be 201.45kg/ha . Similarly, the available potassium content of the surface soil of the plantation site of Eucalyptus hybrid at Titlagarh found to be 251.18kg/ha where as for sub soil it was recorded to be 265.65kg/ha . The available potassium content was lower in surface soil layer in comparison to the sub-surface soil layer.

4.4 Correlation between meterological data, soil data, anatomical and physico-chemical properties of wood

Correlation coefficient among meterological data, soil data anatomical and physico-chemical properties of wood prescribed in Table-16.

Rainfall showed significant positive correlation in case of density of wood (0.393), specific gravity (0.308), pore diameter (0.311) and parenchyma length (0.467).

Relative humidity showed significant correlation in case of density of wood (0.234), pore diameter (0.517) and parenchyma length (0.356).

Cellulose content showed significant correlation in case of density of wood (0.234), vessel length (0.361), parenchyma number (0.401) and holocellulose content (0.521).

Vessel length showed significant correlation in case of pore diameter (0.534).

Available soil nitrogen content showed significant correlation in case of density (0.326) and specific gravity (0.317).

Available phosphorus content of the soils showed significant correlation in case of density of wood (0.254).

Available potassium content of the soils showed significant correlation in case of specific gravity of wood (0.221).

Soil organic carbon content showed significant correlation in case of density of wood (0.271), specific gravity (0.415), Cellulose content (0.302), hemi cellulose content (0.212), lignin content (0.277) and number of pores (0.258)

Table -16 Correlation study of meterological data , soil data , anatomical and physico-chemical parameters of wood

	max temp	*min temp*	*rainfall*	RH (%)	*Density (kg/cm)*	*Specific gravity*	*Cellulose (%)*	*Hemicellulose (%)*	*Lignin (%)*	*number of pores*	*pore dia*	*vessel length*	*pare number*	*pare length*	N	P	K	C
max temp	1.000																	
min temp	0.708**	1.000																
rainfall	-0.331**	0.360**	1.000															
RH (%)	-0.353**	0.206*	0.533**	1.000														
Density(kg/cm)	-0.645**	-0.134	-0.393**	-0.234*	1.000													
Specific gravity	-0.688**	-0.290*	-0.308**	0.058	0.862**	1.000												
Cellulose (%)	-0.179	-0.560**	-0.322**	-0.232*	0.326*	0.310	1.000											
Hemicellulose(%)	0.126	0.534**	0.471**	0.220*	0.277	0.219*	-0.778**	1.000										
Lignin (%)	0.105	0.174	0.119	-0.231*	0.005	0.184	-0.488**	0.237*	1.000									
number of pores	0.032	-0.076	0.311**	0.317**	0.041	-0.050	-0.298*	0.299*	-0.268*	1.000								
pore dia.	-0.341**	-0.080	-0.236*	0.214*	0.263*	0.284*	0.245*	0.160	-0.025	-0.250*	1.000							
vessel length	-0.572**	-0.643**	-0.070	0.085	0.141	0.249*	0.361**	-0.079	-0.293*	0.198	0.534**	1.000						
parenchyma No.	0.476**	0.079	-0.346**	-0.512**	-0.185	-0.263*	0.401**	-0.522**	0.007	-0.042	-0.317**	-0.074	1.000					
parenchyma length	-0.161	0.159	0.467**	0.356**	-0.244*	0.010	0.067	0.041	0.258*	-0.654**	0.216*	-0.054	-0.380**	1.000				
N	0.116	0.225*	-0.218*	-0.063	0.326**	0.317**	0.302*	0.212*	0.277*	0.092	0.287*	-0.256*	-0.305**	0.117	1.000			
P	0.008	-0.095	0.160	0.112	0.254*	0.276*	0.033	0.036	0.056	-0.075	-0.284*	-0.250*	-0.214	0.267*	-0.900**	1.000		
K	0.085	0.213*	-0.201*	-0.072	0.293*	0.221*	-0.067	-0.101	0.189	-0.283*	-0.471	0.053	-0.140	0.128	0.982**	-0.911**	1.000	
C	0.127	0.242*	-0.207*	-0.090	-0.271*	-0.215*	0.169	0.289*	0.208*	0.258*	-0.349**	0.116	0.191	0.096	0.987**	-0.918**	0.993**	1.000

*and** indicates correlation estimate significance at 5% and 1% level respectively

DISCUSSION

The results obtained during the present course of investigation **"**Studies on physical, anatomical and chemical characteristics of *Eucalyptus* hybrid wood from two agro-climatic zones of Odisha**"** are discussed in this chapter under the following heads:

5.1 Studies on Physico-Chemical properties of wood samples of *Eucalyptus* Hybrid

The wood samples from different growth rings of Bissamcuttack varies with cellulose content (30 % - 35 %) , hemicellulose content (17 % - 20 %) and lignin content (29 % -34 %) where as the wood samples from different growth rings of Titlagarh varies with cellulose content (30 % - 44 %) , hemicelluloses content (13 % - 22 %) and lignin content (30 % - 36 %) . In both the sites the cellulose content, hemicellulose content and lignin content is found to vary irregularly from the 1st yr growth ring to 5th year growth ring. This may be because sample is collected from 5 year old *Eucalyptus* hybrid clone where the heart wood development is on preliminary stage and the percentage of sapwood is only about 88.5 % in Bissamcuttack and 86.15% in Titlagarh. However, in the wood sample of 5th year growth (section –V) most of these values showed higher values except lignin content. Similar findings was reported by Downes (2010) mentioning cellulose content increases from pith to the bark portion of the wood samples.

The mean cellulose content (33.4 %) , hemicellulose content (17.40 %) and lignin content (33.20%) is more in Titlagarh in comparison to cellulose content (36 %) , hemicellulose content (16.60 %) and lignin content (31.80 %) of Bissamcuttack (Fig-1) which may be due to distribution, proportion , dimensions of vessels , parenchyma cells , fibres and other anatomical features of wood.

The wood samples from different growth rings of Titlagarh showed variation in density from 952 kg/m^3-986 kg/m^3 whereas Bissamcuttack from 886 kg/m^3- 950 kg/m$^{3.}$ Similarly, the specific gravity of the wood samples from different growth rings of Titlagarh varies from 0.93-0.97 whereas for Bissamcuttack from 0.86 – 0.92. In both the sites the density and specific gravity is found to vary irregularly from the 1st yr growth ring to 5th year growth ring. This may be because sample is collected from 5 year old *Eucalyptus* hybrid clone where the heart wood development is on initial stage.

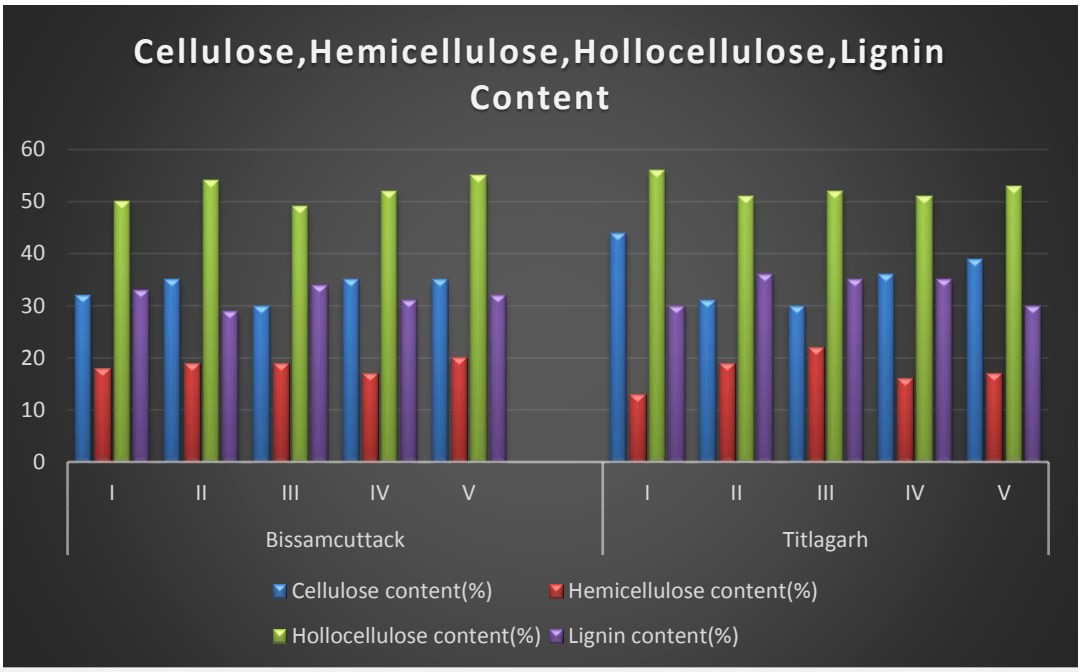


Figure 1: Variation in Cellulose ,Hemicellulose, Hollocellulose, Lignin Content in wood samples.

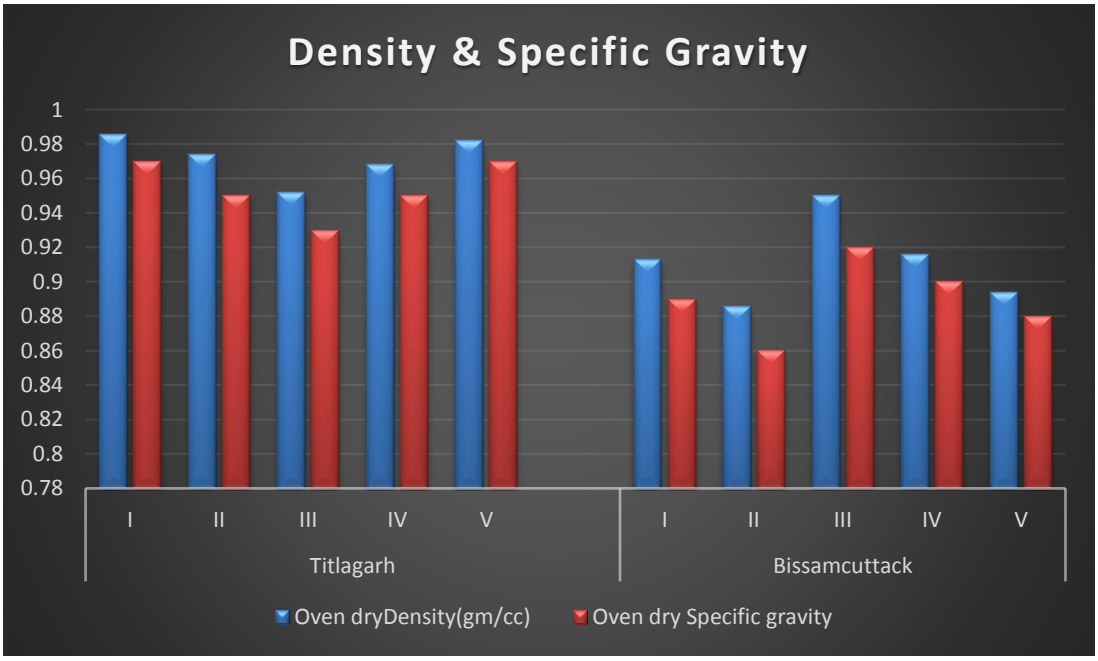


Figure 2: Variation in density and Specific gravity variation in wood.

The mean density (33.20 %) and specific gravity (0.95) is more in Titlagarh in comparison to density (31.80 %) and specific gravity (0.89) of Bissamcuttack (Fig-2) which may be due to higher content of cellulose content, hemicellulose content and lignin content in Titlagarh wood sample in comparison to Bissamcuttack.

5.2 Studies on anatomical variations of *Eucalyptus* hybrid wood grown under different site conditions of Odisha.

The studies on variation in the growth ring width of *Eucalyptus* hybrid found that the maximum width of growth ring (1.00 cm and 1.10 cm) was recorded in the 3rd year growth ring (section-III) of wood collected from Bissamcuttack and Titlagarh respectively. This may be due to the effect of both cambial activity and environmental conditions favouring the growth of the plant during its 3rd year growth period. The mean width of growth ring of wood samples (Fig-3) was higher (0.99 cm) for Bissamcuttack than Titlagarh (0.88 cm) which is due to higher rate of cambial activity, soil and environmental conditions favouring more growth by the same clone under favourable environmental and edaphic conditions at Bissamcuttack.

The maximum vessel number per unit area (20.67/mm^2, 18.33/mm^2) of Bissamcuttack and Titlagarh (Fig-4) respectively was recorded in the section-I of the wood samples for both places, however, the vessel number per unit area in wood samples from both places decreases in direction from pith to bark. However, vessel diameter and vessel length (0.18mm and 0.27mm; 0.21mm and 0.23mm) found higher value in the section -I of the wood samples from Bissamcuttack and Titlagarh which decreased to (0.17mm and 0.24mm; 0.15mm and 0.23mm) in section-II and then gradually increased till section-V (0.19mm and 0.27; 0.20mm and 0.33mm) of the wood samples.

It may be due variation in cambial growth, environmental factors or interaction of both. In both sites, in the 1st year of growth rings, vessels are more abundant, larger in size and length than those formed in the more mature wood nearer to the bark. This due to during 1st year growth *Eucalyptus* hybrid clone may adapts to produce more vessels of wider lumen size and length so as to supply the required water and nutrients for attaining maximum growth for establishment of the tree. From the 2nd onwards till 5th year, no. of vessels/mm^2 area decreased whereas vessel diameter and vessel length decreased during

2nd year growth then increased till 5th year. This may be with the increasing diameter in second year, the total no of pores produced till 2nd year is sufficient to support the supply of minerals and water even if vessel number and vessel diameter decreased. However, from 3rd year onwards till 5th year vessel diameter and vessel length increased with decrease in vessel numbers. In this period of growth, cambium of the tree begins to form wider vessels, larger length and with lower frequency. Besides this vessel diameter size and number also may be affected by environmental and edaphic conditions responsible for water transmission. The variation pattern of vessel frequency, vessel diameter and length found from 3rd yr till 5th yr growth in this study is consistent with the existing reports which indicated an increase in the lumen size of vessels and length as cambial age increases, while vessel frequency decreases (Carvalho, 1997; Hudson *et al.*, 1998; Leal *et al.* 2003; Ramírez *et al.*, 2009). It has also been reported that the average vessel length increases with vessel diameter to maintain the partitioning of hydraulic resistance between lumina and end walls (Hackel *et al*., 2006).

The mean vessel number per unit area is more in Bissamcuttack (18.26) in comparison to Titlagarh (16.99) may be higher conductivity of water in wood vessels of *Eucalyptus* hybrid in Bissamcuttack as it is a comparatively moist place than Titlagarh. Similar findings reported mentioning Vessel Percentage measures indirectly water conductivity into trunk (Villar *et al*. 1994). The mean vessel diameter (0.19mm, 0.30mm) and vessel length (0.17 mm, 0.25 mm) are more in Titlagarh in comparison to Bissamcuttack (Fig-3). This may be due to as cambial age increases in matured wood there is an increase in the lumen size of vessels and vessel length where as vessel frequency decreases.

The numbers of horizontal parenchyma of wood sample collected from Bissamcuttack varies from 15.33/mm^2-18.67/mm^2. The horizontal parenchyma number decreased from 1st year growth (section-I) to minimum (15.33/mm^2) in 3rd year growth (section-III) and then increased for 5th year growth (section-V). This may be due to more requirement of food storage in initial years resulting more synthesis of horizontal parenchyma cells which then decreased till 3rd year growth of plant. After 3rd year till 5th year may be due to effect of environmental irregularities, physiological mechanism of tree or both, the no. of horizontal parenchyma again raised to increase stored food materials required for that period. Palermo *et al*.(2015) reported similar type of

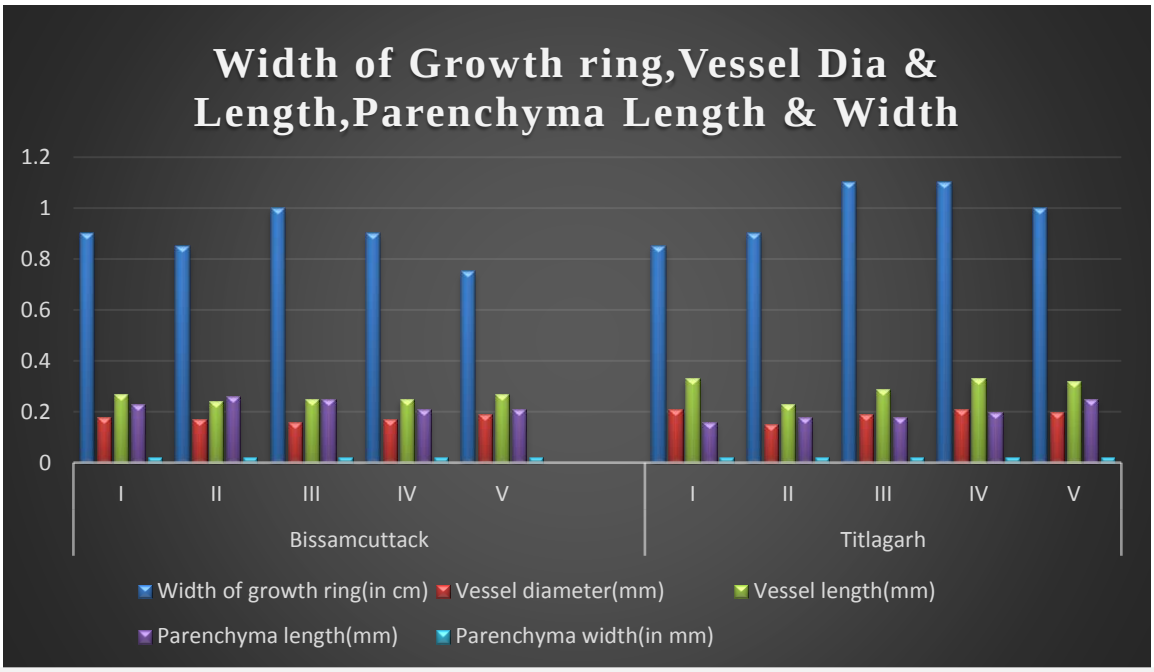


Figure 3: Variation of width of growth ring, vessel diameter & length, Parenchyma length & width in wood samples.

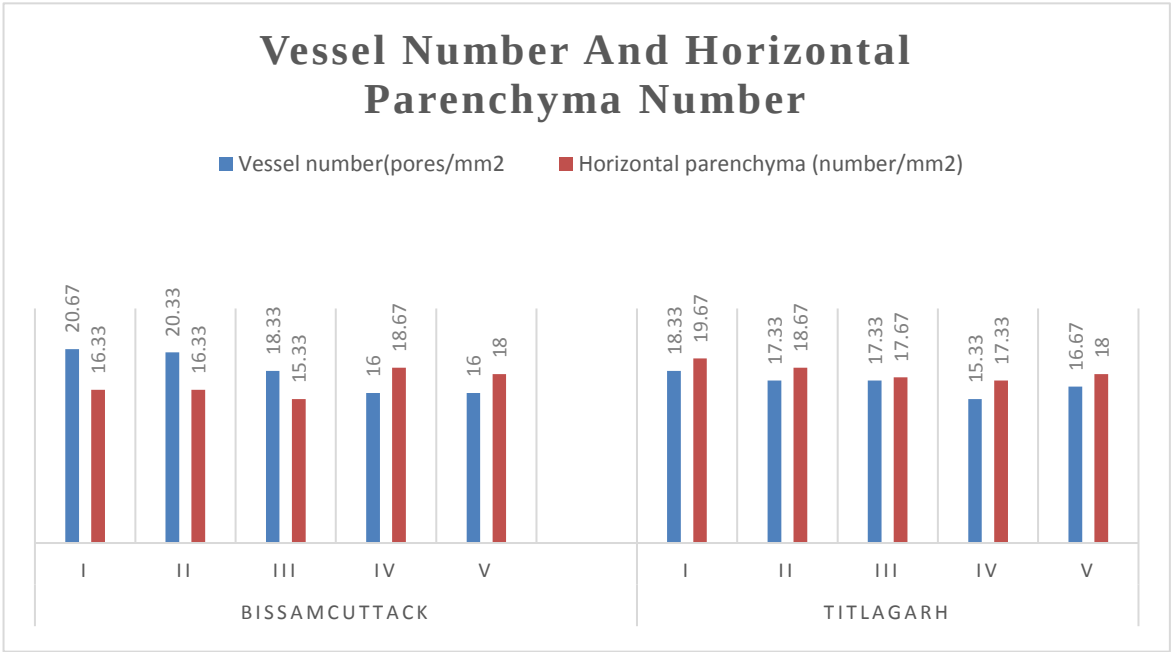


Figure 4: Variation in Vessel number and Horizontal Parenchyma Number in wood ssamples.

observation in *Eucalyptus grandis* that horizontal parenchyma decreased from juvenile stage to minimum in transitional stage and further increased to maximum in matured stage of the plant.

However, in case of Titlagarh, horizontal parenchyma number decreased from maximum (19.67/ mm^2) in 1st year growth (section-I) to minimum (17.33/mm^2) in 4th year growth (section-V) and then increased in 5th year (18.00/mm^2). Horizontal parenchyma number decreased from pith towards matured wood near bark zone may be as the storage of food materials is required more in the initial years of plant growth than in lateral stages. Besides that with age cambial layer produces larger size parenchyma cells. However the increase in parenchyma number in 5th year growth period may be due to environmental irregularities, physiological mechanism of tree or both. Similar findings are reported by Rahman (2005) mentioning horizontal parenchyma number increased or decreased from the pith to about 10 rings and thereafter remained more or less constant.

The mean numbers of horizontal parenchyma (Fig-1) is more in Titlagarh (18.26/ mm^2) in comparison to Bissamcuttack (16.93/mm^2). This may be due to more no .of horizontal parenchyma's are produced for food storage and translocation in the Titlagarh site which is a comparatively drier tract than Bissamcuttack.

The horizontal parenchyma length of wood sample collected from Bissamcuttack varies from 0.21 mm-0.26 mm. Similarly, the horizontal parenchyma length of wood sample collected from Titlagarh varies from 0.16 mm-0.25 mm. The mean horizontal parenchyma length is more in Bissamcuttack (0.23 mm) in comparison Titlagarh to (0.19 mm). In both cases the length of horizontal parenchyma cells increases or decreases in irregular fashion from the pith to the bark of the wood samples. Similar findings was reported by Rahman (2005) mentioning horizontal parenchyma length increased or decreased from the pith to about 10 rings and thereafter remained more or less constant.

In case of Parenchyma width (Fig-3) there is no difference between parenchyma cells of wood samples from Bissamcuttack and Titlagarh.

5.3 Soil Chemical Properties

5.3.1 Soil reaction (pH)

The average surface soil pH of the *Eucalyptus* hybrid plantation site at Raygada found to be 5.59 and Titlagarh to be 4.69 where as the pH of sub-surface soil for Raygada was found to be 5.01 and Titlagarh to be 4.26 (Fig-5) . The soil pH value was maximum in surface soil and decreased in sub-surface soil. In fact around 70% soils of Odisha are acidic because of the high rainfall (1500 mm) in the state due to which most of the bases go down and are deposited in the lower layers (Nanda *et al.*, 2008). It is more seen in the forest area of Odisha because of the contribution of organic acid secreted from the decomposed organic matter which are found in large quantity in the surface horizon of plantations.

5.3.2 Soil Organic Carbon (%)

It was revealed that surface soil organic carbon concentration of plantation site (Fig-5) of *Eucalyptus* hybrid at Rayagada to be 0.50% (medium) and for Titlagarh to be 0.24% 9 (low) where as sub-surface organic carbon concentration of plantation site of *Eucalyptus* hybrid at Rayagada found to be 0.27% (low) and Titlagarh to be 0.19% (low) . The values was maximum in surface soil and decreased downwards in sub-surface soil layer. The higher organic carbon content in the surface layer in comparison to subsurface layer in both cultivated and forest soils have been observed by Mishra (1987); Mishra (2005) and Sahani (2016).

5.3.3 Available Nitrogen

The available nitrogen content of the surface soil of the plantation site of *Eucalyptus* hybrid at Rayagada found to be 119.75 kg/ha and for Titlagarh found to be 133 kg/ha where as the available nitrogen content of sub-surface soil of Rayagada was recorded to be 101.43 kg/ha and Titlagarh to be 114.56 kg/ha (Fig-6) . The available nitrogen content in both sited are considered to be low. The available nitrogen content was maximum in surface soil and decreased downwards in sub-surface soil layer. As organic carbon is mineralised by decomposition of microorganisms to release available nitrogen, the surface layer contains more amount of available nitrogen because of higher content

of organic carbon. Such types of findings have been observed by Mishra (1987) and Sahani (2016) in the soils of forest area of Odisha.

5.3.4 Available Phosphorus

The available phosphorus content (P_2O_5) of the surface soil of the plantation site of *Eucalyptus* hybrid at Rayagada found to be 22.79 kg/ha (low) and Titlagarh to be 18.35 kg/ha (low) where as the available phosphorus content of sub-surface soil of Rayagada was recorded to be 18.68 kg/ha (low) and Titlagarh to be 14.36 kg/ha (low) (Fig-6). The higher amount of available phosphorus content of surface layer would be related to the higher organic matter content in this layer. Similar findings have been achieved by Sahani (2016) while studying the forest soils of Sundargarh district of Odisha.

4.3.5 Available Potassium

The available potassium content (K_2O) of the surface soil of the plantation site of *Eucalyptus* hybrid at Rayagada found to be 196.12 kg/ha and Titlagarh found to be 251.18 kg/ha where as the available potassium content of sub-surface soil for Rayagada to be 201.45 kg/ha and Titlagarh to be 265.65 kg/ha (Fig-6) . The available potassium content in both sites are found to be medium. The available potassium content was lower in surface soil layer in comparison to the sub-surface soil layer. The good amount of available potassium present in both surface and subsurface layer of the plantation site because of the formation of the soils in these areas from potash bearing minerals like feldspar and mica. Similar findings have been observed by Mishra *et al.* (2013); Mishra and Saren (2014) and Mishra *et al.* (2016).

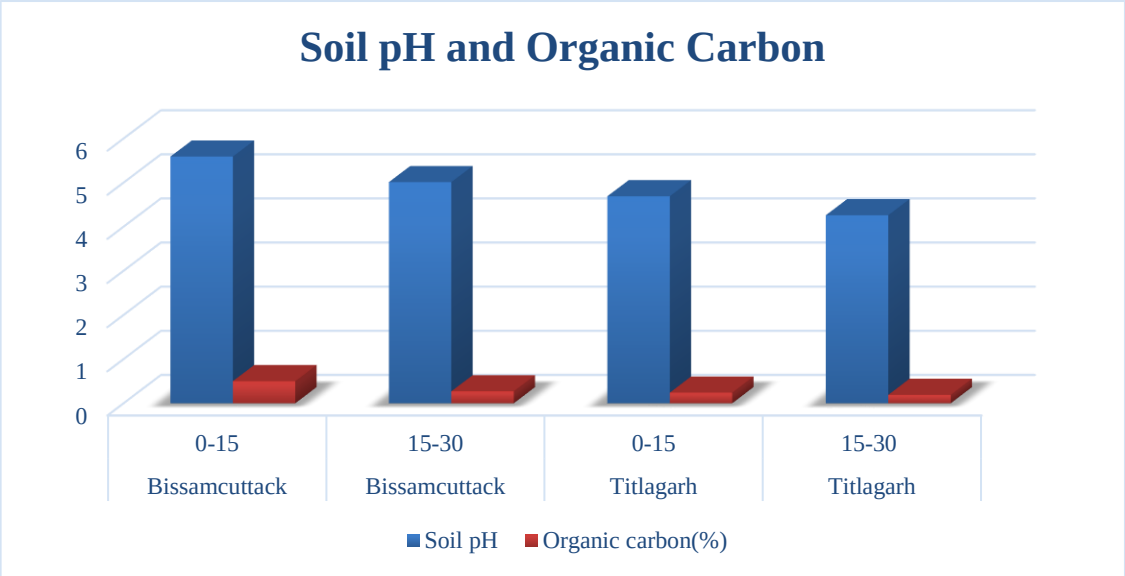


Figure 5: Variation in pH and organic carbon content in the soil layer of both sites.

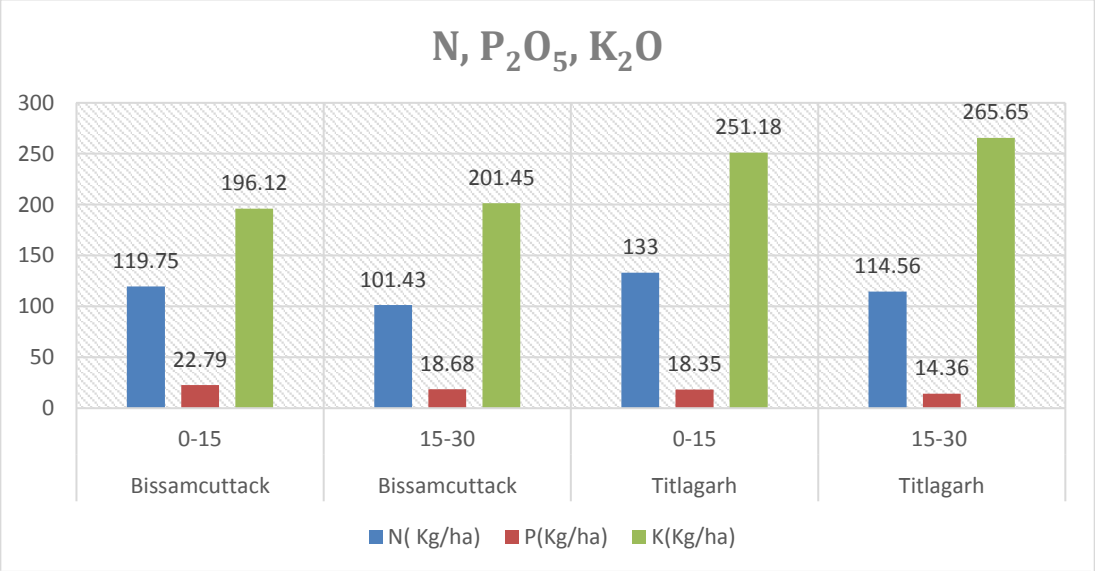


Figure 6: Variation in Nitrogen, Phosphorus and Potassium content in the soil layer of both sites.

SUMMARY

The present investigation entitled, **"**Studies on physical, anatomical and chemical characteristics of Eucalyptus hybrid wood from two agro-climatic zones of Odisha**"** was carried out in the laboratory of College of Forestry, Orissa University of Agriculture and Technology, Bhubaneswar, Odisha during the period 2017-2018. The main objective of the study was:

(i) To study variability in physical and chemical properties of Eucalyptus hybrid wood.

(ii) To assay the anatomical variations of Eucalyptus hybrid wood grown under different site conditions of Odisha.

Under these objectives three experiments were conducted:

1. To study the physico-chemical properties of wood samples of *Eucalyptus* hybrid
2. To study the anatomical properties of wood samples of *Eucalyptus* hybrid
3. To study the soil chemical properties of the plantation sites of *Eucalyptus* hybrid

In the first experiment trees are harvested at stump height and wood discs of 2cm height are cut from the basal portion of the tree. The disc are dried in oven till achieve constant weight. Then from each disc a strip of 2cm (breadth) to be taken along the radius from pith to bark. Each strip is then divided into five sections representing five year growth approximately and labelled as 1st year growth ring (Section- I), 2nd year growth ring (Section- II), 3rd year growth ring (Section- III), 4th year growth ring (Section- IV) and 5th year growth ring (Section- V) respectively. From each section , one cuboid of length of growth ring in cm x breadth of 2cm x height of 2cm (disc height) is prepared and taken for estimation of density and specific gravity for each growth ring . For estimation of chemical properties like cellulose content, hemicellulose content and lignin content, saw dust of 2gm is taken from each growth ring and then analysed.

The study on physical and chemical properties of *Eucalyptus* hybrid wood found that the wood samples from different growth rings of Bissamcuttack varies with cellulose content (30 % - 35 %) , hemicellulose content (17 % - 20 %) and lignin content

(29 % -34 %) whereas the wood samples from different growth rings of Titlagarh varies with cellulose content (30 % - 44 %) , hemicelluloses content (13 % - 22 %) and lignin content (30 % - 36 %) . The maximum cellulose content (35 %) was recorded in the section-II, IV and V; hemi cellulose content (20 %) was recorded in the section-V and maximum lignin content (34 %) was recorded in the section-III of the wood samples from Bissamcuttack. Similarly, maximum cellulose content (44 %) was recorded in the section-I, maximum Hemi cellulose content (22 %) was recorded in the section-III and maximum lignin content (36 %) was recorded in the section-II of the wood samples from Titlagarh.

The mean cellulose content (36 %) , hemicellulose content (17.40 %) and lignin content (33.20 %) is more in Titlagarh in comparison to cellulose content (36 %) , hemicellulose content (16.60 %) and lignin content (31.80 %) of Bissamcuttack

The wood samples from different growth rings of Titlagarh showed variation in density from 952 kg/m^3-986 kg/m^3whereas Bissamcuttack from 886 kg/m^3- 950 kg/m^3.The maximum density (986 kg/m^3) was recorded in the wood section-I from Titlagarh ,however, maximum density (950 kg/m^3) was recorded in the section-III from Bissamcuttack. Similarly, the specific gravity of the wood samples from different growth rings of Titlagarh varies from 0.93-0.97where as for Bissamcuttack from 0.86 – 0.9. The maximum Specific gravity (0.97) was recorded in the section-I from Titlagarh, however, maximum Specific gravity (0.92) was recorded in the section-III from Bissamcuttack.

The mean density (33.20 %) and specific gravity (0.95) is more in Titlagarh in comparison to density (31.80 %) and specific gravity (0.89) of Bissamcuttack.

In the second experiment, Wood samples collected from felled trees and then wood blocks are prepared from the wood discs as per the methodology adopted in experiment-1. For estimation of width of growth rings, it is identified by using hand lens and measured by using vernier calliper. For estimation of anatomical features, Wood blocks were to be macerated with distilled water and glycerine for 7 days. From each block, transversal and tangential micro-sections were obtained using microtome. It is dehydrated with 50 % ethanol. Samples were stained with Safranin for 1 minute, then washed with 50% ethanol and again stained with fast green for 30 second, after that it is placed in distil water to remove excess fast green stain. The sample is then assembled in a slide using glycerol.

Images were then captured using digital microscope connected to a personal computer and a digital camera.

The studies on variation in the anatomical properties of wood samples of *Eucalyptus* hybrid found that the width of growth rings of wood sample collected from Bissamcuttack varies from 0.75cm-1.00cm whereas the width of growth rings of wood sample collected from Titlagarh varies from 0.85cm-1.10cm. The maximum width of growth ring (1.00 cm and 1.10 cm) was recorded in the 3rd year growth ring (section-III) of wood collected from Bissamcuttack and Titlagarh respectively .The mean width of growth ring of wood samples was higher (0.99 cm) for Bissamcuttack than Titlagarh (0.88 cm). The vessel number per unit area of wood sample collected from Bissamcuttack varies from 16.00-20.67cm whereas the vessel number per unit area of wood sample collected from Titlagarh varies from 15.33-18.33. The maximum vessel number per unit area (20.67/mm^2, 18.33/mm^2) of Bissamcuttack and Titlagarh respectively was recorded in the section-I of the wood samples for both places. The mean vessel number per unit area is more in Bissamcuttack (18.26) in comparison to Titlagarh (16.99) .The vessel diameter and vessel length of wood sample collected from Bissamcuttack varies from 0.16 mm-0.19 mm and 0.24 mm-0.27 mm respectively whereas the vessel diameter and vessel length of wood sample collected from Titlagarh varies from 0.15 mm-0.21 mm and 0.23 mm-0.33 mm. However, vessel diameter and vessel length (0.18mm and 0.27mm ; 0.21mm and 0.23mm) found maximum value in the section -I of the wood samples from Bissamcuttack and Titlagarh respectively . The mean vessel diameter (0.19mm ,0.30mm) and vessel length (0.17 mm ,0.25 mm) was found more in Titlagarh in comparison to Bissamcuttack.

The numbers of horizontal parenchyma of wood sample collected from Bissamcuttack varies from 15.33/ mm^2-18.67/ mm^{2}where as the maximum numbers of horizontal parenchyma (18.67 / mm^2) was recorded in the section-V. Similarly, the numbers of horizontal parenchyma of wood sample collected from Titlagarh varies from 17.33/mm^2-19.67/mm^2. The maximum numbers of horizontal parenchyma (19.67/mm^2) was recorded in the section-I. The mean numbers of horizontal parenchyma is more in Titlagarh (18.26/mm^2) in comparison to Bissamcuttack (16.93/mm^2) .The horizontal parenchyma length of wood sample collected from Bissamcuttack varies from 0.21mm-0.26mm whereas the maximum horizontal parenchyma length (0.26mm) was recorded in

the section-II. Similarly, the horizontal parenchyma length of wood sample collected from Titlagarh varies from 0.16mm-0.25mm whereas the maximum horizontal parenchyma length (0.25mm) was recorded in the section-V. Among Bissamcuttack and Titlagarh, the mean horizontal parenchyma length is more in Bissamcuttack (0.23 mm) in comparison to Titlagarh (0.19 mm).

In the third experiment, Samples comprising of the surface (0-15cm) and subsurface (15-30) layers from plantation sites of Bissamcuttack and Titlagarh under Rayagada and Bolangir district were collected to study their physico-chemical soil characteristics. These soil samples were dried under shed, grinded in wooden hammer, passed through 2mm sieve and preserved in polyethylene bags for laboratory study of Soil reaction (pH) , Organic carbon, available Nitrogen , available Phosphorus and available Potassium.

The average surface soil pH of the *Eucalyptus* hybrid plantation site at Raygada found to be 5.59 and Titlagarh to be 4.69 whereas the pH of sub-surface soil for Raygada was found to be 5.01 and Titlagarh to be 4.26. The surface soil organic carbon concentration of plantation site of *Eucalyptus* hybrid at Rayagada to be 0.50% (medium) and for Titlagarh to be 0.24% 9 (low) whereas sub-surface organic carbon concentration of plantation site of Eucalyptus hybrid at Rayagada found to be 0.27% (low) and Titlagarh to be 0.19% (low) .The available nitrogen content of the surface soil of the plantation site of Eucalyptus hybrid at Rayagada found to be 119.75 kg/ha and for Titlagarh found to be 133 kg/ha whereas the available nitrogen content of sub-surface soil of Rayagada was recorded to be 101.43 kg/ha and Titlagarh to be 114.56 kg/ha . The available phosphorus content (P_2O_5) of the surface soil of the plantation site of *Eucalyptus* hybrid at Rayagada found to be 22.79 kg/ha (low) and Titlagarh to be 18.35 kg/ha (low) whereas the available phosphorus content of sub-surface soil of Rayagada was recorded to be 18.68 kg/ha (low) and Titlagarh to be 14.36 kg/ha (low). The available potassium content (K_2O) of the surface soil of the plantation site of *Eucalyptus* hybrid at Rayagada found to be 196.12kg/ha and Titlagarh found to be 251.18kg/ha whereas the available potassium content of sub-surface soil for Rayagada to be 201.45 kg/ha and Titlagarh to be 265.65 kg/ha.

CONCLUSION

On the basis of the result obtained from the present investigation **"**Studies on physical, anatomical and chemical characteristics of *Eucalyptus* hybrid wood from two agro-climatic zones of Odisha**"** following conclusion were drawn

1. Five year old *Eucalyptus* hybrid clone JK-2 grown at Titlagarh found to be better than same clone grown at Bissamcuttack with mean oven dry density (972.40 Kg/m^3), mean oven dry specific gravity (0.95), cellulose content (36.00%), hemi-cellulose content (17.40%) and lignin content (33.20%).

2. *Eucalyptus* hybrid clone JK-2 grown at Titlagarh at 5^{th} year may be used as a better raw material for paper industry due to high cellulose content and also may be recommended for energy plantation due to higher lignin content.
3. Vessel diameter found to be positively correlated with vessel length.

4. Cellulose content found to be positively correlated with density of wood specific gravity, vessel length, vessel diameter and parenchyma number.
5. Number of pores per unit area positively correlated rainfall and Soil organic carbon content.
6. Available soil nitrogen content showed significant correlation in case of density, specific gravity of wood and cellulose content.

In the studies on physical, anatomical and chemical characteristics of *Eucalyptus* hybrid wood clones further work can be done for evaluating the clones in other agro-climatic zones and studying their physical, anatomical and chemical characteristics up to 10 years of age.

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