CHAPTER-II

REVIEW OF LITERATURE
2. REVIEW OF LITERATURE

The Review of Literature pertaining to research programme entitled “Influence of climate on the radial variation of specific gravity and certain anatomical properties in teak (Tectona grandis Linn. f.) from Chandrapur and Thane, Maharashtra” are presented in this chapter under following headings:

2.1 General and gross features of wood

2.2 Radial variation of specific gravity

2.3 Radial variation of anatomical parameters

2.4 Specific gravity and anatomical parameters

2.5 Ring-width and climate relationship

2.6 Specific gravity and climate relationship

2.7 Vessel parameters and climate relationship

2.8 Fibre parameters and climate relationship

2.9 Ray parameters and climate relationship

2.10 Tissue proportion and climate relationship

2.1 General and gross features of wood

Rao and Juneja (1971) reported that Tectona grandis is a ring-porous hardwood. The earlywood vessels are large and few, compared to the latewood vessels which are small and numerous. The heartwood has golden brown or dark brown colour occasionally with black streaks. It has an oily feel with a distinct smell resembling old leather. Wood is moderately hard; moderately heavy with an average specific gravity of 0.650 at 12 per cent moisture content; usually straight grained; medium and uneven textured. Similar observations were also recorded by Bhat et al. (2007).

Bhat and Indira (1997) recorded that heartwood percentage increased consistently with tree age in 13- to 55-year old slow-grown trees of Tectona grandis from Nilambur,
Kerala. They found that heartwood proportion in 13-, 21- and 55-year-old trees was 36.5, 55.2 and 82.8 percent respectively. Similarly, Cordero and Kanninen (2003) also concluded that heartwood proportion in teak increases consistently with increasing tree age and with increasing diameter at breast height.

Cordero and Kanninen (2003) studied 5- to 47-year-old *Tectona grandis* trees from 17 plantations of 11 sites covering different climatic conditions in Costa Rica and observed that wet sites were found to produce less heartwood volume than dry sites, although both presented similar tree sizes at same ages. They explained that a possible reason for this may be due to continuous tree growth in the wet sites throughout the 8 to 12 months of growing period; while in dry sites the shorter growing season causes a more intense tree growth, leading to a greater deposit of inert material. Since wet sites normally present an almost continuous diameter growth, heartwood forms at a lower rate than that on dry sites, where tree growth ceases during the dry months and may be induced the yearly formation of heartwood during this period.

Bhat (2003) revealed that heartwood colour of *Tectona grandis* trees with darker streaks of extractives were often better in the homesteads of drier locality in Kerala than in wet zone and forest plantation. While no significant wood density differences were noticed, timber strength difference was not of practical value. He also reported that planting site with edaphic factor and its interactions with the genetic set up of the trees will have decisive role in influencing the quality of wood from homesteads and plantation localities. Similar observation was also recorded in the study of 7-to 15-year-old trees of *Tectona grandis* from Costa Rica by Moya and Alvarado (2012) who concluded that climatic variables should be considered as the first-order casual variables to explain wood colour variation. Hence, darker wood colour was associated with dry climates; also, with deeper and fertile sites.
Bhat (1998) studied five trees of *Tectona grandis* from 7-, 13-, 20- and 40-year-old plantations and one 147-year-old tree at Nilambur in Kerala. He reported that the mean ring width in 7-, 13-, 20-, 40- and 147-year-old trees were 4.55, 4.24, 0.95, 1.33, and 0.99 mm with the latewood proportion of 92, 90, 48, 44 and 70 percent of mean ring width respectively.

Priya and Bhat (1999) studied the effect of irrigation on plantation-grown trees of *Tectona grandis* at Ramamangalam in Kerala and observed that wood produced by nine 5-year-old trees, which were irrigated throughout their growing period, tended to be diffuse-porous in the first three years of growth. There were little distinction between earlywood and latewood making demarcation between successive growth rings difficult. From the fourth year onwards, ring porosity developed gradually.

Sinha et al. (2014) reported in their study on 120- to 150-year-old *Tectona grandis* trees from Thane Maharashtra, that the annual growth in juvenile period was high with a ring width mean of 4.03 mm and the latewood content represented 76.36% of the annual growth, while annual growth in mature period was low with a ring width mean of 1.24 mm and the latewood content represented 59.41% of the annual growth.

### 2.2 Radial variation of specific gravity

Panshin and De Zeeuw (1980) classified the pattern of pith-to-bark density of both softwoods and hardwoods into three general types. In type 1 pattern, mean density increases from pith to bark in linear or curvilinear fashion, type 2 denotes an initial decrease from pith outward and then increase towards the bark so that density near the bark may be higher or lower than near the pith and type 3 denotes decrease from pith to the bark in linear or curvilinear manner. These radial patterns in density variation might include both age and growth effects in it, and therefore some misunderstanding might arise about the extent of juvenile and mature wood.
Lei et al. (1996) examined on six 80-year-old Quercus garryana trees at breast height and upper height and reported that specific gravity declined almost linearly with cambial age and decreased almost 27% from pith to bark at both heights. Wood from breast height had a highest specific gravity than that from the upper height at any given cambial age. The radial variation of specific gravity in *Q. garryana* from pith to bark, along with that of many ring-porous species, is consistent with Panshin and De Zeeuw’s (1980) type 3 pattern. A significant and negative relationship between specific gravity and cambial age was also reported for Quercus petraea and *Q. robur* (Zhang et al. 1993).

Gartner et al. (1997) reported on six 40-year-old trees of Alnus rubra and Acer macrophyllum from the McDonald-Dunn forest of Oregon State University that specific gravity did not vary significantly with cambial age.

Bhat (1998) studied five 65-year-old plantation-grown Tectona grandis trees at three locations viz. Nilambur, Konni and Aryankavu of diverse environmental conditions in Kerala and found that specific gravity did not show any definite pattern of radial variation in relation to cambial age. He also reported that the mean specific gravity varied significantly between juvenile and mature wood.

Woodcock and Shier (2002) reported in a study of radial trends in specific gravity of 100 individuals of six hardwood trees species, that specific gravity decreased radially in three species (*Quercus rubrum*, Tsuga canadensis and Fagus grandifolia) and increased in another three species (*Acer rubrum*, *Pinus strobes* and *Betula papyrifera*).

Kokutse et al. (2004) studied eighty 6-70 years old trees of Tectona grandis tree from five ecological zones in Togo and revealed that density at 12% moisture content at breast height increased with age in teak. In 11-16 years old trees, density was found to be significantly different compared to trees 40-45 years old and 67 to 70 years old. The density in 11-16 years trees was only 17% lower than trees 67-70 years old. Likewise, in
trees 40-45 years old, density was only 6% lower than trees 67-70 years old but density was not found to be significantly different. Density was only weakly correlated with cambial age and was highly variable between the ages of 6-23 years old, but increases and stabilises above this age.

Radial variation of wood density in 30-40 years old young trees and 37-60 years old mature trees of Quercus suber grown in Portugal was examined by Knapic et al. (2007). They reported that density decreased from pith to bark more rapidly until the 15th rings, and then only slightly. There were no significant differences in the mean density between young and mature trees.

Izekor and Modugu (2010) reported in their study on six 23 years old plantation-grown Tectona grandis trees from Nigeria, that specific gravity increased progressively from pith to bark. It was observed that the specific gravity of wood near the pith decreased generally with increase in height along the longitudinal position of the tree.

Miranda et al. (2011) assessed the wood quality from 50- to 70-year-old Tectona grandis trees from an unmanaged forest in East Timor. He recorded that the mean basic density of wood showed an increasing radial trend from pith to bark at the stem bottom, but in the middle part of the stem the radial differences of wood density were considerably smaller.

Josue and Imiyabir (2011) studied six 15-year old trees of Tectona grandis from Sabah, Malaysia and revealed that the basic density increased radially from pith to intermediate region and then it was more or less uniform towards the bark. The density was not significantly different at height levels.

Radial variation of wood density in five 120- to 150-year-old Tectona grandis trees from Thane Maharashtra was investigated by Sinha et al. (2014). They reported that basic density gradually decreased up to 59 years and finally, it remained more or less constant
towards the periphery with a slight decrease in few outer rings. The pattern of radial variation of basic density was more inherent in the juvenile wood than mature wood resulting from cambial ageing.

Plourde et al. (2015) studied 42 species from tropical trees of Costa Rica and found a significant radial changes in specific gravity. Out of 42 species, 37 species exhibited increasing trend from inner to outer wood and five exhibited decreasing trend. Radial increases were observed in species with inner wood specific gravity below 0.5, whereas radial decreases were observed in species with inner wood specific gravity above 0.7.

2.3 Radial variation of anatomical parameters

Variation of anatomical parameters along radial direction is the best known and most studied within tree variability in wood, which is generally reflected as radial pattern of change in wood characteristics of juvenile and mature wood (Anoop et al. 2014).

2.3.1 Radial variation of fibre parameters

Kokutse et al. (2009) studied 27-31 years old plantation-grown Tectona grandis trees from three ecological zones in Togo and observed that all the fibre parameters increased with tree age in juvenile wood, while fibre length decreased or remained more or less constant with age in mature wood.

Pande and Dhiman (2010) studied the intra-ramet, intraclonal and inter-clonal variations of wood anatomical parameters in three clones of 6 years old Populus deltoides trees grown by macro- and macro propagation techniques and reported that in general the wood element’s dimensions including fibre dimensions increased from pith to periphery.

Izekor and Fuwape (2011) reported in a study of six 15-25 years old trees of Tectona grandis from Edo State Forestry plantations in Nigeria, that the fibre parameters
like fibre length, fibre diameter and cell wall thickness showed increasing radial trend with cambial age while fibre lumen diameter decreased with increase in cambial age.

Radial variations in anatomical characteristics within ramet in 10 clones of *Populus deltoides* raised by WIMCO plantations Ltd at Rudrapur were examined by Pande (2011). He revealed that within ramet variations due to radial location were significant for fibre length with increasing trend from pith to periphery. Similar trend was also reported by in *Populus deltoides* clones by Pande et al. (2012)

Sousa et al. (2014) studied on ten 34-60 years old trees and ten 112-150 years old trees of *Quercus faginea* from two different sites in Portugal and recorded that fibre dimensions such as fibre length, fibre width and fibre wall thickness increasing from pith outwards.

Anoop et al. (2014) reported in their study on anatomical variations in wood properties of 88 years old *Swietenia macrophylla* trees from Kerala, that fibre length increased from pith to periphery, while fibre diameter, lumen diameter and wall thickness increased from pith to middle and then decreased towards periphery.

### 2.3.2 Radial variation of ray parameters

Lev-Yadun (1998) carried out studies on five 25-year-old trees of *Pinus halepensis* and five 16-year-old trees of *Pinus pinea* from Israel and observed that all trees of both *Pinus* species showed a gradual increase in ray height and decrease in ray frequency from the pith outwards.

Rahman et al. (2005) studied the ray dimensions of six Tectona grandis trees from two districts in Bangladesh and found that ray height, ray width and ray frequency increased or decreased from pith to about 10 rings and thereafter remained more or less constant.
Loustarinen and Mottonen (2010) compared several anatomical characteristics between 33 years old plantation and 70-80 years old naturally grown trees of *Betula pendulai* from different growing sites in Finland. They revealed that ray width increased, while ray frequency decreased with cambial age.

Naji et al. (2013) reported in a study on 9 years old plantation of *Hevea brasiliensis* from Malaysia that the radial pattern showed an increasing trend from pith to periphery for ray height and a decreasing trend for ray frequency.

Sousa et al. (2014) investigated on ten 34-60 years old trees and ten 112-150 years old trees of *Quercus faginea* from two different sites in Portugal and observed that ray height and ray width showed an increasing trend from pith outwards.

Anoop et al. (2014) examined the anatomical variations in wood properties of 88 years old *Swietenia macrophylla* trees grown in moist locality of Kerala and reported that ray height and ray width increased and ray frequency decreased from pith to periphery.

**2.3.3 Radial variation of tissue proportion**

Very limited studies have been carried out on tissue proportions, particularly in radial direction.

Ismail et al. (1995) reported that that vessel and ray proportion increased from pith to bark, while fibre proportion decreased in six *Neolamarckia cadamba* trees a trial plot in Mantin, Negeri Sembilan.

Radial variation in tissue proportion in six 80-year-old trees of *Quercus garryana* from Mc Donald-Dunn Forest of Oregon State University, Oregon was examined by Lei et al. (1996). They revealed that fibre proportion decreased slowly for about 20 years and then decreased rapidly towards the bark. The vessel proportion showed the opposite trend, a slow increase for the first few years followed by a rapid increase. The axial parenchyma
proportion increased almost linearly with cambial age, whereas the ray proportion was more or less constant and decreased slightly towards the bark.

Bhat and Indira (1997) investigated on the anatomical variation in four radial positions viz. 4th, 20th, 40th and 65th rings from pith to periphery of 65-year-old Tectona grandis trees from three locations in Kerala and observed that fibre proportion decreased and vessel proportion increased radially with cambial age.

Gartner et al. (1997) studied six 40-year-old trees of Alnus rubra and Acer macrophyllum from Oregon State University, USA and reported that fibre proportion decreased and vessel proportion increased with increasing cambial age, while ray proportion changed little with cambial age. Axial parenchyma proportion showed no significant radial trend.

2.4 Specific gravity and anatomical parameters:

Variation in anatomical structure may cause variation in wood quality. Anatomical characteristics are highly correlated with specific gravity, an important factor in assessment of wood quality (Zobel and van Buijtenen, 1989).

2.4.1 Relationship between specific gravity and fibre parameters

Helinska and Fabisiak (1991) examined 78-year even-aged trees of Quercus petraea from Poland and found a negative correlation between fibre length and specific gravity.

Rao et al. (1997) studied five 87-year-old trees of Quercus robur from Germany and reported that latewood density which generally affects the annual ring density is closely associated with vessel and fibre proportions than with dimensions of fibres.

Rao et al. (2005) studied Clonal variation in basic density and anatomical properties in five 4-5 year old Eucalyptus tereticornis clones from Andhra Pradesh. They did not observe any significant correlation between basic density and fibre parameters like
fibre length, fibre diameter, fibre lumen diameter and fibre wall thickness. Similar observations were also reported by Anoop et al. (2014) in 88 years old *Swietenia macrophylla* trees from Kerala.

Quilho et al. (2006) investigated on five 5.6-year-old and five 6.8-year-old trees of *Eucalyptus grandis* x *Eucalyptus urophylla* from Brazil and found that fibre dimensions namely fibre length, fibre diameter and fibre wall thickness showed highly significant correlation with basic density.

Moya and Tomazelo (2007) reported that wood density was positively correlated with fibre cell wall thickness and negatively correlated with fibre length, fibre diameter and fibre lumen diameter in *Gmelina arborea* trees from dry and moist regions in Costa Rica. They also revealed that wood density variation could be predicted from 76 to 96% for anatomical variation and cell wall thickness was the most important anatomical feature to produce intra-ring wood density variation.

### 2.4.2 Relationship between specific gravity and ray parameters

Very limited literature is available to show the relationship between specific gravity and ray parameters.

Taylor (1969) investigated four species *viz.* *Liriodendron tulipifera*, *Fagus grandifolia*, *Erythrobalanus* spp. and *Leucobalanus* spp and observed that increased ray volume may contribute to increased specific gravity.

Rahman et al. (2005) reported that increase in ray volume which is related to ray frequency showed higher specific gravity in *Tectona grandis* trees from two locations in Bangladesh.

Toong et al. (2014) studied different commercial timbers from Malaysia and recorded that ray width was negatively correlated to compressive strength and ray height was negatively correlated with shear strength.
2.4.3 Relationship between specific gravity and tissue proportion

Purkayastha et al. (1972) carried out anatomical studies of some tested samples of *Tectona grandis* from seven different localities and reported that fibre wall thickness was highly correlated with specific gravity and this relationship was influenced to some extent by the proportion of fibres. Highly significant correlation was found to exist between fibre wall thickness and maximum crushing stress in the samples in which the wall thickness was less than 4 µm.

Purkayastha et al. (1974) studied the variation in anatomical structure and basic density in a 25 year old tree of *Michelia champaca* grown at Newforest, Dehra Dun and noticed that fibre length, fibre diameter and fibre wall thickness contributed 77 percent of variation in density. But they showed that fibre proportion appears to have no significant effect on density.

Fujiwara et al. (1991) compared fifty tree species of Japanese hardwoods to study the relationship between basic density and tissue proportion and revealed that fibre and ray proportions were positively correlated with basic density.

Bhat and Indira (1997) studied four *Tectona grandis* trees of different age groups (13-year, 21-year, 55-year and 65-year) from plantation in Kerala and reported that fibre proportion was positively correlated with wood density, while vessel and parenchyma proportions were negatively correlated.

Rao et al. (2002) investigated within tree variation in anatomical properties of four and half year old grown *Eucalyptus tereticornis* clones and correlated with specific gravity. They found that specific gravity was positively correlated with ray percentage, fiber percentage and negatively correlated with vessel percentage.

Rao et al. (2005) studied the basic density and anatomical properties of five clones of *Eucalyptus tereticornis* developed by ITC Bhadrachalam and reported that ray
proportions were directly correlated with specific gravity. Similar observation was also
reported by Rahman et al. (2005) in *Tectona grandis* trees from Bangladesh.

Sreevani and Rao (2014) studied the relationship between basic density and tissue
proportion in four trees from each of the five *Eucalyptus tereticornis* clones from ITC
Bhadrachalam numbered 3,4,6,7 and 10 planted at Sarapaka, Andhra Pradesh and reported
that basic density was not influenced by tissue proportion.

### 2.5 Ring-width and climate relationship

Shah et al. (2007) explored dendroclimatological potentiality of *Tectona grandis*
trees grown in the natural forests of the central part of India. They reported that
precipitation during June to September of the current year and October of the previous
year had positive influence on the radial growth of teak, whereas January and May
precipitation influenced negatively. Temperature did not show any significant effect on
the growth of teak in this region.

Ram et al. (2008) studied tree-ring-width index chronologies of *Tectona grandis*
from three sites in Central India and revealed that tree-growth and climate relationship
based on correlation analysis showed an important contribution of moisture index and
rainfall rather than the direct influence of the temperature on tree growth during different
seasons. Significant positive relationship of moisture index and rainfall during the
monsoon months as well as on the annual scale with tree-ring width variations over the
region indicated the important role of moisture availability at the root zone.

Deepak et al. (2010) carried out tree-ring analysis of *Tectona grandis* trees from
Dandeli and Shimoga regions in Western Ghats of India and reported that the tree-ring
chronology and climatic data showed several alternating periods of low and high to very
high rainfall years. The common low rainfall years at two sites matched with the most of
drought years of India. It has been found to have good potential to know rainfall pattern, mostly the drought years.

Sinha et al. (2011) studied climate-related tree-growth variability in *Tectona grandis* trees from dry deciduous forests of Mundagod (Karnataka) and Chandrapur (Maharashtra) in Peninsular India and concluded that the pattern of radial growth in teak varies with the local edaphic and climatic conditions, mainly rainfall, relative humidity and temperature as well as soil type of different locations and plays a significant role in influencing the growth of teak.

Sinha (2012) studied relationship between tree-ring widths of *Tectona grandis* and climate from dry deciduous forest of Mundagod and moist deciduous forest of Shimoga from Karnataka and reported that Shimoga which is influenced by two monsoons (South-West and North-East) had wider ring-width in teak than Mundagod which is influenced by only one monsoon (South-West). This study substantiated that the pattern of ring width in teak varies with the local climatic conditions of different sites.

Rathore and Jasrai (2013) investigated tree-ring widths of *Tectona grandis* in Gujarat and reported that ring-width of teak had a sharp correlation with drought years. Hence, the drought condition has a prominent effect on the growth rate of teak trees.

Kumar et al. (2014) demonstrated the use of dendroclimatology in assessing moisture stress response of *Tectona grandis* trees and reported that mean ring-width index and mean sensitivity index of 48 clones of teak had a close association between rainfall and growth. Lag-1 autocorrelation indicated the possibility of carryover effect of rainfall on growth.

2.6 Specific gravity and climate relationship

Wiemann and Williamson (2002) studied the relationship between climate and specific gravity in hardwoods at 19 sites in the United States, Mexico, Guatemala, Costa
Rica, Panama, England, Gabon, and Nigeria and concluded that mean wood specific
gavity decreases with increasing mean annual precipitation, especially among tropical
sites. Variability in specific gravity among species at a site increases much more
dramatically with mean annual temperature than does the mean specific gravity.

Thomas et al. (2007) investigated the effect of temperature on 11 to 19 weeks old
_Eucalyptus grandis_ seedlings and reported that there was a positive relationship between
wood density and temperature in _Eucalyptus grandis_. Wood density increased 20% with
increasing temperature of growth chamber up to 30° C and declined when seedlings grown
at 35° C. The increase in wood density of _E. grandis_ seedlings grown at high temperatures
was related to reductions in lumen transverse area of both xylem vessels and fibre cells
and thicker fiber cell walls. Changes in these anatomical features accounted for 76% of
the observed variation in wood density.

Oliver et al. (2009) studied the impact of climatic factors _viz._ precipitation and
temperature on 6 years old trees of _Populus_ spp from Germany and revealed that wood
density was less sensitive to temperature and precipitation variations. They also reported
that wood density may be affected by factors other than those which affect tree radial
increment and may be more sensitive to environmental changes.

Martinez et al. (2009) investigated relationship between climatic factors and wood
density in 61 species of shrubs in North and South America. They reported that wood
density was more significantly correlated with precipitation and aridity than with
temperature. High wood density was achieved through reductions in cell size and
increases in the proportion of wall relative to lumen.

2.7 Vessel parameters and climate relationship

Pumijumnong and Park (1999) investigated on five _Tectona grandis_ trees in
northern Thailand for dendroclimatology of vessels. They concluded that all vessel
parameters like average vessel area, average vessel diameter, average conductive area, and vessel density of the total ring and of the earlywood were negatively correlated with precipitation during the transitional period between the dry and the wet season. The latewood vessel parameters, however, were negatively correlated with June temperature. The climatic signals of the vessel parameters and of the tree-ring width were different from each other.

Fonti and Garcia-Gonzalez (2004) studied on earlywood vessel chronology of *Castanea sativa* for ecological suitability and revealed that the earlywood vessel area is a suitable ecological indicator. This variable, although not very sensitive, contained environmental information that was different from that stored in all other ring-width and earlywood features. The vessel size was mainly related to the temperature during two physiologically crucial periods for vessel growth, one at the end of the previous vegetation period (during reserve storage) and another at the onset of cambial activity (during cell division and vessel differentiation).

Bhattacharyya et al. (2007) analysed the earlywood mean vessel area of *Tectona grandis* at Parambikulam, Kerala to understand its relationship with the temporal variation of climate. They concluded that precipitation in comparison to temperature of the region had a major role in development of earlywood vessel of tree-rings of teak. Precipitation during October and November months of the previous growth year and April of the current year were related to the development of vessel area in earlywood of an annual ring.

Sinha et al. (2009) studied the relationship between earlywood mean vessel area of *Tectona grandis* at Shimoga, Karnataka and reported that mean vessel area of earlywood was positively associated with the December rainfall of previous year and May of the
current year. High temperature of April month was also closely related with the formation of large size earlywood vessel area.

Rao et al. (2011) investigated on tree-ring analysis of *Tectona grandis* in 10 trees from dry deciduous forest of Chandrapur and 6 trees from moist deciduous forest in Maharashtra. They found that early wood and latewood vessel density were negatively correlated with annual rainfall, whereas earlywood vessel diameter was positively correlated and late wood diameter was negatively correlated with annual rainfall at both sites. However, the earlywood and latewood vessel length were negatively correlated with annual rainfall at dry site and positively correlated at moist site.

### 2.8 Fibre parameters and climate relationship

Honjo (2002) evaluated the relationship between radial variation in fibre length of wood fibres and monthly climatic factors like average temperature and precipitation in *Acacia mangium* trees from Malaysia and revealed that increment in wood fibres was correlated to the monthly precipitation of previous months rather than in the same month.

Moya and Fo (2008) studied thirty mature trees of 9-to12-year-old *Gmelina arborea* from 15 different plantations of tropical dry and wet regions in Costa Rica. They reported that fibre diameter and fibre lumen diameter increased with increase in annual precipitation.

The influence of climate on the fibre properties of five 50-to 60-year-old *Acer velutinum* (maple) trees from Iran was examined by Bakhshi et al. (2011). They found that there was no effect of climate on the fibre length and fibre wall thickness, whereas fibre diameter was positively correlated with precipitation. The fibre diameter correlated with monthly total precipitation of November, June and August and monthly maximum temperature of August and November. In addition, the relationship between fibre diameter
and monthly minimum temperature of January and monthly mean temperature of August were negative and positive respectively.

Xu et al. (2013) studied climatic response of cell characteristics in 40 dominant *Picea crassifolia* trees from China and reported that cell wall thickness responded significantly and positively to temperature, and the response to precipitation was negative, while cell radial diameter responded negatively to temperature and positively to precipitation.

Carrillo et al. (2013) investigated the influence of climate on wood elements in *Prosopis laevigata* from two regions of Mexico and found that higher precipitation and lower temperature, showed higher fibre length, whereas low precipitation and high temperature showed short fibres.

### 2.9 Ray parameters and climate relationship

Very limited investigations is made on ray parenchyma to show the relationship between climatic factors and ray parameters *viz.* ray height, ray width and ray frequency.

Moya and Fo (2008) investigated thirty mature trees of 9-to12-year-old *Gmelina arborea* from 15 different plantations of tropical dry and wet regions in Costa Rica. They revealed that there was no significant relationship between ray parenchyma and annual precipitation.

Moya et al. (2009) studied 13 years old *Tectona grandis* trees in tropical dry and moist conditions of Costa Rica and found that there was no influence of climatic factors *viz.* rainfall and temperature on ray parameters.

Olano et al. (2013) investigated 20 trees of *Juniperus thurifera* from Spain to show the relationship between ray parenchyma and climatic factors. They concluded that ray parenchyma responded to climatic factors at critical stages during the xylogenetic process;
namely at the end of the previous year’s xylogenesis (October) and at the onset of earlywood (May) and latewood formation (August).

2.10 Tissue proportion and climate relationship

Information regarding direct relationship between climatic factors and tissue proportion is very scarce.

Pumijumnon and Park (2001) investigated the relationship between twelve anatomical variables and climatic factors in five Tectona grandis trees and two cores per tree from northern Thailand and concluded that drought years cause the teak to have narrow rings with little or no latewood. By contrast, in a year with adequate water and optimal temperature, the teak develops wide rings with large early wood and latewood.

Martinez et al. (2009) studied wood anatomy in relation to varying aridity along transcontinental transects in 61 species of shrubs in North and South America. They revealed that axial parenchyma proportion was negatively correlated with mean annual precipitation, aridity index and positively correlated with mean annual temperature.