Review of Literature
2. REVIEW OF LITERATURE

The area under *Casuarina* species is increasing day by day due to its popularization as fuel wood species, nitrogen fixing capacity and potential for adaptation to diversified soil and climatic conditions. There is great demand for genuine true-to-type planting seed materials in order to optimize production of species in Northeren dry Zone of Karnataka. In spite of its economic importance, *Casuarina* species have not attracted the attention of the researchers. In the present investigation, morphometric traits and growth performance of species are evaluated for their utility in generating diversity among species. The available information on various aspects of origin, domestication, ecology, growth, tree biomass, phenology, male and female reproductive success and performance of half-sib progenies in five *Casuarina* species is scanty. Hence, the relevant literatures on other fuel wood trees grown under similar situations have also been reviewed in addition to the existing literature on *Casuarina* and the information is organized under the following heads.

2.1. Brief review of work on *Casuarina* species

The genus *Casuarina* belongs to the family of Casuarinaceae, which is native to Australia, Malaysia and Polynesia, with somatic chromosome number of 9 (Barlow, 1983 and Turnbull and Martensz, 1990). Casuarinaceae belongs to the Gondvanic family and consists of four genera (*Allocasuarina, Casuarina, Ceuthostoma*, and *Gymnostoma*) and 97 species including monoecious or dioecious shrubs and trees (Johnson and Wilson, 1989). *Casuarina* species successfully survive in tropical climates, tolerating temperatures up to 47 °C, resistance to frost but sensitive to fire. Species valued mainly for its fuel wood, nitrogen fixing ability and reclamation to saline soil and degraded land.

*Casuarinas* are quite widespread in Australia. The derived Australian genus, Allocasuarina, contains most of the species in the family and appears to be specialized for nutrient deficient sites. Individual *Casuarina* species range in size from bushes of few centimeters high (*C. microstachya*) to tall forest trees of 20-30 m height (*C. cunninghamiana, C. equisetifolia* and *C. cristata*). Species typically regenerate from seed, but *C. glauca, C. obesa* and allies can spread clonally from root suckers. *C. equisetifolia* can be propagated from cuttings (Wilson and Johnson, 1998) and now it
is planted throughout semi-arid tropical regions of Australia, where it has naturalized in some places.

2.1.1. Growth performance of different *Casuarina* species

Five species of *Casuarina* have been recognized for multiple uses and were introduced in Northern dry zone of Karnataka. Area of *Casuarina* plantation needed to produce the required volume of firewood will depend on growth performance of the species (Read *et al.*, 1995).

Morton (1980) reported that performance of different species of *Casuarina* with respect to rate of stem growth was rapid during the first 7 years and then declined. Maximum growth was reached in 20 years, with a life span of 40 to 50 years. The fastest growth rate was reported from Barbados, where a height of 30 feet was attained within 2 years. El-Lakany (1981) registered higher rate of growth and survival for *C. cunninghamiana* followed by *C. glauca* and *C. equisetifolia* underneath sandy loam soil. However, growth performance of *C. glauca* was higher than *C. cunninghamiana* followed by *C. equisetifolia* in heavy clay soils in waterlogged region. El-Lakany (1983) stated that some members of *Casuarinaceae* were prime candidate tree species for establishment of plantations in arid and semi arid regions. In view of their superior qualities as shelterbelts as a source of fuel wood and for soil rehabilitation. Doran and Hall (1983) reported that *C. equisetifolia* performed better than *C. glauca* in saline areas and *C. obesa* in island areas due to fast growth under saline ground water.

Rockwood *et al.*, (1983) reported that early growth was rapid and height increments exceeding 1.5 m per year were common in *Casuarina* stands. *C. equisetifolia* reached upto 32 m in height and 41 cm diameter at breast height while *C. cunninghamiana* reached height of 25 m and diameter of 25 cm. Old stand of *C. glauca* had attained a basal area of 90 m²/ha, composed of trees an average of 19 m height. Initial survival rates for planted trees averaged over 87 per cent.

Zobel and Talbert (1984) suggested that *Casuarina equisetifolia* was initially introduced in India as an ornamental tree due to suitable physical properties and later found to be an efficient fuel wood species due to high calorific value. Torrey and Berg (1988) opined that *Casuarina equisetifolia* grows best in arid and semi arid climate with average annual rainfall of 300 mm. It has nitrogen fixing ability and tolerates both
calcareous and slightly alkaline soils better than *C. glauca* and *C. obesa*. Hence, *Casuarina glauca* was originally planted in Florida as a supplement to *C. equisetifolia*. *C. equisetifolia* was found to be not tolerant to salt, while, *C. cunninghamiana* and *C. glauca* showed salinity resistance (Digiamberardino 1986). Jambulingam (1990) revealed variation of provenance for leaf and height parameters of *Casuarina equisetifolia* in coastal, riverine and inland populations. Natural provenances variations were observed among the slow growers from Australia, Fiji, Guam and Philippines. Growth performance was poor in Australian provenances than Chinese land races.

Zhong *et al.*, (1990) conducted experimental trials on growth performance, survival and root nodulation for *Casuarina equisetifolia*, *C. glauca*, *C. cunninghamiana*, *Allocasuarina torulosa*, *A. littoralis*, *C. cristata* and *C. junghuhiana*. Significantly poor growth performance was recorded in *C. cristata*, followed by *A. torulosa* and *A. littoralis*. However, *C. equisetifolia* and *C. junghuhiana* performed significantly superior for height, survival and root nodulation among species. Rockwood and Geary (1991) registered maximum survival and height (8.0 m) in *Casuarina equisetifolia* compared to *C. cunninghamiana* and *C. glauca* at thick stand density within 82 months. Lalita *et al.*, (1993) revealed that seed germination was reduced and delayed with increase in pH from 8.9 to 10.3 in *Casuarina equisetifolia* and *C. glauca*. Similarly, dry matter production in *C. equisetifolia* has reduced, as soil pH levels increased from normal pH (7.9) to alkaline pH (8.2 to 9.8). However, growth of *C. glauca* increased at range of pH 8.2 - 9.0, but a reduction occurred at pH 9.80. Nitrogen content in *C. equisetifolia* also decreased with increase in pH from 7.9 and in *C. glauca* it increased with pH up to 9.0 and then decreased.

Weinstein (1993) reported that *Casuarina cunninghamiana* followed by *C. glauca* and *Allocasuarina verticillata* were drought resistant provenances under low fertility soil in semi arid regions of Israel. Dubrabata *et al.*, (1995) selected male and female trees randomly from 3 plantations of *Casuarina equisetifolia* in Orissa. Significantly higher volume of wood was observed in male trees than female trees, suggesting the scope for increase in wood biomass production by establishing male plus trees by vegetative propagation techniques. Kimondo (1996) reported that *Casuarina equisetifolia* has shown significant differences between provenances for its diameter and
height in Kenya. Nicodemus et al., (1996) conducted experimental trials in seven provenances of *Casuarina equisetifolia* at two locations in Tamil Nadu. No significant difference was observed in height, diameter and branching habit between locations among provenances. Zong chonglu (1996) registered higher height, diameter and growth performance in *C. equisetifolia* and *C. gluca* when compared to *C. cunninghamiana* and *C. cristata*. Zhong and Bai (1996) reported significant variability in height, diameter, volume and crown spread between seed lots of *Casuarina equisetifolia* in Southern China. Maheswara rao et al., (2001) recorded significantly diverse growth performance in *Casuarina equisetifolia* among provenances. Maximum variation was observed in growth in different provenances from the natural distribution than from land races and local seed source. More than hundred phenotypically superior trees have been selected from the provenance trials for constituting a clonal breeding orchard in island and coastal sites. Nicodemus et al., (2001) reported superior provenances of *Casuarina equisetifolia* based on growth, tree form, wood properties, photosynthetic potential, drought adaptability, disease and pest tolerance and high fruit reproductive success in multi location trials.

2.1.2. Biomass of *Casuarina* species

Rockwood et al., (1983) registered total above ground dry biomass yields of 16.6 t ha⁻¹ year⁻¹ for *C. equisetifolia* at densities of 11,400 trees per hectare and average of 4.3 cm diameter in 7.5 year old natural stands. Biomass yield in *C. equisetifolia* was higher than that of *C. cunninghamiana* and *C. gluca* in this experiment. Megahed and El-lakany (1986) estimated biomass and volume of wood from measurements of height and diameter in *C. gluca* (volume 260 m³ ha⁻¹ and biomass 27 tones ha⁻¹) to be lower than those of *C. cunninghamiana* (volume 295 m³ ha⁻¹ and biomass 34 tones ha⁻¹) in young plantation. El-Osta et al., (1992) reported that total above ground biomass production in *C. cunninghamiana* was higher than that of *C. gluca* at three different sites of Nubariah region. Marcar (1996) reported that production in biomass and growth tolerance ranked in the decreasing order of *C. gluca* > *C. equisetifolia* > *C. cunninghamiana* > *C. cristata* > *C. obesa* under saline soil condition. El-Juhany et al., (2002) reported significantly higher total above ground biomass (400 kg tree⁻¹) and merchantable stem volume (0.37 m³ tree⁻¹) in *Casuarina cunninghamiana* than the *Casuarina* hybrid (175 kg tree⁻¹ and
0.19 m³ tree⁻¹) while *C. glauca* (200 kg tree⁻¹ and 0.21 m³ tree⁻¹) had medium biomass and volume.

Tomar and Gupta (2002) registered significantly higher biomass at 13 month old seedlings than at 9 months in different salinity levels for all the species studied. *Casuarina glauca* had higher biomass (71.55 Mg h⁻¹) accession than *C. obesa* (66.03 Mg h⁻¹) and *C. equisetifolia* (47.99 Mg h⁻¹) at salinity of 20 dS/ml. Rana *et al.*, (2002) evaluated four species viz., *Casuarina equisetifolia*, *Eucalyptus* hybrid, *Dalbergia sissoo* and *Leucaena leueocephala* for higher biomass performance in sodic soil. The total tree biomass attained at the age of eight year was in the order of *Leucaena leueocephala* (199.6 t ha⁻¹) > *C. equisetifolia* (197.3 t ha⁻¹) > *Eucalyptus hybrid* (136.6 t ha⁻¹) > *D. sissoo* (62.2 t ha⁻¹). Ibrahim *et al.*, (2003) studied that growth performance and biomass production of six *Acacia* species (*Acacia asak*, *A. negrii*, *A. seyal*, *A. karroo*, *A. ampliceps* and *A. stenophylla*) in the field at 4 years age. The results showed that both *A. ampliceps* and *A. asak* have 100 per cent survival while *A. negrii* died. *Acacia ampliceps* attained the greatest height, diameter, relative growth rate and above-ground biomass and while *A. asak* recorded lowest parameters among species.

Viswanath *et al.*, (2004) reported that tree above ground biomass production in *Casuarina equisetifolia* varied from 9.31 kg tree⁻¹ to 12.02 kg tree⁻¹ and below ground biomass also varied from 1.83 - 3.77 kg tree⁻¹ under wide row intercropping systems. Chonglu Zhong *et al.*, (2010) revealed that volume of wood, fuel wood production and adoptability of clones were significantly superior in *Casuarina equisetifolia* followed by *C. cunninghamiana*, *C. glauca* and *C. junghuhniana* in nursery and as well as in field under abiotic stress in different areas of China.

### 2.1.3. Physical properties of wood in *Casuarina* and other species

El-Lakany (1981) studied variation in specific gravity, fiber length and extractives content in *C. equisetifolia*, *C. cunninghamiana* and *C. glauca*. The pulp yield appeared to be relatively high in *C. glauca* among various species while other parameters were recorded higher for *C. equisetifolia*. El-Osta and Megahend (1990) estimated the average calorific value of *C. glauca* and *C. cunninghamiana* at 4700 cal g⁻¹ and 4870 cal g⁻¹ respectively in Egypt. However, wood properties viz., volume, specific gravity and strength were better in *C. equisetifolia* than *C. glauca*, *C. cunninghamiana* and *C. obesa*. 
EI-Osta (1992) reported that average specific gravity for sampled trees of *Casuarina* species (*C. glauca, C. cunninghamiana* and *C. obesa*) ranged from 0.472 to 0.760. The gross heat of combustion reached a maximum value of 5093 cal g⁻¹ for *C. obesa* and average values for moisture content was highest at 129.06 per cent for *C. cunninghamiana*.

EI-Osta and Megahend (1992) reported specific gravity with range of 0.472 – 0.760 and calorific value 4970 cal g⁻¹ to 5093 cal g⁻¹ with highest for *C. glauca* followed by *C. obesa* and *C. equisetifolia* under afforestation programme. Puri *et al.*, (1994) reported wood calorific value has variation ranging from 18.7 to 20.8 MJ kg⁻¹ for indigenous and 17.3 to 19.3 MJ kg⁻¹ for exotics species of *Casuarina*. It was observed that indigenous species are suitable for fuel wood due to high wood density, low ash content and low nitrogen per cent. The fuel wood value index was found to be high for *Casuarina equisetifolia* than exotic tree species. Significantly higher fuel wood promising tree species were in the order of *C. equisetifolia* > *Acacia nilotica* and *Zyzophus mauritiana*. Lin *et al.*, (1999) stated that density and strength of wood significantly affected wood properties at different heights of *Casuarina equisetifolia*.

Varghese *et al.*, (2001) studied the effect of genetic variation on wood density and fiber dimensions in *Casuarina* species. The effect of planting site had a major influence on the quality of wood production. Wood density values varied from 0.662 g/cm³ to 0.803 g/cm³ among nine seed lots tested at a coastal site, Pondicherry and 0.593 to 0.706 g/cm³ among 7 seed lots at an island location. However, variation in wood density was observed in one seed lot (0.638 to 0.779 g/cm³) when raised at four locations in Sadivayal. Ye *et al.*, (2005) recorded that standing biomass and calorific value of *Casuarina equisetifolia* community were higher (15,681.84 g m⁻² and 317,795.31 kJ m⁻² respectively) on red earth eolian sandy soil than on homogeneous eolian sandy soil (5129.87 g m⁻² and 10575.50 kJ m⁻² respectively) in Dongshan county of Fujian Province. Jitendra Kumar (2008) registered that net biomass energy productivity in *Acacia auriculiformis* stand ranged from 4.14 x 10 kg ha⁻¹ yr⁻¹ to 4.87 x 10 ha⁻¹ yr⁻¹ at six year plantation. Calorific value of wood increased with increase in diameter classes. Sugumaran and Seshadri (2009) reported that calorific value of fresh biomass and pyrolysed charcoal was maximum for *Casuarina equisetifolia* leaf litter (18.48 MJ kg⁻¹
and 28.28 MJ kg\(^{-1}\)) and minimum in oil palm fruit bunch (16.96 MJ kg\(^{-1}\) and 18.46 MJ kg\(^{-1}\)) respectively.

2.1.4. Effect of Casuarina species on physico-chemical parameters of soil

*Casuarina* species contributes a lot of organic matter to the soil in the form of leaves, twigs, branches and reproductive parts etc., which after decomposition result in the formation of organic matter and releases different nutrients. This contribution of *Casuarina* to soil varies according to the composition of litter and differs from species to species. The nature and organic matter produced after decomposition of litter depends on the dominant tree species present and site characteristics of the area, which regulate the physico chemical properties of the soil.

According to El-Lakany (1986) nodulation substantiate the high efficiency of *Casuarina* as a nitrogen fixer and soil improver. Dommergues *et al.*, (1995) conducted experiment to assess the ability of nitrogen fixation in genus of *Casuarina*. The amount of nitrogen fixation was highly significant in *C. equisetifolia* (100.0 kg ha\(^{-1}\)) compared to *C. cunninghamiana* (92.0 kg ha\(^{-1}\)).

Nik Muhamad *et al.*, (1998) registered that highest values of total nitrogen, available phosphorous and exchangeable potash underneath of *Casuarina equisetifolia* followed by *Acacia mangium* and *Ceiba pentandra*, probably due to the higher accumulation of organic matter through litter fall compared to control plots. However, available phosphorus was highest in *C. equisetifolia* followed by *A. mangium* and *Ceiba pentandra*. Zimpfer *et al.*, (1999) confined that soil collected near *Casuarina cunninghamiana* had higher total N, NO\(_3\), organic matter, P, Mg, K, Ca, pH, and cation exchange capacity than non-cropped areas. Homogenates of *C. cunninghamiana* leaves and stems increased the number of infective units of *Frankia*, when inoculated and incubated for 3 months in an artificial soil. Thus, it seems that *C. cunninghamiana* is able to alter soil chemical properties and possibly favor its specific micro-symbiotics in soil.

Andrew and Jose (2001) revealed that physical and chemical effects of litter of *Casuarina* to soil properties are important factors determining the difference in annual plant community structure of *Carrichtera annua, Danthonia caespitosa* inside and outside *Casuarina* groves. In arid lands of southern Australia the density of herbaceous plants was less inside *Casuarina* groves. However, soil collected inside groves had higher
contents of organic carbon and total nitrogen than soil outside the groves. Madhanraj et al., (2011) studied physico-chemical properties of the soil under plantation of 19 species of *Casuarina* at Nalvedhpathy in terms of pH (7.9 to 8.8), electrical conductivity (1.06 to 1.31 dS m$^{-1}$) cation exchange capacity (8.67 to 10.11 c.mol proton$^+$ kg$^{-1}$), organic carbon (0.04 to 0.21%), available nitrogen (0.011 to 0.022 %), available phosphorus (0.002 to 0.005 %), available potassium (0.013 to 0.051 ppm), available zinc (0.47 to 0.57 ppm), available iron (2.13 to 2.90 ppm), available copper (0.22 to 0.31 ppm), available manganese (1.38 to 1.53 ppm), calcium (3.1 to 5.1 mg kg$^{-1}$), magnesium (3.2 to 4.1mg kg$^{-1}$), sodium (0.23 to 0.79 mg kg$^{-1}$) and potassium (0.02 to 0.08 mg kg$^{-1}$). All parameters were significantly higher under plantation than un-cropped site during different seasons.

Singh et al., (2011) conducted experimental trials to compare the impact of ten year old plantation of ten multipurpose tree species viz., *Casuarina equisetifolia*, *Terminalia arjuna*, *Azadirachta indica*, *Prosopis juliflora*, *Pongamia pinnata*, *Prosopis alba*, *Acacia nilotica*, *Eucalyptus tereticornis*, *Pithecellobium dulce* and *Cassia siamea* in terms of tree growth, biomass yield and physico-chemical properties of sodic soils representing major tract of salt-affected soils of the Indo-Gangetic alluvial plains. Maximum (100 %) survival was recorded for *Casuarina equisetifolia* followed by *Terminalia arjuna, Prosopis juliflora, Pongamia pinnata* and *Pithecellobium dulce* while, minimum survival (50%) was found in *Prosopis alba*. Tree height was maximum in *Eucalyptus tereticornis* (9.3 m) followed by *Casuarina equisetifolia* (8.2 m) and minimum in *Cassia siamea*. *Casuarina equisetifolia* produced highest aerial biomass (70.27 Mg ha$^{-1}$) followed by *Acacia nilotica* (63.09 Mg ha$^{-1}$) and *Prosopis juliflora* (53.11 Mg ha$^{-1}$). Significant improvement in soil pH and electrical conductivity, exchangeable sodium percentage, organic carbon and available N, P and K were recorded underneath trees than uncropped site. Significant reduction in soil bulk density (from 1.57 to 1.21 mg m$^{-3}$) and increase in porosity (40.7 to 54.3%) and infiltration rate (2.10 mm day$^{-1}$ to 26.30 mm day$^{-1}$) was recorded under tree plantations. It is concluded that tree species like *Casuarina equisetifolia*, *Acacia nilotica* and *Prosopis juliflora* significantly impacted soil properties, which could help to rehabilitate the sodic wastelands in region.
2.2. Phenology and floral biology of *Casuarina* species

Olson *et al.*, (1954) and Parrotta (1993) reported that species of *Casuarina* have minute male flowers which are crowded in rings among grayish scales. Female flowers lack sepals but have pistils with small ovaries and threadlike dark red styles. In warm climates, flowering and fruiting occur throughout the year. The peak flowering period appears to be April to June with fruiting from September to December and minimum seed bearing age is 2 to 5 years. Morton (1980) reported occurrence of flowering and fruiting throughout the year in *C. equisetifolia* and consequently, time of seed collection varies from place to place. The peak flowering period appears to be April through June and fruiting from September to December. *C. equisetifolia* flowers occur twice a year, starting from 3 to 5 years after germination. While flowers bloom in February to April and September to October, ripening of fruits occur in June and December. Durairaj and Wilson (1981) stated recorded 41 per cent monoecious trees from plantation of 15 various *Casuarina* species. The pistillate trees had significantly higher growth (14 per cent in diameter at breast height) over staminate trees.

Boland *et al.*, (1984) reported that terminal appearance of male flowers or lateral spikes in whorls in *Casuarina equisetifolia*. Male flower consists of 1 anther and 1-2 perianth parts which are often hooded over the top of the anther, there are 2 lateral bracteoles below each flower and both the perianth parts and the bracteoles are closely appraised to the stamen before anthesis. As per Woodall and Geary (1985), *Casuarina cunninghamiana*, *C. equisetifolia* and *C. glauca* has distinctive needle with leaf teeth ranging 6-8 in numbers and branchlet diameter of 0.7-0.8 mm. Staminate spike terminal is 0.6 - 2.5 cm long with floral bracts enveloping stamens invisible around teeth before anthesis in monoecious trees. Boland *et al.*, (1996) stated that drooping branchlets of *Casuarina cunninghamiana* has male spikes 1.2 - 4.0 cm long, 7-10 whorls cm⁻¹ and anthers 0.8 mm long.

Nicodemus *et al.*, (2001) reported variation in flowering duration among different provenances of *C. equisetifolia*. Seed lots of landrace started flowering at the age of two years whereas flowering was not earlier than 4 years in natural provenances. Similarly, more than 50 per cent of trees of Indian and Chinese seed lots started flowering in a 3 year old breeding population. Sex changes are known in clones of *Casuarina*
*equisetifolia* in India. The constant males, females and monoecious individual genders have been accounted for 59, 26, and 4 per cent across the population respectively. Protein content significantly differed during flowering and non-flowering seasons in *Casuarina* (Warier et al., 2001). *Casuarina equisetifolia* is monoecious species and self-compatible when compared to dioecious trees of *C. cunninghamiana* and *C. glauca*. Hybrid seed production is possible by wind pollination when male and female trees of these species grew within range of each species (Ho et al., 2002).

According to Elbert and Roger (2003) male and female flowers cluster apparently on dioecious *Casuarina glauca* with light brown color, cylindrical shape with length of 2 - 4 cm and 8 mm diameter and consisting of one stamen less than 3 mm long with two tiny sepal scales at base in male. Female flower clusters are short stalked lateral heads about 6 mm in diameter and consisting of pistil and small ovary with long thread like style. Populations of *Casuarina equisetifolia* have predominantly dioecious trees with a small percentage of monoecious trees. Its male inflorescences occur on terminal elongated spikes 7- 40 mm long and borne in whorls 7 - 11.5 number cm⁻¹ of spike. Female flowers are cone shaped, ellipsoid, 5-10 mm long and borne on lateral woody branches. Branchlets are 15 - 38 cm, long and formed by numerous segments of article each 5 - 8 mm long and 7- 8 per node (Pinyopusarerk et al., 2004 and Yashoda et al., 2004).

Nagrajan et al., (2006) observed predominant dioecious trees with low proportion of monoecious as the known sexual strategy among seventeen populations of *Casuarina equisetifolia*. Flowering occurs twice in a year coinciding with the South West and North East monsoons. *C. equisetifolia* exhibits strong anemophilous adaptations, high pollen output, large stigmatic surface and light weighing winged fruits. Pollen is viable up to 99 per cent, storable in 4°C up to three months with no loss in fertility. Local land races produce 10 to 20 time higher seeds than the exotic landraces. Controlled pollination resulted in lower seed set than open pollination. Selfing leads to normal seed set in monoecious trees.

Whistler and Elevitch (2006) proved that inflorescence is unisexual which occur in pistil late heads and staminate spikes in monoecious trees of *Casuarina equisetifolia*. Female head is 1.0 cm diameter wide and flowered laterally at the nodes of the branches,
each flower subtended by one bract and two bracteoles, perianth absent, ovary superior, with a bifid style bearing two elongate, red, linear stigmas with each flower subtended by two oval shaped bracteoles. Staminate spikes are elongate, 8–70 mm long, borne at the ends of the branches. Flowering apparently occurs twice yearly. William (2008) reported vigorous drooping in branchlets with 6-10 teeth, articles 4-9 mm long and 0.4 -0.7 mm diameter. Male spikes were 1.2 - 4.0 cm long with 7-10 whorls cm⁻¹ and anther 0.8 mm long in dioecious trees of *Casuarina cunninghamiana*.

### 2.2.1. Reproductive biology of Casuarina species

Midgley *et al.*, (1983) recorded that *Casuarina equisetifolia* produce about 20-60 g seeds kg⁻¹ of cone and number of seeds is about 300,000-700,000 kg⁻¹ of cone. Freshly collected seeds have a relatively high viability of 80 - 90 per cent and low viability of 30 - 40 per cent was reported for seeds after 1 - 2 years storage. Seed germination is completed within 2 weeks after sowing. Seedlings reach up to 10 - 15 cm height within 6-10 weeks and are transplanted into containers and maintained for 5 - 8 months duration in nursery to attain a height of 50 - 70 cm for planting out in field. Woodall and Geary (1985) noticed that male flowers are born in slender, cylindrical spikes at the twig tips in Casuarinaceae. *Casuarina equisetifolia* flower is subtended by 3 or 4 bracts, consists of a single stamen and fruits form woody cones in Australia.

Nagarajan *et al.*, (2001) conducted provenances and established a colonial hedge orchard for breeding trials in *Casuarina equisetifolia*, in which male trees flower two weeks ahead than female and flowering occurred in two distinct seasons. Local landraces mature early and have ten to twenty times higher reproductive output than natural provenances. The proportion of male, female and non-flowering individuals considerably vary within populations. Reproductive success is higher in open pollination as compared to controlled pollination. Monoecious trees were self compatible resulting in normal seed set. *Casuarina equisetifolia* provenances from the natural distribution range showed poor flowering and fruiting. Malaysia, Thailand, Australia, Papua New Guinea and Solomon Islands provenances recorded less fruits (450 - 1200) tree⁻¹ when compared to landraces from China, Vietnam and India which produced more number of fruits (3000-6000) tree⁻¹ (Nicodemus *et al.*, 2001).
2.2.2. Reproductive biology of other species

Balalia and Chauhan (1994) recorded anther dehiscence times (hours) between 6.00 AM to 7.00 AM in Dalbergia regia. Santalum album (sandal) is a predominantly out breeding species though its flower structure was designed for self- pollination. Sandal does produce seeds by selfing and self incompatibility was observed to some extent. Heterostyle was noticed in some genotypes. Pollinating agents are bees, butterflies and beetles for natural out crossing (Sindhuveerendra and Ananthapadmanabha 1996).

Tewari et al., (2002) conducted experimental trial in Dalbergia sissoo for pod formation during hybridization based on 6.94 per cent to 9.9 per cent of pollen available from other sources. Karthiayini et al., (2004) observed phenology changes viz., leaf fall, leaf bud break, flowering, fruiting and seed maturity in Swietenia macrophylla. Out of 87 flowers inflorescence\(^{-1}\) only 1.0 per cent developed into fruits. Afq and Chauhan (2008) found that the duration of flowering ranged from 26 – 49 days and mean time taken to development of flower bud has between 21 – 25 days. Maximum anther dehiscence was between 7.00 AM to 8.00 AM in Bauhinia variegata. Reproductive biology and breeding behavior in Karanja (Pongamia pinnata) reveals that initiation of buds appeared along with new foliage during first half of April, inflorescence raceme, consists of 43 – 88 numbers with peak flowering acquired from 13 – 21 days and pod development from June to August. The dehiscence of anthers started 2 – 3 hours prior to anthesis and stigma receptivity approximately one hour after dehiscence and continued till 15000 hours (Dhillon et al., 2009).

2.3. Variability of fruit and seed parameters in Casuarinas species

Morton (1980) reported a cone diameter of 10 – 20 mm and shape slightly longer than wide in Casuarina species. Seeds are 3 – 5 mm long, grayish and pale brown color in Florida and Australian condition. Woodall and Geary (1985) recorded that cone was 10 – 20 mm in diameter and slightly longer than width, in which seed is 6 – 8 mm long and pale brown colour in Casuarina equisetifolia. Kondas (1990) reported that seed of Casuarina equisetifolia reached maximum weight and germinability closed by 18 weeks after maturity. Seeds retain better viability when stored at subfreezing (-7 °C) or close to freezing (3°C) temperature, with moisture content ranging from 6 to 16 per cent up to 2
In Hawaii, seeds have been successfully stored in sealed polyethylene bags at 1°C temperature.

Olson et al., (1993) reported that cone width is about 10 to 24 mm, composed of numerous individual winged seeds light brown color in *Casuarina equisetifolia*. Parrotta (1993) recorded 8 to 20 mm diameter for cone, normally comprised of numerous individual seeds in *Casuarina* species. Each fruit is surrounded by 2 bracteoles and bract that splits apart at maturity and releases winged light brown seed. The immature fruits of the genus are green to gray and become brown to reddish brown when ripe. Male flower articles are 4 – 9 mm long with 0.4 – 0.7 mm diameter, also 9 – 18 mm long cones with 7 - 9 mm diameter, broadly acute bracteoles and 3.5 – 5.0 mm long seeds observed in *Casuarina cunninghamiana* (Boland et al., 1996).

Mahadevan et al., (1999) reported variability in seed, cone and seedling attributes among progenies of *Casuarina equisetifolia*. Ellipsoid female flowers are 5 – 10 mm long which is borne on lateral woody branches. Matured cone is 10 – 24 mm long, 9 – 13 mm in diameter with winged seed 6 – 8 mm long and dull brown color in *Casuarina equisetifolia* (Pinyopusarerk et al., 2004). Cones were slightly longer than wide, slightly hairy and composed of small single winged seed in *Casuarina equisetifolia* (Yashoda et al., 2004).

Whistler and Elevitch (2006) suggested that cone matured within 18 – 20 weeks after anthesis and peak flowering occurred from April to June and development of the fruits, from September to December in *Casuarina equisetifolia*. Cone is 1.2 – 2.2 cm long with 0.7 – 1.3 cm diameter and seed enclosed within a nut is borne in the cone 4 – 5 mm long. William (2008) documented that cone length is about 9 – 18 mm with 7 – 9 mm diameter bracteoles broadly acute and ferruginous to white pubescent becoming glabrous and samara is 3.5 – 5.0 mm length in *Casuarina cunninghamiana*. Seed size and shape of cone were found smaller in *Casuarina cunninghamiana* than *C. equisetifolia* (Wilson and Johnson 2008).

2.3.1. Cone and seed grading

The most essential factor for the success of plantation is the ready availability of quality seeds. The quality of seed is totally responsible for the future return / performance of each and every seedling. Environment influences the development of the seed and genetic
variability cause variations in seed dimensions even within a single species. Cone or seed of woody plants exhibit a great range of variation for shape, size, colour and behavior in species. In order to produce a crop of seedlings which emerge and grow uniformly, grading of seed on size is a useful practice in forestry (Willan, 1985).

Halos (1983) graded cones into different classes of size, viz. small (<14 mm), medium (15 – 20 mm) and large (>21 mm) in Casuarina equisetifolia. Significantly higher viability and germination percentage was obtained from large size when compared to smaller size of cone. Moideen et al., (1990) observed significantly higher germination and vigor in the graded South Dakota blower seed when compared to unprocessed seed lots in Casuarina equisetifolia. Evaluation of cones were done on base of grading viz., light (< 4.0 g), medium (4.1 – 6.0 g) and heavy (>6.1 g) weight and fascinatingly seeds from heavy weight of cone has been shown high germinability. Similarly, high density of seeds retained at the highest air speed setting had a best grading for superior germination. A comparison among four graded of seeds with ungraded seeds indicated greater germination and vigor from higher weight of cone.

Agboola (1993) stated that germination rate of small size seed was faster and inferior when compared to large seed in various tropical trees species. Viswanath et al., (1995) reported that bigger sized seeds (>14 mm diameter) germinated faster than smaller seed and had better growth performance during the first year in teak. Indira et al., (2000) suggested that size of seed did not have any significant influence for seedling survival and growth in teak, while fruits with < 9 mm diameter size had shown low germination percentage leading to fewer seedlings. Slobodnik and Guttenberger (2000) recommended upgrading the germination performance of C. equisetifolia seed lots through grading technique. However, lower germination was shown in one seed lot probably due to the presence of non-germinal seed such as empty seeds, insect damaged seeds and dead seeds. Umarani and Vanangamudi (2002) confirmed that graded seed lots based on size (seed mass) resulted in better germination from larger (167 mg/100 seeds) than smaller (105 mg/100 seeds) size seeds. Similarly, use of specific gravity separator resulted in better germination from heavier seeds than light weight ones. Sudhakar and Jijeesh (2008) opined that decrease in the size of drupe results in poor germination when compared to increased size of seed in teak.
2.4. Seed germination of *Casuarina* species

The aim of the germination test is to furnish reliable information on the field planting value of a seed. The test results can be used to compare the quality of different species seed lots. Germination must be uniform and be reproducible in seed testing laboratories. Seeds require certain favorable conditions for ensuring higher germination. The most important requirements are substrata, moisture, temperature, light and pre-treatments.

Gupta and Prasad (1988) reported higher seed germination in *Casuarina equisetifolia* only when field temperature was at 30 °C after final count of 22 days. El-Lakany *et al.*, (1989) registered less number of seeds per cone for *Casuarina cunninghamiana* (32.3) than *C. glauca* (70.3) and the hybrid (75.1) with average germination percentage for autumn and spring collected seeds. The highest percentage of germination has occurred in autumn collected seeds for *C. glauca* (70.0 %), *C. cunninghamiana* (60.3%) and their hybrid (71.6 %) in raised bed. According to El-Lakany *et al.*, (1990), superior seed germination and growth of seedlings occurred from freshly collected seed and seed stored upto 8 month and 20 month at normal room temperature. The number of seeds per cone was less in *Casuarina cunninghamiana* than *C. glauca* and the hybrid. Germination was higher in autumn collected seeds in all species and hybrid, but species differences were not much (54.2 – 61.5 % in the autumn and 34.0 – 44.3 % in the spring). Seed moisture content increased and germinability reduced after 20 month storage.

Olson *et al.*, (1993) registered 44 – 57 per cent of seed germination in *Casuarina glauca* and *C. cunninghamiana* within 28 to 32 days respectively at 20 °C temperature with a 16 hour photoperiod. Boland *et al.*, (1996) reported that seed germination in *Casuarina* species was completed within 2 to 3 weeks. While, seeds collected from dioecious trees of *Casuarina equisetifolia* tend to produce seedling populations at 1:1 ratio of male and female plants, the ratio may vary among individuals. Tony (2006) substantiated variation for seed longevity in various species viz., *Casuarina pauper* and three *Acacia* species under different storage periods and seed banks. Seed viability was lower in *A. oswaldii* seed banks under storage for 1 – 2 years among species tested. Shivakumar *et al.*, (2007) recommended that seed require at least 2 to 3 weeks duration
for germination in *Casuarina equisetifolia*. Seed collected from dioecious trees tend to produce seedling populations of male and female (1:1) plants but this ratio may vary.

### 2.4.1. Influence of substratas for seed germination
Substrata serve as moisture reservoirs and provide a surface or medium on which the seed can germinate and the seedlings grow. The commonly used substratas are paper, seed tray and nursery beds. Impacts of substrata on seed germination were assessed and suitable substrata recommended optimizing germination and growth performance in many studies.

Larsen (1965) recommended that seed trays can be used for Eucalyptus and *Casuarina* seeds which allow sufficient space for germination and seedling development. The trays used are commercial meat trays that have a clear plastic lid and dimensions of 30 cm x 20 cm x 4 cm. El-Lakany and Shepherd (1983) conducted experimental trials for seed germination on raised nursery bed using four species viz., *Casuarina equisetifolia*, *C. cunninghamiana*, *C. glauca* and reputed hybrids (*C. cunninghamiana* X *C. glauca*). *C. equisetifolia* had higher seed germination among the species in raised bed. Significant differences were observed for seed germination both between and within *C. glauca* and *C. cunninghamiana*. Ng and Matasri (1987) reported rapid seed germination in *Casuarina equisetifolia* at high temperatures with 50 per cent of viability in seed bed substrata. Jambulingam (1990) reported that seed collected from riverine source were superior for germination and better seedling height growth in root trainers when compared to inland and coastal sources in *Casuarina equisetifolia*.

AOSA (1993) and Rai (1990) observed initiation of seed germination from 4 days which completed within 22 days after seed sowing at optimized 30 °C under well lighted conditions. Soaking seeds in 1.5 % solution of potassium nitrate for 36 hours enhances higher germination. Germination ranges from 40 % to 90 % for fresh seeds and 5 % to 25 % for seeds stored in airtight containers at 4 °C for 1 year. Significant positive relationship was between size of cone and seed germination rate under alternating temperatures of 20 °C / 30 °C on the top of moist blotter paper.

According to Lalita *et al.*, (1993) variation for seed germination was exhibited under increasing or decreasing salinity stress in *Casuarina equisetifolia* and *C. glauca*. Significantly higher seed germination was in *C. equisetifolia* than *C. glauca* at EC of 10.0 ds m⁻¹. Seed germination percentage was higher in *C. glauca* than *C. equisetifolia* at EC...
of 5.0 ds m\(^{-1}\). Parrotta (1993) revealed higher seed germination at an optimal density of 1,000 to 7,500 seeds (seeds wt. 10.0 g / m\(^2\)) covered with 0.5 cm layer of sandy loams soil and peat moss under full sunlight in *Casuarina equisetifolia*. It produces an average of 18,000 seedlings kg\(^{-1}\) of seeds from river source.

Whistler and Elevitch (2006) evaluated viability of stored seed for various species viz., *Casuarina cunninghamiana*, *C. glauca* and *Casuarina* hybrid under different storage periods from 8 to 20 months at room temperature. Moisture content of seed increased in 20 months of storage and germination per cent declined compared to freshly collected seeds in all species. Average values of seed germination observed for fresh, 8-month and 20-month stored seeds was 62.4 %, 62.8 % and 15.1 % for *C. glauca*, 54.3 %, 58.7 % and 13.7 % for *C. cunninghamiana* and 59.6 %, 55.2 % and 13.51 % for *Casuarina* hybrid respectively.

Kader *et al.*, (2001) reported that staining pattern of the embryo (fully stained, embryo darkly stained and moderately stained, both not stained) indicated seed viability of *Swietenia macrophylla*. Results showed no significant differences in viability estimates obtained by the tetrazolium and hydrogen peroxide tests and the germinability determined by actual germination test. Vanangamudi *et al.* (2001) revealed that 1 % tetrazolium chloride solution serve to identify the viable and nonviable seeds in *Albizia lebbeck*, *Acacia nilotica*, *Azadirachta indica* and *Casuarina equisetifolia*. Positive correlation was recorded between viability percentage estimated by the tetrazolium test and the standard germination test. Wood *et al.* (2005) used tetrazolium (TZ) stain technique to compare staining for classification of viable or non viable seeds in 171 species from 27 families and including 4 genera of *Casuarina*.

Jabbar *et al.*, (2010) investigated comparative growth performance of *Albizia procera* seedlings grown in poly bag, nursery bed and root trainers with an aim to select suitable container for seed germination as well as quality seedlings for large scale plantation programme. Vigour index, quality index, imbibitions period, energy period and root shoot ratio were estimated for each treatment. Seed germination percentage was higher in nursery bed among container. Seedlings raised in poly bags of 23 x 15 cm size showed superior performance in respect to germination and other growth parameters.
Poly bag size of 23 x 15 cm is suitable in the nursery for quality seedling production of *Albizia procera*.

**2.4.2. Effect of pre sowing treatments for seed germination in *Casuarina* species**

A common method used for propagation of *Casuarina* is easy from seed which require any pre-treatment prior to sowing. Germination of the seed of *Casuarina* species is usually quite easy by normal seed raising methods. Hence, some essential pre-treatments are imposed for promoting better germination. Villiers (1972) described dormancy as being state of arrested development where by seeds possesses some mechanism preventing their germination. Beadle (1952) recommended soaking the seeds in water for 24 hours, provided all excess water was subsequently removed from the fruits to prevent water logging the seed to break dormancy. Seeds of some species such as *Artipex* contain chemical inhibitors which must be leached out before germination can occur. Other species which may respond to cold water soaking are some species of *Grevillea* and *Hakea*.

Schopmeyer (1974) observed that seeds have germinated (91%) in water medium after exposure to light for 6 hours per day for 4 to 6 week compared to control Casuarinas. ISTA Rules (1993) recommend paper methods in terms of seed germination test. Thus paper should not be so wet so as to find a film of water around the finger. Peterson and Cooper (1979) suggested that moisture potentials be pre-determined for each species. They also found great variation in individual analysts' interpretations of the amount of water needed in a germination test.

Poggenpoel (1978) reported that seeds of most Australian *Acacias* and *Casuarina* species require some form of boiling water pretreatment in order to promote germination. There are a number of species or specific seed lots which respond better to a hot water treatment with 90°C for 1 minute. Clemens *et al.*, (1977) found that two species of *Acacia* gave lower germination responses with scarification than with hot water treatments. The disadvantage of the hot or boiling water treatment is that it may not affect all seeds in the sample. Differing responses was found to hot water temperature and length of treatment in five Acacia species. Germination increased with severity of treatment up to a point where seed mortality was reached.
Boland et al., (1980) recorded that pre-chilling also known as cold-moist stratification can be used to break embryo dormancy in some Eucalypts. This pretreatment subjects seeds to a cold moist environment. El-Lakany (1981) stated effects of salinity on seed germination and seedling growth of Casuarina species. Germinability decreased as the salt concentration increased irrespective of the species and the effects of NaCl was more harmful than CaCl₂. C. glauca appeared to be more sensitive than the C. equisetifolia. Moideen et al., (1990) reported that seeds of Casuarina equisetifolia soaked in 1.5 per cent of KNO₃ recorded higher germination and vigor index compared to water soaked seeds.

Ezek and Adonis (1993) studied various pre-sowing seed soaking tests for inducing the seeds of Casuarina equisetifolia to germinate better than under natural condition. Seed germination percentage in untreated seed ranged from 7 – 17 % over 6 days. The most effective treatment was GA₃ (0.1 mM) followed by NaNO₃ (0.1 mM) and H₂SO₄ (0.1mM) and ABA (0.1mM) for increased percentage of seed germination by less than 62 per cent. Rai (1990) opined that Casuarina seeds are usually sown without pretreatment, although soaking seeds for 36 hours in a 1.5% solution of potassium nitrate reportedly enhances germination by 92 % for fresh seeds and 40 % for seeds stored in airtight containers at 4 °C for 1 year.

Umarani (1999) opined that pre sowing seed treatment in Casuarina equisetifolia soaked with various chemicals viz., cytozyme, mixalo, potassium nitrate and calcium oxychloride at different concentrations. Significantly higher seed germination percentage and seedling vigour index was reported in KNO₃ and CaOCl than the other treatments. Anandalakshmi et al., (2001) reported absence of dormancy in Casuarina equisetifolia seeds and germination ranged from 40 – 50 per cent. It was also observed that sowing seed with treatments did not increase the seed germination when compared to control. However, pre-storage seed treatments with chemicals would increase the shelf life of seed germination.

2.4.3. Effect of pre sowing treatments for seed germination in other species
Seeds of different species of Pinus, Picea, Larix, Cunninghamiana, Ptatychladus, Hippophaceae and Vitex germinated better when they were previously soaked in water for 15 to 24 hours. Soaking for more than 24 hours was detrimental to the germination of
all the species (Ma and Liu, 1986). However, seeds of teak soaked in running water for 96 hours before sowing in the nursery showed better germination (Mioma 1986). Mukhopadyaya et al., (1990) found that in Peltoforum ferrugenium in general 12 or 14 hours of seed soaking in GA3 and KNO3 solution or 6 hours of soaking in thiourea solution significantly increased the seed germination percentage and was superior to other treatments. Ramakrishanan et al., (1990) observed that soaking of Ailanthus excelsa seeds in 2.5 per cent KNO3 gave an increase of 28 per cent in germination compared to control.

Roy (1992) stated the maximum germination percentage of Albizzia lebbeck was achieved under (0.3 %) KNO3 treatment. Bhattacharya et al., (1991) reported better germination and vigour index in Eucalyptus hybrid seeds when treated with GA3 (100 ppm) and KN03 (500 ppm) than the control. Catalan et al, (1991) conducted experiments for pre-sowing seed treatment in Prospopis flexuosa and P. alba seeds and observed better germination in hot water with improved scarification than the control. Vanangamudi (1993) registered significantly enhanced germination in Azadirachta indica soaked in 2 % potassium nitrate with 12 % moisture content for 24 h after few hours air drying. Bonney (1994) reported that ripened seed of Boronia and Eriostemon need to be placed in moving water for many hours to help leach out inhibitors to promote better germination.

Kanak shanai et al., (1995) reported that a strong barrier to water supply entry into the seed is located in the upper part of the palisade cells. This could be removed effectively by abrasion with sand paper on the seed coat of Leucaena leucocephala. Susila and Effendi (1995) showed that seeds of Pterocarpus indicus soaked in cold water for 6, 12, 18, 24 and 30 hours or in hot water for 2 minutes could overcome dormancy and the best germination percentage was obtained in the cold treatment than control. Prasad and Nautiyal (1996) opined that soaking the seeds in hot water and mechanical scarification gave better germination percentage and removed dormancy in Bauhinia racemosa.

2.5. Half sib progenies of Casuarina species
Narayan et al., (1978) studied the effect of water stress on growth, nodulation and nitrogen fixation in Casuarina equisetifolia. Shoot and root length, shoot and root
weight, nodule size and number of nodules and weight of seedling decreased with increase in the water stress. El-Lakany (1981) registered significant higher growth and tolerance to 30 per cent concentration of CaCO$_3$ in the soil for *Casuarina glauca* seedlings than *C. cunninghamiana* and *C. equisetifolia*.

Halos (1983) observed growth variation in seedling height due to differences in their cone size and number of seeds g$^{-1}$ among the provenance of *Casuarina equisetifolia*. *Casuarina equisetifolia* is one of most suitable planting stocks in saline soils and dry regions preferred over other species in China (El-Lakany *et al.*, 1990). Growth performance of seedling and significantly height growth was in *Casuarina equisetifolia* than *C. cunninghamiana* and *C. glauca* in field condition (Pan *et al.*, 1990). Parrotta (1993) recommended ideal seedling selection can be done when it reaches plantable size from 20 to 50 cm in height after 8 months growth in *Casuarina equisetifolia*. Rao *et al.*, (2001) conducted progeny trial in which plant height, girth at ground level, girth at breast height, axis persistence and straightness had significant variation among the 16 families of *Casuarina equisetifolia*.

Tamar and Gupta (2002) suggested that 13 month old progenies of *C. equisetifolia* and *C. glauca* performed superior than 9 month old saplings with higher growth than *C. obesa* and *C. cunninghamiana*. Boby *et al.*, (2004) described seedling growth on inoculation with mycorrhizal fungi when compared to uninoculated seedling in *Casuarina equisetifolia*. *Glomus mosseae* gave maximum response for height, stem girth, root length and shoot length among different mycorrhizal fungi inoculation. Significantly higher seedling height (47.30 cm), collar diameter (3.08 mm), total dry weight (4.5 g), shoot dry weight (3.04 g), root dry weight (1.47 g) and quality index (0.26) were found in five month growth when compared to 3 months of *Casuarina equisetifolia* (Rathore *et al.*, 2004).

**2.5.1. Biomass production and nutrient content in progenies of *Casuarina* species**

Paul and Bowen (1985) found that *Casuarina* species differed in growth responses to inoculation with *Frankia* from five sources. *Casuarina equisetifolia* had formed higher number of nodules than *C. cunninghamiana* which had only two nodules. Observed effectiveness was related to nodule development after infection and the ability of
developed nodules to fix N\textsubscript{2}. El-Lakany (1987) described variation in root nodule formation in *Casuarina equisetifolia*, *C. cunninghamiana* and *C. glauca* in nurseries and field plantations. Root nodulation varied between species and between sites within species. *C. glauca* had formed significantly higher nodules on root and fixed nitrogen at a higher rate when compared to other species. Sougoufara *et al.*, (1987) suggested conspicuous difference in nodule numbers among two clones of *Casuarina equisetifolia*. One of the clones was shown to fix 1.6 times more nitrogen and produce a biomass 2.6 times higher than the other clone, with inoculation having been achieved with the same strain of *Frankia*.

Sellstedt (1988) reported higher total nitrogen content in *Casuarina equisetifolia* than *C. glauca*, *C. cristata* and *C. obesa* within 150 days at nursery. Dawson *et al.*, (1989) described that root nodules per seedling was significantly higher in *C. cunninghamiana* and *C. glauca* than seedlings of *C. equisetifolia* and *C. cristata*. Srivastava and Ambasht (1994) confirmed that total nitrogen deposition by rainfall was 11.1 kg ha\textsuperscript{-1} year\textsuperscript{-1} and through needle fall was 13.6 kg ha\textsuperscript{-1} year\textsuperscript{-1} and 16.5 kg ha\textsuperscript{-1} year\textsuperscript{-1} in 5 year old and 8 year respectively in stands of *Casuarina equisetifolia*. Net deposition of nitrogen as an effect of canopy added directly to the available nutrient pool of soil.

Lalita and Dikshit (1994) revealed significant increase in the dry matter in needles and stem of *Casuarina obesa* followed by *C. glauca*, *C. cunninghamiana* and *C. equisetifolia* with increasing soil sodicity. While, yields of *C. equisetifolia* decreased with increase in soil sodicity, *Casuarina obesa* and *C. glauca* produced comparatively more dry matter under sodicity than *C. cunninghamiana* and *C. equisetifolia*. The effect of sodicity was more pronounced on needles than on stems in all the 4 species. Sodium concentration in plant parts increased with increasing sodicity, whereas concentration of potassium, calcium, magnesium, nitrogen and phosphorus were decreased.

Bino and Kanua (1996) estimated dry leaf litter weight of 3.3 t ha\textsuperscript{-1} year\textsuperscript{-1} for the first three years of growth which was higher at 7 – 8 t ha\textsuperscript{-1} year\textsuperscript{-1} for 10 – 15 year old *Casuarina* plantation. Estimates of nutrient returns to the soil from leaf litter were 39, 3.0 and 10 (kg ha\textsuperscript{-1} year\textsuperscript{-1}) of N, P and K respectively for the first three years of growth and 84 – 123 kg N ha\textsuperscript{-1} year\textsuperscript{-1} for 10 – 15 year old trees. Hosur *et al.*, (1997) reported
significantly higher total nitrogen content in *Casuarina equisetifolia* compared to *C. cunninghamiana* and *C. cristata*.

Sellstedt and Atkins (1999) reported that free proline and nitrogen content increased in *Casuarina cunninghamiana* followed by *C. equisetifolia* and *C. glauca* when inoculated with Frankia. In *C. glauca* asparagines were the major amino acid in the root sap followed by proline, while in symbiotic *C. cunninghamiana* arginine accounted for more than 25 per cent of the amino compounds. Sayed *et al.*, (2002) stated that inhibition of nodulation can be attributed to high concentrations of some elements and compounds that were either found in *C. equisetifolia* litter or found in soil. In general, plant growth decreased as more litter was added. Plant total nitrogen content was also reduced after increasing the litter concentration. The inhibitory effect of high litter concentrations was mainly on plant growth and to a lesser extent on plant nodulation by Frankia strains.

Liang *et al.*, (2003) studied proline accumulation in twigs of *Casuarina* under different growth conditions. The results showed that free proline content and the PM ATPase activities from unfavorable growth conditions were obviously higher than those from favorable environment. Hence, *Casuarina* responded to osmotic stress by increasing osmotic material content and the proton transportation activities of PM ATPase.

Thiyageshwari *et al.*, (2003) described variation in nutrient content in *Casuarina equisetifolia* within 20 days after sown. Nitrogen (1.90 %), phosphorus (0.23 %), potassium (2.45 %), Ca (2.49 %) and Mg (0.36 %) were recorded in seedling growth in a mixture of sand and vermi compost in the ratio of 1:1 which was significantly higher nutrient concentration than the control.

Chiharu and Hideo (2006) reported that free proline content of the shoots increased with increasing NaCl concentration in the culture solution and reached 13.5 µmol g⁻¹ fresh weight in *Casuarina equisetifolia*, which is highly tolerant to salt stress and primarily synthesize proline as a major compatible solute to adjust the osmotic pressure when Na⁺ accumulates in the cells to maintain cell homeostasis under salt stress conditions. Sougoufara *et al.*, (2009) found conspicuous differences in nodule numbers in a preliminary screening experiment among seedlings of *Casuarina equisetifolia*. One of the clones was shown to fix 1.6 times more nitrogen and produce a biomass 2.6 times higher than the other clone when inoculated with the same strain of Frankia.
2.6. Variability, heritability and genetic advance

Heritability estimates have an important place in tree breeding as it provides an evaluation of the relative strengths of genetic and environmental influences. It is useful for ranking the traits in tree improvement programme as it indicates the degree of transfer of a character from parents to its offspring.

2.6.1. Variability in different Casuarina species

Ying and Bagley (1976) described strong genetic control of phenological traits in *Casuarina equisetifolia*. Inflorescence recorded higher genetic variability in a particular environment. Durairaj and Kondas (1981) observed variation for vigour, stem form, shape, crown, branch angle and size of cones among the species of *Casuarina*. Schmidtling (1983) suggested increased heritability for male flowers increased with age. Heritability was found to vary from 20 % - 46 % in females and 34 % to 56 % males. Among 161 clones, 32 clones accounted for 42 to 54 per cent of clonal contribution in female and 83 to 96 per cent male in *Casuarina equisetifolia*. Hence clonal contribution for male parents was unbalanced compared to that of female parents.

El-Lakany and Yuness (1985) found significant variation for height and diameter growth at the age of two and three years among provenance of *Casuarina equisetifolia*. The tallest tree was nearly four times the height of the shortest, which confirmed the high intra provenance variation. Sougoufara et al., (1986) studied variability in survival rate of *Casuarina cunninghamiana* and *C. glauca* among provenances. However, genetic variability for nitrogen fixation potential was high among clones of *Casuarina equisetifolia*. El-lakany (1990) observed significant variation for height and diameter of *Casuarina glauca* at the age of 7 years and non significant variation at the age of 2.5 years among the provenances.

El-Lakany et al., (1990) showed significant inter and intra provenance differences for survival, height and diameter at breast height in *Casuarina glauca* and *C. cunninghamiana* at age of 7 years. Turnbull (1990) suggested low intra specific genetic variation in *Casuarina equisetifolia* followed by *C. glauca, C. cunninghamiana, C. junghuhniana, C. grandis* and *C. oligodon* in arid region. Hence, intra specific genetic variations have been confined in various species of *Casuarina*. Moran (1992) reported genetic variation in *Casuarina cunninghamiana* by analyzing 19 allozyme loci using 50
seedlings from each of 20 provenances. The overall genetic diversity was high compared to many other species. A significant fraction (26.4 %) of the total genetic diversity could be apportioned between populations.

Paramathma et al., (1994) observed significant variability in height, diameter and other growth forms of germplasms among fifty six genotypes in *Casuarina equisetifolia*. Ashok kumar and Gurumurthi (1996) recommended that larger variability in the base population of *Casuarina equisetifolia* provides abundant opportunity for selection. The coefficient of variation was high for stem, root weight; wood volume and total biomass in population and less variation were for diameter at breast height and wood density. According to Zhong et al., (1996) genetic gain was moderate for all the characters and maximum for diameter at breast height (49.24%) in *Casuarina equisetifolia*. Heritability was higher for eleven traits and moderate for survival per cent in *Casuarina junghuhniana*.

Arya et al., (1997) described significant differences for seedling height with increased genotypic coefficient of variation and phenotypic coefficient of variation in early stage among progenies in *Casuarina equisetifolia*. Kumaravelu (1997) showed higher heritability and genetic advance for weight of cone followed by seed surface area and seed weight in *Casuarina equisetifolia*. Ashok Kumar and Gurumurthi (1998) reported high heritability estimates in height (86 %), bole volume (85 %), diameter at breast height (80 %) and diameter at ground level (73 %) at twelve month age among clones of *Casuarina equisetifolia*. Mahadevan et al., (1999) revealed lower heritability for height, diameter and nodule number of *Casuarina equisetifolia* progenies and maximum heritability for shoot weight at two locations. Magnitude of genetic advance was higher for growth characters than the cone and seed traits. The estimated heritability and genetic advance increased from 12 months onward to 36 months after planting for all the variables.

Rao et al., (2001) reported significant difference for height, girth ground length, girth at breast height and straightness among provenances in *Casuarina equisetifolia*. Genetic advances showed high heritability for the characters axis persistence and straightness, while moderate estimates of heritability were recorded for height, girth at ground length and girth at breast height. Varghese et al., (2001) described higher
heritability in wood (density, moisture content) and bark thickness but non-significant correlation existed between growth and wood traits. Bark thickness varied between locations and was high in *Casuarina junghuhiana*. Wood density would be crucial in deciding Runkel ratio and other pulping traits in *Casuarina* species. Nayak *et al.*, (2002) registered higher variability for different parameters such as size of fruit, number of seeds per fruit, seed weight and germination per cent in *Casuarina equisetifolia*.

2.6.2. Variability of other species

Nelson and Tauer (1987) observed high heritability for first and second year date of leaf fall and number of branches per decimeter and these traits were under simple genetic control in *Populus deltoids*. Toky (1996) reported significant variations for height, diameter, branch number and biomass among 12 provenances of *Albizia lebbek*. There were significant correlations between height and diameter at breast height with the latitude of seed source origin. The heritability estimates were height (23.6 %), diameter at breast height (20.3 %), crown spread (24 %) and bole biomass (17.3 %) in semi-arid and arid regions. Afaq and Chauhan (2006) observed significant differences in seedling height, seedling diameter, inter-nodal length, number of leaves, leaf area, shoot fresh weight, shoot dry weight, root fresh weight, root dry weight, shoot root ratio and seedling biomass among 24 half sib families of *Bauhinia variegata*. Root dry weight exhibited the maximum variability expressed as PCV and GCV. Leaf area showed high heritability with high genetic advance, on the contrary fresh shoot weight exhibited high heritability with low genetic advance.

Dhillon *et al.*, (2009) reported significant variability for collar diameter and plant height at nursery stage among 11 progenies of *Melia azadirachta*. The heritability was observed to be medium for diameter and height. The genetic gain and variation coefficients for diameter were also relatively higher under field conditions. Luna and Singh (2009) recorded that heritability values for height, diameter and clean bole were high with high genetic gains among 11 candidate plus trees of Eucalyptus hybrid. Similarly straightness exhibited high heritability with high genetic gain for axis persistence. The significant genotypic and phenotypic correlation found between height and diameter suggests that improvement in one character will be accompanied by another.
2.7. Correlation studies

Correlation co-efficient analysis helps to determine the nature and degree of relationship between any two measurable characters. It resolves the complex relations between important characters which are of immense help in the selection of suitable clones. But a measure of correlation does not consider the dependence of one variable on the other. The direct contribution of each component to the cone and wood volume yield and the indirect effect it has through its association with other components cannot be differentiated from mere correlation studies.

2.7.1. Correlation studies in Casuarina species

Jambulingam (1989) described a significant positive correlation between total biomass and other traits viz., girth at breast height, stem weight and volume in *Casuarina equisetifolia*. El-lakany (1990) reported significant correlation between height and latitude of seed source in provenance trial of *Casuarina cunninghamiana* and non significant in both *C. glauca* and *C. equisetifolia*. Moran (1992) registered a significant positive correlation between genetic diversity and height growth in *Casuarina cunninghamiana* provenance. Paramathma *et al.*, (1994) documented significant correlation between survival and tree height in *Casuarina equisetifolia* provenance. Total dry weight was exhibited positive and significant correlation with all others characters.

Kumaravelu (1997) reported positive correlation of height with diameter at breast height (0.97), needle weight (0.89), branch weight (0.81) and basal diameter (0.86) at genotypic level of *Casuarina equisetifolia*. Also rate of height growth at nursery stage was strongly correlated to the growth in the field after two years. Ashok Kumar and Gurumurthi (1998) exhibited that height highly correlated with other growth characters of *Casuarina equisetifolia*. Main bole volume expressed maximum association for diameter at ground level. Such positive correlation also existed between stem straightness and axis persistence.

Ashok Kumar (2001) revealed that volume index expressed positive association with chlorophyll 'a', chlorophyll 'b', total chlorophyll, collar diameter, height, suitability index and needle length in provenance of *Casuarina equisetifolia* at both phenotypic and genotypic levels. The tree height and collar diameter were inter associated among themselves and in combination with number of branches and suitability index enhance
the volume index. Mahadevan et al., (1999) registered significant correlation between seed weight, roundness shape for height and diameter in *Casuarina equisetifolia* progeny at both juvenile and mature stages. Seed 2D surface area had high direct and indirect effect on collar diameter at 60 month after sowing.

El-Juhany et al., (2002) predicted both total above ground biomass and merchantable volume by using parameters viz., diameter at breast height, total height and merchantable height in *Casuarina cunninghamiana*, *C. glauca* and hybrid of *Casuarina*. The correlation coefficients of these relationships were highly significant but differed according to species. Tomar and Gupta (2002) revealed significant positive correlations of salinity with tree height (R = 0.81) and diameter (R= 0.76) for 13 months old saplings compared to 9 month old ones in *Casuarina glauca* and *C. obesa*. The total tree biomass significantly differed based on height and girth.

Kumaravelu et al., (2004) reported correlation coefficients for juvenile characters (6 months after sowing) and observed significant correlation of height, basal diameter, suitability index, needle weight, branch weight, bark thickness, pole weight and total biomass for adult (36 months after sowing) characters in *Casuarina equisetifolia*. Ashok Kumar and Paramathama (2005) reported that genotypic correlation was higher than phenotypic correlations among 44 clones in *Casuarina equisetifolia*. Seedling height, collar diameter, number of branches, survival percentage chlorophyll content and suitability index were strongly associated with volume index.

### 2.8. Path analysis

Association between characters measured in terms of correlation coefficients does not give a complete picture of the causal mechanism of their association. Path coefficient analysis is more useful in the partitioning of correlation into the components of direct and indirect effects. Path coefficient analysis is a simple standardized regression coefficient which apportions the correlation co-efficient into direct and indirect effect of a set of individual variables on the dependent variable and measures the relative importance of the causal factors involved (Dawey and Lu, 1959). Path coefficient analysis is being extensively utilized for understanding the complex traits in breeding programmes.
2.8.1. Path analysis of different *Casuarina* species

Paramathma et al., (1994) reported direct contribution of root length, shoot length, root weight and diameter at breast height to biomass in *Casuarina equisetifolia*. However, maximum positive direct effect upon total biomass was exerted by nodule weight followed by diameter at breast height. Ashok Kumar et al., (1996) revealed maximum positive direct effect of tree height, diameter at ground level, diameter at breast height and number of branches on biomass production which was shown higher in male than in female trees of *Casuarina equisetifolia*. Kumaravelu (1997) reported that diameter at breast height exerted its direct positive effect on total volume and indirectly via pole weight in *Casuarina equisetifolia*. Positive correlation of pole weight with biomass was evident due to partially direct effect and indirect effect through branch weight and volume.

Ashok Kumar and Gurumurthi (1998) described positively direct effect of diameter at breast height, girth at breast height and height upon wood volume production. Similarly diameter at breast height exerted the maximum direct effect on total biomass production for both genders in *Casuarina equisetifolia*. Ravichandran and Balasubbramanian (2000) confirmed that height and diameter at breast height had maximum direct effect on the wood volume production in *Casuarina equisetifolia* in Southern Ethiopia. Ashok Kumar (2001) observed direct influence of height upon volume index, collar diameter, survival per cent and total chlorophyll content in *Casuarina equisetifolia*. Number of branches and needle length showed positive direct effect with low magnitude. Ashok Kumar and Paramathama (2005) confirmed direct effect of seedling height, total chlorophyll content and number of branches on suitability index among 44 clones of in *Casuarina equisetifolia*. Maximum positive indirect effect on volume index was exerted by number of branches.

2.8.2. Correlation and path analysis of other species

Gera et al., (1999) revealed that among 14 characters, polyphenol content, number of branches, pod length and germination per cent had higher direct or indirect effects upon height in *Dalbergia sissoo*. Kareddy et al., (2003) reported that kernel yield was significantly and positively correlated with fruit yield, fruit size and fruit weight in charoli (*Buchanania lanzan*). Highest direct positive effects on fruit yield was from
physical and chemical characters contributing towards kernel yield per plant. Positive direct and indirect effect of fruit yield and fruit weight respectively was recorded.

Kumar and Siddiqi (2004) observed correlation of dry biomass with seedling height, root length, collar diameter; numbers of leaves per plant and leaflet area were positive and significant. Seedling height, root length, collar diameter and number of leaves per plant had direct effect upon dry biomass production of Albizia lebbeck. Devagiri et al., (2006) reported highly significant positive correlation between total numbers of nodules and root length in Dalbergia sissoo. Significant biomass production was associated with dry matter and numbers of root nodules. Korti Rawat et al., (2006) revealed that seed length, seed width and thickness, weight and volume were positively correlated with each other in Pinus wallichiana.

2.9. D² analysis in Casuarina species

Jambulingam (1989) identified 8 genetically distinct clusters from 32 families of Casuarina equisetifolia, in which cluster I was largest with 11 families, cluster IV and cluster V shown wide difference in mean values for height, diameter and number of branches. Ashok Kumar (1995) conducted experimental trials for genetic divergence of 42 clones of Casuarina equisetifolia using ward’s hierarchical method of grouping and identified 12 clusters. Cluster II was found to have the fastest growing male clone, whereas cluster VIII had the fastest growing female clone.

Ashok Kumar and Gurumurthi (2000) studied the genetic divergence of high yielding clones at the age of 12 months in Casuarina equisetifolia. On the basis of cluster distance, 42 clones were grouped into 12 clusters, and inter and intra-cluster distance calculated. Mean cluster values showed significant variation among the clusters for all the traits. Cluster II had the fastest growing male clone and cluster 8 had the fastest growing female clone. Balsubramanian and Gurumurthi (2001) described 10 distinct clusters among grouping of 52 clones using D² analysis in Casuarina equisetifolia. Fast growing clones are physiologically active throughout the year whereas low productive clones modulate in their productivity according to the availability of moisture. Physiological parameters viz., photosynthesis, transpiration, stomata conductance and inter cellular CO₂ concentration may be considered as selection criteria for advance generation breeding.
Kumaravelu (2001) classified 77 progenies into 12 clusters in *Casuarina equisetifolia* clonal evaluation trial. Cluster XI had maximum mean values for height, dbh, pole weight, bark thickness and cluster X for total biomass, needle and branch weight. Based on inter-cluster distance clusters IX, X and XI were found highly divergent from the other clusters. Total biomass contributed maximum percentage towards genetic divergence followed by needle weight, branch weight, dbh, height, pole weight and bark thickness.

Dorothy (2003) reported that Casuarinaceae (Gondwanic family) had a unique combination of morphological characters not comparable to any other family. Until recently, the 96 species in the family were classified in a single genus *Casuarina*. A recent morphological revision of the family resulted in the splitting of *Casuarina* into four genera * Allocasuarina, Casuarina, Ceuthostoma*, and *Gymnostoma*. This study used *matK* sequence data from 76 species of Casuarinaceae and 8 outgroup taxa to examine the phylogenetic structure within the Casuarinaceae.

Hood *et al.*, (2009) evaluated genetic diversity among 30 plus trees for important seed and seedling traits using “Mahalanobis” $D^2$ analysis and showed grouping of these trees into eight clusters. Cluster VI was the largest and consisted of seven trees followed by Clusters I and IV with six trees each. Cluster III had only one tree. Intra-cluster $D^2$ values revealed that cluster VIII was most diverse followed by cluster IV, V, I, and cluster II. Maximum inter-cluster distance was observed between clusters III and VIII followed by between cluster V and VIII, cluster IV and VIII and cluster III and V. On the basis of high cluster mean and wide genetic distance, the superior plus trees of cluster III (PT 19) and cluster V (PT-8, PT-18, PT.24) may be used as potential parents in *Pongamia pinnata* for tree improvement programme.

*Casuarina* species are one of the most important fuel wood and nitrogen fixing trees grown in tropical and sub-tropical regions. The research aimed at recommending fast growing, drought resistant and superior species which have desirable growth and biomass. Hence, the present experiment has been designed to develop a seedling seed orchard after evaluation and selection of superior species. A brief review of the literature relating to origin, domestication, ecology, floral traits and phenology available information have been presented.