

**MORPHOLOGICAL DIVERSITY AND
VEGETATIVE PROPAGATION STUDIES OF
Casuarina spp. UNDER PUNJAB CONDITIONS**

Thesis

**Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of**

**MASTER OF SCIENCE
in
FORESTRY
(Minor Subject: Fruit Science)**

By

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(L-2018-A-83-M)**

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LUDHIANA - 141 004**

2021

CERTIFICATE-I

This is to certify that the thesis entitled, “**Morphological diversity and vegetative propagation studies of *Casuarina* spp. under Punjab conditions**” submitted for the degree of **Master of Science**, in the subject of **Forestry** (Minor subject: **Fruit Science**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Manpreet Singh (L-2018-A-83-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE – II

This is to certify that the thesis entitled, “**Morphological diversity and vegetative propagation studies of *Casuarina* spp. under Punjab conditions**” submitted by **Manpreet Singh (L-2018-A-83-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **Master of Science** in the subject of **Forestry** (Minor subject: **Fruit Science**) has been approved by the Student’s Advisory Committee along with the External Examiner after an oral examination on the same.

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ABSTRACT

The present study entitled, "Morphological diversity and vegetative propagation studies of *Casuarina* spp. under Punjab conditions" comprised of experiments on evaluation of *Casuarina* clones established at two sites i.e. Chak Ruldu Singh Wala University Farm, Bathinda and University Seed Farm Ladhawal, Ludhiana whereas vegetative propagation trial was conducted at main experimental area of Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana. In clonal evaluation experiment, eight clones of *Casuarina* were evaluated under different environments for different morphological traits for which the data were recorded at the age of 2 ¼ and 3 ¼ years. Estimates of phenotypic coefficient of variation, genotypic coefficient of variation and heritability reflected the predominance of heritable variation for most of the characters under study. Clone IFGTB CH 5 registered its superiority for tree height, clear bole height, axis persistence, stem straightness and branch thickness while clone IFGTB CH 2 registered its superiority for diameter at breast height, crown spread, number of branches and tree stem volume. Flowering and fruiting were highest in clones IFGTB CH 5 and IFGTB CJ 108. Index score analysis proved the superiority of clone IFGTB CH 2 which recorded the highest score followed by clone IFGTB CH 5. In vegetative propagation experiment, clone IFGTB CH 4 registered its superiority for sprouting, survival, days taken for sprouting and number of branches and clone IFGTB CH 5 was superior for plant height, number of primary roots, root fresh weight and root dry weight. Cutting diameter of <0.3cm resulted in maximum survival, days taken for sprouting, plant height and number of branches.

Keywords: *Casuarina*, Clonal evaluation, Morphological diversity, Hardwood cutting, Vegetative propagation

Signature of Major Advisor

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ਸਾਰ-ਅੰਸ਼

“ਜੋੜ-ਤੋੜ ਜਾਤੀ ਦੀ ਪੰਜਾਬ ਦੇ ਹਾਲਤਾਂ ਵਿੱਚ ਸ਼ਕਲੀ ਵਿਭਿੰਨਤਾ ਅਤੇ ਬਨਸਪਤੀ ਵੰਸ਼ਵਾਧੇ ਦਾ ਅਧਿਐਨ” ਚੱਕਰੁਲਦੂ ਸਿੰਘ ਵਾਲਾ ਯੂਨੀਵਰਸਿਟੀ ਫਾਰਮ, ਬਠਿੰਡਾ ਅਤੇ ਯੂਨੀਵਰਸਿਟੀ ਬੀਜ ਫਾਰਮ ਲਾਡੋਵਾਲ, ਲੁਧਿਆਣਾ ਵਿਖੇ ਲੱਗੇ ਹੋਏ ਜੋੜ-ਤੋੜ ਦੇ ਕਲੋਨਾਂ ਦਾ ਮੁਲਾਂਕਣ ਕੀਤਾ ਗਿਆ, ਜਦੋਂਕਿ ਬਨਸਪਤੀ ਵੰਸ਼ਵਾਧੇ ਦਾ ਪ੍ਰਯੋਗ, ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ ਦੇ ਜੰਗਲਾਤ ਅਤੇ ਕੁਦਰਤੀ ਸਰੋਤ ਵਿਭਾਗ ਦੇ ਮੁੱਖ ਪ੍ਰਯੋਗਿਕ ਖੇਤਰ ਦੇ ਵਿੱਚ ਕੀਤਾ ਗਿਆ। ਕਲੋਨ ਮੁਲਾਂਕਣ ਦੌਰਾਨ, ਜੋੜ-ਤੋੜ ਦੇ ਅੱਠ ਕਲੋਨਾਂ ਦਾ ਵੱਖੋ-ਵੱਖਰੇ ਵਾਤਾਵਰਣ ਵਿੱਚ, ਵੱਖ-ਵੱਖ ਸ਼ਕਲੀ ਗੁਣਾਂ ਲਈ ਮੁਲਾਂਕਣ ਦੌਰਾਨ, ਜੋੜ-ਤੋੜ ਦੇ ਅੱਠ ਕਲੋਨਾਂ ਦਾ ਵੱਖੋ-ਵੱਖਰੇ ਵਾਤਾਵਰਣ ਵਿੱਚ, ਵੱਖ-ਵੱਖ ਸ਼ਕਲੀ ਗੁਣਾਂ ਲਈ ਮੁਲਾਂਕਣ ਕੀਤਾ ਗਿਆ, ਜਿਸ ਲਈ ਅੰਕੜੇ 2¼ ਅਤੇ 3¼ ਸਾਲ ਦੀ ਉਮਰ ਵਿੱਚ ਦਰਜ ਕੀਤੇ ਗਏ। ਬਾਹਰੀ ਸ਼ਕਲੀ ਪਰਿਵਰਤਨ ਗੁਣਾਂਕ, ਜੀਨ-ਰੂਪ ਪਰਿਵਰਤਨ ਗੁਣਾਂਕ ਅਤੇ ਵਿਰਾਸਤੀ ਅਨੁਮਾਨ ਦੁਆਰਾ ਜ਼ਿਆਦਾਤਰ ਗੁਣਾਂ ਵਿੱਚ ਵਿਰਾਸਤੀ ਪਰਿਵਰਤਨ ਦੀ ਪ੍ਰਮੁੱਖਤਾ ਨੂੰ ਦਰਸਾਇਆ ਗਿਆ। ਕਲੋਨ ਆਈ.ਐਫ.ਜੀ.ਟੀ. ਬੀ. ਸੀ.ਐੱਚ. 5 ਰੁੱਖ ਦੀ ਉੱਚਾਈ, ਸਾਫ਼ ਤਣੇ ਦੀ ਉੱਚਾਈ, ਧੁਰੇ ਦੀ ਦ੍ਰਿੜਤਾ, ਤਣੇ ਦਾ ਸਿੱਧਾਪਣ ਅਤੇ ਟਾਹਣੀਆਂ ਦੀ ਮੋਟਾਈ ਵਿੱਚ ਸਭ ਤੋਂ ਵਧੀਆ ਰਿਹਾ, ਜਦੋਂਕਿ ਆਈ.ਐਫ.ਜੀ.ਟੀ.ਬੀ. ਸੀ.ਐੱਚ. 2, ਛਾਤੀ ਦੀ ਉਚਾਈ ਤੇ ਤਣੇ ਦਾ ਵਿਆਸ, ਸਿਰ ਦਾ ਘੇਰਾ, ਟਾਹਣੀਆਂ ਦੀ ਗਿਣਤੀ ਅਤੇ ਤਣੇ ਦੇ ਆਇਤਨ ਵਿੱਚ ਸਭ ਤੋਂ ਵਧੀਆ ਰਿਹਾ। ਫੁੱਲ ਅਤੇ ਫਲ, ਆਈ.ਐਫ.ਜੀ.ਟੀ.ਬੀ. ਸੀ.ਐੱਚ. 5 ਅਤੇ ਆਈ.ਐਫ.ਜੀ.ਟੀ.ਬੀ. ਸੀ.ਜੇ. 108 ਕਲੋਨਾਂ ਵਿੱਚ ਸਭ ਤੋਂ ਵੱਧ ਸਨ। ਸੁਚਾਤਮਕ ਸਕੋਰ ਵਿਸ਼ਲੇਸ਼ਣ ਨੇ ਆਈ.ਐਫ.ਜੀ.ਟੀ.ਬੀ. ਸੀ.ਐੱਚ. 2, ਜਿਸ ਦੇ ਅੰਕ ਸਭ ਤੋਂ ਵੱਧ ਸਨ, ਦੀ ਉੱਤਮਤਾ ਨੂੰ ਪ੍ਰਮਾਣਿਤ ਕਰ ਦਿੱਤਾ। ਇਸ ਤੋਂ ਬਾਅਦ ਕਲੋਨ ਆਈ.ਐਫ.ਜੀ.ਟੀ.ਬੀ. ਸੀ.ਐੱਚ. 5 ਨੇ ਅੰਕ ਹਾਸਿਲ ਕੀਤੇ। ਬਨਸਪਤੀ ਵੰਸ਼ਵਾਧਾ ਪ੍ਰਯੋਗ ਵਿੱਚ ਕਲੋਨ ਆਈ.ਐਫ.ਜੀ.ਟੀ.ਬੀ. ਸੀ.ਐੱਚ. 4 ਫੁਟਾਅ, ਬਚਾਅ, ਫੁਟਾਅ ਲਈ ਲਏ ਗਏ ਦਿਨ ਅਤੇ ਟਾਹਣੀਆਂ ਦੀ ਗਿਣਤੀ ਵਿੱਚ ਸਭ ਤੋਂ ਉੱਤਮ ਰਿਹਾ, ਅਤੇ ਕਲੋਨ ਆਈ.ਐਫ.ਜੀ.ਟੀ.ਬੀ. ਸੀ.ਐੱਚ. 5 ਬੂਟੇ ਦੀ ਉਚਾਈ, ਮੁੱਖ ਜੜ੍ਹਾਂ ਦੀ ਗਿਣਤੀ, ਤਾਜਾ ਜੜ੍ਹ ਦਾ ਭਾਰ ਅਤੇ ਸੁੱਕੀ ਜੜ੍ਹ ਦੇ ਭਾਰ ਵਿੱਚ ਸਭ ਤੋਂ ਉੱਤਮ ਰਿਹਾ। ਬਚਾਅ, ਫੁਟਾਅ ਦੇ ਲਈ ਲਏ ਗਏ ਦਿਨ, ਪੌਦੇ ਦੀ ਉਚਾਈ ਅਤੇ ਟਾਹਣੀਆਂ ਦੀ ਗਿਣਤੀ ਵਿੱਚ ਕਲਮ ਦਾ <0.3 ਸੈ.ਮੀ. ਵਿਆਸ ਸਭ ਤੋਂ ਉੱਤਮ ਪਾਇਆ ਗਿਆ।

ਮੁੱਖ ਸ਼ਬਦ: ਜੋੜ-ਤੋੜ, ਕਲੋਨ ਮੁਲਾਂਕਣ, ਸ਼ਕਲੀ ਵਿਭਿੰਨਤਾ, ਬਨਸਪਤੀ ਵੰਸ਼ਵਾਧਾ, ਸਖਤ ਲਕੜ ਕਲਮ ।

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CHAPTER-I

INTRODUCTION

Casuarina is a fast growing and evergreen tree belonging to the family Casuarinaceae. It is also known as Australian pine, she-oak, jor-tor, yar etc. *Casuarina* is native to Australia, Southeast Asia, the Indian subcontinent, eastern Africa and island of the western Pacific Ocean. In India, it was introduced in the year 1860 in Karwar District in Karnataka.

Casuarina generally grows in the coastal regions, swamps, and on the bank of rivers. It can survive under both wet and dry areas: however, it is sensitive to frost. *Casuarina* grows in loamy, sandy and clay soil. It requires pH between 4.8 – 8.4 and can easily tolerate moderate soil salinity and seasonal flooding. It can also thrive in alkaline regions. It is a deep-rooted wind firm tree and plays an important role in protecting the coastal area from erosion which strengthens its role in agroforestry systems of the coastal regions. Wood of *Casuarina* tree is used for pulp, paper making, poles, fuel wood, etc. It can produce a high quality of charcoal even from their green branches. Small branches and litter are even used in brick kilns and pottery as a fuel. Its bark is used for tanning. The roots possess medicinal properties and are used to treat diarrhoea, dysentery and stomach ache.

Casuarina trees can attain a diameter of 60 cm and height up to 40 m and may possess a buttressed base. The flowering occurs twice a year in spring during February-April and in autumn during September-October. Fruits (cones) appear in the month of June and December though variations can take place in flowering and fruiting in different localities. It is a light-demanding and fast-growing tree species.

Casuarinas are widely planted in the subtropics, tropics and mediterranean countries because of their fast growth rate and have adaptability to wide environmental conditions. Among different species of Casuarinaceae family, *Casuarina equisetifolia* has gained much attention throughout the world due to their multiple end-uses (Turnbull, 1990). The species later spread in Tamil Nadu, West Bengal, Orissa and Andhra Pradesh. Nicodemus (2009) estimated that about 500,000 ha of area is under *Casuarina* plantation in the coastal states of Orissa, Andhra Pradesh, Tamil Nadu and Puducherry. According to another estimate, India has an estimated area of 800,000 ha of plantations of *Casuarina* in India (Pinyopusarerk and Williams, 2000).

In Punjab, area under forest and tree cover is very less and has vast potential to bring more area under tree cover. Adoption of Poplar, Eucalypts, dek, etc. by farmers has helped in increasing their income and improving their socio-economic conditions. However, there is a need to screen and select fast growing tree species which can be successfully cultivated under Punjab conditions. *Casuarina* is one such tree species which hold great potential for growing

under Punjab conditions owing to short rotation period. It makes the nitrogen available to plants by fixing atmospheric nitrogen into the soil and then to roots thus reduces dependability on the additional nitrogen supplement. The nitrogen-fixing ability, fast-growing habit and adaptability in a wide range of climatic and soil conditions including nutrient and moisture limited sites makes *Casuarina* a preferred choice for plantation under commercial forestry for amelioration. Due to its nitrogen fixing ability it will be helpful in improving their income by reducing the cost of production. Under saline and alkaline soil conditions which are present in about two lakh of hectare area in Punjab, it can be a good option and generate a source of income for farmers. Due to short rotation period required for pulp and paper production in an agroforestry system, it suits the need of an average Indian farmer with small landholding (Rawat *et al* 2011). Its fast growth and desirable stem form characteristics make it an ideal species for agroforestry systems (Viswanath *et al* 2001). *Casuarina* has high calorific value and can help in meeting the demand of fuelwood for rural people easily. *Casuarina* is also cultivated as windbreakers as well as ornamental trees. *Casuarina* has specially modified leaves structure like scaly which prevents them from water loss through transpiration. For achieving the higher productivity, there is a need to identify superior clones for high growth performance.

Vegetative propagation methods are preferred for multiplication of genetically superior clones. Keeping in view the fast growth rate, short rotation period and multipurpose uses, there is a need to evaluate the growth potential of this tree species under Punjab conditions for its adoption by farmers. Furthermore, vegetative propagation method needs to be standardized as these enable to produce true to type plants and multiplication of superior clones. Keeping in view the above facts, present investigation was undertaken with the following objectives:

1. To evaluate the growth potential of different clones of *Casuarina* spp. under Punjab conditions.
2. To standardize the vegetative propagation through stem cuttings.

CHAPTER-II

REVIEW OF LITERATURE

The effect of different environment on the morphological traits of species as well as the effect of different cutting sizes and treatment of different growth regulators at certain concentrations on the survival and growth performance of cuttings has been reviewed in this chapter. This chapter provide an over view on research work done by different scientists on clonal evaluation as well as on vegetative propagation experiments. The available literature on the specific problem provide the basis for selection and solution of any research problem. The literature refers to the present investigation entitled “Morphological diversity and vegetative propagation studies of *Casuarina* spp. under Punjab conditions” were collected and reviewed under the following headings:

2.1 Clonal variation for morphological traits

2.2 Estimation of genetic characters

2.3 Vegetative propagation studies

2.1 Clonal variation for morphological traits

Mehta (1990) conducted a study on evaluation of Six poplar clones under different environments of Himachal Pradesh. Clones of different species of poplar *Populus deltoides*, *Populus* × *euramericana*, *Populus doitoides*, *Populus yunnanesis*, *Populus nigra* × *trichocarpa*, and *Populus* regenerate were evaluated for different parameters. The maximum mean height was recorded by site bajaure (226.0cm) followed by dhaulakuan (186.6cm), jaach (180.2cm) and shilly (79.7cm). The maximum diameter was observed under the site bajaure (14.7mm) followed by jaach (11.9mm), Dhaulakuan (11.6mm) and shilly (6.9mm) whereas the internode length was observed highest in bajaure (4.76cm) followed by dhaulakuan (4.07cm) and the lowest was recorded by the site shilly (3.07cm).

Prasad *et al* (1998) conducted a clonal test of 40 locally selected clones, a progeny test of 16 wind-pollinated families of local origin and a family-in-provenance test of 100 wind-pollinated families of *Casuarina equisetifolia*. All tests were planted in 1996 at the Regional Forest Research Centre, Rajahmundry, Andhra Pradesh, India. Height, stem straightness and axis persistence were measured in the family tests at the age of 6 and 12 months. The height was measured at the age of 12 months for clonal testing. The provenances spread across the range of natural and land-race populations were tested and demonstrated a good growth potential at site (Rajahmundry). Nevertheless, natural provenances from Thailand and Malaysia generally showed superior growth, whereas the land-race populations frequently demonstrated superior stem straightness.

Lamba (1999) evaluated progenies of *Dalbergia sissoo* and found that at the age of 14 months after transplantation, the progenies showed significant variation for basal diameter,

plant height, unbranched height, number of branches, stem straightness and crown diameter in both seedling orchard and clonal seed orchard. The phenotypic variation coefficient was observed maximum for number of branches (32.17) and minimum recorded for the basal diameter (10.03) in clonal seed orchard, whereas in seedling seed orchard maximum phenotypic coefficient of variation was recorded for stem straightness (28.87) and minimum for the basal diameter (7.99).

Singh (2001) conducted a study of *Populus deltoides* clonal evaluation for shoot and roots characters at nursery stage. Fifteen clones were selected from different locations. The maximum girth was recorded in clone 154 and minimum girth was recorded in clone Uday. The shoot length was observed highest for clone 28 and lowest shoot length was recorded by clone Bahar whereas the root length was maximum in clone 146 followed by the clone 154 and the minimum root length was recorded in the clone 181. However, the fresh and dry weight of shoot was maximum in clone 154 and the minimum was observed in clone 146. The fresh and dry weight of roots were recorded maximum by the clone 154 and the minimum was recorded by the clone Bahar and Uday.

Juhany *et al* (2002) laid out an experiment to evaluate the above ground biomass and stem volume of *Casuarina* in Saudi Arabia. Three different species of *Casuarina*, *C. glauca*, *C. cunninghamiana*, and hybrid produced from both species *C. cunninghamiana* X *C. glauca* were planted at spacing 1.5×2.5m in Agricultural Research station, Dirab near Riyadh, Saudi Arabia. The maximum stem volume ($0.37\text{m}^3\text{tree}^{-1}$) and biomass (400kg tree^{-1}) was recorded by the *C. cunninghamiana* followed by *C. glauca* which recorded the stem volume ($0.21\text{ m}^3\text{ tree}^{-1}$) and biomass (200 kg tree^{-1}) whereas the minimum stem volume ($0.19\text{ m}^3\text{ tree}^{-1}$) and biomass (175 kg tree^{-1}) was observed in hybrid of *C. cunninghamiana* X *C. glauca*.

Lin *et al* (2003) conducted a study on *Casuarina junghuhniana* for different growth traits in Dianbai, Guangdong Province in southern China. The experiment was established in CRBD consisting of 28 seed lots taken from Australia Tree Seed Centre Among all, the seed lot number, 13950, 19240, 17877, 17878, 19491, 19489 and 19490 were screened out as better provenances. The genetic gains were 49.61% for single tree volume, 22.73% for DBH and 16.08% for tree height.

Pinyopusarerk *et al* (2004) conducted international provenance trials on *Casuarina equisetifolia* in which 59 provenances were selected and 38 trials were established in 20 different countries. The data were recorded on different morphological parameters (Growth, stem form, branching habit, branching habit and reproduction). Mean survival varied from very poor (23% recorded in Orissa India) to very good (more than 85% in most countries). The height and diameter were lower in China, India, Vietnam and Thailand. The differences between provenances were not significant. The result for the branching habit showed that

most trees had fine branches. In reproduction phase most trials had flower bearing at the age of 26-32 months interval.

Varghese *et al* (2007) laid out an experiment to evaluate different clones of *Eucalyptus camaldulensis* at different sites (Panampally, Karunya, Kulathupuzha, Sathyavedu and Pudukkottai) in south India and parameters such as survival, height and DBH were recorded. The result showed that maximum height was attained at Pudukkottai site (5.68m) followed by Sathyavedu (5.20m) and the minimum height was recorded by Panampally (4.33m). Maximum survival was recorded by the Panampally (98%) followed by Pudukkottai (95%) and the minimum survival was observed in Sathyavedu (80%) whereas the maximum DBH was observed at Sathyavedu (5.15cm) followed by Karunya (4.64cm) and the least DBH was recorded at site Kulathupuzha (3.42cm).

Kannan *et al* (2012) conducted trials on clonal testing of *Casuarina* at Mayiladumparai involving 87 clones. Three seed raised accessions were also included in the trial as check. All the trials were laid out in Randomized Incomplete Block Design with 6 replications (3 ramets per replication) at 3x1.5 m spacing. The maximum height growth was recorded by Clone 81 (9.6 + 1.21 m). It was found at par with 41 other clones. Diameter at breast height (dbh) ranged from 28.31 to 55.90mm (Clone 22) with a standard deviation of 9.74 mm. Clone 81 ranked first for volume index (d^2h) and 46 other genotypes were found at par with it.

Blada *et al* (2014) conducted a study to check growth, straightness and survival at the age 32 years in F_1 hybrid population of *Pinus strobus* $\times$ *P. wallichiana*. The experimental design consisted 28 hybrid full-sib families and two open pollinated families of the parent species of *Pinus strobus* $\times$ *P. wallichiana*. The trial was established in a complete randomized block design with three blocks, with 6 to 12 seedlings per linear plot and 3 $\times$ 3 m spacing. Diameter at breast height, tree height, tree volume, stem straightness and tree survival were the five measured traits. Highly significant differences were found between eastern white pine female parents for stem straightness, survival and all growth traits. The contribution of the additive variance to the phenotypic one was 65.7% for diameter, 58.6% for height, 50.5% for volume, 70.4% for stem straightness and 73.4% for tree survival.

Kannan *et al* (2014) studied the growth performance of ninety clones of *C. equisetifolia* in a sodic site at Moorthipalayam, Karur district, Tamil Nadu. Eighty-seven clones and three seed raised progenies selected by IFGTB were tested in an incomplete RBD with six replications. The variation of inter species clones showed a significant difference among them at the age of 3 years which could be observed with reference to their growth. Clone TNCN 1 recorded the minimum height (5.47 m) and clone TNVM 3 recorded the maximum tree height (10.68 m). The standard deviation and mean values for height were 1.58 m and 7.91 m, respectively. The minimum and maximum values recorded for DBH were

28.12 mm (Clone TNCN 1) and 72.23 mm (Clone CE 83), respectively. The mean and standard deviation for DBH were 53.86 mm and 14.51 mm, respectively. The values estimated for minimum and maximum biomass index were 4940.08 cm³ and 52190.24 cm³ respectively. Clone TNCN 1 registered the lowest value for biomass index and which was at par with other seven other clones. The top 10 clones that exhibited superior growth on the basis of biomass index were CE 2003/5, CE 224, CE 243, CE 220, CE 9, CE 83, CE 327, CE 347, CE 268 and TNVM 3.

Kindo *et al* (2014) conducted a study at Kangowe, Tanzania in which thirteen *Casuarina* provenances were laid out using a randomized complete block design with four replications to check performance in terms of growth, survival, volume, height and diameter. It was observed that *Casuarina equisetifolia* from Montazah National Park, Egypt provenance had the lowest survival (48.8%), lowest mean diameter (8.6cm), lowest mean height (16.2m), lowest mean volume (22.1m³ha), lowest mean biomass production (23.5t/ha) and lowest wood basic density (617kg/m³), whereas *Casuarina equisetifolia* from Wagait Tower, Indonesia, had the highest survival (87.5%), highest mean diameter (14.8cm), highest mean height (24.3m), highest mean volume (66.4m³), highest biomass production (72.9t/ha) and highest wood basic density (731kg/m³).

Ma *et al* (2014) carried out a study on evaluation of 17 *Casuarina equisetifolia* clones grown at two sites for tree height, diameter at breast height, individual volume, axis persistence, stem straightness and survival percentage were assessed in the trial. The result proved that genetic variations were significantly different for all 6 growth traits for tree growth indices at each site and for the genotype and site interaction among all 17 clones. The analysis of genetic correlation showed that the height, diameter at breast height, survival percentage and individual volume had highly significant correlation. In addition, the mean genetic gains in height, individual volume, diameter at breast height, axis persistence, survival percentage and stem straightness were 6.5%, 10.9%, 4.8%, 3.7%, 8.1% and 1.5%, respectively. Selection of three superior clones were made on the basis of result from the 17 clones.

Ma *et al* (2014) conducted a study on genetic analysis of 6 traits of 4-year-old *Casuarina glauca*. The significant differences were recorded for height, diameter at breast height, stem straightness, tree volume and survival percentage and non-significant for stem axis persistence. The heritability of the six characters varied from 0.02-0.55, i.e. heritability for stem straightness (0.55), survival percentage (0.48), height (0.28), diameter at breast height (0.17), and volume (0.10), and the result showed that first five traits can be used individually for selection of *C. glauca* provenances. The genetic correlation for growth characters height, diameter at breast height and volume was highly significant, but non-significant for the quality traits i.e. for axis persistence, stem straightness and survival

percentage, which indicated that the three quality traits were independent from each other. In another aspect, the coefficient of variation varied from 31.5% (survival percentage) to 91.8% (height).

A multilocation field trial consisting of 10 clones of *Casuarina junghuhniana* and 2 clones of *Casuarina equisetifolia* were conducted at three different locations in Tamil Nadu, India under different environmental and climatic conditions to assess the survival rate, height, diameter and stem straightness parameters. It was found that two clones of *Casuarina junghuhniana* performed better than the others in terms of growth. It was also observed that best clone of *C. junghuhniana* in terms of growth also had better pulp content than the other clones (Nicodemus *et al* 2014).

Vidyasagaran and Paramathma (2014) conducted the study for measure the tree dimensions as such as height, diameter at breast height or their combination in which by destructive sampling and regression analysis they determined the dry weight of *C. equisetifolia*. For testing reliability of predicted data, the values which were predicted and observed for all the dependent variable were plotted together. They concluded that predicted and observed values were very close to each other in the case of root, bark, bole, age, branch and total biomass.

Nicodemus *et al* (2015) conducted a study to evaluate six species of *Casuarina* (*C. cristata*, *C. cunninghamiana*, *C. equisetifolia*, *C. glauca*, *C. junghuhniana* and *C. obesa*) in which their twenty provenances were field tested for stem straightness, growth, bark, fibre and wood characters in a district of Tamil Nadu, India. After twelve years, *C. junghuhniana* produced 54% volume more than the widely cultivated species, *C. equisetifolia*. In the study, it was concluded that *C. junghuhniana* was fast growing and more acceptable than *C. equisetifolia* and other four species.

Behera *et al* (2016) conducted a study for clonal evaluation of *Eucalyptus* and recorded several parameters such as for several parameters such as plant height, diameter at breast height and volume of tree. In their study they found that clone B2253 (23.60m) attained maximum height whereas clone P405 (18.53m) registered the minimum height. In DBH, clone P413 (16.07) ranked first for the DBH and clone P405(11.47cm) and P1 (11.47cm) both having the lowest DBH whereas for volume clone, P2045 (0.28m³) and B2253 (0.28m³) were recorded the highest total volume and clone JK02 (0.16 m³) hold last rank for total volume.

Kaur (2016) conducted a study on various clones of *Eucalyptus* and observed different morphological and physiological parameters. In her study, fourteen different clones of *Eucalyptus* were selected for observing plant height, number of branches and leaf characteristics. The clone PE-10 had narrow-lanceolate leaves and the remaining all clones showed lanceolate leaf shape. The minimum height was recorded in clone PE-8 and maximum in clone C-413. The maximum collar diameter was observed in clone PE-11 and

PE-13 whereas the clone C-413 was at par with these clones. The number of branches was recorded maximum in clone PE-7 and PE-11. The highest fresh weight was observed in clone PE-13 and lowest was observed in clone PE-8.

Singh *et al* (2016) conducted a study for evaluation and selection of *Salix* clones for different uses. Trials were established at USF Ladhawal and Alam wala forest site and result showed that at USF Ladhawal clone UHFS-13 recorded the maximum plant height as well as collar diameter. While the overall performance of other clones on the basis of collar diameter and plant height was recorded in following order UHSF-11, UHFS-20, UHSF-1 and UHSF-19 and on the basis of performance in growth factors and increment, clones UHFS-1 and UHFS-19 were suitable for water-logged conditions and broader adaptability. The order of performance at Alam wala site from higher to lower was clone UHFS-3, UHFS-11, UHFS-16 and UHFS-21. For good growth and minimum number of branches clone, UHFS-4, UHSF-7 and UHFS-15 were found promising whereas for phytoremediation or biofuel the order of suitable clones from best to good was UHSF-1, UHFS-3, UHFS-19 and UHFS-20.

Liao *et al* (2017) conducted a study on different clones of *Dalbergia sissoo* for selection the superior clone among all the clones. Twenty clones were selected and evaluated in which clone 9 and 10 were recorded significantly higher for height and diameter than the other clones followed by the clones 12, clone 19 and clone 20. The height and diameter of clones 9 and 10 was 70% greater than their mother tree. The clone 9 and 10 both were recorded 30% greater height and diameter than the control.

Pradhan *et al* (2017) evaluated different clones of *Tectona grandis* (ORPUB 1, ORPUB 2, ORPUB 3, ORPUB 5, ORPUB 8, ORPUB 9, ORPUB 9, ORPUB 10, ORPUB 11, ORPUB 12, ORPUB 13, ORPUB 18, ORPUB 20, ORPUB 21, ORANP 1 and ORANP 2) at the age of 31-32 years for different growth parameters such as plant height, diameter, flower production, fruit production etc. They found that among the all clones, ORPUB 18 recorded the maximum height and ORPUB 13 registered the minimum height as compared to all other. In diameter clone ORPUB 18 was recorded the maximum diameter followed by the ORPUB 20 and ORPUB 13 recorded the minimum diameter. In flower production ORPUB 9 recorded maximum production and ORPUB 10 having minimum production of flower whereas fruit production is highest in ORPUB 21 and minimum fruit production was recorded in ORPUB 13.

Namdol (2018) evaluated twenty hybrid clones of *Populus deltoides* Bartr. involving twenty hybrid clones and two controls developed by UHF Nauni. Clone S₁X 17/92 (9-4) recorded the highest height, Kranti X39N (17-5) performed best for collar diameter (2.74cm) and volume (1976.93cm³). Overall performance was superior in clone Kranti X 39N (17-5) followed by the clone S₁ X S₇C₁₁.

Nelson *et al* (2018) conducted a study involving 69 clones of poplar for growth, stability, and genotype x environment (GxE) interaction at the age of five years on six sites in Minnesota. Average performance for basal area and diameter at breast height were 72.11 cm² and 93.5 mm, respectively, over the all sites. Site mean performance for DBH varied from 79.4 to 109.0 mm. The clone BA grown fastest among all the clones, which was 49% greater than population mean and 64% greater than the mean of the two commercial standards. Clone, site, and clone x site effects were recorded significant in the ANOVA. Clonal ranking remained same under all the sites. Seventy-four clones recorded changes in growth between sites and twenty-six percent of clones showed a little change in growth between sites and among all the clones whereas fifteen percent of clones were stable and fast growing.

Sharma *et al* (2019) evaluate the growth performance of 17 different improved genotype of *Melia dubia*. Their seedlings were established under RBD design and the data of different genotypes were recorded on two growth parameters i.e. height and collar diameter at the age of one year. After one-year G-241(4.99cm) ranked first for the total height followed by the G-231(4.84cm) and the minimum height was recorded for G-75(2.66cm) the variation in the height was shown among all the genotype whereas the diameter of different genotype also showed the significant variation among them, in which G-261(4.89mm) was having the maximum diameter and G-256 (1.55mm) was recorded.

Pie *et al* (2020) conducted a study on seven different clones of *Populus* planted on three different sites (the Fujin Forestry Centre in Fujin {FJ}, the Cuihai Forestry Center in Qiqihaer {CH} and the Lishu Forestry Center in Siping {LS}) in north east china. Seven clones were selected for the trial (10, 18, 23, 28, 50, 51 and 30) which are made up by making crosses between two different species of Poplar (*P. deltoides* and *P. nigra* cv. 'shandi'). The plantation was established in Randomised block design having plot size of six trees in 2017 and the observations was recorded at the age of 1 year. Average height and diameter of the clones were recorded on the three sites are 3.27 m and 36.99 mm, respectively. Maximum height (4.00 m) and diameter (48.49mm) were recorded by the site CH. On site CH, the maximum average height (4.38 m) was recorded in clone 28, which was higher than the average value on CH, FJ and LS sites by 0.38, 2.52 and 0.42 m, respectively and Clone 28 also registered the maximum diameter (53.06 mm) at site CH.

2.2 Estimation of genetic characters

Haapanen *et al* (1997) conducted a study on Scots Pine for estimation of genetic parameter for growth and quality traits. The observations were recorded on 9 different parameters (tree height, stem diameter, branch diameter, crown width, branch angle, stem straightness, branch number, stem straightness, branching score and overall score) assessed visually. Tree height with crown forming traits made favourable genetic relationship than

other traits. The maximum genetic correlation was measured in branch diameter and two visually evaluated quality traits while the slightly negative correlation was found between the branch diameter and branch angle.

Gwaze *et al* (2001) laid out an experiment to evaluate genotype $\times$ environment interactions (G $\times$ E) for stem height and straightness at the age of 2, 10, 14 and 23 years for *Pinus taeda* L. at 4 different sites of Zimbabwe. Genetic correlation for height varied from low (0.18) to high (0.95) at different sites and for stem straightness it varied from -0.13 to 0.95 (low to high) for sites A and C, for B and D sites, it was consistently high (>0.84) at age of more than 2 years. Genetic correlations for straightness were recorded high between sites A and C and sites B and D whereas for the height, even a single environmental factor could not influence G $\times$ E, which make it problematic to classify the different environments.

Arnold and Cuevas (2003) laid out an experiment to check the genetic variation in survival, growth and stem straightness in *Eucalyptus urophylla*, *Acacia crassicaarpa* and *Acacia mangium* in Philippines. The material used for planting i.e. seed lots of different species were representing the wide natural geographical ranges. At the age of three years, the average height and diameter was recorded for all species were 9.3m and 8cm, respectively whereas the maximum height (10.9m) and diameter (12.2cm) were recorded by *A. mangium*. *E. urophylla* recorded the better stem straightness than *A. crassicaarpa* and *A. mangium*.

Mahmood *et al* (2003) laid out a trial on *Eucalyptus camaldulensis* to check genetic variation for growth and stem straightness in which 114 families and six local seed lots were evaluated for growth, survival and stem form. The observations were recorded up to the age of 5 years. The maximum survival was recorded at Wiluna (89%), whereas the maximum height and diameter were recorded 10.2m and 9.2cm, respectively at De Grey river site. The stem straightness was good to very good for most of the provenances. The heritability for individual tree with in the provenance was recorded 0.14%, 0.11% and 0.15% for height, diameter and stem straightness.

High heritability accompanied by high genetic advance for several growth parameters have earlier been reported in *Eucalyptus tereticornis* (Kumar *et al* 2007).

Silva and Graudal (2008) conducted a study on *Pinus kesiya* for growth and wood quality in which seven different trials was established in South Africa, Colombia, Swaziland, Zimbabwe and Vietnam. Total volume, branch diameter, stem straightness, fox tailing and forking were measured at the age of 5, 6, 7 or 8 years. In most of the trials, survival percentage was exceeding 85%. Out of seven trials, significant variance for forking exhibited in only four trials. Across-site analysis for single traits specified that the practical importance was not great for the examined traits of genotype by environment interaction, as the most of the provenances did not display relevant ranking changes across trial sites. Analysis across the sites showed that provenance correlations involving total volume per hectare, forking and

stem straightness were statistically significant. However, these characters were adversely and significantly correlated with fox tailing.

Baltunis *et al* (2009) laid out an experiment to check the phenotypic response of different genotypes of Radiata Pine in Australia. The data were observed over the different environments and quantified by estimating the genotype by environment interaction (GxE) for growth, stem straightness, wood density, and branching characteristics. Heritability was recorded maximum for density followed by the branch angle and the minimum was registered for branch size. GxE interactions for stem straightness, density and branch angle were recorded smaller within the two regions whereas the least G x E interaction was recorded by the branch angle and branch size whereas tree diameter recorded highest interaction.

Callister *et al* (2011) laid out experiment on the genetic analysis of different parameters of *Eucalyptus* in the south of western Australia for estimation of genetic parameters of growth and form traits that affect log value in full-sib families. In their study, it was concluded that the mean single-site heritability was 0.11 ± 0.01 for diameter at breast height (DBH), 0.09 ± 0.02 for branch thickness, 0.28 ± 0.05 for stem straightness, and 0.05 ± 0.02 for forking incidence. Dominance effects were significant at the level of $p < 0.05$ at four different sites for branch thickness and DBH and at another three sites (one population) for straightness.

Dhillon *et al* (2011) laid out experimental trials for evaluation of plus tree progenies of *Eucalyptus tereticornis* in Ludhiana, Punjab. The material of plantation/seeds were taken from Australia, Orissa, Tamil Nadu, West Bengal, Haryana, Chhattisgarh and Punjab and planted in RBD block with plot size of 5 plants and 3 replications. The observations were recorded on height and DBH while volume was calculated from the data of these two traits. The result showed significant differences for all three traits among the progenies. The progenies 16547/JD1570, L-76/98, CU-4, 16547/JD1569, MTP/ET-5, L-83/98, 19010, L-42/98 and CU-10 recorded the higher volume than control.

Cappa *et al* (2012) estimated genetic parameters for growth, pilodyn penetration, stem straightness, survival and relative bark thickness in five open pollinated provenance trials of *Eucalyptus viminalis*. Overall average survival of the plants in all trial was 62.4%. The local land races performed contradictorily in the study. The heritability for average individual-tree was recorded 0.17 for total height and 0.27 for diameter and was moderate too low (average of 0.20) for stem straightness and relative bark thickness (0.16). The additive genetic correlations recorded between diameter and height were reliably high and positive (0.90). The additive genetic correlations were recorded high between pilodyn penetration and growth variables (0.58). Relative bark thickness showed a negative correlation with diameter (0.39) and height (-0.51).

Positive and significant correlations among seed traits in *Pongamia pinnata* has been

observed earlier by Kumar (2012, 2014), Kumar and Kaushik (2015).

Luechanimitchit *et al* (2017) estimated the genetic parameters of 29 clones of *Casuarina junghuhniana* planted in Thailand. Clones were compared for their height, survival, stem volume and diameter for six consecutive years and compared with Thai benchmark clone which was commercially-deployed. Stem form (stem straightness and axis persistence) and habit of branching (branch angle, branch thickness and branch density) were scored at the age of four years. At each measurement, variation was observed among the clones for all traits. It was observed that growth have a positive correlation with the branch angle and negatively with branch thickness and no correlations with stem form. There was a strong correlation of age-age for growth and help us in the selection for stem volume.

Weng *et al* (2017) conducted a study on Jack Pine for estimating different parameters as stem straightness, volume and branch angle at three different sites (Londonderry, Macklem and Flavelle). The data were collected during 8-11 years age. Survival percentage was recorded maximum (93%) at the age of 8 years and the least survival (83%) was recorded at the age of 11 years. Tree volume increased from 1.16 to 4.29m³ during 8-11 years. Among all sites, Flavelle recorded least volume for growth and almost half of the trees were recorded straight boles (category = 1), whereas on the other both sites, most of the trees had moderately to severely crooked boles. Flavelle site recorded the maximum number of horizontal (90°) branches (48% of total tree branches), and these trees registered superiority in volumes than trees having upward branches (45°) whereas the tree of remaining two sites recorded the branch angle of 45°.

Belaber *et al* (2018) conducted study on five progenies of *Pinus elliottii* var. *elliottii* (PEE) × *Pinus caribaea* var. *hondurensis* (PCH) F₁ for growth, stem straightness, and branch quality at three different stages (at the age of 3, 5 and 7 years). Broad-sense heritability was recorded for height and diameter were 0.53 and 0.47, respectively. Low to moderate heritability recorded for stem straightness (<0.26) and the heritability for branch angle was 0.28 to 0.33. However, the highest genetic correlation was recorded for growth traits and stem straightness.

Eight different clones of *Casuarina* were evaluated to check the salt tolerance ability of species. Soil were treated with saline water consisting NaCl at concentration 0, 40, 80 and 120 mM. Significant genotypic variation was observed among *Casuarina* clones for tolerance to saline conditions and clone IFGTB CJ 108 was found most tolerant clone to saline condition (Bassi *et al* 2020).

2.3 Vegetative propagation studies

Lundquist and Torrey (1984) reported achievement in rooting of softwood cuttings of *Casuarina junghuhniana* and *C. equisetifolia* by treating them with plant growth hormones. They undertook a study for rapid propagation of young *Casuarina* plants from stem cutting

for experimental work to produce clonal material by taking mature wood cutting from trees between one and six years old it can be "softwood" or "hardwood" cuttings. It showed that juvenile or young stem cuttings took less time to root than the older material but that both mature hardwood and softwood cuttings which were treated with auxin could be rooted appropriately.

Surendran and Seethalakshmi (1987) laid out experiment and gave treatment at two concentrations each (100 and 10 ppm) of five growth regulating substances (GRS) (indole butyric acid, IBA; indole acetic acid, IAA; naphthyl acetic acid, NAA; boric acid, BA and Coumarin, Cou) to check their effectiveness on rooting of the cuttings. At monthly interval treatments were repeated to check the influence on rooting caused by season. Results showed that all the three factors, i.e., their concentration, season and GRS (Genome Report System), had a significant effect in cuttings on the induction of rooting.

Schroeder and Walker (1990) cuttings were taken from one-year-old shoots of two species of poplar (*Populus × deltoides* 'Walker' and *Populus jackii* 'Northwest') from stooling beds were collected in late fall. The minimum diameter (9.0 mm) was recorded by the cuttings taken from basal portion of branch, middle and distal locations on the poplar shoot. The cuttings taken from the basal portion of shoots of 'Walker' poplar recorded the maximum rooting (87.6%) and growth (103.8cm) followed the cuttings taken from middle portion which recorded rooting of 78.8% and growth of about 103.4 cm. Least rooting (67.6%) and growth (88.8 cm) was recorded by the cuttings taken from the distal end. In 'Northwest' species, the cuttings taken from the basal portion recorded the maximum rooting (84.4%) and growth (94.7cm) under field conditions, followed the cuttings taken from middle portion which recorded rooting and growth 78.4% and 90.5 cm, respectively and the minimum rooting (64.4%) and growth (84.3cm) was recorded by the cuttings taken from distal locations. Rooting in the greenhouse was superior as compared to the field. Cuttings taken from 'Walker' species had lesser roots and buds per cutting than 'Northwest', however, under field condition, superiority for growth was recorded by the cuttings taken from 'Walker' species.

Henry *et al* (1992) conducted a study to investigate the effects of season (timing), IBA application, genotype, crown position, type of cutting (straight vs. heel), cutting length and stock plant age upon adventitious rooting of stem cuttings of eastern red cedar (*Juniperus virginiana* L.). The experiment revealed that maximum rooting was recorded from the hardwood cuttings taken from four years old tree and treated with IBA at 5000ppm concentration in January. Straight cuttings, with or without a light wound, rooted at a significantly higher percentage (78%) than heel cuttings (52%). With 30-year-old trees, cuttings from the lower third of the crown rooted at a significantly higher percentage (67%) than cuttings from the middle third (43%). Better rooting was obtained with straight (68%)

than heel (47%) cuttings.

Goh *et al* (1995) conducted a study to develop method for clonal propagation of *Casuarina sumatrana* stem cuttings. Cuttings taken from softwood mature stem were rooted at a high percentage (about 60–70%). To increase the percentage of survival rate and rooting of the stem cuttings, a quick-dip in NAA (1–10mm) solution for 5 second followed by sand culture and keeping them under high humidity condition. Rooting in lateral and terminal shoot cuttings which were derived from 10-year-old superior trees of *Casuarina equisetifolia* L. was achieved after 20 days when their basal ends dipped in indole-3-butyric acid at the concentration of 20ppm for three hours.

Azzera (1996) carried out two separate studies on vegetative propagation through stem cuttings to determine the rooting ability of *Acacia mangium* Willd. and *Casuarina cunninghamiana* Miq. in various levels of hormone concentrations using several types of rooting media. *A. mangium* cuttings showed 46.67 per cent rooting success while *C. cunninghamiana* cuttings produced 47.78 per cent. There were no significant effects on the type of growing medium, type of cuttings and levels of concentration of IBA on the average number and length of micro roots produced by *A. mangium*.

Rout *et al* (1996) reported successful rooting in cuttings of the lateral and terminal shoot taken from ten-year-old superior trees of *Casuarina equisetifolia* L. in different sex groups. When the basal end of the cuttings was dipped in indole-3-butyric acid (IBA) at a concentration of 20ppm for three hours then it achieved rooting after 20 days. Shoots derived from monoecious parts and female plants rooted lesser than the male plants, and the terminal shoots were less responsive to rooting than the lateral shoots. In both terminal and lateral shoot cuttings the metabolic activities varied in different sex groups.

Pal *et al* (1996) carried out an experiment to study the effect of several phenolic and IBA compounds on the rooting and growth of cladode segments of *Casuarina equisetifolia*. 1,000, 5,000 and 10,000 ppm concentrations of IBA and 100-ppm concentration of most of the phenolic compounds promoted rooting and the growth of cladode segments. Nevertheless, the promotion of rooting and the growth of the segments are better when treated with 1000 ppm IBA when the phenolic compound was applied as a pre-treatment instantly before the auxin treatment as compared to other doses of the IBA (i.e. 5000 and 10000ppm).

Parthiban *et al* (1996) conducted a study on vegetative propagation of few multipurpose trees viz. *Casuarina equisetifolia*, *Azadirachta indica*, *Ceiba pantandra*, *Thespesia populnea* and *Gmelina arborea* through cuttings. Double noded stem cuttings were taken from the superior phenotype of all the species growing at FCRI, Mettupalayam. All the cuttings were treated with different concentration of auxins i.e. @ 1000, 2000, 3000 and 4000 ppm and kept under the mist chamber. The humidity of the area was maintained at 70-80%. In their study it was concluded that cuttings of *C. equistifolia* and *T. populnea*

recorded the maximum height and the among the different doses of auxin cuttings treated @ 2000 and 3000ppm recorded better as compared to other concentrations.

Alberto *et al* (1998) conducted a study on different plant parts (including root systems) for growth and biomass accumulation of three different species (*Eucalyptus urophylla*, *E. pellita* and *E. camaldulensis*) planted at three different spacings (3×3 m, 4×3m and 3×1.5m) and at three different age classes (15, 31 and 41 months). To estimate biomass per-tree, a series of equations were produced from spacing, height, diameter and age, and biomass of per-hectare by using spacing, age and a tally of tree heights and diameters. Total average productivity at age of 41 months was in the order *E. camaldulensis* < *E. pellita* < *E. urophyll*. With increase in spacing, stem of individual tree increased in total biomass and diameter; however, there was reduction in per hectare production of total biomass production. *Eucalyptus pellita* 41.3 vs. 28.9, *E. camaldulensis* 35.1 vs. 26.9 and *E. urophylla* had 64.8 vs. 42.8 Mg per hectare at 3×3m, 4×3 m vs. 3 ×1.5m spacings, respectively. Increased spacing levels also decreased the relative amount of growth allocated to the bole of the tree.

Deuther *et al* (1998) conducted a study on vegetative propagation of conifers in Yale University, USA. Three species of pine and one of hemlock were tested and treatments of IBA were also evaluated. Among all the species, no rooting was observed in red pine (*P. resinosa*) during trial period. The maximum (52.5%) rooting was recorded in Lace-bark Pine (*P. bungeana*) taken from a 10-year-old tree in January and planted in sand under warm greenhouse conditions. In Japanese Red Pine (*P. densiflora*) 25.7% rooting was recorded in cuttings taken from branches during December from a 15-year-old tree, and 17.1% rooting was recorded in those cuttings which taken from cone less branches. However, in Hemlock (*Tsuga canadensis*) the maximum rooting was observed in cuttings taken from 4-year-old. The treatments of indole-butyric acid significantly increased the rooting in cuttings among both ages of trees.

Rawat *et al* (2001) screened of 75 clones of *Populus deltoides* in nursery stage and established in eastern Indo-Gangetic condition. Group of 11 clones was observed as UD-36, UD-5502, D124, D121, 34-N, 40-N, 25-N, 82-26-5, 90-12, UD-4707 and UD-6502 potential clones among all clones. The eleven clones that were showed their potential among other. This group of potential clones was closely followed by another group of 12 clones.

Chang (2003) assessed the effect of plant growth regulators and cutting age on rooting, sprouting and morphological characters of neem, shisham and poplar. Three different plant growth regulators IAA, IBA and NAA were used to treat the cuttings at different concentration level @ 250ppm, 500ppm and 1000ppm each. Result showed that the cuttings treated with IBA @ 1000ppm is best treatment as compared to all other treatment.

Joshi and Natiyal (2004) carried out an experiment to determine the influence of

diameter of cuttings on growth, establishment and stock quality of 5 provenances of poplar under nursery condition for two consecutive years. Results of analysis indicated that increase in diameter of cuttings significantly increased sprouting and survival % and number of roots. The cuttings of intermediate thickness (15-20cm) gave maximum juvenile growth at the end of growing season.

Verma and Bangarwa (2005) examined inter character correlation for 8 growth character in 62 clones of *Populus deltoides* at nursery condition in 3 different environments (three districts of Haryana i.e. hisar, karnal and Kurukshetra). Strong positive correlation was found among sprouting %, survival %, basal diameter, tree height, invariability in all 3 environments. Correlation coefficients indicated the feasibility of selection of clones simultaneous for low tapering and higher values of total height as well as basal diameter.

Henrique *et al* (2005) studied effect of plant growth regulators on rooting of *Pinus* cuttings. The cuttings with 4-6cm in length were treated with different levels of plant growth regulators and planted in tubes filled mixture of carbonized rice hulls (50%) and vermiculite (50%) and placed under polyethylene house containing intermittent mist system for 60 days. The cuttings were treated with IBA (indole-3-butyric acid), NAA (α -naphthalene acetic acid) and with PBZ (paclobutrazol) by putting the base of cuttings in the solution for 2 seconds. After 60 days, they found that the cuttings treated with IBA produced the higher number of rooted cuttings as compared to cuttings treated with NAA whereas the most effective treatment was IBA with paclobutrazol at concentration @ IBA 4000mg L⁻¹ plus 100mg L⁻¹.

Mundt (2006) conducted an experiment on vegetative propagation of timber producing some commercial species (*Tectona grandis* Linn. F, *Pterocarpus macrocarpus* Kurz, *Millettia pendula* benth. and *Gmelina arborea*) of Myanmar. The experiment was conducted to find out effectiveness of different growth regulators. The result showed that maximum number of roots were recorded by *Pterocarpus macrocarpus* Kurz (78%) followed by *Tectona grandis* Linn. F (65%) and the minimum rooting was recorded by *Millettia pendula* benth. (62%). Among the treatments, maximum rooting was recorded in *Millettia pendula* benth. (84.9%) followed by *Gmelina arborea* (72.5%) and the minimum rooting was recorded by *Tectona grandis* Linn. (50%).

Luna and Kumar (2006) conducted a study in which effects of different growth regulators (1000, 2000 and 3000 ppm of IBA, IAA and NAA) on the rooting ability, sprouting percentage, sprout length, number of leaves, number of roots and length of roots in juvenile shoot cuttings of *Melia composita* from March 2005 to September 2005 under intermittent mist conditions. IBA 3000 ppm produced the best results giving highest rooting 57.14%, roots per rooted cutting 3.92 and mean root length 4.31 cm in 45-50 days. Among the months, July planted cuttings gave the best results. The technology can be used to multiply superior genotypes for tree improvement and mass propagation for afforestation

programmes.

Almeida *et al* (2006) conducted a study to assess the efficiency of adventitious rooting in cuttings of tree shoots obtained from tree severance, stem ringing and from the epicormic shoots on trimmed branches of *Eucalyptus cloeziana* trees, as well as the effect of IBA on the adventitious rooting of the same cuttings. Stump shoots were taken from 15- and 5-years old tree respectively. Trees of 20, 15 and 5 years old were used by the means of stem ringing, and 20-year-old trees were used by pruned branches. Induction of stump shoots showed better results for the cuttings taken from the 5-year-old trees than the 15-year-old trees. Cuttings taken from 5-year-old trees gave better outcomes without IBA, while those originating from the 15-year-old trees offered better rooting which treated with the IBA.

Chauhan *et al* (2009) conducted a study to find out the effect of plant growth regulators on stem cutting of *Populus deltoides*. The study revealed the highly significant differences among the different treatments of IAA, IBA, GA, NAA and Kinetin individually at different concentrations of 1500ppm and 2000 ppm. The survival percentage of cuttings was higher in case of control followed by cuttings treated with IBA (1500 ppm concentration) and NAA (2000 ppm concentration). The lowest survival percentage was observed in cuttings treated with Kinetin (2000 ppm concentration). The maximum number of sprouting and number of leaves was found in cuttings treated with IBA (1500 ppm concentration) followed by the cuttings treated with NAA (2000 ppm concentration), respectively. Cuttings treated with IBA hormone (1500 ppm concentration) recorded the maximum length of the root. The total moisture content and root shoot ratio was significantly higher in IBA hormone treated cuttings.

Naidu and Jones (2009) reported that the cutting length can affect both the plug colonisation and rooting of container-grown stock. Using hedges from conventional clone banks established in the ground, four cutting length treatments (13, 10, 8 and 5 cm) were tested using five *Eucalyptus grandis* × *E. urophylla* clones. The smallest cutting length had the lowest number of leaves, rooting, root dry mass, shoot dry mass and number of roots per cutting. Root plug score (i.e. plug colonisation) was lowest for a cutting length of 5 cm and highest for the 8 cm cutting length. Then it is suggested that cutting length for operational production should be 8–10 cm approximately.

Ho *et al* (2010) investigated the vegetative propagation techniques of *Casuarina equisetifolia* through cuttings and rooting quality of water cultured in *C. equisetifolia*. Using a newly developed method, young branch cuttings were grown in water culture. To identify ideal conditions for water culture reproduction, several cuttings aged 3 and 6 months were treated with naphthalene acetic acid (NAA) at concentration of 50 ppm. Cutting length of <10 cm had well rooting quantity than 10~15-cm cuttings. The rooting percentage was higher in the cuttings in which wound was treated (86.7%) as compared to the cuttings without wound

treatment (73.3%).

Abidin and Metali (2011) studied the effect of plant growth regulator on rooting of cuttings taken from *Dillenia suffruticosa*. Two kinds of cuttings with or without leaves were selected and treated with IBA, NAA and IAA at different concentrations by dipped the cutting in solution or a quick-dip method and planted the treated cuttings in rooting media and kept in a greenhouse under misting condition. The rooting and survival percentage, length and number of new roots produced, relative growth rate based on stem diameter and stem length, and number and area of leaves were observed at the interval of a 4-week for 24 weeks. The leafy cuttings and leafless cuttings treated with distilled water after 4 weeks and 16 weeks, respectively did not survive. All of the leafy stem cuttings treated with NAA at 0.10% and 0.20%, and with IAA at 0.20% were survived for 24 weeks. Stem cuttings containing leaves treated with NAA (0.10 and 0.20%) but not ABA, had formed significantly longer and more numbers of roots than cuttings in the any other treatments after 8 weeks. Stem cuttings with leaves treated with IAA (0.10%) had a greater number of new leaves and have greater leaf area as compared to the cuttings of other treatments after 8 weeks. Relative growth rate of leafy stem cuttings showed no significant difference after 8 weeks among the different treatments. The result of this study showed that treatments with NAA (0.10-0.20% and IAA 0.10%) and not IBA have developed shoots and roots from stem cuttings containing roots.

Sharma *et al* (2017) studied the growth performance of hybrid seedlings of willow in nursery stage. 15 different families of willow were evaluated. Maximum height (347.48cm) and basal diameter (18.98mm) was recorded in the family PN 227 x SI-64-007 followed by family PN 227 x NZ 1179 whereas the number of branches was recorded maximum in PN 227 x NZ 1140 family.

Singh *et al* (2018) studied the effect of cutting treatments and potting media in *Melia composita*. Significant effect of pre-planting cutting treatment and rooting media was observed on sprouting and rooting percentage. During spring season, maximum rooting (40.0%) was recorded in cuttings treated with IBA 3000 ppm which was significantly higher than all the other pre-planting cutting treatments. Among different rooting media, maximum rooting was recorded in cuttings planted in coco peat media (26.67%). During rainy season, maximum rooting (36.67%) was recorded in cuttings treated with IBA 3000 ppm which was significantly higher than all other pre-planting treatments.

CHAPTER-III

MATERIALS AND METHODS

The present study entitled, "Morphological diversity and vegetative propagation studies of *Casuarina* spp. under Punjab conditions" comprised of experiments on evaluation of *Casuarina* clones established at two sites. The studies on vegetative propagation of *Casuarina* clones were undertaken under controlled conditions of polyhouse. Experimental details, the methodology adopted for conducting experiments and observations recorded are described as follows:

3.1 Evaluation of clones for growth and quality traits

3.2 Vegetative propagation

3.3 Statistical analysis

3.4 Index score analysis

3.5 Correlation studies

3.6 Clustering of genotypes

3.7 Path analysis

3.1 Evaluation of clones for growth and quality traits

3.1.1 Geographical Location

The studies on clonal evaluation of *Casuarina* under agroclimatic conditions of Punjab were conducted at two sites viz. Ruldu Singh Wala University Farm, Bathinda situated at 30°00'66" N latitude and 74°78'20" E longitude at an elevation of 211 m above the mean sea level, representing the semi-arid region of Punjab and University Seed Farm, Ladhowal, Ludhiana situated at 30°59'28"N latitude and 75°52'38" E longitude at an elevation of 240 m above the mean sea level representing the central plains of Punjab.

3.1.2 Climate

The climate of both experimental sites i.e. Ruldu Singh Wala University Farm, Bathinda and University Seed Farm, Ladhowal is sub-tropical with hot and dry summer (April-June), humid monsoon (July- September) and cold winters (December-February). Mean monthly meteorological data of both sites during the study period is depicted in Fig. 3.1 and 3.2.

3.1.3 Methodology:

The experiment comprised of eight clones of *Casuarina* spp. (four clones of *C. equisetifolia* x *C. junghuhniana* and four clones of *C. junghuhniana*) planted at two sites during September 2016 at a uniform spacing of 4x2m². The experiment was laid out in Randomized Block Design with three replications with four plants in each replication. Irrigation was given as and when required. Clonal material was procured from Institute of

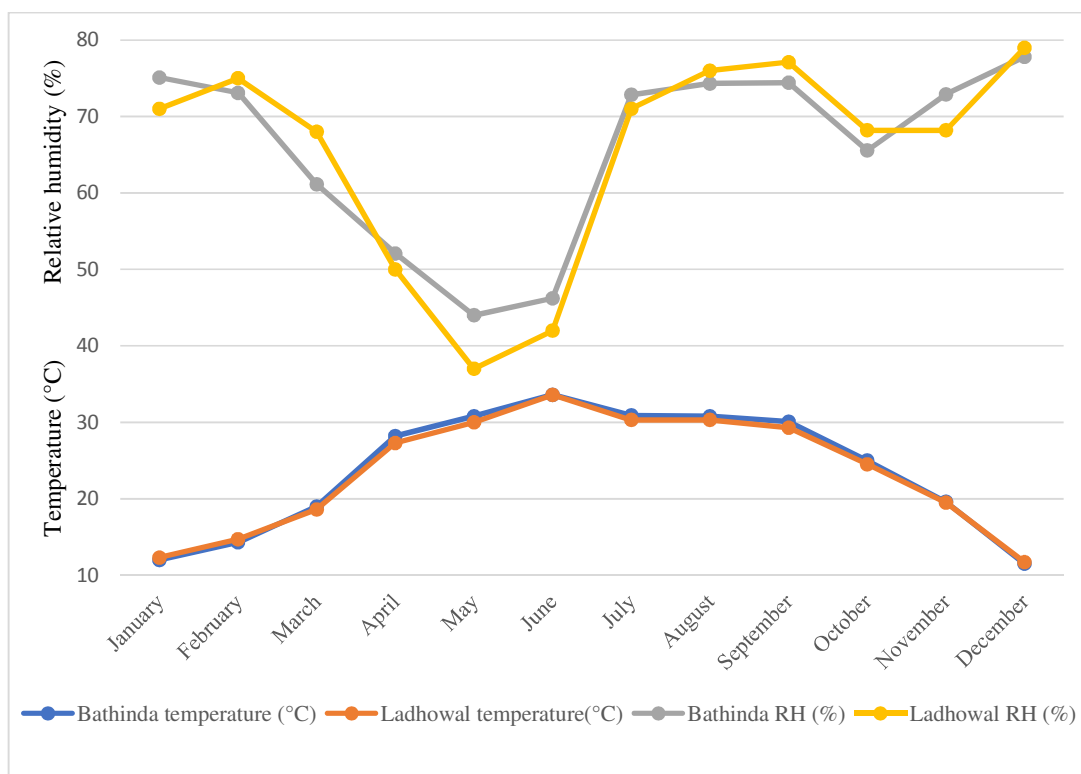


Fig. 3.1: Monthly average temperature and relative humidity of the experimental sites for year 2019

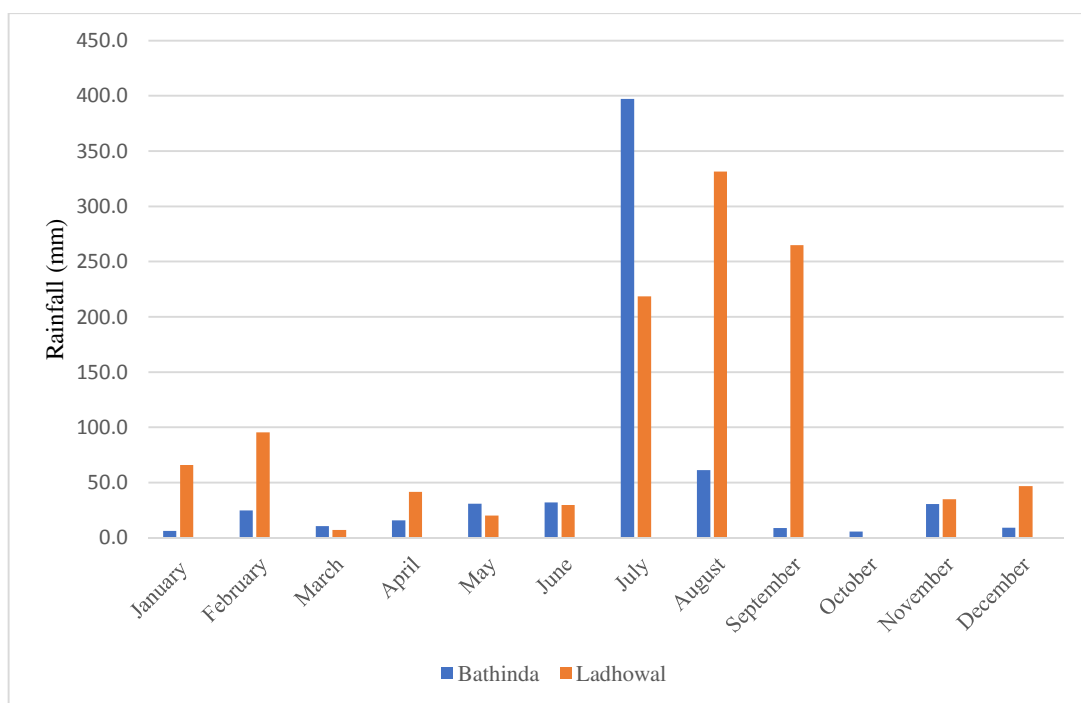


Fig. 3.2: Monthly average rainfall of the experimental sites for year 2019

Forest Genetics and Tree Breeding, Coimbatore (Tamil Nadu). Details of clones are given in Table 3.1. Clone number IFGTB CH 4 did not survive under semi-arid conditions of Punjab therefore this clone has not been considered for comparing performance under different environments.

Table 3.1 Description of clones of *Casuarina* spp. used in the present study

S. No.	Clone number	Taxa
1	IFGTB CH-1	Interspecific hybrid (<i>C. equisetifolia</i> x <i>C. junghuhniana</i>)
2	IFGTB CH-2	Interspecific hybrid (<i>C. equisetifolia</i> x <i>C. junghuhniana</i>)
3	IFGTB CH-5	Interspecific hybrid (<i>C. equisetifolia</i> x <i>C. junghuhniana</i>)
4	IFGTB CH-6	Interspecific hybrid (<i>C. junghuhniana</i> x <i>C. equisetifolia</i>)
5	IFGTB CJ-7	<i>Casuarina junghuhniana</i>
6	IFGTB CJ-9	<i>Casuarina junghuhniana</i>
7	IFGTB CJ-10	<i>Casuarina junghuhniana</i>
8	IFGTB CJ-108	<i>Casuarina junghuhniana</i>

3.1.4 Description of soil of both sites:

Soil properties of the experimental sites under different environments is given in Table 3.2. Experimental soil at University Seed Farm, Ladhowal and Chak Ruldu Singh Wala University Farm, Bathinda was loamy texture and sandy loam soil, respectively. Soils of the two environments different for soil organic carbon content which was higher at University Seed Farm, Ladhowal than Chak Ruldu Singh Wala University Farm, Bathinda.

Table 3.2 Physio-chemical properties of the experimental sites

Depth of sample	pH	Electrical conductivity (mS/cm)	Organic carbon (%)	Phosphorous (kg/acre)	Potash (kg/acre)	Location
0-15cm	8.3	0.11	0.15	1.2	240	Chak Ruldu Singh Wala University Farm, Bathinda
15-30cm	8.2	0.12	0.09	1.8	249	
30-45cm	8.3	0.12	0.12	1.2	195	
45-60cm	8.4	0.11	0.12	1.2	225	
0-15cm	8.2	0.19	0.57	1.2	249	University Seed Farm, Ladhowal
15-30cm	8.2	0.23	0.48	1.2	249	
30-45cm	8.2	0.18	0.57	1.8	228	
45-60cm	8.3	0.28	0.66	1.2	210	

3.1.5 Observations recorded

Following observations on quantitative and qualitative traits of trees were recorded during December 2018 (at the age of 2 ¼ years) and December 2019 (at the age of 3 ¼ years)

as follow:

i. Tree height (m)

Tree height was measured as the perpendicular distance between the ground to the top of the stem by using Ravi altimeter at the interval of six months i.e. December 2018. June 2019 and December 2019.

ii. Diameter at breast height (cm)

The diameter of the stem was measured by using tree calliper from two directions perpendicular to each other at the breast height (1.37m from ground level) at the interval of six months i.e. December 2018. June 2019 and December 2019. Average of the two values was calculated.

iii. Current annual increment (CAI) and mean annual increment (MAI) for tree height and diameter at breast height

CAI for tree height and diameter at breast height was calculated by subtracting the growth recorded in December 2018 from growth recorded in 2019 for both tree height and diameter while MAI for tree height and diameter at breast height was measured by dividing the total height and diameter growth respectively recorded in December 2019 by the age of trees i.e. 3 ¼ years.

iv. Clear bole height (m)

Clear bole height is the distance between ground and first crown forming branch which was recorded in December 2019.

v. Crown spread (m²)

Crown spread is the area covered by the crown and was measured by multiplying the length and width of tree crown in December 2019.

vi. Number of branches

The number of branches were counted in one-meter length on the main stem from the lower end of the crown/ from first crown forming branch in December 2019 to measure the branch density.

vii. Tree stem volume

Tree stem volume was estimated by using the formula: $\frac{1}{3} \pi (D/2)^2 h$

Where d is diameter at breast height and h is tree height

viii. Branch angle

The angle formed by branches at the point of insertion with the main stem was measured and scoring was given in following manner:

Score 1 = If angle formed by branches is $< 60^\circ$ with the main stem

Score 2 = If angle formed by branches is $> 60^\circ$ with the main stem

ix. Axis persistence

Axis persistence was measured by scoring given in followed manner:

- 1 = Main stem forked into multiple stems at ground level
- 2 = Main stem forked into multiple stems in the 1st quarter from the ground level of the tree.
- 3 = Main stem forked into multiple stems in the 2nd quarter from the ground level of the tree
- 4 = Main stem forked into multiple stems in the 3rd quarter from the ground level of the tree
- 5 = Main stem forked into multiple stems in the 4th quarter from the ground level of the tree
- 6 = Main stem forked into multiple stems at top of the tree from the ground level of the tree

x. Stem straightness

Stem straightness was measured by scoring given in the followed manner

- 1 = Very crooked i.e. > 2 serious bends were recorded on the main stem.
- 2 = Slightly crooked i.e. > 2 small bends or ≤ 2 serious bends were recorded on the main stem.
- 3 = Almost straight i.e. 1–2 small bends were recorded on the main stem.
- 4 = Completely straight i.e. no bend was recorded on the main stem.

xi. Branch thickness

Branch thickness was measured by scoring given in the followed manner

- 1 = More than 3 branches of tree were recorded the diameter $> \frac{1}{3}$ of the main stem diameter at the insertion point and considered under very heavily branched tree.
- 2 = 1–3 branches of tree were recorded the diameter $> \frac{1}{3}$ of the main stem diameter at the insertion point and considered under heavily branched tree.
- 3 = branches of tree were recorded the diameter $\leq \frac{1}{3}$ of the main stem diameter at the insertion point and considered under light branched tree.
- 4 = branches of tree were recorded the diameter $\leq \frac{1}{4}$ of the main stem diameter at the insertion point and considered under very light branched tree.

xii. Flowering

Flowering was measured in the following manner:

Low: Flowering in less than 25% of the total crown area

Medium: Flowering in 25-50% of the total crown area

High: Flowering in more than 50% of the total crown area.

xiii. Fruiting

Fruiting was measured in the following manner

Low: Fruiting in less than 25% of the total crown area

Medium: Fruiting in 25-50% of the total crown area

High: Fruiting in more than 50% of the total crown area.

3.2 Vegetative propagation

The study was conducted under controlled condition (polyhouse) in main field area, Department of Forestry & Natural Resources, Punjab Agricultural University, Ludhiana. The temperature and relative humidity were maintained inside the polyhouse i.e. temperature at

30-35°C and relative humidity of 80-85%. Continuously misting was done with nozzle fitted on the roof.

3.2.1 Methodology:

Six clones of *Casuarina* viz. clone numbers IFGTB CH-1, CH-2, CH-4, CH-5, CH-6 and CJ-7 were used for the present investigation. Branches were collected from one year old plants during the second week of April. Branches were taken in the early morning to avoid desiccation. The cuttings of different sizes i.e. <0.3cm, 0.3-0.6cm and 0.6-0.9cm were prepared with the help of secateurs by giving sharp cut and planted in polythene bags filled with soil immediately after collection. The experiment was established in split-plot design with six clones in the main plot and cutting sizes in the sub plots Each treatment combination was replicated thrice with 10 cuttings in each replication. Cuttings were treated with Indole butyric acid (2000 ppm) before planting. The water was provided to the cuttings in the form of mist inside the chamber and weeds were removed manually.

3.2.2 Observations recorded

The data were recorded on different morphological parameters as follow:

i. Sprouting percentage

The sprouting percentage was calculated by using the formula:

$$\text{Sprouting percentage} = \frac{\text{Number of cuttings sprouted}}{\text{Total number of cuttings planted}} \times 100$$

The survival percentage was calculated by using the formula:

$$\text{Survival percentage} = \frac{\text{Number of cuttings survived}}{\text{Total number of cuttings planted}} \times 100$$

ii. Days taken for sprouting

Days taken for sprouting were recorded by counting the number of days taken by cuttings of different clones from the time of planting to completion of sprouting.

iii. Plant height (cm)

Plant height was measured from the point of origin of branch on the main stem to the tip of the plant by using the scale at the age of eight months.

iv. Collar diameter (mm)

Collar diameter was measured 1cm above point of origin of branch on cutting by using the vernier caliper at the age of eight months.

v. Number of branches

The number of branches was measured by counting the branches on the main stem i.e. grown between base and tip of the main stem at the age of eight-months.

vi. Number of primary and secondary roots

The number of primary roots was measured by counting the number of roots originated from the cutting base. Number of secondary roots was measured by counting the

roots on the primary root system at the age of eight months.

vii. Root length (cm)

Root length was measured from the base of the cutting to the tip of the longest root by using scale at the age of eight months.

viii. Root fresh weight (g/plant)

Root fresh weight was measured by weighing the fresh roots after separation from the plant base by using the electronic weighing machine.

ix. Root dry weight (g/plant)

After weighing the fresh weight, the roots were placed in a brown paper envelope in a hot air oven at 54°C till the dry weight reached constant. The observation was recorded at the end of the experiment i.e. after eight months of the planting of cuttings.

3.3 Statistical analysis

The replicated data pertaining to different growth and qualitative traits were subjected statistical analysis as suggested by Gomez and Gomez (1984) for interpretation of results.

3.3.1 Analysis of variance

The replicated data of all the traits were recorded for testing the clones on different sites, clone x site interaction and vegetative propagation studies were statistically analysed as suggested by Gomez and Gomez (1984)

Source of variation	Degree of freedom	Mean of square	Fcal
Replication	(r-1)	Mr	
Treatments	(ab-1)	Mt	Mt/Me
Interaction (A × B)	(a-1) × (b-1)	MSAB	MSAB/Me
Error	(r-1) × (ab-1)	Me	
Total	(rab-1)		

Where,

r = Number of replications

t = Number of treatments

Mr = Mean sum of squares due to replications

Mt = Mean sum of squares due to treatments

MSAB = Mean sum of squares due to (seed source X genotype) interaction

Me = Mean sum of squares due to error

The components of variance for evaluation of clones were calculated by using mean square value as:

$$\text{Error variance} \quad (\sigma^2_e) = Me$$

$$\text{Genotypic variance} \quad (\sigma^2_g) = \frac{Mt - Me}{r}$$

Phenotypic variance $(\sigma^2_p) = \sigma^2_g + \sigma^2_e$

3.3.2 Standard Error Differences

Standard error difference was measured by using the formula:

$$\text{Standard error (S.E.)} = \sqrt{\frac{2 \cdot \text{Me}}{r}}$$

Where,

Me = Error mean square

r = Number of replications

3.3.3 Critical difference (CD)

CD was estimated to compare the treatment means for all the characters. CD were calculated by using Standard error (S.E.) for the difference of two means and value of treatments which calculated in table at 5% level of significance (t) as follows:

$$\text{CD} = \text{SEd} \times t \text{ at } 5\% \text{ error degree of freedom}$$

3.3.4 Coefficient of variation

Both genotypic and phenotypic coefficients of variations were calculated by using the formula suggested by Burton (1952) as:

$$\text{GCV} = (\sigma_g \times 100)/n$$

$$\text{PCV} = (\sigma_p \times 100)/n$$

Where n was mean of that particular characters

3.3.5 Heritability (broad sense)

Heritability in broad sense was calculated by using the formula suggested by Johnson et al (1955).

$$\text{Heritability (\%)} = h^2 = (\sigma^2_g / \sigma^2_p) \times 100$$

Where, σ^2_g = Genotypic variance,

σ^2_p = Phenotypic variance

3.3.6 Genetic advance (% of mean)

The expected genetic gain for each character was estimated by using the formula suggested by Lush (1949) at 5% selection intensity as:

$$\text{GA (\% of mean)} = (K \cdot \sigma_p \cdot h^2)/n$$

Where, K = selection differential (2.06)

σ_p = phenotypic standard deviation

h^2 = heritability in broad sense

n = general mean

3.4 Correlation Coefficient

The correlation coefficient among different characters was calculated by using the formula:

$$r = \frac{\sum (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum (X_i - \bar{X})^2 \sum (Y_i - \bar{Y})^2}}$$

Where,

X_i = Value of an individual character

Y_i = Value of other individual character

$\bar{n}$ = Mean of parental values

$\bar{Y}$ = Mean of all clones

3.5 Index score analysis

Index score analysis was carried out by using the data of morphological characters i.e. tree height, diameter at breast height and number of branches. Scores assigned to different growth parameters falling in different class intervals under different environments are given below:

Ruldu Singh Wala University Farm, Bathinda

Scores Characters	1	2	3
Tree height (m)	9.25-10.98	10.99-12.71	12.72-14.44
Diameter (cm)	7.75-9.14	9.15-10.53	10.54-11.93
Number of branches	13.33-15.00	11.67-13.32	10.00-11.66

University Seed Farm, Ladhawal, Ludhiana

Scores Characters	1	2	3
Tree height (m)	11.46-12.59	12.60-13.73	13.74-14.88
Diameter (cm)	9.75-10.53	10.54-11.32	11.33-12.11
Number of branches	10.80-11.97	9.62-10.79	8.44-9.61

3.6 Clustering of genotypes

The genotypes were clustered with the assistance of computer software programme DARwin (Perrier and Jacquemoud-Collet 2006) to study the genetic diversity on the basis of morphological traits. The data were applied to unweighted pair group method with arithmetic mean (UPGMA) analysis to generate a dendrogram. Genetic similarity coefficients between various genotypes (in pair-wise comparisons) were calculated from the morphological data matrix using dice coefficient from genotypic diversity values.

3.7 Path analysis

Path coefficient analysis having direct and indirect paths was worked out as per the method as suggested by Dewey and Lu (1959).

CHAPTER IV

RESULTS AND DISCUSSION

The present investigation entitled “**Morphological diversity and vegetative propagation studies of *Casuarina* spp. under Punjab conditions**” was carried out at Chak Ruldu Singh Wala Farm, Bathinda and University Seed Farm, Ladhowal, Ludhiana to select the superior clones of *Casuarina* spp. with better growth performance under semi-arid and central plains of Punjab and optimizing the cutting size for vegetative propagation of *Casuarina* clones carried out in polyhouse. The data results obtained in the present study are discussed under the following broad heads.

4.1 Evaluation of clones for growth and quality traits

4.1.1 Clonal variation for morphological traits

4.1.2 Index score analysis

4.1.3 Estimation of genetic parameters

4.1.4 Correlation studies

4.1.5 Path analysis

4.1.6 Clustering of genotypes

4.2 Vegetative propagation studies

4.2.1 Effect of cutting size and clones on different parameters

4.2.2 Estimates of genetic parameters

4.2.3 Correlation studies

4.2.4 Path analysis

4.1 Evaluation of clones for growth and quality traits

Performance of different clones of *Casuarina* spp. evaluated under different environment for various morphological traits is described as below:

4.1.1 Clonal variation for morphological traits

The observations in clonal evaluation trials were recorded on the growth and quality characteristics i.e. tree height, diameter at breast height and fruiting during December 2018 and December 2019. The other parameters including clear bole height, number of branches, crown spread, tree stem volume, branch angle, axis persistence, branch thickness and stem straightness were recorded once in December 2019 while flowering was recorded during June-July 2019.

4.1.1.1 Tree height (m)

The mean performance of different clones of *Casuarina* for tree height under different environments is presented in Table 4.1. The analysis of variance reflected significant variation among different clones at Bathinda and Ladhowal. Genotype X environment interaction was also significant.

The perusal of data revealed that under semi-arid conditions of Punjab, clone IFGTB CH 5 registered the maximum tree height (14.44m) followed by clone IFGTB CH 2 (13.95m) and clone IFGTB CH 1 (12.50m). Clone IFGTB CH 5 was found significantly superior to clone numbers IFGTB CH 1, IFGTB CH 6, IFGTB CJ 7, IFGTB CJ 9, IFGTB CJ 10 and IFGTB CJ 108. Clones IFGTB CH 1, IFGTB CH 2, IFGTB CH 5 and IFGTB CJ108 attained more tree height than general mean which indicated the above average performance of these clones. However, the clone IFGTB CH 6 recorded the least tree height (9.25m) and was statistical at par with the clone IFGTB CJ 10 (9.73m).

Under central plains of Punjab, clone IFGTB CH 5 recorded the maximum tree height (14.87m) closely followed by the clone IFGTB CH 2 (14.56m). Clone IFGTB CH 5 was significantly superior to clones IFGTB CH 6, IFGTB CJ 7, IFGTB CJ 9, and IFGTB CJ 10. Clones IFGTB CH 1, IFGTB CH 2, IFGTB CH 5 and IFGTB CJ 108 attained more tree height than general mean which indicated the above average performance of these clones. However, clone IFGTB CH 6 recorded the least tree height (11.46m) which were statistical at par with the clone IFGTB CJ 9 (11.70m).

Table 4.1: Performance of various clones of *Casuarina* for tree height (m) under different environments at the age of 3 ¼ years in Bathinda and Lathowal

Clone	Bathinda	Lathowal	Mean
IFGTB CH 6	9.25	11.46	10.36
IFGTB CJ 7	11.15	12.41	11.78
IFGTB CJ 9	10.55	11.70	11.13
IFGTB CJ 10	9.73	11.93	10.83
IFGTB CH 1	12.50	14.06	13.28
IFGTB CH 2	13.95	14.56	14.26
IFGTB CH 5	14.44	14.87	14.66
IFGTB CJ 108	12.24	14.21	13.23
General mean	11.73	13.15	

CD (5%) for Bathinda = 1.75, Lathowal = 1.64 and Genotype × environment = 1.62

Overall mean of all clones for tree height was higher under central plains of Punjab (13.15m) than under semi-arid conditions (11.73m) which reflected that agro-climatic condition of central plains of Punjab was better suited for tree height than semi-arid conditions. Genotype X environment interaction was statistically significant for tree height which indicated that environment played a significant role in tree height performance of different clones. Critical perusal of mean performance of clones averaged over both the environments indicated the superiority of clone IFGTB CH 5 (14.66m) followed by IFGTB CH 2 (14.26m). However, clone IFGTB CH 6 recorded the least tree height (10.36m) among all the clones. Higher tree height at Lathowal as compared to Bathinda may be attributed to

the presence of high organic carbon in soil at Ladhawal site and also received rainfall for longer period than Bathinda which affect the moisture content of soil as well as air and help in boosting the overall growth of tree. Results obtained in the present study are in conformity with the earlier reports. Kindo *et al* (2014) also recorded variation in *Casuarina* provenances for different growth traits as survival, volume, height and diameter in Tanzania. Pradhan *et al* (2017) recorded significant differences among the teak clones for different traits such as height, diameter, flower and fruit production.

The current annual increment (CAI) and mean annual increment (MAI) of different clones of *Casuarina* for tree height under different environments are presented in Fig 4.1. The perusal of data reveals that under semi-arid region of Punjab, clone IFGTB CH 2 recorded the maximum CAI (3.75m) followed by the clone IFGTB CH 1 (3.30 m) and the minimum CAI (1.13 m) in clone IFGTB CJ 10. Clone IFGTB CH 5 registered the maximum MAI (4.44m) followed by clone IFGTB CH 2 (4.29m) and the least MAI (2.84m) recorded for the clone IFGTB CH 6. Under central plains of Punjab, clone IFGTB CH 5 recorded maximum CAI (2.92m) followed by the clone IFGTB CH 1 (2.75 m) and the minimum CAI was recorded by clone IFGTB CJ 7 (1.77 m). Similarly, in semi-arid conditions, MAI of clones in central plains was greater than CAI for each clone. Clone IFGTB CH 5 recorded the highest MAI (4.57 m) followed by the clone IFGTB CH 2 (4.48 m) and the least MAI (3.52 m) was recorded by the clone IFGTB CH 6 (Fig 4.1).

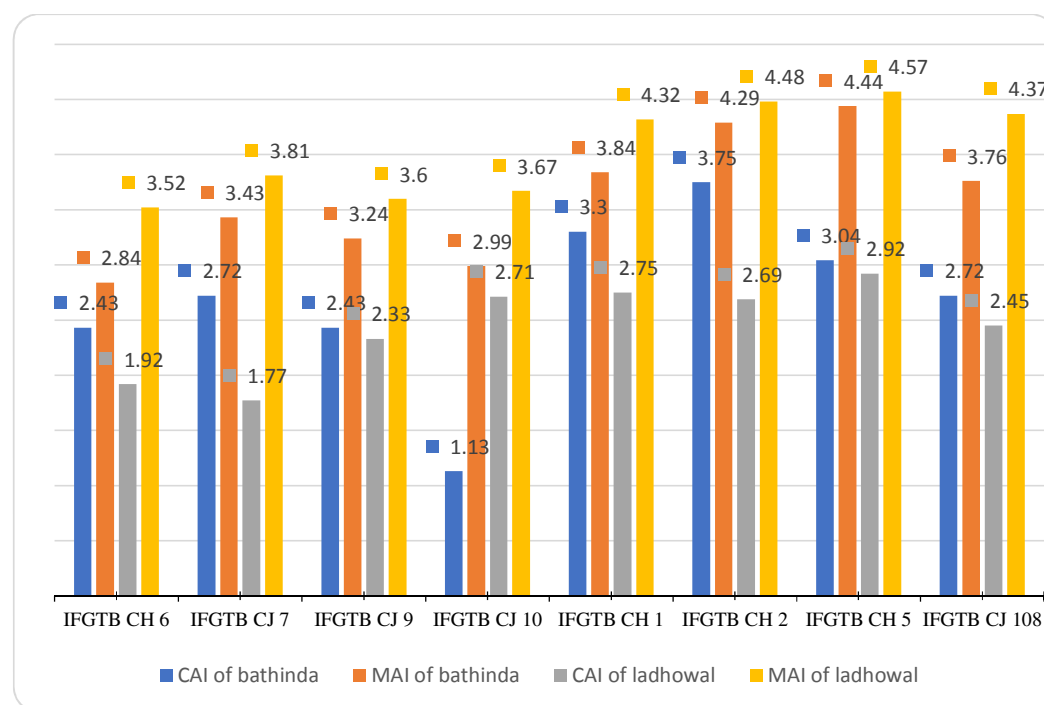


Fig 4.1: Variation among different clones of *Casuarina* for CAI and MAI of tree height under different environments

The data revealed that general mean of CAI was recorded higher (2.69 m) in semi-

arid conditions of Punjab and the general mean of MAI was registered greater (4.04 m) by the clones under central plains of Punjab. The CAI reached its culmination point and then started decreasing greatly at both the sites (semi-arid conditions of Punjab and central plains of Punjab) whereas among all the clones, clone IFGTB CH 2 recorded highest CAI for Bathinda site while clone IFGTB CH 5 recorded highest CAI for University Seed Farm, Ladhawal. The MAI was recorded greater than the CAI under both sites. The data on the increment is necessary to decide the rotation period, tending operations, growing stock etc activities in forest and the intersection point of CAI and MAI was suggest the silvicultural rotation period.

4.1.1.2 Diameter at breast height (cm)

The mean performance of different clones of *Casuarina* for diameter at breast height under different environments is presented in Table 4.2. The data revealed that in semi-arid regions of Punjab, clone IFGTB CH 2 recorded significant maximum diameter at breast height (11.93cm) followed by clone IFGTB CH 5 (11.67cm) and clone IFGTB CH 1 (10.70cm) but these clones were statistically at par with each other. Clone IFGTB CH 2 recorded significant superiority over the clones IFGTB CH 6, IFGTB CJ 7 and IFGTB CJ 10. Clones with more than the general mean were in order IFGTB CJ 9, IFGTB CH 1, IFGTB CH 2 and IFGTB CH 5 Whereas the clone IFGTB CH 6 recorded the least diameter (7.75cm) and at par with clone IFGTB CJ 10 (8.42cm).

In central plains of Punjab, it was observed that clone IFGTB CH 2 recorded maximum diameter (12.11cm) closely followed by the clone IFGTB CH 5 (11.64cm). Both of these clones were statistically at par with each other. Clone IFGTB CH 2 recorded significant superiority over the clones IFGTB CH 6 and IFGTB CJ 10. Least DBH (9.75cm) was recorded by clone IFGTB CH 6

Among the both sites, the overall mean of clones under the central region of Punjab was recorded the higher diameter (10.84cm) than as compared to semi-arid region of Punjab (10.02 cm) which indicates that the environment of central plains was much supportive for diameter increase than semi-arid climatic conditions of Punjab. Among the both environments, the average of mean performance of clones revealed that clone IFGTB CH 2 recorded the maximum diameter at breast height (12.02 cm) followed by clone IFGTB CH 5 (11.66cm) which were at par with each other statistically and clone IFGTB CH 6 recorded the minimum diameter (8.75cm) at breast height. Genotype x environment interaction was significantly different for the diameter at breast height which intimate that the clone performed differently under different environmental conditions. Ladhawal environment was much supportive for the growth of diameter at breast height as it possesses high organic carbon content in soil along with higher rainfall which is favourable for tree species it can became a reason for Ladhawal site possess higher DBH than Bathinda site. Kannan *et al* (2012) also recorded significant variation among the clones for diameter and other growth

traits for *Casuarina*. Luechanimitchit *et al* (2017) observed significant variation among the clones of *Casuarina* for diameter growth in Thailand.

Table 4.2: Performance of various clones of *Casuarina* for diameter at breast height (cm) under different environments at the age of 3 ¼ years in Bathinda and Ladhawal

Clone	Bathinda	Ladhawal	Mean
IFGTB CH 6	7.75	9.75	8.75
IFGTB CJ 7	9.23	10.74	9.99
IFGTB CJ 9	10.63	10.77	10.70
IFGTB CJ 10	8.42	10.07	9.24
IFGTB CH 1	10.70	10.51	10.61
IFGTB CH 2	11.93	12.11	12.02
IFGTB CH 5	11.67	11.64	11.66
IFGTB CJ 108	9.83	11.14	10.49
General mean	10.02	10.84	

CD (5%) for Bathinda = 2.19, Ladhawal = 1.76 and Genotype × environment = 1.76

The current annual increment (CAI) and mean annual increment (MAI) of different clones of *Casuarina* for diameter at breast height under different environments is presented in Fig 4.2. The data depicted that under the semi-arid region of Punjab, the maximum CAI (3.45 m) was recorded by the clone IFGTB CH 2 followed by the clone IFGTB CJ 108 (3.20 m)

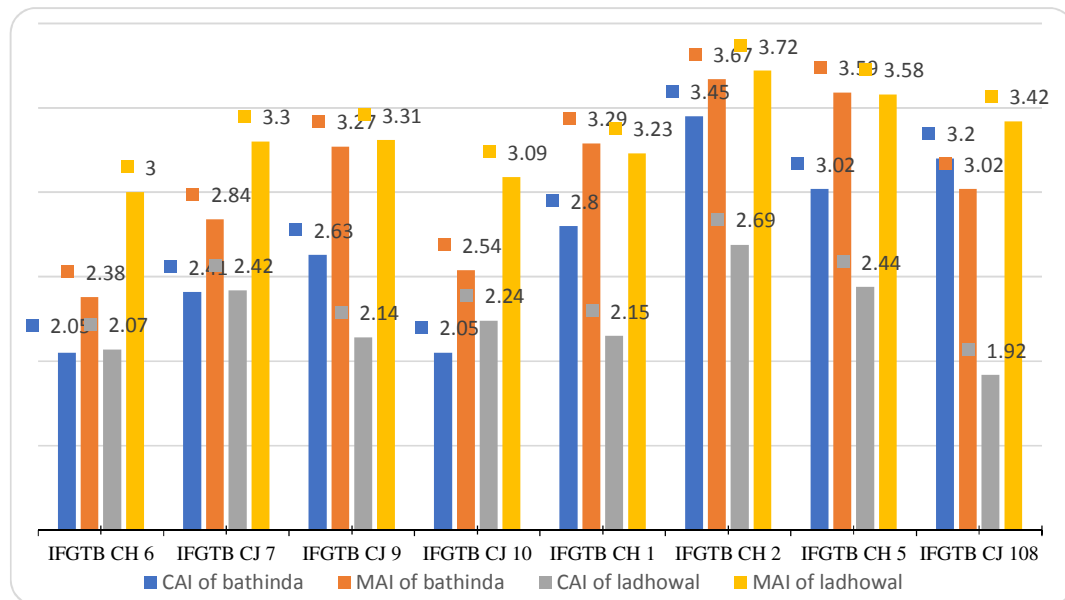


Fig. 4.2: Variation among different clones of *Casuarina* for CAI and MAI of diameter at breast height under different environments

and the minimum CAI (2.05 m) was recorded by the clone IFGTB CH 6 and IFGTB CH 10. Maximum MAI was recorded by the clone IFGTB CH 2 (3.67 m) closely followed by IFGTB CH 5 (3.59 m) and clone IFGTB CH 1 (3.29 m) and the least MAI was recorded by the clone IFGTB CH 6 (2.38 m). Under the central plains of Punjab clone IFGTB CH 2 registered the

maximum CAI (2.69 m) followed by clone IFGTB CH 5 (2.44m) and the minimum CAI was recorded for the clone IFGTB CH 108 (1.92 m). The MAI was recorded maximum (3.72 m) by the clone IFGTB CH 2 closely followed by clone IFGTB CH 5 (3.58 m) and the least (3.00 m) MAI was recorded by clone IFGTB CH 6 (Fig 4.2).

Overall mean performance of clones under semi-arid region of Punjab for CAI was recorded higher (2.70 m) than central plains of Punjab, while mean performance of clones for MAI was recorded maximum (3.33 m) by the clones under central plains of Punjab (Fig 4.2). Similarly, as height trait, the CAI for diameter at breast height reached their culmination point and then decreased rapidly at both the sites (semi-arid conditions of Punjab and central plains of Punjab). Among all the clones, the CAI was recorded lower than the MAI under both sites.

4.1.1.3 Clear bole height (m)

The mean performance of different clones of *Casuarina* for clear bole height under different environments was observed significant (Table 4.3). In semi-arid region of Punjab, it was observed that clone IFGTB CH 5 attained the maximum clear bole height (3.18m) followed by the clone IFGTB CH 2 (2.65m) which were statistically at par with each other and the clone IFGTB CJ 9 recorded the least clear bole height (2.40m) among all clones. Clone IFGTB CH 5 was significantly superior to the clones IFGTB CH 1, IFGTB CH 6, IFGTB CJ 7, IFGTB CJ 10 and IFGTB CJ 108. The clones which recorded the clear bole height more than the general mean are IFGTB CH 2 and IFGTB CH 5 that indicate mean performance of these clones are greater than the average mean.

In the central plains of Punjab, it was observed that clone IFGTB CH 2 registered the highest clear bole height (2.38m) followed by the clone IFGTB CH 6 (2.36m). Clone IFGTB CH 2 recorded its significant superiority over the clone IFGTB CJ 9. Clones IFGTB CH 2, IFGTB CH 5 and IFGTB CH 6 attained clear bole height more than the general mean. The least clear bole height (2.16m) was recorded by the clone IFGTB CJ 9.

Clones planted under semi-arid region of Punjab recorded higher clear bole height (2.57m) than the central region of Punjab at USF Ladhawal (2.26m). The statistical result showed significant differences for Genotype x environment interaction which indicated that clones behaved differently under semi-arid region and central plains of Punjab and hence semi-arid conditions were favourable for attaining the higher clear bole height. Critical perusal of mean performance of clones averaged over both the environments indicated the superiority of clone IFGTB CH 5 was recorded the maximum clear bole height (2.73 m) followed by clone IFGTB CH 2 (2.51 m) and the minimum clear bole height (2.28 m) was registered by IFGTB CJ 9 for both environment conditions. The similar results as in present study were recorded in the study conducted by the Alberto *et al* (1998) in which he found the significant differences among the different species of *Eucalyptus* of different ages at different spacing.

Table 4.3: Performance of various clones of *Casuarina* for clear bole height (m) under different environments at the age of 3 ¼ years in Bathinda and Lathowal

Clone	Bathinda	Lathowal	Mean
IFGTB CH 6	2.52	2.36	2.44
IFGTB CJ 7	2.47	2.21	2.34
IFGTB CJ 9	2.40	2.16	2.28
IFGTB CJ 10	2.55	2.24	2.39
IFGTB CH 1	2.40	2.25	2.32
IFGTB CH 2	2.65	2.38	2.51
IFGTB CH 5	3.18	2.29	2.73
IFGTB CJ 108	2.45	2.21	2.33
General mean	2.57	2.26	

CD (5%) for Bathinda = 0.64, Lathowal = 0.21 and Genotype × environment = 0.45

4.1.1.4 Crown spread (m²)

The mean performance of different clones of *Casuarina* for crown spread under different environments is presented in Table 4.4. The perusal of data indicated clone IFGTB CH 2 recorded maximum crown spreading (25.09m²) followed by clone IFGTB CJ 9 (24.00m²) and clone IFGTB CH 5 (23.70 m²) under semi-arid conditions of Bathinda. Clone IFGTB CH 2 was found significantly superior from the clone IFGTB CH 6 and IFGTB CJ 7. However, clone IFGTB CH 6 (15.13 m²) recorded the least crown spreading. Clones that recorded the crown spreading greater than the general mean were IFGTB CJ 9, IFGTB CJ 10, IFGTB CH 2, IFGTB CH 5 and IFGTB CJ 108.

Under the central plains of Punjab, all the clones showed variation among each other in which clone IFGTB CJ 108 (31.77 m²) recorded the maximum crown spreading followed by the clone IFGTB CH 2 (31.60 m²) and clone IFGTB CJ 10 recorded the minimum crown spreading (18.55 m²) among all the clones. Clone IFGTB CJ 108 significantly superior over the clones IFGTB CH 6, IFGTB CJ 7, IFGTB CJ 10 and IFGTB CH 1. Clones IFGTB CJ 9, IFGTB CH 2, IFGTB CH 5 and IFGTB CJ 108 was recorded the higher crown spreading than general mean.

Among the both sites, the mean performance of all clones under the semi-arid zone of Punjab was recorded the lower crown spreading (21.35 m²) as compared to the crown spreading (24.12 m²) recorded by the clones under the central plains of Punjab which indicated that the clones under semi-arid condition of Punjab performed better than central plains of Punjab. Genotype x environment interaction was statistically significant for crown spreading which indicated that clones interacted differently under various environments. Minimum crown spreading (16.86 m²) was recorded by the clone IFGTB CH 6 for both sites while clone IFGTB CH 2 registered maximum crown spreading (28.35 m²) followed by clone

IFGTB CJ 108 (27.21 m²) both of these clones were at par with each other. Organic carbon content was higher than Bathinda site which allows the growth of branches which make dense and greater crown of a tree and higher rainfall made moisturised air and soil conditions which also became supportive for the leafy growth of tree and it is the major reason for variation among the clones of *Casuarina* for crown spread. Similar results were recorded in the study conducted by Haapanen *et al* (1997) in which they found that the clones of Scots Pine recorded variation among each other for crown spreading and other morphological traits as well as made a favourable relationship genetically with the tree height.

Table 4.4: Performance of various clones of *Casuarina* for Crown spreading (m²) under different environments at the age of 3 ¼ years in Bathinda and Ladhowal

Clone	Bathinda	Ladhowal	Mean
IFGTB CH 6	15.13	18.60	16.86
IFGTB CJ 7	16.51	21.00	18.76
IFGTB CJ 9	24.00	24.55	24.28
IFGTB CJ 10	23.11	18.55	20.83
IFGTB CH 1	20.68	20.06	20.37
IFGTB CH 2	25.09	31.60	28.35
IFGTB CH 5	23.70	26.87	25.29
IFGTB CJ 108	22.65	31.77	27.21
General mean	21.35	24.12	

CD (5%) for Bathinda = 6.88, Ladhowal = 10.20 and Genotype × environment = 8.31

4.1.1.5 Number of branches (Density)

The mean performance of different clones of *Casuarina* for number of branches under different environments is presented in Table 4.5. The smaller number of branches on the main stem were considered favourable for the purpose of production a good quality wood. As the branches increased on the main stem the number of nodes were also increased which decrease the value of commercial wood. So, in the recorded data the clone bear lesser number of branches was considered as best and the higher number of branches was considered under poor performance of clone for wood production.

It is evident from the data presented in Table 4.5 that the under semi-arid conditions of Punjab, clone IFGTB CH 1 recorded the maximum number of branches (15.00) followed by clone IFGTB CJ 9 (13.67). Among the clones in semi-arid region, IFGTB CH 2 was significantly inferior from the clones IFGTB CH 1 and IFGTB CJ 9. Clones IFGTB CJ 10, IFGTB CH 2, IFGTB CH 5, IFGTB CH 6 and IFGTB CJ 108 attained a smaller number of branches than general mean of the site, while clone IFGTB CH 2 recorded the minimum number of branches (10.00).

Under central plains of Punjab, it was observed that clone IFGTB CJ 7 having the maximum number of branches (11.97) followed by the clone IFGTB CJ 9 (10.86) and the clone IFGTB CH 6 recorded least number of branches (8.44). Clone IFGTB CH 6 recorded significant superiority over the clones IFGTB CJ 7, IFGTB CJ 9, IFGTB CJ 10 and IFGTB CH 1. Clones that attained a lesser number of branches than general mean are IFGTB CH 1, IFGTB CH 2, IFGTB CH 5.

Among both environments, the mean performance of all clones under the semi-arid region of Punjab recorded the higher number of branches (12.63) than the central plains of Punjab (10.00) which indicates that environment of semi-arid region of Punjab supports greater number of branches as compared to central plains of Punjab. The statistical result for the Genotype x environment interaction was significantly different for the number of branches which intimate that the clone performed differently under different environmental conditions. Critical perusal of mean performance of clones averaged over both the environments indicated the inferiority of clone IFGTB CH 2 recorded minimum number of branches (9.56) followed by the clone IFGTB CH 6 (10.39) and the clone IFGTB CH 1 registered maximum number of branches (12.53) for mean performance of both environments. Lamba (1999) also recorded variation among the clones of *Dalbergia sissoo* for the number of branches. Singh *et al* (2016) observed significantly variation among the clones of *Salix* for number of branches under Punjab conditions.

Table 4.5: Performance of various clones of *Casuarina* for number of branches under different environments at the age of 3 ¼ years in Bathinda and Ladhowal

Clone	Bathinda	Ladhowal	Mean
IFGTB CH 6	12.33	8.44	10.39
IFGTB CJ 7	12.83	11.97	12.40
IFGTB CJ 9	13.67	10.86	12.26
IFGTB CJ 10	12.44	10.83	11.63
IFGTB CH 1	15.00	10.06	12.53
IFGTB CH 2	10.00	9.11	9.56
IFGTB CH 5	12.33	9.44	10.89
IFGTB CJ 108	12.42	9.33	10.88
General mean	12.63	10.00	

CD (5%) for Bathinda = 3.22, Ladhowal = 2.42 and Genotype × environment = 2.46

4.1.1.6 Tree stem volume (m³)

The mean performance of different clones of *Casuarina* for tree stem volume under different environments is presented in Table 4.6. The data revealed that in semi-arid regions of Punjab, clone IFGTB CH 2 recorded maximum tree stem volume (0.054m³) followed by clone IFGTB CH 5 (0.052 m³) which were statistically at par with each other. Clone IFGTB

CH 2 recorded significant superiority over the clones IFGTB CH 6, IFGTB CJ 7, IFGTB CJ 9, IFGTB CJ 10, IFGTB CH 1 and IFGTB CJ 108. Clones that recorded tree stem volume more than the general mean was in order IFGTB CH 1, IFGTB CH 2 and IFGTB CH 5 whereas the clone IFGTB CH 6 recorded the least tree stem volume (0.016 m³) and at par with clone IFGTB CJ 10 (0.019 m³).

In central region of Punjab, clone IFGTB CH 2 recorded the maximum tree stem volume (0.059 m³) followed by clone IFGTB CH 5 (0.053 m³) and clone IFGTB CJ 108 (0.049 m³). Clone IFGTB CH 2 significantly superior over the clones IFGTB CH 1, IFGTB CH 6, IFGTB CJ 7, IFGTB CJ 9 and IFGTB CJ 10 whereas the clones which are superior from the general mean was IFGTB CH 2, IFGTB CH 5 and IFGTB CJ 108. Clone IFGTB CH 6 was recorded the minimum tree stem volume (0.029 m³).

Table 4.6: Performance of various clones of *Casuarina* for tree stem volume under different environments at the age of 3 ¼ years in Bathinda and Ladhowal

Clone	Bathinda	Ladhowal	Mean
IFGTB CH 6	0.016	0.029	0.022
IFGTB CJ 7	0.024	0.038	0.031
IFGTB CJ 9	0.031	0.036	0.033
IFGTB CJ 10	0.019	0.032	0.025
IFGTB CH 1	0.037	0.040	0.038
IFGTB CH 2	0.054	0.059	0.056
IFGTB CH 5	0.052	0.053	0.052
IFGTB CJ 108	0.031	0.049	0.040
General mean	0.033	0.042	

CD (5%) for Bathinda = 0.014, Ladhowal = 0.017 and Genotype × environment = 0.015

Among both sites, the overall mean of clones under the central region of Punjab was recorded the higher stem volume (0.042 m³) than as compared to the semi-arid region of Punjab (0.033 m³) which help in understanding that the environment of central plains of Punjab was more supportive than the environment of semi-arid conditions for tree stem volume. The statistical result showed the significant difference for Genotype x environment interaction which indicated that clones were reacted differently under semi-arid region and central plains of Punjab. The mean performance of both sites was observed in which the

superiority for the stem volume was registered by the clone IFGTB CH 2 having the maximum stem volume (0.056 m³) followed by clone IFGTB CH 5 (0.052 m³) and the clone IFGTB CH 6 recorded the minimum stem volume (0.022 m³) among both environments. Result of the present study demonstrated the significant variation among the clones as well as among the both sites. Similar results were reported in the study conducted central region of Saudi arabia by Juhany *et al* (2002) in which significant variation was recorded by the clones of *Casuarina* for tree stem volume character. Luechanimitichit *et al* (2017) recorded significant variation among the different clones of *Casuarina* and recorded higher heritability for tree stem volume in their study.

4.1.1.7 Branch angle

The mean performance of different clones of *Casuarina* for branch angle under different environments is presented in Table 4.7. In semi-arid region of Punjab, clones IFGTB CJ 9, IFGTB CH 2, IFGTB CH 5 and IFGTB CH 6 recorded the highest scoring (1.50) for branch angle followed by clone IFGTB CJ 108 (1.42) and the minimum scoring (1.00) was recorded by clone IFGTB CH 1. Clones IFGTB CH 2, IFGTB CH 5, IFGTB CH 6, IFGTB CJ 9 and IFGTB CJ 108 recorded higher scoring than the general mean and statistical result was non-significant for the semi-arid conditions of Punjab. Whereas in central plains of Punjab, it was observed that clone IFGTB CH 5 registered the maximum scoring (2.00) closely followed by clone IFGTB CH 1 (1.89) and clone IFGTB CJ 10 (1.83) and the lowest scoring (1.39) was recorded by clone IFGTB CJ 7. Clone IFGTB CH 5 significantly superior to the clones IFGTB CJ 7 and IFGTB CH 2 while the clones IFGTB CH 1, IFGTB CH 5, IFGTB CH 6 and IFGTB CJ 10 scored more than the general mean.

Overall mean of both sites represented that the higher branch angle (1.69) was recorded under the central plains than the semi-arid region of Punjab (1.36) which indicated that the semi-arid condition of Punjab was favourable for less branch angle.

Lesser the branch angle with the main stem will help in increasing the quality of wood production. It was observed from the above results that under semi-arid region of Punjab branches of clone IFGTB CH 1 remain closer to the main stem or bear branches at an angle less than 60° with the main stem considered as best. Clone IFGTB CH 2, IFGTB CH 5, IFGTB CH 6 and IFGTB CJ 9 performed poorly for the branch angle traits. Under central plains of Punjab, clone IFGTB CJ 7 was considered as best clone i.e. bear branches at an angle less than 60° with the main stem and clone IFGTB CH 1 performed poorly for the specified trait. Luechanimitichit *et al* (2017) found significant variation among different clones of *Casuarina* for branch angle character as well as for other growth parameters. Belaber *et al* (2018) recorded moderate to high heritability for branch angle with the main stem in Radiata Pine.

Table 4.7: Performance of various clones of *Casuarina* for branch angle under different environments at the age of 3 ¼ years in Bathinda and Ladhowal

Clone	Bathinda	Ladhowal
IFGTB CH 6	1.50	1.75
IFGTB CJ 7	1.33	1.39
IFGTB CJ 9	1.50	1.53
IFGTB CJ 10	1.17	1.83
IFGTB CH 1	1.00	1.89
IFGTB CH 2	1.50	1.44
IFGTB CH 5	1.50	2.00
IFGTB CJ 108	1.42	1.75
Mean	1.36	1.69
CD (5%)	NS	0.49

4.1.1.8 Axis persistence

The mean performance of different clones of *Casuarina* for axis persistence under different environments is presented in Table 4.8. The perusal of data given in Table 4.8 indicated that under semi-arid conditions of Punjab, clone IFGTB CJ 10 registered the highest scoring (5.89) for the axis persistence among the different clones followed by the clones IFGTB CH 2 (5.75) and IFGTB CJ 108 (5.75) and the lowest scoring for axis persistence was recorded by the clones IFGTB CH 1 (5.00) and IFGTB CH 6 (5.00). All the clones were recorded higher scoring than the general mean except clones IFGTB CH 1, IFGTB CH6 and IFGTB CJ 9. Clone IFGTB CJ 10 significantly superior over the clone IFGTB CH 1, IFGTB CH 6 and IFGTB CJ 9. In the central plains of Punjab, clone IFGTB CH 5 recorded the maximum scoring (5.78) closely followed by clone IFGTB CJ 108 (5.75) and minimum scoring (5.00) was recorded by clones IFGTB CH 2 and IFGTB CH 6. Clones recorded the higher scoring than the general for axis persistence are IFGTB CH 1, IFGTB CH 5, IFGTB CJ 108, IFGTB CJ 7 and IFGTB CJ 10.

Among both sites, the overall mean of sites demonstrated that the axis persistence from the higher quarter (5.49) of the tree in central plains of Punjab than semi-arid region of Punjab (5.46) which revealed that the environment of central plains of Punjab was much favourable for axis persistence trait than semi-arid region of Punjab.

Forking of the main stem into multiple stems decreased the value and weight of wood production. The tree with a single main stem attained higher height and DBH than the tree forked into multiple stems. The observed data evidently showed that under the semi-arid conditions of Punjab clone IFGTB CJ 10 was best as it forked into multiple stems at near about the top, whereas the clone IFGTB CH 1 and IFGTB CH 6 poorly performed among all

the clones as it forked in 4th quarter of tree from the lower end. Similar results were recorded in the study conducted by Prasad *et al* (1998) in which significant variation was recorded in axis persistence among the provenances of *Casuarina* planted at different sites. Luechanimitichit *et al* (2017) recorded significant variation among different clones of *Casuarina* for axis persistence trait.

Table 4.8: Performance of various clones of *Casuarina* for axis persistence under different environments at the age of 3 ¼ years in Bathinda and Ladhowal

Clone	Bathinda	Ladhowal
IFGTB CH 6	5.00	5.00
IFGTB CJ 7	5.50	5.47
IFGTB CJ 9	5.25	5.64
IFGTB CJ 10	5.89	5.67
IFGTB CH 1	5.00	5.67
IFGTB CH 2	5.75	5.00
IFGTB CH 5	5.58	5.78
IFGTB CJ 108	5.75	5.75
Mean	5.46	5.49
CD (5%)	0.54	NS

4.1.1.9 Stem straightness

The mean performance of different clones of *Casuarina* for stem straightness under different environments is presented in Table 4.9. It was evident from the available data that under semi-arid regions of Punjab, clone IFGTB CH 5 recorded the maximum scoring (3.33) for the stem straightness which proved that this clone possesses the complete straightness in stem followed by clone IFGTB CH 2 (3.25). All clones scored higher than the general mean except clone IFGTB CH 6 and IFGTB CJ 9. Clone IFGTB CH 5 recorded their significant superiority over the clone IFGTB CJ 9. The minimum scoring (2.50) was registered by clone IFGTB CJ 9 which means that the stem of the trees was almost straight or slightly crooked which affects the quality of wood. Under central plains of Punjab, scoring for stem straightness was recorded highest (3.50) by clone IFGTB CH 5 having a completely straight stem without any bend and considered as best clone among all other and closely followed by clone IFGTB CH 2 (3.31) and the minimum scoring (2.75) was recorded by clone IFGTB CJ 7 and was poor performer for stem straightness trait among all other clones (posing slightly crooked stem). Clones IFGTB CH 2, IFGTB CH 5 and IFGTB CJ 108 recorded higher scoring than the general mean. Clone IFGTB CH 5 significantly superior among all the clones except IFGTB CH 1 and IFGTB CJ 108.

Among the both sites, the higher scoring (3.04) for stem straightness was registered

under the central plains of Punjab represented that the climatic condition of the sites was more favourable than semi-arid region of Punjab (2.99). Nicodemus *et al* (2015) showed similar result in their study which demonstrated the significant variations among the different species for the stem straightness. Significant variation was recorded among different sites and among the clones of *Casuarina* (Nicodemus *et al* 2014). Prasad *et al* (1998) observed that the different land-races recorded variation for stem straightness in *Casuarina equisetifolia*. Luechanimitichit *et al* (2017) observed similar results for stem straightness in *Casuarina* clones.

Table 4.9: Performance of various clones of *Casuarina* for stem straightness under different environments at the age of 3 ¼ years in Bathinda and Ladhowal

Clone	Bathinda	Ladhowal
IFGTB CH 6	2.83	3.00
IFGTB CJ 7	3.00	2.75
IFGTB CJ 9	2.50	2.83
IFGTB CJ 10	3.00	3.00
IFGTB CH 1	3.00	2.89
IFGTB CH 2	3.25	3.31
IFGTB CH 5	3.33	3.50
IFGTB CJ 108	3.08	3.11
Mean	2.99	3.04
CD at (5%)	0.53	0.43

4.1.1.10 Branch thickness

The mean performance of different clones of *Casuarina* for branch thickness under different environments is presented in Table 4.10. The perusal of data given Table 4.10 indicated that under semi-arid conditions of Punjab, clone IFGTB CH 5 registered the maximum scoring (3.50) for branch thickness possess the diameter of branches $\leq 1/4^{\text{th}}$ of the main stem diameter and well-thought-out as the best performer among all clones followed by the clone IFGTB CJ 10 (3.00). The clones IFGTB CH 2, IFGTB CH 5, IFGTB CJ 9, IFGTB CJ 10 and IFGTB CJ 108 recorded the higher value than the general mean. Clone IFGTB CH 5 was significantly superior over all clones except IFGTB CJ 10. Whereas the minimum scoring (1.33) was registered by the clone IFGTB CH 6 revealed that the branches on the trees of this clone having diameter more than $1/3^{\text{rd}}$ of the main stem diameter which considered under poor performer as they compete with the main stem and somewhat reduce the height and diameter of the main stem, as well as the nodes, become thicker reduce the value of economical wood. However, under central plains of Punjab, the maximum scoring (3.43) for the branch thickness was registered by the clone IFGTB CH 5 having branches of

diameter $\leq 1/4^{\text{th}}$ of the main stem diameter which is good for growth characters of the tree followed by clone IFGTB CJ 10 (3.17). Clone IFGTB CH 5 recorded their significant superiority among all the clones except IFGTB CJ 10. Clone IFGTB CH 2, IFGTB CH 5, IFGTB CJ 10 and IFGTB CJ 108 recorded higher scoring than the general mean. The minimum scoring (1.08) was registered by clone IFGTB CH 6 considered under a heavily branched tree. Overall mean performance of both sites indicated that the scoring for the branch angle was registered higher under the semi-arid conditions of Punjab which means that thicker branches (2.40) were present in clones under the central plains of Punjab whereas thin branches (2.46) were observed at semi-arid conditions of Punjab. Luechanimitichit *et al* (2017) recorded the similar result as current study and recorded variation among the different clones of *Casuarina* for branch thickness character. Callister *et al* (2011) recorded variation significantly among the clones of *Eucalyptus* for branch thickness and axis persistence.

Table 4.10: Performance of various clones of *Casuarina* for branch thickness under different environments at the age of 3 ¼ years in Bathinda and Ladhawal

Clone	Bathinda	Ladhawal
IFGTB CH 6	1.33	1.08
IFGTB CJ 7	1.83	1.92
IFGTB CJ 9	2.50	2.19
IFGTB CJ 10	3.00	3.17
IFGTB CH 1	2.00	1.61
IFGTB CH 2	2.75	2.94
IFGTB CH 5	3.50	3.43
IFGTB CJ 108	2.83	2.89
Mean	2.46	2.40
CD (5%)	0.63	0.43

4.1.1.11 Flowering

The mean performance of different clones of *Casuarina* for flowering under different environments is presented in Table 4.11. It was evident from the available data that similar result for flowering was recorded under both the sites (semi-arid region of Punjab and the central plains of Punjab) in which clones IFGTB CH 5 and IFGTB CJ 108 registered the high flowering while medium flowering was observed in clone IFGTB CH 2 and the clone IFGTB CH 1 registered the low flowering, whereas the remaining clones did not bear the flowering under both the environments. Clones IFGTB CH 1, IFGTB CH 2, IFGTB CH 5 and IFGTB CJ 108 had borne flowering which demonstrated that the clones were adapted to the climatic conditions of Punjab whether it was semi-arid or central plains environment by entering into the reproductive phase. Pradhan *et al* (2017) recorded variation for flowering in *Tectona*

grandis. Pinyopusarerk *et al* (2004) recorded significant variation among the clones of *Casuarina equisetifolia* for flowering at different ages.

Table 4.11: Performance of various clones of *Casuarina* for flowering under different environments at the age of 3 ¼ years in Bathinda and Ladhowal

Clone	Bathinda	Ladhowal	Mean
IFGTB CH 6	NO	NO	NO
IFGTB CJ 7	NO	NO	NO
IFGTB CJ 9	NO	NO	NO
IFGTB CJ 10	NO	NO	NO
IFGTB CH 1	Low	Low	Low
IFGTB CH 2	Medium	Medium	Medium
IFGTB CH 5	High	High	High
IFGTB CJ 108	High	High	High

4.1.1.12 Fruiting

The mean performance of different clones of *Casuarina* for fruiting under different environments is presented in Table 4.12. The perusal of data given in table 4.12 revealed that clones IFGTB CH 5 and IFGTB CJ 108 had borne fruiting on more than 50% of the total crown area, clone IFGTB CH 2 fruiting in 25-50% of the total crown area and the clone IFGTB CH 1 recorded the fruiting in less than 25% of the total crown, whereas the remaining clones did not bear fruit till the time at which data was recorded. Pradhan *et al* (2017) observed medium to high fruit production by the different clones. Similar results were observed by Luechanimitichit *et al* (2017) in which they recorded variation among the different clones of *Casuarina equisetifolia* for fruiting characters.

Table 4.12: Performance of various clones of *Casuarina* for fruiting under different environments at the age of 3 ¼ years in Bathinda and Ladhowal

Clone	Bathinda	Ladhowal	Mean
IFGTB CH 6	NO	NO	NO
IFGTB CJ 7	NO	NO	NO
IFGTB CJ 9	NO	NO	NO
IFGTB CJ 10	NO	NO	NO
IFGTB CH 1	Low	Low	Low
IFGTB CH 2	Medium	Medium	Medium
IFGTB CH 5	HIGH	High	High
IFGTB CJ 108	HIGH	High	High

4.1.2 Index score analysis

Index score analysis was used to classify *Casuarina* clones on the basis of some

important morphological characters. Scores were given to each clone on the basis of their performance for different traits and are presented in Table 4.13. Clone attaining maximum total scores was considered superior.

Score 1 to 3 was assigned to different clones for different traits falling in different class intervals for a specific trait. The maximum score (18) was recorded by clone IFGTB CH 2 for all the characters followed by clone IFGTB CH 5 (17) and clone IFGTB CH 108 (14). Clone IFGTB CJ 10 obtained the least score (7) was classified as inferior clone on the basis of analysis (Table 4.14).

Table 4.13: Distribution of index scoring to different *Casuarina* clones for morphological traits.

Clone	Tree height		Diameter at breast height		Number of branches		Total Score
	Bathinda	Ladhowal	Bathinda	Ladhowal	Bathinda	Ladhowal	
IFGTB CH 6	1	1	1	1	2	3	9
IFGTB CJ 7	2	1	2	2	2	1	10
IFGTB CJ 9	1	1	3	2	1	1	9
IFGTB CJ 10	1	1	1	1	2	1	7
IFGTB CH 1	2	3	3	1	1	2	12
IFGTB CH 2	3	3	3	3	3	3	18
IFGTB CH 5	3	3	3	3	2	3	17
IFGTB CJ 108	2	3	2	2	2	3	14

Table 4.14: Index scoring to different clones

		CH 6									
CJ 10		CJ 9	CJ 7		CH 1		CJ 108			CH 5	CH 2
7	8	9	10	11	12	13	14	15	16	17	18

4.1.3 Estimation of genetic parameters

Variation among the different clones are the most important factors for the selection of superior clones and demonstrating the adaptability of species. Estimation of genetic variability was an important factor in making strategies for improvement programs in species. Additive and non-additive component of variation are two constitutes of genetic variability. The variation present among the clones and influence of the environment was represented by heritability and genetic advance. The value of genetic control on the traits was represented by the heritability. Heritability and genetic gain are important component and used for future improvement of species.

Variability and genetic parameters were estimated for different growth and quality traits i.e. tree height, diameter at breast height, clear bole height, crown spread, number of

branches, tree stem volume, branch angle, axis persistence, stem straightness, branch thickness, flowering, and fruiting. The genetic components i.e. mean, range, genotypic coefficient of variation (%), phenotypic coefficient of variation (%), heritability, genetic advance and mean genetic advance (%) are presented in Table 4.15 for both the environment.

4.1.3.1 Variability estimation and genetic parameters in semi-arid region of Punjab

The data available in Table 4.15 depicts the variation among the clones for different growth traits. The range of variation among the clones for different morphological traits was 9.25-14.44m for tree height, 7.75-11.93cm for diameter, 2.40-3.18m for clear bole height, 15.13-25.09m² for crown spread, 10.00-15.00 for number of branches, 5.00-5.89 for axis persistence, 1.00-1.50 for branch angle, 2.50-3.33 for stem straightness, 1.33-3.50 for branch thickness and 0.016-0.054m³ for tree stem volume.

The value for the genotypic coefficient of variation was recorded highest (39.44%) for tree stem volume followed by the branch angle (27.27%). The moderate genotypic coefficient of variation was recorded for the tree height (15.34%), followed by crown spread (14.02%), diameter at breast height (13.04%), while the low values were registered for number of branches (7.33%), stem straightness (6.20%), clear bole height (5.74%), axis persistence (5.42%) and the lowest genotypic coefficient of variation was recorded for the branch angle (0.00%).

Phenotypic coefficient of variation was recorded highest for tree stem volume (46.99%) followed by branch thickness (30.89%), branch angle (26.33%) and crown spread (23.04%) respectively while an average phenotypic coefficient of variation was recorded for diameter at breast height (18.03%) followed by tree height (11.73%), number of branches (16.32%), clear bole height (15.37%), and stem straightness (11.89%). However, the least phenotypic coefficient of variation was recorded for the axis persistence (7.83%).

Maximum heritability was recorded for branch thickness (77.93%) closely followed by the tree height (76.25%) and tree stem volume (70.45%). Moderate values for heritability was registered for diameter at breast height (52.27%) followed by axis persistence (47.98%), crown spread (37.04%) and stem straightness (27.19%) while the low heritability was recorded for number of branches (20.18%) followed by the clear bole height (13.94%) and the least heritability was recorded for branch angle (8.65%).

The value of genetic advance was recorded maximum for crown spread (3.78) followed by tree height (3.24) and the least genetic advance was registered for branch angle (0.06). Whereas, the genetic gain in percent was recorded high to moderate for tree stem volume (68.20%) followed by branch thickness (49.58%), tree height (27.60%), diameter at breast height (19.41%) and crown spread (17.58) due to influence of additive gene action on these traits. Whereas the low genetic gain was recorded for axis persistence (7.74), number of branches (6.78), stem straightness (6.66) and clear bole height (4.41) while the minimum

genetic gain (4.09%) was recorded for branch angle which means these traits were influenced by non-additive gene action.

Table 4.15 Variability estimates and genetic parameters for growth and quality traits of *Casuarina* under semi-arid conditions of Punjab

Parameter	Mean	Range	Coefficient of variance (%)		h ² (%)	Genetic advance	Genetic gain (%)
			PCV	GCV			
Tree height (m)	11.73	9.25-14.44	17.57	15.34	76.25	3.24	27.60
Diameter (cm)	10.02	7.75-11.93	18.03	13.04	52.27	1.95	19.41
Clear bole height (m)	2.58	2.40-3.18	15.37	5.74	13.94	0.11	4.41
Crown spread (m ²)	21.49	15.13-25.09	23.04	14.02	37.04	3.78	17.58
Number of branches	12.63	10.00-15.00	16.32	7.33	20.18	0.86	6.78
Axis persistence	5.47	5.00-5.89	7.83	5.42	47.98	0.42	7.74
Branch angle	1.36	1.00-1.50	26.33	0.00	8.65	0.06	4.09
Stem straightness	3.00	2.50-3.33	11.89	6.20	27.19	0.20	6.66
Branch thickness	2.47	1.33-3.50	30.89	27.27	77.93	1.22	49.58
Tree stem volume	0.03	0.016-0.054	46.99	39.44	70.45	0.02	68.20

4.1.3.2 Variability estimation and genetic parameters in central plains of Punjab

The data available in Table 4.16 depicts the variation among the clones for different growth traits. Range of variation for tree height was 11.46-14.87m, 9.75-12.11cm for diameter at breast height, 2.16-2.38m for clear bole height, 18.60-31.77m² for crown spread, 8.44-11.97 for number of branches, 5.00-5.78 for axis persistence, 1.39-2.00 for branch angle, 2.75 -3.50 for stem straightness, 1.08-3.43 for branch thickness and 0.029-0.059m³ for tree stem volume.

The maximum phenotypic coefficient of variation was recorded for branch thickness (35.54%) followed by the tree stem volume (31.68%) and crown spread (30.06%) while the moderate phenotypic coefficient of variation was recorded for branch angle (18.99%) closely followed by number of branches (17.10%), tree height (12.20%), stem straightness (10.50%), and diameter (10.42%). The lower values for the phenotypic coefficient of variation were registered for axis persistence (9.70%) and lowest was recorded for clear bole height (5.50%).

Genetic coefficient of variation was recorded maximum for branch thickness (34.01%) followed by tree stem volume (20.33%), crown spread (17.91%), tree height (9.88%), branch angle (9.86%), number of branches (9.83%), stem straightness (6.80%), diameter (4.81%), axis persistence (1.90%) and the least genotypic coefficient of variation was recorded for clear bole height (1.38%).

The value of heritability was recorded high for the branch thickness (91.57%) followed by the tree height (65.62%) while moderate heritability was measured for stem

straightness (41.98%) closely followed by tree stem volume (41.19%), crown spread (35.51%), number of branches (33.06%), branch angle (26.94%), and diameter (21.31%). Low heritability was recorded by clear bole height (6.26%) and the least heritability was recorded for axis persistence (3.83%).

Highest values for the genetic advance were recorded for crown spread (5.31) followed by tree height (2.17) and the least value was recorded for tree stem volume (0.01). However, the genetic gain was recorded higher for branch thickness (67.04%) and moderate genetic gain was registered for tree stem volume (26.88%), crown spread (21.99%), tree height (16.49%), number of branches (11.65%) and branch angle (10.54%) respectively. The high and moderate heritability represents that the additive gene action was strongly influenced in these traits. The low genetic gain was registered for stem straightness (9.08%), followed by diameter (4.58%), axis persistence (0.77%) and clear bole height (0.71%), respectively. this signifies that the non-additive gene was responsible for influenced these traits.

Table 4.16 Variability estimates and genetic parameters for growth and quality traits of *Casuarina* traits under central plains of Punjab.

Parameter	Mean	Range	Coefficient of variance (%)		h ² (%)	Genetic advance	Genetic gain (%)
			PCV	GCV			
Tree height (m)	13.15	11.46-14.87	12.20	9.88	65.62	2.17	16.49
Diameter (cm)	10.84	9.75-12.11	10.42	4.81	21.31	0.50	4.58
Clear bole height (m)	2.26	2.16-2.38	5.50	1.38	6.26	0.02	0.71
Crown spread (m ²)	24.13	18.60-31.77	30.06	17.91	35.51	5.31	21.99
Number of branches	9.89	8.44-11.97	17.10	9.83	33.06	1.15	11.65
Axis persistence	5.50	5.00-5.78	9.70	1.90	3.83	0.04	0.77
Branch angle	1.72	1.39-2.00	18.99	9.86	26.94	0.18	10.54
Stem straightness	3.05	2.75-3.50	10.50	6.80	41.98	0.28	9.08
Branch thickness	2.40	1.08-3.43	35.54	34.01	91.57	1.61	67.04
Tree stem volume	0.04	0.029-0.059	31.68	20.33	41.19	0.01	26.88

Under semi-arid region of Punjab, heritability and genetic gain were recorded highest by tree stem volume and branch thickness, while high heritability and moderate genetic gain were recorded by tree height, diameter crown spread and axis persistence. Whereas under central plains of Punjab, branch thickness and tree height were recorded the maximum heritability and genetic gain and the traits as crown spread, number of branches, stem straightness and tree stem volume possess moderate heritability and genetic gain. The data was demonstrated that for the selection purpose higher weightage must be given these traits. Results obtained from the present study are in conformity with the earlier report (Luechanimitichit *et al* 2017) in which moderate to high PCV, GCV, genetic heritability and

genetic advance were observed in height, diameter at breast height, branch thickness and tree stem volume. Ma *et al* (2014) also recorded low to high heritability (0.02-0.55) for genetic gain in height, individual volume, diameter at breast height, axis persistence, and stem straightness. The study conducted by Lin *et al* (2007) in which they recorded higher to lower value genetic gains for growth traits i.e. tree volume, DBH, and tree height respectively from. A similar study conducted by Blada *et al* (2014) calculate the phenotypic coefficient of variation and the result was recorded from moderate to high in height, diameter, volume, and stem straightness.

4.1.4 Correlation studies

Correlation analysis is needed to check the effect of one trait on the other. In the present study phenotypic correlation coefficient were measured for qualitative and quantitative traits of the *Casuarina* clones on each other.

4.1.4.1 Estimation of phenotypic correlation analysis of different morphological traits in the semi-arid conditions of Punjab

The data in Table 4.17 revealed that the tree height showed a highly significant positive correlation with tree stem volume (0.9400), stem straightness (0.5355), diameter (0.8821) and branch thickness (0.5440) while having significant correlation with crown spread (0.5079). Highly significant phenotypic correlation was observed for diameter at breast height with tree stem volume (0.9328), tree height (0.8821), crown spread (0.6738) and branch thickness (0.5448). Whereas, the non-significant phenotypic correlation was observed in all other traits. Clear bole height registered significant phenotypic correlation with branch thickness (0.4197). Crown spread showed a highly significant phenotypic correlation with diameter (0.6738), branch thickness (0.7562) and tree stem volume (0.5464). Crown spread had significantly positive phenotypic correlation with tree height (0.5079) while for the remaining characters, phenotypic correlation was non-significant. A significant phenotypic correlation was found in axis persistence with branch thickness (0.4583) and stem straightness (0.4917). Branch angle registered non-significant correlation with all the characters. In stem straightness trait, highly significant phenotypic correlation was observed for stem straightness with tree height (0.5355) and significant phenotypic correlation was observed with axis persistence (0.4917) and tree stem volume (0.4134). Branch thickness showed a highly significant phenotypic correlation with tree height (0.5440), diameter (0.5448) crown spread (0.7562) and tree stem volume (0.5543) and the significant phenotypic correlation was found with axis persistence (0.4583) and clear bole height (0.4197). Whereas, tree stem volume registered a highly significant correlation with tree height (0.9400), diameter (0.9328), crown spread (0.5464) and branch thickness (0.5543) while the significant phenotypic correlation was recorded with stem straightness (0.4134).

Table 4.17: Phenotypic correlation among morphological characters of *Casuarina* spp. for semi-arid conditions of Punjab.

	Tree height	Diameter	Clear bole height	Crown spread	Number of branches	Axis persistence	Branch angle	Stem straightness	Branch thickness
Diameter	0.8821**								
Clear bole height	0.3031	0.2112							
Crown spread	0.5079*	0.6738**	0.3167						
Number of branches	-0.3019	-0.3056	0.1098	-0.179					
Axis persistence	0.1378	0.0686	0.2241	0.3847	-0.245				
Branch angle	0.0984	0.0048	-0.3105	-0.003	-0.368	-0.0189			
Stem straightness	0.5355**	0.2808	0.0853	0.1176	-0.238	0.4917*	0.1597		
Branch thickness	0.5440**	0.5448**	0.4197*	0.7562**	-0.359	0.4583*	0.0122	0.1846	
Tree stem volume	0.9400**	0.9328**	0.2588	0.5464**	-0.424	0.1252	0.1039	0.4134*	0.5543**

*Significant at 5%: 0.4133

**Significant at 1%: 0.5256

4.1.4.2 Estimation of phenotypic correlation analysis of different morphological traits in the central plains of Punjab

The data in Table 4.18 revealed that the tree height showed a highly significant phenotypic correlation with diameter (0.6967), crown spread (0.5576), stem straightness (0.5370) and tree stem volume (0.8486) whereas the significant phenotypic correlation was not found with any. Diameter at breast height recorded highly significant phenotypic correlation with tree stem volume (0.9495), crown spread (0.7676) and tree height (0.6967) while the significant phenotypic correlation was found in stem straightness (0.4612). In clear bole height, non-significant phenotypic correlation was recorded with all the characters. Crown spread recorded highly significant phenotypic correlation with tree height (0.5576), diameter (0.7676) and tree stem volume (0.7288) while the other showed a non-significant phenotypic correlation with crown spread. Number of branches having a non-significant phenotypic correlation with all the characters. Axis persistence showed a highly significant phenotypic correlation with branch angle (0.5500) whereas with the other characters non-significant phenotypic correlation was observed. High significant phenotypic correlation was found in branch angle with axis persistence (0.5500) and with the other characters phenotypic correlation was non-significant. Stem straightness showed a high significant phenotypic correlation with tree height (0.5370) and tree stem volume (0.5343). The significant phenotypic correlation was recorded with diameter (0.4612) and branch thickness (0.5026). However, significant phenotypic correlation was found in branch thickness with stem straightness (0.5026). Whereas, in tree stem volume trait, highly significant phenotypic correlation was recorded with tree height (0.8486), diameter (0.9495), crown spread (0.7288) and stem straightness (0.5343) while the remaining all traits it showed non-significant phenotypic correlation.

4.1.5 Path analysis

Path analysis is important tool to understand the direct and indirect effect of different traits on a specific character. The data presented in Table 4.19 depicts the direct effect and indirect effects of different traits on tree stem volume at semi-arid region of Punjab. Diameter at breast height exerted the maximum direct effect (0.5942) followed by tree height (0.4797) whereas the indirect effect was registered higher by tree height through DBH (0.5241) followed by crown spread through diameter (0.4004) Paths analysis for different traits in central plains of Punjab is presented in Table 4.20. The maximum direct effect on tree volume was caused by diameter at breast height (0.7356) followed by tree height (0.3300). However, the indirect effect was recorded highest by crown spread through diameter (0.5647) followed by tree height through diameter (0.5125).

Table 4.18: Phenotypic correlation among morphological characters of *Casuarina* spp. for central plains of Punjab.

	Tree height	Diameter	Clear bole height	Crown spread	Number of branches	Axis persistence	Branch angle	Stem straightness	Branch thickness
Diameter	0.6967**								
Clear bole height	0.2775	0.2040							
Crown spread	0.5576**	0.7676**	0.2038						
Number of branches	-0.2525	0.0227	-0.3609	-0.0950					
Axis persistence	0.2390	0.1316	-0.0932	-0.0954	0.2553				
Branch angle	0. 2289	-0.0335	-0.0278	-0.0391	-0.0358	0.5500**			
Stem straightness	0.5370 **	0.4612 *	0.2956	0.2013	-0.3820	0.1347	0.1657		
Branch thickness	0.3595	0.3619	-0.0593	0.4069	-0.0462	0.1719	0.1306	0.5026*	
Tree stem volume	0.8486 **	0.9495**	0.3659	0.7288**	-0.0971	0.1796	0.0600	0.5343**	0.3784

*Significant at 5%: 0.4133

**Significant at 1%: 0.5256

Table 4.19: Path analysis for phenotypic correlation in semi-arid region of Punjab

	Tree height	Diameter	Clear bole height	Crown spread	Number of branches	Axis persistence	Branch angle	Stem straightness	Branch thickness
Tree height	0.4797	0.5241	0.0169	-0.0720	0.0360	0.0060	0.0037	-0.0170	0.0126
Diameter	0.3791	0.5942	0.0118	-0.0995	0.0364	0.0030	0.0002	-0.0089	0.0126
Clear bole height	0.1303	0.1255	0.0558	-0.0449	-0.0131	0.0098	-0.0116	-0.0027	0.0097
Crown spread	0.2183	0.4004	0.0177	-0.1417	0.0214	0.0168	-0.0001	-0.0037	0.0175
Number of branches	-0.1297	-0.1816	0.0061	0.0254	-0.119	-0.0107	-0.0137	0.0076	-0.0083
Axis persistence	0.0592	0.0408	0.0125	-0.0545	0.0293	0.0437	-0.0007	-0.015	0.0106
Branch angle	0.0423	-0.0029	-0.0173	0.0005	0.0439	-0.0008	0.0373	-0.0051	0.0003
Stem straightness	0.2301	0.1668	0.0048	-0.0167	0.0284	0.0215	0.0059	-0.0318	0.0043
Branch thickness	0.2338	0.3237	-0.0234	-0.1071	0.0428	0.0200	0.0005	-0.0059	0.0231

Table 4.20: Path analysis for phenotypic correlation in central plains of Punjab

	Tree height	Diameter	Clear bole height	Crown spread	Number of branches	Axis persistence	Branch angle	Stem straightness	Branch thickness
Tree height	0.3300	0.5125	0.0425	-0.0337	-0.0017	0.0006	0.0024	-0.0199	0.0160
Diameter	0.2299	0.7356	0.0312	-0.0464	0.0002	0.0003	-0.0003	-0.0171	0.0160
Clear bole height	0.0916	0.1500	0.1531	-0.0123	-0.0024	-0.0002	-0.0003	-0.0171	-0.0026
Crown spread	0.1840	0.5647	0.0312	-0.0605	-0.0006	-0.0002	-0.0004	-0.0075	0.0181
Number of branches	-0.0833	0.0167	-0.0553	0.0057	0.0067	0.0006	-0.0004	0.0141	-0.0021
Axis persistence	0.0789	0.0968	-0.0413	0.0058	0.0017	0.0023	0.0057	-0.0050	0.0076
Branch angle	0.0756	-0.0246	-0.0043	0.0024	-0.0002	0.0013	0.0103	-0.0061	0.0058
Stem straightness	0.1772	0.3393	0.0452	-0.0122	-0.0026	0.0003	0.0017	-0.0370	0.0223
Branch thickness	0.1186	0.2663	-0.0091	-0.0246	-0.0003	0.0004	0.0013	-0.0186	0.0444

4.1.6 Clustering of genotypes

The clustering of genotype is important for calculating the diversity and similarities among the different clones. To check the environmental effect on the species and their different clones clustering was needed. It helps in formation of dendrogram. The values of nodes represent the level of diversity among the clones and similarity was measured by the Dice similarity coefficient. Clustering of genotype was described as following:

4.1.6.1 Clustering of genotypes based on morphological traits for semi-arid conditions of Punjab

The morphological data were subjected to un-weighted pair group method with arithmetic mean (UPGMA) to see the genetic relationship among eight genotypes (Fig 4.3). Cluster analysis was used to group the genotypes based on their important morphological traits. All the genotypes were divided into two major clusters. Cluster 1 is further divided into two sub clusters cluster 1A and cluster 1B. Cluster 1A included three genotypes namely IFGTB CJ 108, IFGTB CH 5 and IFGTB CH 2 and cluster 1B had only two genotypes namely IFGTB CJ 10 and IFGTB CJ 9. Cluster 2 had three genotypes namely IFGTB CJ 7, IFGTB CH 6 and IFGTB CH 1. It was observed that all the genotypes were clustered into groups and sub groups on the basis of their genetic relationship irrespective of their geographical distribution. The study clearly indicated that these genotypes were phenotypically distinct individuals. This may be attributed due to mutations, cross-pollination and environmental interaction.

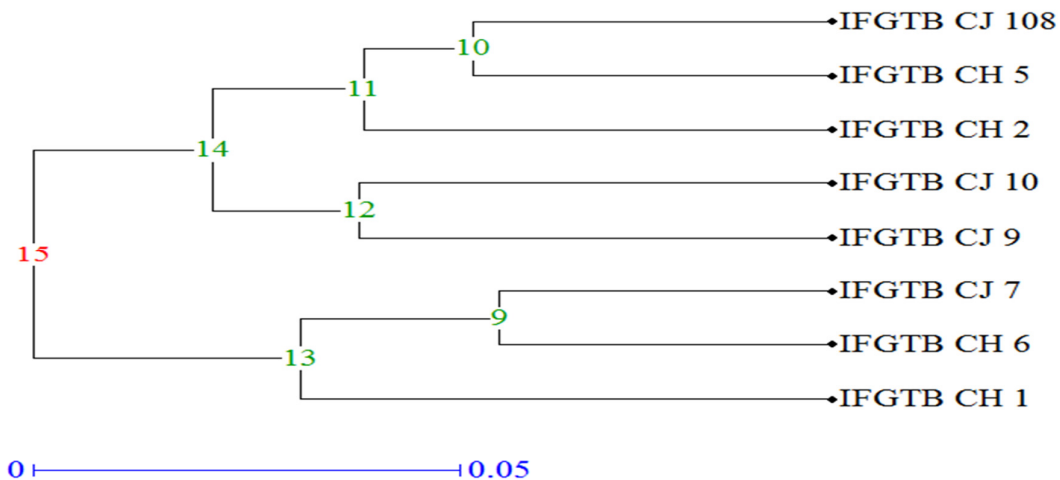


Fig.4.3: Dendrogram illustrating genetic relationship among eight genotypes generated by UPGMA tree analysis on basis of morphological traits at Ruldu Singh Wala University Farm, Bathinda.

Genetic similarity between two genotypes within the cluster based on morphological traits was estimated by Dice similarity coefficient (Table 4.21). The similarity coefficient ranged from 81.3 to 92.2 percent among genotypes. The similarity coefficient was ranged from 0.922 to 0.876 in cluster 2 whereas it was ranged from 0.916 to 0.855 in cluster 1.

Highest genetic similarity (92.2 %) was observed between two genotypes namely IFGTB CH 6 and IFGTB CJ 7, followed by 91.6 percent among IFGTB CH 5 and IFGTB CJ 108.

Table 4.21: Similarity coefficient based on morphological traits estimated by dice similarity coefficient for Ruldu Singh Wala University Farm, Bathinda

Genotypes	IFGTB CH 6	IFGTB CJ 7	IFGTB CJ 9	IFGTB CJ 10	IFGTB CH 1	IFGTB CH 2	IFGTB CH 5
IFGTB CJ 7	<u>0.922</u>						
IFGTB CJ 9	0.813	0.813					
IFGTB CJ 10	0.813	0.813	0.889				
IFGTB CH 1	0.876	0.876	0.813	0.813			
IFGTB CH 2	0.813	0.813	0.855	0.855	0.813		
IFGTB CH 5	0.813	0.813	0.855	0.855	0.813	<u>0.890</u>	
IFGTB CJ 108	0.813	0.813	0.855	0.855	0.813	<u>0.890</u>	<u>0.916</u>

4.1.6.2 Clustering of genotypes based on morphological traits for central plains of Punjab

The morphological data were subjected to un-weighted pair group method with arithmetic mean (UPGMA) to see the genetic relationship among eight genotypes (Fig 4.4). The different genotypes were grouped for cluster analysis on the basis of their morphological characters. Under the central plains of Punjab, all the genotype was divided into two clusters i.e., cluster 1 and cluster 2. Cluster 1 comprised of five clones i.e. IFGTB CH 1, IFGTB CH 6, IFGTB CJ 7, IFGTB CJ 9 and IFGTB CJ 10 whereas cluster 2 contained the clone IFGTB CH 2, IFGTB CH 5 and IFGTB CJ 108. Clustering into two groups was done on the basis of their genetic relation. The present study designated the phenotypic variation between the clones and data in fig 4.4 revealed the occurrence of phenotypic variation among the genotypes. The phenotypic variation among the clones was due to environmental effect, mutation and cross-pollination.

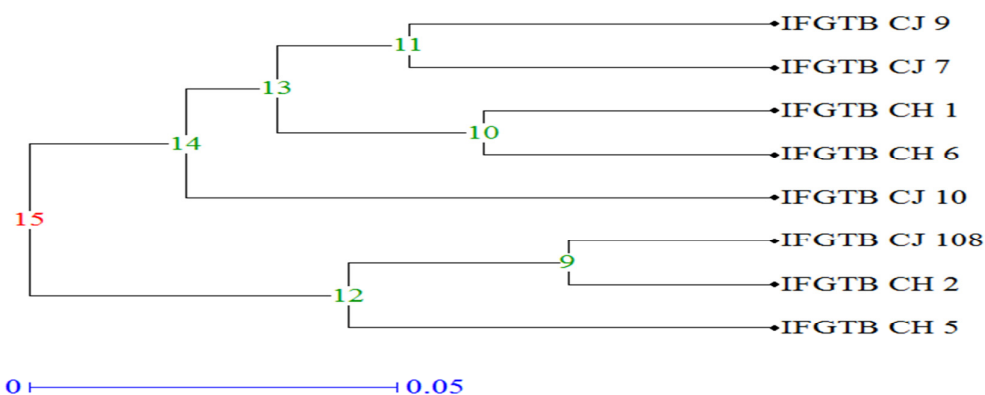


Fig. 4.4: Dendrogram illustrating genetic relationship among eight genotypes generated by UPGMA tree analysis on basis of morphological traits at University Seed Farm, Ladhowal

Genetic similarity between two genotypes within the cluster based on morphological traits was estimated by Dice similarity coefficient (Table 4.22). The similarity coefficient among the genotype was ranged between 79.8-94.4 percent. In cluster 1, the range of similarity coefficient was 0.921 to 0.884 and in cluster 2, the similarity coefficient ranged from 0.944 to 0.840. The maximum genetic similarity (94.4%) was recorded between clone IFGTB CJ 108 and IFGTB CH 2, followed by the combination of clone IFGTB CH 1 and IFGTB CH 6 (92.1%).

Table 4.22: Similarity coefficient based on morphological traits estimated by dice similarity coefficient for central plains of Punjab

Genotypes	IFGTB CH 6	IFGTB CJ 7	IFGTB CJ 9	IFGTB CJ 10	IFGTB CH 1	IFGTB CH 2	IFGTB CH 5
IFGTB CJ 7	0.865						
IFGTB CJ 9	0.865	<u>0.901</u>					
IFGTB CJ 10	0.840	0.840	0.840				
IFGTB CH 1	<u>0.921</u>	0.865	0.865	0.840			
IFGTB CH 2	0.798	0.798	0.798	0.798	0.798		
IFGTB CH 5	0.798	0.798	0.798	0.798	0.798	0.884	
IFGTB CJ 108	0.798	0.798	0.798	0.798	0.798	<u>0.944</u>	0.884

4.1.6.3 Clustering of genotypes based on morphological traits for both sites

The morphological data were subjected to un-weighted pair group method with arithmetic mean (UPGMA) to see the genetic relationship among eight genotypes (Fig 4.5). All the genotypes were divided into two major clusters i.e. cluster 1 and cluster 2 whereas 1 was sub divided into two i.e. cluster 1A and cluster 1B. The genotypes were divided into two groups/clusters on the basis of morphological characters for cluster analysis. Cluster 1A

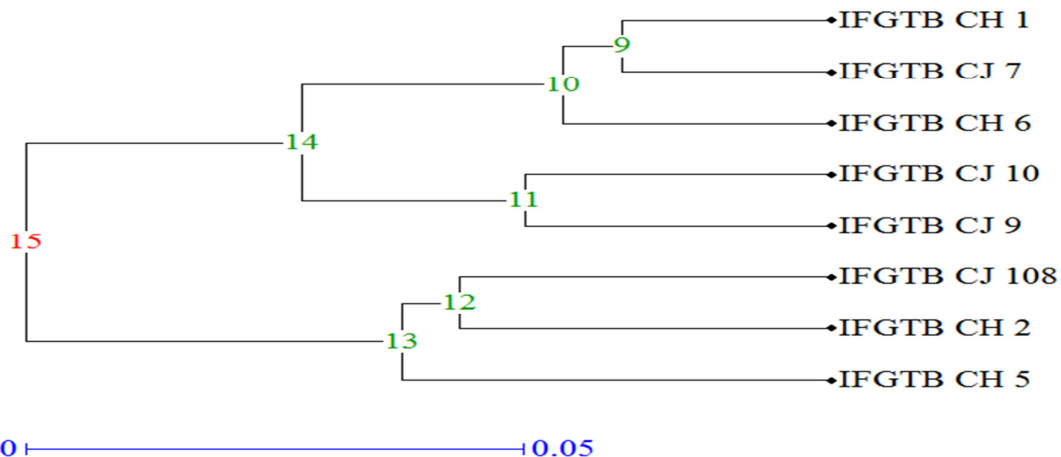


Fig. 4.5: Dendrogram illustrating genetic relationship among eight genotypes generated by UPGMA tree analysis on basis of morphological traits (mean of two sites)

comprises the three genotypes i.e. IFGTB CH 1, IFGTB CJ 7 and IFGTB CH 6 while cluster 1B is comprised of two genotypes viz. IFGTB CJ 10 and IFGTB CJ 9. Cluster 2 included three genotypes IFGTB CH 2, IFGTB CH 5 and IFGTB CJ 108. The clustering of genotype was based on the morphological traits besides the geographical distribution. The study revealed the phenotypic variation among the genotype which indicated that the variation can be accredited by mutation, cross pollination and environmental interaction.

Genetic similarity between two genotypes within the cluster based on morphological traits was estimated by dice similarity coefficient (Table 4.23). The coefficient of similarity among the genotype was ranged from 95.8 to 83.4 percent. In cluster 1, the coefficient of similarity was ranged between 0.958 to 0.894 while in cluster 2, the range of coefficient of similarity was 0.925 to 0.914. The maximum genetic similarity (95.8%) was recorded between two genotypes are IFGTB CH 1 and IFGTB CJ 7, followed by the two combination i.e. among IFGTB CH 6 and IFGTB CJ 7 & IFGTB CH 6 and IFGTB CH 1 (94.6%).

Table 4.23: Similarity coefficient based on morphological traits estimated by dice similarity coefficient for both sites

Genotypes	IFGTB CH 6	IFGTB CJ 7	IFGTB CJ 9	IFGTB CJ 10	IFGTB CH 1	IFGTB CH 2	IFGTB CH 5
IFGTB CJ 7	<u>0.946</u>						
IFGTB CJ 9	0.894	0.894					
IFGTB CJ 10	0.894	0.894	<u>0.938</u>				
IFGTB CH 1	<u>0.946</u>	<u>0.958</u>	0.894	0.894			
IFGTB CH 2	0.838	0.838	0.838	0.838	0.838		
IFGTB CH 5	0.838	0.838	0.838	0.838	0.838	0.914	
IFGTB CJ 108	0.838	0.838	0.838	0.838	0.838	<u>0.925</u>	0.914

The genotypes in clusters which showed wide divergence among each other was selected and retained for future improvement programme as similar to study of Hedge and Varghese (2008) that selected the genotype of *Eucalyptus camaldulensis* from cluster which showed largest mean values for growth traits for future hybridisation program to develop superior hybrid. Similarly, Behera *et al* (2017) were also selected the clusters of *Eucalyptus* for breeding programme which represent the higher mean value for different growth traits.

4.2 Vegetative propagation studies

Performance of different clones and cutting size, estimation of genetic parameters, correlation and path analysis are presented as under:

4.2.1 Effect of cutting size and clones on different parameters

In vegetative propagation trial, observations were recorded on survival and sprouting percentage, days taken for sprouting, plant height, collar diameter, root length, number of branches, number of primary and secondary roots, fresh weight of root and dry weight of roots at the age of eight months after planting of cuttings (December 2019).

4.2.1.1. Sprouting and survived percentage

The mean performance of plants raised from cuttings of different clones of *Casuarina* for sprouting as influenced by cutting size is presented in Table 4.24. Among the different clones, maximum sprouting of cutting was recorded in clone IFGTB CH 4 (69.61%) followed by clone IFGTB CH 2 (68.88%) and IFGTB CH 5 (67.48%). Cuttings of diameter range 0.3<0.6 cm was recorded the highest sprouting (66.28%) and cuttings of diameter <0.3 cm recorded the lowest sprouting (65.44%). The perusal of data revealed non-significant differences among clones cutting sizes and interaction between clone and cutting sizes for sprouting percentage which proved that the sprouting of cuttings was not influenced by different cutting sizes.

Table 4.24: Effect of cutting sizes on the sprouting (%) of *Casuarina* cuttings

Sprouting (%)	Cutting diameter (cm)			
Clone	<0.3	0.3<0.6	0.6<0.9	MEAN
IFGTB CH 1	62.50	60.86	53.33	58.90
IFGTB CH 2	66.66	72.58	67.39	68.88
IFGTB CH 4	64.70	71.42	72.72	69.61
IFGTB CH 5	63.15	67.30	72.00	67.48
IFGTB CH 6	71.40	64.00	65.00	66.80
IFGTB CJ 7	64.20	61.50	66.70	64.13
Mean	65.44	66.28	66.19	

CD (5%) for Clones = NS, Cutting diameter = NS, and Clone × Cutting diameter = NS

The mean performance of plants raised from cuttings of different clones of *Casuarina* for survival as influenced by cutting size is presented in Table 4.25. A perusal of data in Table 4.25 revealed the significant variation among the different clones and cutting diameter. Clone IFGTB CH 4 (37.75%) registered maximum sprouting followed by clone IFGTB CH 5 (36.88%). Clone IFGTB CH 4 recorded significant superiority over the clones IFGTB CH 1, IFGTB CH 2 and IFGTB CJ 7 whereas, clone IFGTB CH 2 (33.22%) recorded minimum survival percentage followed by clone IFGTB CH 1 (34.09%). Among different cutting sizes plants raised from the diameter size <0.3cm recorded highest survival (40.01%) followed by

cutting size 0.3<0.6cm (34.24%) whereas, the plant raised from the cutting of diameter 0.6<0.9cm was ranked last for survival (31.95%) that showed the variation in different cutting sizes but the statistical result was non-significant for the different cutting sizes. Clone × Cutting diameter interaction was statistically significant for survival percentage. Plants raised from cuttings having diameter size <0.3cm of clone IFGTB CH 6 recorded the maximum survival (42.85%) which was greater than all other plants raised from cuttings taken from different clones and their sizes followed by cutting of diameter size <0.3cm of clone IFGTB CH 5 (42.10%) whereas the minimum survival (24.19%) was registered by the plants raised from clone IFGTB CH 2 having diameter size 0.3<0.6cm. The result demonstrates the variation among the different clones and cutting diameters. Blada *et al* (2014) recorded the observation at different ages and found variation among the different clones of *Pinus*. Pinyopusarek *et al* (2004) also observed significant variation among the clones of *Casuarina* for sprouting and survival percentage.

Table 4.25: Effect of cutting sizes on the survival (%) of *Casuarina* cuttings

Survival (%)	Cutting diameter (cm)			
Clone	<0.3	0.3<0.6	0.6<0.9	MEAN
IFGTB CH 1	37.50	34.78	30.00	34.09
IFGTB CH 2	40.70	24.19	34.78	33.22
IFGTB CH 4	41.17	35.71	36.36	37.75
IFGTB CH 5	42.10	36.53	32.00	36.88
IFGTB CH 6	42.85	36.00	30.00	36.28
IFGTB CJ 7	35.71	38.23	28.57	34.17
Mean	40.01	34.24	31.95	

CD (5%) for Clones = 1.71, Cutting diameter = NS, and Clone × Cutting diameter = 2.96

4.2.1.2. Days taken for sprouting

The mean performance of cuttings taken from different clones of *Casuarina* for days taken for sprouting is influenced by cutting size is presented in Table 4.26. It is evident from the data presented in Table 4.26 that clone IFGTB CJ 7 (7.55) took the maximum number of days for sprouting and considered as a poor performer for the trait followed by IFGTB CH 2 (7.22) and the minimum number (3.00) of days were taken by clone IFGTB CH 4 for sprouting. Among different cutting sizes, the plant raised from cutting of diameter 0.3<0.6cm registered the maximum number of days (6.78) taken for sprouting followed by the cutting diameter 0.6<0.9cm (5.16) while the cuttings of diameter size <0.3cm recorded the least number of days (4.66) taken for sprouting. The cutting diameter 0.3<0.6cm recorded significant superiority over the cutting diameter <0.3. The interaction between clones × cutting diameter was statistically non-significant. Clone × Cutting diameter interaction was

recorded non-significant for days taken for sprouting. Plants raised from cuttings of clone IFGTB CH 4 with cutting diameter of 0.3<0.6cm recorded least number of days taken for sprouting (2.33) followed by clone IFGTB CH 4 with cutting size 0.6<0.9 (2.66), however, the plants raised from the cuttings of clone IFGTB CJ 7 having diameter 0.3<0.6cm observed as taking the maximum number of days (10.33) have taken for sprouting. Results obtained in the present study are in conformity with the earlier studies of Luna and Kumar (2006) who observed significant variation among the clones and different cuttings sizes of *Melia composita* for the days taken for sprouting character.

Table 4.26: Effect of cutting sizes on the days taken for the sprouting of *Casuarina* cuttings

Days have taken for sprouting	Cutting diameter (cm)			
Clone	<0.3	0.3<0.6	0.6<0.9	MEAN
IFGTB CH 1	3.33	7.00	6.00	5.44
IFGTB CH 2	6.66	8.66	6.33	7.22
IFGTB CH 4	4.00	2.33	2.66	3.00
IFGTB CH 5	3.33	6.33	5.00	4.89
IFGTB CH 6	4.00	6.00	5.33	5.11
IFGTB CJ 7	6.66	10.33	5.66	7.55
Mean	4.66	6.78	5.16	

CD (5%) for Clones = 1.60, Cutting diameter = 2.08, Clone × Cutting diameter = NS

4.2.1.3. Plant height

The mean performance of plants for plant height of cuttings taken from different clones of *Casuarina* is influenced by different sizes and their interactions are given in Table 4.27. Significant variation was observed among various clones and cutting sizes at the age of eight months, IFGTB CH 5 recorded maximum plant height (46.80cm) which was significantly superior over the clones IFGTB CH 1, IFGTB CH 2, IFGTB CH 4, IFGTB CH 6 and IFGTB CJ 7. Clone IFGTB CH 2 recorded minimum plant height (35.80cm) followed by clone IFGTB CJ 7 (36.70cm). However, the plants raised from cuttings of <0.3 cm diameter was recorded significantly superior in plant height (46.63 cm) over the diameter size 0.3<0.6cm (38.90) and 0.6<0.9 cm (36.60 cm). The plants raised from the cuttings having a diameter <0.3cm of clone IFGTB CH 4 recorded the maximum plant height (58.60 cm) followed by the plants raised from the cutting of clone IFGTB CH 5 having diameter size <0.3 (51.80cm) although the minimum plant height (29.20cm) was recorded by the plant raised from the cuttings of clone IFGTB CH 2 having diameter size of 0.6<0.9 cm.

The data recorded at different plant age revealed that in the overall mean performance of different clones, clone IFGTB CH 5 was performed better than all other clones for plant height at the age of 6- and 8-months during the nursery stage when propagated through the

cutting. Whereas among the different sizes of cutting, cutting diameter <0.3cm was achieved the greater plant height than other cutting sizes at the age of 3, 6 and 8-month-old (at nursery stage) which proved that the herbaceous cutting of *Casuarina* clones taken from one-year-old growth was best for multiplication of cuttings through cutting. Significant variations were recorded in plant height among different clones. Similar results were recorded in the study conducted by the Behera *et al* (2016) and found the significant variation among the clones of eucalyptus at different ages.

Table 4.27: Effect of cutting sizes on the plant height of *Casuarina* cutting observed at the age of 8 months.

Height (cm)	Cutting diameter (cm)			
Clone	<0.3	0.3<0.6	0.6<0.9	MEAN
IFGTB CH 1	38.70	40.40	36.90	38.67
IFGTB CH 2	46.10	32.10	29.20	35.80
IFGTB CH 4	58.60	34.70	37.30	43.53
IFGTB CH 5	51.80	48.10	40.50	46.80
IFGTB CH 6	45.30	43.60	39.40	42.77
IFGTB CJ 7	39.30	34.50	36.30	36.70
Mean	46.63	38.90	36.60	

CD (5%) Clones = 2.89, Cutting diameter = 2.04, and Clone × Cutting diameter = 5.00

4.2.1.4 Collar diameter (mm)

The mean performance of plants for collar diameter of cuttings taken from different clones of *Casuarina* is influenced by different sizes is given in Table 4.28. The data revealed that among the different clones, clone IFGTB CJ 7 recorded the maximum collar diameter (7.81mm) followed by the clone IFGTB CH 6 (7.19mm). Clone IFGTB CJ 7 was recorded the significant superiority over the clones IFGTB CH 1, IFGTB CH 2, IFGTB CH 4, IFGTB CH 5 and IFGTB CH 6. The minimum collar diameter (6.17mm) was attained by the clone IFGTB CH 2 and poor performer for collar diameter trait at the nursery stage. Whereas in different cutting diameter sizes, cuttings taken from diameter size 0.6<0.9cm attained the maximum collar diameter (7.68) followed by diameter size 0.3<0.6cm (6.71mm). The cutting diameter 0.6<0.9cm recorded their significant superiority over cutting diameter 0.3<0.6cm and <0.3cm. The least collar diameter (5.69) was recorded by the <0.3cm diameter size of cuttings. Cutting diameter size 0.6<0.9mm was favourable to achieve the higher collar diameter of plants and the cutting diameter <0.3cm was performed poorly for plant collar diameter. Clones × Cutting diameter interaction was statistically significant for collar diameter which indicated that different cutting diameters played a significant role in the collar diameter performance of different clones. Plants raised from cuttings having diameter size <0.3-0.6cm of clone IFGTB CJ 7 recorded the maximum collar diameter (8.03mm) which

was greater than all other plants raised from cuttings taken from different clones and their sizes and closely followed by cutting of diameter size <0.6-0.9cm of clone IFGTB CJ 7 (8.01mm) whereas the minimum collar diameter (3.84mm) was registered by the plants raised from clone IFGTB CH 4 having diameter size <0.3cm. Similarly, as in the above traits, the data showed the effect of different diameters of cuttings on the collar diameter trait. Similar results were recorded by the Sharma *et al* (2019) in which collar diameter was significantly different among the different clones of *Melia dubia*. Namdol (2018) also categorized poor and good clones of *Populus deltoides* for collar diameter traits on the basis of their performance.

Table 4.28: Effect of cutting sizes on the collar diameter of *Casuarina* cutting observed at the age of 8 months.

Collar diameter	Cutting diameter (cm)			
Clone	<0.3	0.3<0.6	0.6<0.9	MEAN
IFGTB CH 1	4.72	7.21	7.71	6.55
IFGTB CH 2	4.44	6.27	7.81	6.17
IFGTB CH 4	3.84	6.99	7.78	6.20
IFGTB CH 5	6.08	5.45	7.17	6.24
IFGTB CH 6	7.67	6.30	7.60	7.19
IFGTB CJ 7	7.39	8.03	8.01	7.81
Mean	5.69	6.71	7.68	

CD (5%) Clones = 0.47, Cutting diameter = 0.16, and Clones × Cutting diameter = 0.40

4.2.1.5 Number of branches

The mean performance of plants of different clones of *Casuarina* for the number of branches is influenced by the different diameter of cuttings presented in Table 29. The result of statistical analysis was non-significant for the clones and cutting diameter but the data depicted variation among the different clones in which clone IFGTB CH 4 (1.88) possess the highest mean performance for the number of branches than all other clones followed by clone IFGTB CJ 7 (1.77) and the Clone IFGTB CH 5 (1.52) recorded the lowest mean performance for the number of branches than all other clones. Variation was also recorded among the different cutting diameters for the number of branches in which 0.3<0.6 cm diameter size recorded the greatest number of branches (1.82) followed by diameter size 0.6<0.9 (1.80) whereas the diameter size <0.3 cm of cuttings having the least number of branches (1.41). Clonex Cutting diameter interaction was statistically significant for number of branches trait and proved that the impact of different cutting sizes on the number of branches was definite. It was also observed that the plants raised from the cuttings of IFGTB CH 4 whose diameter is 0.3<0.6 cm having the highest number of branches (2.40) followed by clone IFGTB CJ 7 cuttings having diameter size 0.6<0.9 (2.10) and IFGTB CH 4 plants raised from cuttings having diameter <0.3 cm was recorded the minimum number of branches (1.25) but the

results were statistically at par for different clones and cutting sizes but clone x cutting size interaction was significant. Similar results were recorded in the study conducted by Sharma *et al* (2017) in which they found significant variation among the different clones of willow as in the present study.

Table 4.29: Effect of cutting size on the number of branches of *Casuarina* cuttings

Number of branches	Cutting diameter (cm)			
Clone	<0.3	0.3<0.6	0.6<0.9	MEAN
IFGTB CH 1	1.80	1.75	1.30	1.62
IFGTB CH 2	1.40	1.60	1.75	1.58
IFGTB CH 4	1.25	2.40	2.00	1.88
IFGTB CH 5	1.30	1.63	1.62	1.52
IFGTB CH 6	1.33	1.75	2.00	1.69
IFGTB CJ 7	1.40	1.80	2.10	1.77
Mean	1.41	1.82	1.80	

CD (5%) Clones = NS, Cutting diameter = NS, and Clones × Cutting diameter = 1.03

4.2.1.6 Number of primary and secondary roots

The mean performance of plants for number of primary roots of cuttings taken from different clones of *Casuarina* is influenced by cutting size is given in Table 4.30. Data revealed a significant variation among different clones. The maximum number of primary roots (12.70) was recorded by clone IFGTB CH 5 followed by clone IFGTB CJ 7 (12.49). Clone IFGTB CH 5 recorded its significant superiority for the number of primary roots over the clones IFGTB CH 1, IFGTB CH 2, IFGTB CH 4 and IFGTB CH 6. The minimum number of primary roots was recorded by clone IFGTB CH 2 (7.13) followed by clone IFGTB CH 1 (9.02). Among three different diameter sizes, it was observed that the diameter size 0.3<0.6 cm registered their significant superiority in number of primary roots (12.23) over the diameter size 0.6<0.9 cm (9.77) and the minimum number of primary roots was recorded by diameter size <0.3 cm (8.59). Clone × Cutting diameter which designated that different cutting sizes of clones was performed differently for number of primary roots trait. The plant raised from cutting size 0.3<0.6 cm of clone IFGTB CH 5 recorded the higher number of primary roots (18.30) of the plant followed by IFGTB CJ 7 having diameter size 0.3<0.6 cm (17.80) whereas the least number (5.65) of primary roots were observed from IFGTB CH 2 plants raised from cuttings of diameter size <0.3cm. Variation was recorded by different cutting diameter among the clones was showed that how a clone was reacted for trait i.e. number of primary roots when propagated through the cuttings of different diameters and also check the effect of different cuttings diameter on the characters.

Table 4.30: Effect of cutting sizes on the number of primary roots of *Casuarina* cuttings

Number of primary roots	Cutting diameter (cm)			
Clone	<0.3	0.3<0.6	0.6<0.9	MEAN
IFGTB CH 1	8.66	9.40	9.00	9.02
IFGTB CH 2	5.65	6.50	9.25	7.13
IFGTB CH 4	7.50	9.80	11.30	9.53
IFGTB CH 5	12.40	18.30	7.40	12.70
IFGTB CH 6	6.33	11.60	13.00	10.31
IFGTB CJ 7	11.00	17.80	8.66	12.49
Mean	8.59	12.23	9.77	

CD (5%) Clones = 0.99, Cutting diameter = 0.70, and Clones × Cutting diameter = 1.72

The mean performance of plants for number of secondary roots of cuttings taken from different clones of *Casuarina* are influenced by cutting size and their interactions are given in Table 4.31. Data revealed significant differences among different clones, the Clone IFGTB CH 6 (47.30) having the significant superiority in the number of secondary roots followed by the Clone IFGTB CH 1 (30.08). Clone IFGTB CH 6 registered significant superiority in the number of secondary roots among all clones. The minimum number of secondary roots were recorded by IFGTB CH 5 (11.17) and followed by IFGTB CJ 7 (17.43). However, the data presented in the Table 4.31 showed the significant variation for the different diameter sizes, the diameter size 0.6<0.9cm recorded the maximum number (28.67) of secondary roots and the minimum number of secondary roots (19.57) was observed from the diameter size <0.3 cm. Cutting diameter 0.6<0.9cm registered significant superiority among the sizes <0.3cm.

Table 4.31: Effect of cutting sizes on the number of secondary roots of *Casuarina* cuttings

Number of secondary roots	Cutting diameter (cm)			
Clone	<0.3	0.3<0.6	0.6<0.9	MEAN
IFGTB CH 1	18.33	22.60	49.30	30.08
IFGTB CH 2	29.20	21.40	22.40	24.33
IFGTB CH 4	13.50	17.40	21.60	17.50
IFGTB CH 5	7.40	11.60	14.50	11.17
IFGTB CH 6	37.40	63.50	41.00	47.30
IFGTB CJ 7	11.60	17.50	23.20	17.43
Mean	19.57	25.67	28.67	

CD (5%) Clones = 1.63, Cutting diameter = 1.15, and Clones $\times$ Cutting diameter = 2.83 and 0.6<0.9 cm. Clonex Cutting diameter which designated that different cutting sizes of clones was performed differently for the number of secondary roots. Among all clones and their different sizes, the plants raised from cuttings diameter 0.3<0.6 cm of IFGTB CH 6 recorded the significantly highest number (63.50) of secondary roots followed by the cutting diameter 0.6<0.9cm of IFGTB CH 1 (49.30) and the lowest number of secondary roots (7.40cm) was recorded by IFGTB CH 5 having a diameter size <0.3cm.

4.2.1.7 Root length

The mean performance of plants for root length of cuttings taken from different clones of *Casuarina* is influenced by cutting size is given in Table 4.32. Significant variation was recorded among different clones, their cutting sizes, and interaction of both at the age of eight months, clone IFGTB CH 5 (47.23cm) recorded its superiority in root length followed by the clone IFGTB CJ 7 (39.83cm). In statistical analysis, Clone IFGTB CH 5 recorded the significant superiority among all the clones i.e. IFGTB CH 1, IFGTB CH 2, IFGTB CH 4, IFGTB CH 6 and IFGTB CJ 7. Whereas the clone IFGTB CH 2 (23.93cm) recorded minimum total length. Clone IFGTB CH 5 significantly superior over all other clones, The recorded data specified that the 0.6<0.9 cm diameter size of cuttings ranked first for the total root length (41.29cm) as well as significantly superior over the diameter size 0.3<0.6 cm (34.94cm) and <0.3 cm (24.79cm) which also own the minimum root length. Clonex Cutting diameter interaction was statistically significant for root length which indicated that different cutting sizes of different clones were performed dissimilar for the trait. However, the plants raised from the cuttings of IFGTB CH 5 having a diameter 0.6<0.9cm recorded the longest root length (59.25cm) followed by the cutting diameter 0.3<0.6cm of similar clone IFGTB CH 5 (46.25), and the smallest root length (16.60cm) was recorded by <0.3 cm diameter size of IFGTB CH 2.

Table 4.32: Effect of cutting sizes on the root length of *Casuarina* cuttings

Root length	Cutting diameter (cm)			
Clone	<0.3	0.3<0.6	0.6<0.9	MEAN
IFGTB CH 1	19.50	27.80	36.50	27.93
IFGTB CH 2	16.60	25.50	29.70	23.93
IFGTB CH 4	23.10	35.50	41.30	33.30
IFGTB CH 5	36.20	46.25	59.25	47.23
IFGTB CH 6	17.75	35.30	36.40	29.82
IFGTB CJ 7	35.60	39.30	44.60	39.83
Mean	24.79	34.94	41.29	

CD (5%) Clones = 3.07, Cutting diameter = 2.17, and Clones $\times$ Cutting diameter = 5.33

4.2.1.8 Root fresh weight

The mean performance of plants for root fresh weight of cuttings taken from different clones of *Casuarina* is influenced by cutting size is given in Table 4.33. Significant variation among various clone at the age of eight months, clone IFGTB CH 5 (3.55gm) ranked first for the total root fresh weight followed by clone IFGTB CH 4 (2.80gm), whereas the clone IFGTB CH 2 (1.21gm) recorded minimum root fresh weight followed by the clone IFGTB CJ 7 (1.85gm). Clone IFGTB CH 5 was significantly superior over the clones IFGTB CH 1, IFGTB CH 2, IFGTB CH 4, IFGTB CH 6 and IFGTB CJ 7. Among the different diameter sizes of cuttings, 0.6<0.9 cm diameter size recorded maximum root fresh weight (2.88gm) which was significantly superior over all other clones and followed by the diameter size 0.3<0.6 cm (2.18gm) and the minimum root fresh weight (1.87gm) was observed in <0.3 cm cutting diameter. Clones × Cutting diameter interaction was statistically significant for root fresh weight which indicated that different cutting diameters showed variation in the mean performance of the weight of fresh root. Among different clones and cutting diameters, the plants raised from cuttings of clone IFGTB CH 5 having diameter 0.6<0.9 was recorded maximum fresh weight of root (4.15gm) than other plants, whereas the minimum weight of fresh root (1.02gm) was observed from the plants raised from the 0.3<0.6 cm cutting diameter of clone IFGTB CH 2.

Table 4.33: Effect of cutting sizes on the root fresh weight of *Casuarina* cuttings

Root fresh weight in grams	Cutting diameter (cm)			
Clone	<0.3	0.3<0.6	0.6<0.9	MEAN
IFGTB CH 1	1.26	1.83	2.71	1.93
IFGTB CH 2	1.15	1.02	1.47	1.21
IFGTB CH 4	2.47	2.82	3.11	2.80
IFGTB CH 5	2.63	3.86	4.15	3.55
IFGTB CH 6	1.98	2.25	3.28	2.50
IFGTB CJ 7	1.73	1.28	2.55	1.85
Mean	1.87	2.18	2.88	

CD (5%) Clones = 0.30, Cutting diameter = 0.21, and Clones × Cutting diameter = 0.53

4.2.1.9. Root dry weight

The mean performance of plants for root dry weight of cuttings taken from different clones of *Casuarina* is influenced by cutting size is given in Table 4.34. Data depicted significant differences among the various clones, their different sized cuttings, and their interaction. It is evident from the data that at the age of eight months, clone IFGTB CH 5 (1.43gm) recorded the significant superiority for the root dry weight followed by clone IFGTB CH 6 (1.20gm) whereas the IFGTB CH 2 recorded a minimum root dry weight

(0.58gm) followed by the IFGTB CH 1 (0.85gm). Clone IFGTB CH 5 significantly superior over all other clones. Among all the clones and cutting diameter, it was observed that 0.6<0.9 cm diameter registered the maximum root dry weight (1.24gm) and significant superior over the other diameter sizes. Whereas the lowest root dry weight (0.87gm) was observed from cutting diameter size <0.3 cm. Clones × Cutting diameter interaction was statistically significant for the root dry weight. However, the plants raised from the cuttings having diameter 0.3<0.6cm of clone IFGTB CH 5 recorded significantly superior for the dry weight of roots (1.58gm) closely followed by clone IFGTB CH 5 having diameter 0.6<0.9cm (1.57gm) and the minimum root dry weight (0.42gm) was recorded by clone IFGTB CH 2 having diameter 0.3<0.6 cm. The result of data in Table 4.34 revealed that the cuttings of different diameters had profound effect on root dry weight among the clones.

Table 4.34: Effect of cutting sizes on the root dry weight of *Casuarina* cuttings

Root dry weight in grams	Cutting diameter (cm)			
Clone	<0.3	0.3<0.6	0.6<0.9	MEAN
IFGTB CH 1	0.50	0.87	1.19	0.85
IFGTB CH 2	0.55	0.42	0.76	0.58
IFGTB CH 4	1.08	1.09	1.24	1.14
IFGTB CH 5	1.13	1.58	1.57	1.43
IFGTB CH 6	1.02	1.08	1.5	1.20
IFGTB CJ 7	0.95	0.69	1.19	0.94
Mean	0.87	0.96	1.24	

CD (5%) Clones = 0.19, Cutting diameter = 0.13, and Clones × Cutting diameter = 0.17

4.2.2 Estimates of genetic parameters

Variability and genetic parameter were estimated for sprouting, survival, days taken for sprouting and several growth traits viz. plant height, collar diameter, number of branches, number of primary roots, number of secondary roots, root length, root fresh weight and root dry weight. In which mean, range, phenotypic coefficient of variation (%), genotypic coefficient of variation (%), heritability (%), genetic advance and genetic gain (%) was calculated (Table 4.35).

The variation ranged between 53.33-72.71% for sprouting, 24.18-43.09% for survival, 2.33-10.33 for days taken for sprouting, 29.2-58.6 for plant height, 3.84-8.03mm for collar diameter, 1.33-2.40 for number of branches, 5.66-18.3 for number of primary roots, 7.40-49.3 for number of secondary roots, 16.6-46.25 for root length, 1.02-4.15 gm for root fresh weight and 0.42-1.58 gm for root dry weight.

The perusal of data revealed that the higher value for the genotypic coefficient of variation was recorded for number of secondary roots (45.66%) followed by root fresh weight

(38.55%), root dry weight (34.54%), and days taken for sprouting (33.89%) while the lower value for the genotypic coefficient of variation was registered for number of branches (7.33%) closely followed by sprouting (7.67%).

The highest phenotypic coefficient of variation was observed in number of secondary roots (46.22%) followed by root fresh weight (41.85%), root dry weight (41.21%), days taken for sprouting (38.02%), number of branches (36.47%), root length (27.98%), collar diameter (26.52%), plant height (24.31%) and survival (13.42%) whereas the minimum phenotypic coefficient of variation was registered for sprouting (12.39%).

Higher heritability was observed in number of secondary roots (97.61%) closely followed by collar diameter (90.91%), plant height (88.55%), survival (86.20%), root fresh weight (84.85%), root length (84.81%), days taken for sprouting (79.47%), number of primary roots (73.65%) and root dry weight (70.26%) which represented the strong influence of additive gene action on the traits whereas the remained characters were influenced by the non-additive genes as they show low values of heritability (38.25%) for sprouting and least heritability was observed in number of branches (4.04%).

Genetic advance was calculated highest for number of secondary roots (22.56) followed by the plant height (17.36) and the least value was recorded for number of branches (0.05). However, the higher value for genetic gain was observed in number of secondary roots (92.94%) followed by root fresh weight (73.15%), days taken for sprouting (62.24%), root dry weight (59.65%), collar diameter (49.65%), root length (48.88%) and plant height (44.35%) and least genetic gain was found for number of branches (3.04%).

The data in table 4.35 revealed that the maximum characters as such survival, days taken for sprouting, plant height, collar diameter, number of secondary roots, root length, and root fresh & dry weight registered the higher heritability as well as genetic gain which reflect that these traits were governed by the additive gene action and can be heritable to the next generation which is very important for the selection of superior clones whereas the remaining traits were showed the low level of heritability and genetic gain and governed by the non-additive genes. Rawat *et al* (2018) evaluated the clones on the basis of their performance recorded by different poplar clones for various growth traits (Lower and higher). Namdol *et al* (2018) estimated high heritability and genetic gain in *Populus deltoides* for different traits such as height, collar diameter, bud length and leaf area. The correlation coefficient was recorded higher for total height and basal diameter in the study conducted to check the performance of different genotypes of *Populus deltoides* for the morphological traits (Verma and Bangarwa 2005).

Table 4.35: Variability and genetic estimates for morphological traits of *Casuarina* clones

Parameter	Mean	Range	Coefficient of variance (%)		h ² (%)	Genetic advance	Genetic gain (%)
			PCV	GCV			
Sprouting (%)	65.96	53.33-72.71	12.39	7.67	38.25	6.34	9.77
Survival (%)	35.45	24.18-43.09	13.42	12.46	86.20	8.45	23.84
Days taken for sprouting	5.53	2.33-10.33	38.02	33.89	79.47	3.76	62.24
Plant height (cm)	40.71	29.2-58.6	24.31	22.88	88.55	17.36	44.35
Collar diameter (mm)	6.69	3.84-8.03	26.52	25.28	90.91	3.04	49.65
Number of branches	1.68	1.33-2.4	36.47	7.33	4.04	0.05	3.04
Number of primary roots	10.20	5.66-18.3	20.11	17.26	73.65	2.51	30.52
Number of secondary roots	24.63	7.4-49.3	46.22	45.66	97.61	22.56	92.94
Root length (cm)	33.65	16.6-46.25	27.98	25.77	84.81	13.08	48.88
Root fresh weight	2.30	1.02-4.15	41.85	38.55	84.85	1.35	73.15
Root dry weight	1.02	0.42-1.58	41.21	34.54	70.26	0.48	59.65

4.2.3 Correlation studies

4.2.3.1 Estimation of phenotypic correlation analysis of different morphological traits in the vegetative propagation trial

Sprouting was registered a non-significant phenotypic correlation with all other characters. Survival also recorded non-significant phenotypic correlation with all traits. Days taken for sprouting was registered non-significant phenotypic correlation with all characters. Collar diameter showed a highly significant phenotypic correlation with the number of primary roots (0.5316) and root length (0.7409) whereas the significant phenotypic correlation was found with number of secondary roots (0.4033). In number of branches, non-significant phenotypic correlation was found with all recorded traits. Number of primary roots registered highly significant correlation was recorded with collar diameter (0.5316), root length (0.6582), root fresh weight (0.5670) and root dry weight (0.5582). Number of

secondary roots registered the significant phenotypic correlation with collar diameter (0.4033). Highly significant phenotypic correlation of root length was found with collar diameter (0.7409), number of primary roots (0.6582) root fresh weight (0.6839) and root dry weight (0.6899), whereas with the other characteristics, it recorded a non-significant phenotypic correlation. Root fresh weight showed highly significant phenotypic correlation with the number of primary roots (0.5670), root length (0.6839) and root dry weight (0.9219). Root dry weight was recorded highly significant phenotypic correlation with number of primary roots (0.5582), root length (0.6899) and root fresh weight (0.9219) whereas the non-significant phenotypic correlation showed for all the remained characters. Plant height registered non-significant phenotypic correlation for all other characters (Table 4.36).

4.2.4 Path analysis

Direct and indirect effect of different characters on root dry weight are presented in Table 4.37. To estimate the direct and indirect effect of a specific trait on other characters path analysis is an important tool and help us in understanding the response of different traits on root dry weight characters. The maximum direct effect was registered for root fresh weight (0.2828) followed by collar diameter (0.2772) and the least direct effect was registered for number of branches (-0.1215) whereas the highest indirect effect was recorded by the combination root length through collar diameter (0.2486) closely followed by number of secondary roots (0.2301) through root fresh weight while least indirect effect was recorded by sprouting through root fresh weight (-0.2209).

Table 4.36 Correlation among morphological traits of *Casuarina* clones at nursery stage

	Sprouting	Survival	Days taken for sprouting	Collar diameter	Number of branches	Number of primary roots	Number of secondary roots	Root length	Root fresh weight	Root dry weight
Survival	0.2540									
Days taken for sprouting	0.3743	-0.0172								
Collar diameter	-0.1970	-0.6944	0.2914							
Number of branches	0.0634	0.0511	0.0239	0.2330						
Number of primary roots	-0.1061	-0.2062	-0.2341	0.5316**	0.1980					
Number of secondary roots	-0.4657	-0.4921	0.0445	0.4033*	-0.2401	0.0457				
Root length	-0.0497	-0.5705	0.0918	0.7409**	0.1987	0.6582**	0.3908			
Root fresh weight	-0.1527	-0.2767	-0.3141	0.2168	0.0006	0.5670**	0.2111	0.6839**		
Root dry weight	-0.0928	0.3696	-0.3367	0.2269	-0.1283	0.5582**	0.2926	0.6899**	0.9219**	
Plant height	-0.0801	0.3347	-0.5061	-0.7412	-0.3159	-0.2808	-0.1947	-0.3943	0.2411	0.2776

*Significant at 5%; 0.3961

**Significant at 1%: 0.5051

Table 4.37: Path analysis for phenotypic correlation in vegetative propagation experiment

	Sprouting	Survival	Days taken for sprouting	Plant height	Collar diameter	Number of branches	Number of primary roots	Number of secondary roots	Root length	Root fresh weight
Sprouting	0.0057	-0.0251	-0.0223	-0.0712	-0.0829	0.0151	-0.1021	-0.1562	-0.0352	-0.2209
Survival	-0.0013	-0.1092	-0.0033	0.0625	-0.2050	-0.0209	-0.0517	-0.1296	-0.0533	-0.1438
Days taken for sprouting	-0.0034	-0.0096	-0.0372	-0.0483	0.0002	0.0198	-0.1080	-0.0362	-0.0070	-0.1049
Plant height	0.0019	-0.0318	-0.0084	0.2149	-0.1639	0.0048	-0.0738	0.0324	-0.0384	-0.0118
Collar diameter	0.0017	0.0809	0.0	-0.1271	0.2772	-0.0029	0.1315	0.0848	0.0704	0.1748
Number of branches	0.0007	-0.0187	0.0061	-0.0085	0.0065	-0.1215	0.0147	-0.0622	-0.0004	-0.0486
Number of primary roots	0.0028	0.0270	0.0192	-0.0751	0.1745	-0.0086	0.2089	0.0202	0.0432	0.1696
Number of secondary roots	0.0038	0.0596	0.0057	0.0294	0.0991	0.0318	0.0178	0.2374	0.0460	0.2301
Root length	0.0026	0.0742	0.0033	-0.1052	0.2486	0.0005	0.1151	0.1392	0.0785	0.2097
Root fresh weight	0.0045	0.0555	0.0138	-0.0090	0.1733	0.0209	0.1252	0.1931	0.0582	0.2828

CHAPTER-V

SUMMARY

The present study entitled “**Morphological diversity and vegetative propagation studies of *Casuarina* spp. under Punjab condition**” was carried out at Chak Ruldu Singh Wala Farm, Bathinda and University Seed Farm, Ladhawal, Ludhiana to evaluate different clones of *Casuarina* spp. for morphological behaviour. Studies on vegetative propagation of *Casuarina* clones was carried out under polyhouse conditions in Main experimental area, Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana to optimize best cutting diameter for vegetative propagation in different clones of *Casuarina*. Observations on morphological traits viz. tree height, diameter at breast height, clear bole height, crown spread, number of branches, tree stem volume, branch angle, axis persistence, stem straightness and branch thickness were recorded twice (at the age of 2 ¼ and 3 ¼ years) at both locations. In vegetative propagation experiment, observations were recorded on sprouting, survival, days taken for sprouting, plant height, collar diameter, number of branches, number of primary roots, number of secondary roots, root length, root fresh weight and root dry weight.

In experiment on evaluation of *Casuarina* clones, the mean value for tree height, diameter at breast height, clear bole height, crown spread, number of branches, tree stem volume, branch angle, axis persistence, stem straightness, and branch thickness ranged between 9.25-14.44m, 7.75-11.93cm, 2.40-3.18m, 15.13-25.09m², 10.00-15.00, 0.016-0.054m³, 1.00-1.50, 5.00-5.89, 2.5-3.33 and 1.33-3.50 under the semi-arid region of Punjab while for central plains of Punjab mean value ranged between 11.46-14.87m, 9.75-12.11cm, 2.16-2.38m, 18.60-31.77m², 8.44-11.97, 0.029-0.056m³, 1.39-2.00, 5.00-5.78, 2.75-3.50 and 1.08-3.43 for above mentioned characters.

Under semi-arid region of Punjab, mean value for growth traits i.e. tree height, diameter at breast height, clear bole height, crown spread, number of branches, axis persistence, Branch angle stem straightness, branch thickness and for tree stem volume were 11.73m, 10.02cm, 2.58m, 21.49m², 12.63, 5.47, 1.36, 3.00, 2.47, and 0.03m³, respectively whereas under the central plains of Punjab, the observed mean value for growth traits i.e. tree height, diameter at breast height, clear bole height, crown spread, number of branches, axis persistence, Branch angle, stem straightness, branch thickness and tree stem volume were 13.15m, 10.84cm, 2.26m, 24.13m², 9.89, 5.50, 1.72, 3.05, 2.40, 0.04 m³, respectively.

Overall mean performance for morphological traits at both sites revealed that the clones IFGTB CH 2 and IFGTB CH 5 were best performers for growth parameters. Clone IFGTB CH 2 recorded tree height (14.26m), diameter at breast height (12.02cm), clear bole height (2.51m), number of branches (9.56) and tree stem volume (0.056m³) while IFGTB CH

5 registered tree height was 14.66m, diameter at breast height was 11.66cm, clear bole height was 2.73m, number of branches was 10.89 and tree stem volume was 0.052m³.

Index score analysis for important traits viz. tree height, diameter at breast height and number of branches demonstrated that Clone IFGTB CH 2 recorded the maximum score (18) closely followed by the clone IFGTB CH 5 (17) while the clone IFGTB CJ 10 registered the least scoring (8) followed by the clones IFGTB CH 6 and IFGTB CJ 9 both scored 9 for the traits.

The values for PCV under the semi-arid region of Punjab were highest for tree stem volume (46.99%) followed by branch thickness (30.89%), diameter at breast height (18.03%) and tree height (17.57%) while the lowest value was registered by axis persistence character (7.83%). GCV was recorded highest for tree stem volume (39.44%) followed by branch thickness (27.27%). The lowest value was registered for axis persistence character (5.42%). However, for central plains of Punjab, maximum PCV was recorded in branch thickness (35.54%) followed by tree stem volume (31.68%) and crown spread (30.06%) and lowest PCV was registered for clear bole height (5.50%). GCV was recorded highest in branch thickness (34.01%) followed by tree stem volume (20.33%) and crown spread (17.91%). The minimum GCV was recorded for clear bole height (1.38%).

Under semi-arid region of Punjab, the higher value for heritability was observed for branch thickness (77.93%), tree stem volume (70.45%) and tree height (76.25%) while the minimum heritability was observed for branch angle (8.65%) and genetic gain was observed maximum in tree stem volume (68.20%), branch thickness (49.58%), and tree height (27.60) while the minimum genetic gain was observed for branch angle (4.09%) Whereas under the central plains of Punjab, heritability was recorded maximum for branch thickness (91.57%) followed by tree height (65.62%) and the minimum heritability was recorded for axis persistence (3.83%). Genetic gain was recorded maximum for branch thickness (67.04%) followed by tree stem volume (26.88%) and crown spread (21.99%) and genetic gain was recorded for clear bole height (0.71%).

Highly significant phenotypic correlation at semi-arid region of Punjab was observed tree stem volume with tree height (0.9400) followed by tree stem volume with diameter (0.9328), diameter and tree height (0.8821), branch thickness with crown spread (0.7562), crown spread with diameter at breast height (0.6738), tree stem volume with crown spread (0.5464), tree stem volume and branch thickness (0.5543), branch thickness with diameter at breast height (0.5448) and branch thickness with tree height (0.5440). Whereas under central plains of Punjab, high significant phenotypic correlation was found for tree stem volume with diameter at breast height (0.9495), tree stem volume with tree height (0.8486), crown spread and diameter at breast height (0.7676), tree stem volume and crown spread (0.7288), diameter at breast height with tree height (0.6967), crown spread and tree height (0.5576), branch angle

with axis persistence (0.5500) and tree stem volume with stem straightness (0.5343)

Path analysis for phenotypic correlation demonstrated the direct and indirect effect of the traits on the performance of tree stem volume. The maximum direct effect was registered for diameter at breast height (0.5942) and the least value for direct effect was recorded for crown spread (-0.1417) while the indirect effect was registered maximum by tree height for diameter at breast height (0.5241) and the lowest indirect effect was registered by diameter for number of branches diameter (-0.1816) under the semi-arid region of Punjab. Under the central plains of Punjab, the highest value was registered for diameter at breast height (0.7356) and the least direct effect was registered for crown spread (-0.0605) whereas the indirect effect was observed higher in crown spread for diameter (0.5647) and the least effect was registered by number of branches for tree height (-0.0833).

In clustering of genotypes maximum genotypic diversity was registered between cluster 1 and cluster 2 (15) followed by between cluster 1A and cluster 1B (14) while the low level of diversity (9) was recorded between clone IFGTB CJ 7 and IFGTB CH 1 under the semi-arid region of Punjab. Under the central plains of Punjab, higher level of diversity (15) was recorded between cluster 1 and cluster 2 whereas the lowest (9) level of diversity was found with in clone IFGTB CH 2 and IFGTB CJ 108. However, for the both sites the maximum (15) level of diversity was observed between cluster 1A along 1B with cluster 2 and the lowest level of diversity (9) was recorded in clone IFGTB CH 1 and IFGTB CJ 7.

The mean value for the morphological traits i.e. sprouting, survival, days taken for sprouting, plant height, collar diameter, number of branches, number of primary roots, number of secondary roots, root length, root fresh weight and root dry weight ranged between 53.33-72.71% , 24.18-43.09, 2.33-10.33, 29.2-58.6cm, 3.84-8.03mm, 1.33-2.4, 5.66-18.3, 7.4-49.3, 16.6-46.25, 1.02-4.15, 0.42-1.58 respectively.

Among different clones, clone number IFGTB CH 5 was superior among all the clones for different plant height collar diameter, number of primary roots, root length, root fresh weight, root dry weight and whereas the clone IFGTB CH 4 recorded their superiority for sprouting, survival and number of branches. Among the different cutting size, cutting diameter 0.3<0.6cm cutting diameter was recorded their superiority for sprouting, survival, days taken for sprouting, plant height and number of primary roots traits while cutting diameter 0.6<0.9cm was superior for collar diameter, number of secondary roots, root length, fresh weight of roots and dry weight of roots.

Highest value for phenotypic coefficient of variation was recorded for number of secondary roots (46.22%) followed by root fresh weight (41.85%), root dry weight (41.21%) and days taken for sprouting (38.02%) while the least value for PCV was registered for sprouting (12.39%). Genotypic coefficient of variation was recorded for number of secondary roots (45.66%) followed by root fresh weight (38.55%), root dry weight (41.21%) and days

taken for sprouting (33.89%) while the least value for GCV was registered for number of branches (7.33%).

The values for heritability was recorded higher for number of secondary roots (97.61%), collar diameter (90.91%), survival (86.20%), plant height (88.55%), root fresh weight (84.85%) root length (84.81%) and days taken for sprouting (79.47%) and lower heritability was registered for number of branches (4.04%) whereas genetic gain was recorded higher for number of secondary roots (92.94%), root fresh weight (73.15%), days taken for sprouting (62.24%), root dry weight (59.65%), collar diameter (49.65%), root length (48.88%) and while the lowest genetic gain was registered for number of branches (3.04%).

Highly significant phenotypic correlation was recorded between root dry weight with root fresh weight (0.9219) followed by root length with collar diameter (0.7409) and root dry weight with root length (0.6899) and the lowest significant phenotypic correlation with in collar diameter with plant height (-0.7412) followed by collar diameter and survival (-0.6944).

Maximum direct effect on root dry weight was registered by root fresh weight (0.2828) and the least direct effect was registered for number of branches (-0.1215) whereas the highest indirect effect was recorded by the combination root length for branch angle (0.2486) closely followed by number of secondary roots and root fresh weight (0.2301) while least indirect effect was recorded by combination of sprouting for root fresh weight (-0.2209).

Conclusion

- In clonal evaluation experiment, clones IFGTB CH 2 and IFGTB CH 5 performed outstandingly for most of morphological characters under both central plains and semi-arid conditions of Punjab. Index score analysis revealed superiority of clone IFGTB CH 2 followed by the IFGTB CH 5.
- The values for phenotypic coefficient of variation under the semi-arid region of Punjab was recorded highest by tree stem volume (46.99) while the least value was recorded by axis persistence character (7.83) whereas under central plains maximum values was registered by the branch thickness (35.54) and least phenotypic coefficient of variation by clear bole height (5.50)
- In semi-arid conditions of Punjab, genotypic coefficient of variation was recorded highest for tree stem volume (39.44) and lowest value was registered for branch angle character (0.00).
- Under semi-arid conditions of Punjab, higher value for heritability was observed for branch thickness (77.93) while the minimum heritability was observed for branch angle (8.65) and genetic gain was observed maximum for tree stem volume (68.20) while the minimum genetic gain was observed for branch angle (4.09).

- Under central plains of Punjab, heritability was recorded maximum for branch thickness (91.57) minimum heritability was recorded for axis persistence (3.83). Genetic gain was recorded maximum for branch thickness (67.04) and minimum genetic gain was recorded for clear bole height (0.71).
- Maximum genotypic diversity was registered between cluster 1 and cluster 2 at both sites but the clusters was made up of different combinations of clones.
- Path analysis revealed that maximum direct effect was registered by diameter at breast height for tree stem volume at Chak Ruldu Singh Wala University Farm, Bathinda and University Seed Farm Ladhowal, Ludhiana (0.5942 and 0.7356, respectively).
- In vegetative propagation experiment, cutting diameter <0.3cm recorded maximum values for cuttings plant survival, days taken for sprouting, plant height and number of branches. Among the different clones, clone IFGTB CH 5 was superior among all the clones for different traits i.e. plant height, collar diameter, number of primary roots, root length, root fresh weight and root dry weight.
- Phenotypic coefficient of variation was recorded highest for number of branches (46.22) while least PCV was registered for sprouting (12.39). Whereas, GCV was recorded highest for number of branches (45.66) while least GCV was registered for sprouting (7.67).
- High heritability was recorded for number of secondary roots (97.61) whereas the low heritability was observed for number of branches (4.04). Genetic gain was recorded maximum for number of secondary roots (92.94) and low genetic gain was observed in number of branches (3.04).

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