STUDYING ADAPTABILITY OF EUCALYPTS CLONES TO WATER LOGGED AND EFFLUENT IRRIGATED ENVIRONMENTS

Thesis

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

MASTER OF SCIENCE
in
FORESTRY
(Minor Subject: Plant Breeding and Genetics)

By

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CERTIFICATE I

This is to certify that the thesis entitled, "**Studying adaptability of Eucalypts clones to water logged and effluent irrigated environments**" submitted for the degree of M.Sc., in the subject of **Forestry** (Minor subject: **Plant Breeding and Genetics**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Parmeet Singh Dhillon** 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, **"Studying adaptability of Eucalypts clones to water logged and effluent irrigated environments''** submitted by **Parmeet Singh Dhillon** (**L-2015-A-79-M**) to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **M.Sc.** in the subject of **Forestry** (Minor subject: **Plant Breeding and Genetics**) has been approved by the Student's Advisory Committee after an oral examination on the same.

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ABSTRACT

The present study entitled 'Studying adaptability of Eucalypts clones to water logged and effluent irrigated environments' was carried out at different locations during 2016 to 2018. Nine *Eucalyptus* clones were studied under effluent irrigated conditions. Survival varied from 95 to 100 per cent and differences among clones were non-significant. Clone C-413 was observed as most promising clone regarding mean height. In terms of DBH, PE-5 attained the highest and PE-8 got the lowest rank. In the second experiment, eight clones were studied under three different soil types. Out of three soil types- S_1 (Normal soil), S_2 (Salt affected soil) and S_3 (Mixed soil), all the clonal plants raised in S_1 soil registered maximum plant height, collar diameter and number of leaves and branches. Significantly lowest values were found under S_2 (Salt affected soil). Significant differences among clones were observed for all growth traits recorded at various ages. Clone PE-11 showed the maximum plant height, collar diameter and number of leaves; clones C-405 and PE-11 recorded significantly higher values in terms of number of branches. S_1 (Normal soil) showed the maximum values for dry shoot and root biomass. Under salt affected conditions, the relative ranking of *Eucalyptus* clones for stem biomass were PE-11> C-2169 >P-27> P-23> C- 405 > C-2135 > P- 48> C-2013. The third experiment had two clones viz. PE-1 and C-413, were studied under two water table depths (30 cm and 60 cm). The differences between the clones as well as between the water table depths were found to be significant. At 60 cm water table depth, the height and collar diameter were significantly higher. The performance of clone C-413 was found significantly superior to PE-1 in terms of mean height. With respect to collar diameter, non-significant differences were found between the clones. The present study revealed huge variation in *Eucalyptus* clones for various abiotic stresses.

Keywords: *Eucalyptus*, Survival, Soil types, DBH, Variation

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Signature of Major Advisor **Signature of the Student**

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ਸਾਰ-ਅੰਸ਼

ਮੌਜੂਦਾ ਅਧਿਐਨ "ਸੇਮ ਅਤੇ ਗੰਦੇ ਪਾਣੀ ਦੁਆਰਾ ਸਿੰਚਿਤ ਹਾਲਾਤਾਂ ਵਿੱਚ ਸਫੈਦੇ ਕਲੋਨਾ ਦੀ ਅਨੁਕੂਲਤਾ ਦਾ ਅਧਿਐਨ" ਸਿਰਲੇਖ ਹੇਠ 2016 ਤੋਂ 2018 ਦੌਰਾਨ ਵੱਖ-ਵੱਖ ਜਗ੍ਹਾ ਤੇ ਕੀਤਾ ਗਿਆ। ਫੈਕਟਰੀ ਨੂੰ ਗੰਦੇ ਪਾਣੀ ਨਾਲ ਸਿੰਚਿਤ ਹਾਲਾਤਾਂ ਵਿੱਚ ਸਫੈਦੇ ਦੇ 9 ਕਲੋਨਾ ਦਾ ਅਧਿਐਨ ਕੀਤਾ ਗਿਆ। ਸਾਰੇ ਹੀ ਕਲੋਨ 95-100% ਤੱਕ ਜੀਵਤ ਰਹੇ ਅਤੇ ਇਸ ਸੰਬੰਧ ਵਿੱਚ ਉਹਨਾਂ ਦੀ ਕਾਰਗੁਜਾਰੀ ਇੱਕ ਜਿਹੀ ਸੀ। ਕਲੋਨ ਸੀ-413 ਦੇ ਪੌਦੇ ਲੰਬਾਈ ਦੇ ਲਿਹਾਜ ਨਾਲ ਸਭ ਤੋਂ ਜ਼ਿਆਦਾ ਉਚਾਈ ਵਾਲੇ ਸੀ, ਕਲੋਨ ਦੇ ਤੌਰ ਤੇ ਦੇਖਿਆ ਗਿਆ ਹੈ। DBH (ਮੋਟਾਈ) ਦੇ ਰੂਪ ਵਿੱਚ ਪੀਈ-5 ਦਾ ਦਰਜਾ ਸਿਖਰਤਾ ਅਤੇ ਪੀਈ-8 ਦਾ ਸਭ ਤੋਂ ਹੇਠਲਾ ਸੀ। ਦੂਸਰੇ ਤਜ਼ਰਬੇ ਵਿੱਚ, ਅੱਠ ਕਲੋਨਾਂ ਨੂੰ ਤਿੰਨ ਵੱਖ-ਵੱਖ ਤਰ੍ਹਾਂ ਦੀ ਮਿੱਟੀਆਂ ਵਿੱਚ ਲਗਾਇਆ ਗਿਆ। ਤਿੰਨਾ ਮਿੱਟੀਆਂ S_1 (ਆਮ ਮਿੱਟੀ), S_2 (ਖਾਰੀ ਮਿੱਟੀ) ਅਤੇ S_3 (ਮਿਸ਼ਰਿਤ ਮਿੱਟੀ) ਵਿੱਚੋਂ S_1 ਵਿੱਚ ਪੌਦਾ ਲੰਬਾਈ, ਮੋਟਾਈ, ਪੱਤਿਆਂ ਅਤੇ ਟਹਿਣੀਆਂ ਦੀ ਸੰਖਿਆ ਸਭ ਤੋਂ ਵੱਧ ਸੀ। ਖਾਰੀ ਮਿੱਟੀ ਇਹਨਾਂ ਦਾ ਮਾਨ ਅਰਥਪੂਰਨ ਤੌਰ ਤੇ ਘੱਟ ਸੀ। ਵੱਖ-ਵੱਖ ਅਵਸਥਾ ਉੱਪਰ ਰਿਕਾਰਡ ਕੀਤੇ ਵਿਕਾਸ ਮਾਪਦੰਡਾਂ ਕਲੋਨਾਂ ਵਿੱਚ ਅਰਥਪੂਰਨ ਤੌਰ ਤੇ ਭਿੰਨਤਾ ਦੇਖੀ ਗਈ। ਪੀਈ-11 ਕਲੋਨ ਵਿੱਚ ਸਭ ਤੋਂ ਵੱਧ ਪੌਦਾ ਲੰਬਾਈ, ਮੋਟਾਈ ਅਤੇ ਪੱਤਿਆਂ ਦੀ ਸੰਖਿਆ ਸਭ ਤੋਂ ਵੱਧ ਅਤੇ ਸੀ-405 ਅਤੇ ਪੀਈ-11 ਕਲੋਨ ਵਿੱਚ ਟਾਹਣੀਆਂ ਦੀ ਸੰਖਿਆ ਅਰਥਪੂਰਨ ਤੌਰ ਤੇ ਵੱਧ ਪਾਈ ਗਈ। S_1 ਮਿੱਟੀ (ਆਮ ਮਿੱਟੀ) ਵਿੱਚ ਜੜ੍ਹਾਂ ਅਤੇ ਤਣਾਂ ਦਾ ਸੁੱਕਾ ਭਾਰ ਸਭ ਤੋਂ ਵੱਧ ਪਾਇਆ ਗਿਆ। ਖਾਰੀਆਂ ਹਾਲਾਤਾਂ ਵਿੱਚ ਤਣਾ ਬਾਇਓਮਾਸ ਵਿੱਚ ਇੱਕ ਦੂਜੇ ਦੇ ਸਬੰਧ ਵਿੱਚ ਸਫੈਦੇ ਦੇ ਕਲੋਨਾ ਦੀ ਰੈਂਕਿੰਗ ਪੀਈ-11>ਸੀ-2167>ਪੀ-27>ਪੀ-23>ਸੀ-405>ਸੀ-2135>ਪੀ-48>ਸੀ-2013 । ਤੀਸਰੇ ਤਜ਼ਰਬੇ ਵਿੱਚ ਦੋ ਕਲੋਨ ਪੀਈ-1 ਅਤੇ ਸੀ-413, ਸਮੇਂ ਦੇ ਦੋ ਪੱਧਰ (30 cm ਅਤੇ 60 cm) ਉੱਪਰ ਅਧਿਐਨ ਕੀਤੇ ਗਏ। ਕਲੋਨ ਅਤੇ ਪਾਣੀ ਦੇ ਪੱਧਰ ਵਿੱਚ ਫਰਕ ਅਰਥਪੂਰਨ ਪਾਇਆ ਗਿਆ। 60 cm ਪਾਣੀ ਦੇ ਪੱਧਰ ਤੇ ਔਸਤ ਲੰਬਾਈ ਅਤੇ ਮੋਟਾਈ ਅਰਥਪੂਰਨ ਤੌਰ ਤੇ ਵੱਖ ਪਾਏ ਗਏ। ਕਲੋਨ ਸੀ-413, ਪੀਈ-1 ਤੋਂ ਪੌਦਾ ਲੰਬਾਈ ਦੇ ਲਿਹਾਜ ਨਾਲ ਬਿਹਤਰ ਪਾਇਆ ਗਿਆ। ਪਰ ਮੋਟਾਈ ਵਿੱਚ ਦੋਨੇ ਕਲੋਨ ਇਕੋ ਜਿਹੇ ਸੀ। ਮੌਜੂਦਾ ਅਧਿਐਨ ਅਜੈਵਿਕ ਤਨਾਅ ਵਿੱਚ ਸਫੈਦੇ ਕਲੋਨਾ ਵਿੱਚ ਬਹੁਤ ਵੱਧ ਫਰਕ ਦਰਸਾਉਂਦਾ ਹੈ।

ਮੁੱਖ ਸ਼ਬਦ: ਸਫੈਦਾ, ਸਰਵਾਈਵਲ, ਸੋਇਲ ਕਿਸਮਾਂ, ਮੋਟਾਈ, ਵਿਭਿੰਨਤਾ

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CHAPTER-I

INTRODUCTION

Eucalyptus is a versatile genus, belongs to Myrtaceae family which can adapt to a varied range of edaphic and climatic conditions (Goor and Barney 1968). It can grow in a wide variety of soil conditions but for its proper growth it needs fertile, well-drained sandy loamy to loamy soils having suitable moisture. *Eucalyptus* is very fast growing tree and attains a height of about 30 m and more with a straight clean bole in a short rotation of about 8-10 years. Among 700 species of *Eucalyptus,* majority are native of Australian continent. It was introduced in India in the early 18th century. In Punjab, it was introduced in 1860 by the Director of canals on Madhopur Headworks. In India, the majority of *Eucalyptus* plantations on government, forest, farm lands, community lands and along road / rail / canal strips are of seed origin. Large scale eucalypt plantations in the country were planted for various reasons varying from state to state. These plantations were raised to rejuvenate the denuded and barren hilly areas and replace the degraded natural forests (Anon 1979). Most of the *Eucalyptus* plantations in India were raised during the time span of 1960 -1980.

Eucalyptus hybrid and *E. tereticornis* are the two most widely planted *Eucalyptus* in India. Many species can tolerate flooding or swamp lands and are given vernacular names accordingly (Parsons *et al* 1991, Ladiges and Kelso 1997) e.g. flooded gum (*E. grandis*), swamp gums (*E. camphora* and E. *ovate*), river red gum (*E. camaldulensis*) and swamp mahogany (*E. robusta*). Species intolerance to waterlogging generally shows no morphological changes and no recovery of gas exchange during exposure to the waterlogged condition (Tang and Kozlowski 1982).

Seepage from canals, rivers and water channels often causes waterlogging in the adjoining areas. Water logging and secondary salinization is becoming a serious problem, as it affects the most fertile lands and cause loss to the tune of Rupees 8.60 million per year (Balasubramanium *et al* 2004). In Punjab, 2.64 m ha area faces the problem of waterlogging. Bio drainage is a simple permanent and efficient method to reclaim such areas by planting the forest tree species that can tolerate waterlogging and possess high transpiration capacity. *Eucalyptus* sp. has is emerged as the most suitable tree species under such marshy areas (Balasubramanium *et al* 2004, Chhabra and Thakur 1998, Ram *et al* 2011).

Soil salinity and poor quality water are responsible for increased desertification in arid areas throughout the world (Szabolcs 1992). For the purpose of reclamation of salt affected lands, approaches like use of chemical amendment and engineering methodologies has been purposed (Ashraf 1994 and Flowers 2004). It is very costly to reclaim highly salt affected lands with the use of chemicals. Saline agriculture is an eco-friendly and economically sustainable method to cope salinity by way of many species is available with high salt tolerance (Aslam *et al* 1993). A number of strategies have been projected by which salt tolerant trees can reduce the soil salinity. Such strategy comprises decrease in soil pH (Mashali 1991), release of organic acids and complex energy sources by roots (Dormaar 1988) and so forth.

The enlargement and maintenance of sustainable agro-ecosystem on highly saline areas is an easier scheme with perennial plant species, therefore planting such salt tolerant forest tree species on salt-affected areas is an environmental friendly and economically valuable approach to manage the salinity level where ground water is correspondingly extremely saline. *Eucalyptus* can tolerate and adapt to wide range of environments and it is an eco-friendly approach to cope with the salinization of lands. Many studies have proved inter specific variation in *Eucalyptus* for salt tolerance, on basis of greenhouse (McComb *et al* 1989) and field trials (Zohar 1982). Morabito *et al* (1996) also found the significant difference among various clones of *Eucalyptus microtheca* under different salinity levels. Many *Eucalyptus* species demonstrate tolerance to environmental stress factors such as salinity or drought and it is appropriate for afforestation in arid and salt affected areas (Zohar 1982).

The partially treated sewage waste, industrial waste and farm waste and it released into a natural body of water is generally known as effluent, and the such treated waste used for irrigation in plants is called as effluent irrigation. Waste water used for irrigating plantation is a popular substitute to river discharge (Stewart and Boardman 1991) and thus river water is protected by such efforts. The preference for irrigating tree plantations over agricultural crops has been credited to the high promising growth rates (Cromer *et al* 1983, Stewart and Flinn 1984, Stewart *et al*. 1988) and the testified high rates of water use (Morris and Wehner 1987, Stewart 1988).Moreover, effluents in the food-processing industries, liquor industries, dairy farms and municipal sewerage treatment plants have great amounts of nutrients such as phosphorus, nitrogen and so on. Though, nutrient unavailability is the main cause for plants and crops not succeeding their potential growth capacity (Mitchell and Robertson 1992). According to Marecos *et al* (1989) the effluents should be used as a nutrients rich water resource to irrigate plantation and it is a good approach to replace commercial fertilizers. On the other hand, continual effluent irrigation could change the properties of soil like change in nutrient concentration, pH and so on. (Russell *et al* 1988, Falkiner and Smith 1997).

Tree breeding is the application of genetic principles and reproductive principles for enhancing wood productivity or tolerance to biotic/ abiotic stresses. Considerable genetic diversity exists in *Eucalyptus* as this genus is of high outcrossing nature and natural hybridization between species of the genus is often found (Eldridge *et al* 1993). The high variation for tolerance to salt affected sites and marshy lands has been reported (Davison and Tay 1985, Thomson 1988, Farrell *et al* 1996, Grieve *et al* 1999, Marcar *et al* 2002a). These variations can be captured through selection of tolerant genotypes to abiotic stresses and by using planting stock originated from the tolerant trees (Chaitanya *et al* 2002).

Several institutes of India had initiated the tree improvement programme on *Eucalyptus* and developed many clones. Punjab Agriculture University, Ludhiana has recently developed new clones on the basis of their growth and tolerance to insects and diseases. These clones need to be studied for adaptability to abiotic stresses like waterlogging, salinity etc. Therefore the present study entitled "Studying adaptability of Eucalypts clones to water logged and effluent irrigated environments" had been planned with the following objectives:

1. To study the tolerance of the *Eucalyptus* clones under field conditions irrigated with industrial effluents.
2. To compare the tolerance and growth of *Eucalyptus* clones under simulated conditions of waterlogging.

CHAPTER-II

REVIEW OF LITERATURE

Many studies have been conducted in India and abroad on various aspects of use of *Eucalyptus* for amelioration of waterlogging and salt affected sites. The literature is reviewed under following heads

2.1 Tolerance of *Eucalyptus* species to waterlogging and salinity

2.2 Use of effluents for irrigating tree species

2.1 Tolerance of *Eucalyptus* species to waterlogging and salinity

Dabral (1970) evaluated the growth of 4 species of forest trees such as *Dalbergia latifolia, Eucalyptus citriodora, Pinus roxburgii* and *Populas casale* under the unlimited water supply. At the different ages, each group consumed 2.58, 1.41, 8.89, 3.04 mm of water per gram dry matter produced, respectively.

Gomes and Kozlowski (1980) carried out an experimental and found that flooding for up to 40 days induced morphological changes and reduced growth of six week old *Eucalyptus camaldulensis* and *E. globulus* seedlings. Both species produced abundant adventitious roots that originated near tap root and original lateral roots. In both species, dry weight increment of shoots was reduced more than dry weight increment of roots. Adaptation to flooding appeared to be greater in *E. camaldulensis* than *E. globulus*.

Davison and Tay (1985) induced the waterlogging conditions in pots and raised seedlings (3-4 months) of *E. marginata*. They found that continuous waterlogging decreased the water movement into plants due to blockage of xylem vessels. The transpiration rate of continuously waterlogged plants decreased significantly.

Rawat *et al* (1985) recorded the observations such as stomatal behaviour, transpiration and growth of *Eucalyptus* saplings under the varying moisture levels. They observed that *Eucalyptus* hybrid used ideal water at 15 per cent moisture without any severe reduction in the dry matter. Loss in Transpiration was noted by weighing potted plants and pots without plants at the same moisture at 48 hour intervals. Height, collar diameter and number of leaves were recorded at the interval of about one month. Polystyrene film impressions of the leaves were occupied and studied to determine the number of open and closed stomata. When soil moisture increased it showed that plants transpired water bountifully. Partial stomata closure occurs when moisture in the soil was limited, ultimately it leads to reduced transpiration rate.

Liu and Dickman (1992) studied the effects of drought and flooded anxiety on two poplar clones by plotting a trial. Two poplar clones [Tristis (*P. tristis* x *P. balsamifera* and Eugenei (*Populus* x *euramericana*)] grown under two levels of nitrogen and varying moisture levels. During initial stages of water logging conditions no such severe effect was seen on the clones but 18 days after the leaf size of Tritis was reduced. On the other hand, drought conditions reduced the leaf expansion in clone Eugenei. Results showed that maximum production roots was noticed in well watered pots whereas it was minimum in flooded pots and low to medium in water stress treatment. The stem biomass of clone Eugenei was noted as maximum in flooded conditions. In case of clone Tritis stem biomass was highest under drought conditions. It was noticed that there was a significant difference between the performances of both clones.

Sun and Dickinson (1993) evaluated 19 tree species under the saline stress conditions. The experiment was conducted in glass house and five salinity levels were taken into consideration. On the basis of salt stress tolerance, significant variation was observed among the species. Performance of species by means of survival was transformed noticeably at different salinity levels. It was observed that the performance of *Eucalyptus robusta*, *E. argophloia*, *E. camaldulensis* and *E. drepanophylla* was outstanding in salt stress levels and such species are noted as salt tolerant species.

White *et al* (1994) studied the effect of water stress on the growth traits of *Eucalyptus globulus and E. nitens*. The leaf area was strongly correlated with collar area at 0.15 m above ground. These relationships were then used to estimate leaf area index over the whole plantation for all treatments. Leaf area index was high in *E. globulus* than *E. nitens*, and within species leaf area index was significantly increased by irrigation. The highest leaf area index was significantly increased by irrigation. The highest leaf area indices were 4.2 and 3.6 respectively; in the irrigated Rheban and King island seed lots of *E. globulus*.

Omari (1994) evaluated the effect of different irrigation levels on four *Acacia* species such as *Acacia oswaldii, Acacia ligulata and Acacia victoria.* These species were subjected to four different levels of irrigation (0.25, 0.50, 0.75 and 1.0 liters equivalent to 24, 41, 57 and 64% of soil water content) under certain condition of temperature and humidity. During the experiment, response was assessed on the basis of final height, increased diameter, per cent increase in height, per cent cumulative increase in plant height and relative growth rate. Irrigated seedlings of *A. oswaldii* at the 0.25 litre level, and seedling of *A. ligulata* at the 0.50 litre level, and seedlings of *A. stenophylla* and *A. victoriae* at the 0.75 litre level for about 180 days gave the maximum increase in plant height in a respective way.

Sasse and Sands (1995) correlated the responses of cuttings and seedlings of *Eucalyptus globulus* Labill. to water tension in a nine week greenhouse experiment. Within each treatment they observed the height growth rates of cuttings and seedlings were quite similar. During water stress treatments growth rates of both cuttings and seedlings were reduced. Under well-watered conditions, cuttings and seedlings used same amounts of water. Plants were not irrigated at the end of the experiment. Seedlings kept under stressed conditions survived lesser as compared to well watered treatment. Cuttings from the water-stress treatments were died at higher soil water contents.

Gurovich *et al* (1996) studied the effect of different irrigation regimes on *Eucalyptus globulus* growth and water use. The effect of different amount of irrigation water on daily evapotranspiration (ET) was investigated. Tree height diameter growth was significantly lower in case of both water deficit and excess water, as compared to normal (100% ET) and 125 percent treatments.

Morabito *et al* (1996) studied the response of *Eucalyptus microtheca* clones to NaCl in vitro. Three clones of *E.microtheca* (43, 42 and 37) raised under different salinity levels (0-140 mM NaCl). For about three months these clones were grown and growth traits were recorded. It was seen that with increase in salinity the growth and survival of the clones were decreased dramatically. Under 70 mM NaCl concentration, shoot elongation of clone number 42 and 37 were adversely affected and on the other hand there was no such bad affect was observed on the growth of clone 43. In the high salinity levels, succulence of Clones 42 and 43 was much higher as compared to Clone number 37.

A study was conducted by the Osorio *et al* (1998) to evaluate the effects on *Eucalyptus globulus* Labill. under three irrigation levels (well watered, moderate soil water deficit and severe soil water deficit. Three different clones such as MP11, AR3 and CN44 were studied in experiment. Observations were noticed by the means of transpiration efficiency and leaf intrinsic gas exchange efficiency and they were increased under water stress. Because of stomatal closure, transpiration efficiency was virtually similar in moderate and severe water stress levels.

Grieve *et al* (1999) screened clones of *E. camaldulensis* and *E. rudis* in controlled environment by irrigating the posts with saline water of varying salinity levels. At 16.4 dsm^{-1}, the biomass reduction was 50 percent. Clones 4501, 4590 and 4573 were the most promising ones.

Viero *et al* (2000) evaluated the growth and morphological characters of *Eucalyptus grandis* under the increasing level of water by the means of hydrogel. Results from this experiment indicate that there was increase in leaf area index of plants. There was about 39 % and 23.7 % increase in the leaf area index, for water and hydrogel respectively. Moreover, these trials shown that the increased level of water made a positive impact on the survival of the seedlings.

Florentine and Fox (2002) investigated the adaptation to long term waterlogging of semi-arid eucalyptus species and found that long-term waterlogging of *E. victix* seedlings significantly increased the seedling diameter. Flooding reduces photosynthesis, transpiration and stomatal conductance. A comparative study of flood tolerance in semi-arid eucalypt species suggested that those species intolerant of flooding seldom express morphological adaptations and fail to recover from physiological damage. Flooding significantly reduced the transpiration rate and stomatal conductance.

The salt tolerance of seedlings from of 15 wide-ranging Australian seed sources (provenances) of *E. camaldulensis* was investigated in pots under varying degree of salinity (Marcar *et al* 2002 b). Significant differences were found among provenances in height and shoot dry weight. Differences in provenance response to treatment were found for dry weight but not for height. Reductions in shoot dry weight due to NaCl and high pH ranged from 42.9 % to 82.0 % and 4.3 % to 51.7 % respectively. Provenances from Lake Hindmarsh-SE (Victoria) and Lake Albacutya-N (Victoria) had relatively high tolerance to both stresses whereas those from Lake Albacutya-S (Victoria), Lowan Valley (Victoria), Silverton (New South Wales) and Katherine (Northern Territory) had low tolerance to both stresses. Provenances from De Grey River and Fitzroy River (Western Australia) were most tolerant of high pH.

Marcar *et al* (2002 a) conducted three experiments to evaluate variation in salt and waterlogging tolerance among and within provenances and families of *Eucalyptus grandis* and *E. globulus* Labill. Subsp. *globulus*. Five families of *E. grandis* from each of seven provenances) and 2 (four families of *E. globulus* from each of six provenances), Four treatments—control (C), salt (S; 75 and 150 mol m^{-3}), waterlogging (W) and combined salt and waterlogging (SW)—were applied to seedlings planted in sand-filled pots. In experiment 3, the above treatments were applied to 9-week-old (*E. globulus*; four families) and 12-week-old (*E. grandis*; four families) seedlings cultured as above, but in this case, salt concentrations were incrementally increased from 150 to 450 mol m^{-3}, and a larger number of seedlings used than for the previous experiments. For both species height and shoot dry weight was reduced much more by combined salt and waterlogging than by either treatment alone. Shoot dry weights for S, W and SW treatments were reduced by 49, 77 and 80 %, respectively, for *E. grandis* and by 28, 70 and 73%, respectively, for *E. globulus*. Large differences in growth were found among families within provenances and among provenances, irrespective of treatment.

Close and Davidson (2003) reported the morphological and nutritional changes in the imposed waterlogged plants of *E. nitens*. After eight months, morphological adaptations were in the form of adventitious and aerenchymatous roots and hypertrophy of stems. Foliar calcium (1.3-fold), potassium (2-fold) and phosphorus (2.4-fold) were lower and iron (5.6-fold) was higher in waterlogged than control saplings. Stem Ca (1.7-fold) was lower, whereas Mn (1.8-fold) and Fe (117-fold) were higher in waterlogged than control saplings. Distinct purple pigmentation was observed in xylem tissues of waterlogged saplings. A significant reduction in the maximum photosynthetic rate and photochemical efficiency was observed in waterlogged compared to control saplings.

Silva *et al* (2004) evaluated the performance of 5 commercial hybrids of *E. globulus* grown under dissimilar water availability conditions kept at 20, 35, 50 and 65 percent water retention capacity. Observations were noted for total height, collar diameter, number of leaves, leaf area and dry weight of leaf and root/shoot ratio. All of the features were adversely affected by reduced availability of water. H_2O scarcity resulted in a greater reduction in the dry weight production when it is compared to number of leaves, diameter and height. Hybrids like H2 and H5 were found to be healthier to tolerate a drought.

Barret *et al* (2005) investigated the effects of waterlogging and salinity on the water relations of *Eucalyptus gracilis* F. Muell. Presence and depth of the saline groundwater had relatively little effect on the water relations of the trees even when large differences in tree health were visible. Predawn water potential, stomatal conductance and foliar sodium and potassium concentrations were similar for all individuals independent of the depth and salinity of the groundwater. As expected, the severity of water stress increased over summer when predawn water potentials became progressively more negative and foliar salt concentrations increased. These changes occurred in all plants independent of depth or salinity of the groundwater.

Paydar *et al* (2005) reported the long term effects of planting *E. grandis* in irrigated areas with shallow and salt affected water tables by the help of various models. In the model AIPSIM, it was noted that if 1000 mm approx. irrigation is given to the plantation then good effect on tress can be seen. This model was tried in contradiction of measured data and used to pretend a kind of different environmental conditions and management options. Depending upon the irrigation and groundwater salts, *E. grandis* trees might be effective only up to a few years. Optimum response of trees to irrigation is only expected with fresh water and scheduled irrigation if 1750 mm per year water is given to plantation. It was concluded if more than recommended water is given to the plantation for irrigation purposes then it could be very harmful to the plantation.

Kogawara *et al* (2006) investigated the effect of root hypoxia on two tree species and found that the growth of the *Melaleucia cajupati* seedling was not reduced by the hypoxic treatment, whereas growth of the *E. camaldulensis* seedling was reduced markedly, indicating that *M. cajupati* is more tolerant of root hypoxia than *E. camaldulensis*. The capacity of the *E. camaldulensis* seedlings to transport photo assimilate to the roots decreased significantly in response to root hypoxia.

Nasim *et al* (2007) studied the growth of the *Eucalyptus camaldulensis* on saline areas. They observed the impact of plants on soil by testing the electrical conductivity, pH, organic matter and infiltration rate. Two different sites were selected and about sixteen plants were chosen and graded as poor and good in 8:8. Observations like DBH, number of branches, plant height and so on were recorded to check the performance of plants. Performance and growth of *E. camaldulensis* plants at both sites was considerably affected by salinity as compared with other plantations grown on other fields. The soil pH was quite lower in soil under good trees than in soil under poor trees at all depths and at both sites.

Tatagiba *et al* (2007) evaluated the growth of six *Eucalyptus* clones under various irrigation levels. The growth traits like leaf area, root and shoot growth and total dry matter were recorded from plants, grown in plastic vases and subjected to different levels of water deficit. Clones like 1, 2 and 4 were noted as the most tolerant clones, undoubtedly because of highest accumulation of total dry matter in them under this water category. No significant difference was noted on the height of clone number 2 and 4 with and without water deficit. Under water deficit, clone 3 experienced a big reduction in leaf area. Moreover, there was no dramatic difference in the diameter of all the clones at the both conditions of water levels.

Youngsukying and Nakasathien (2008) established a hydroponic system and this method was applied to screen the clones of *Eucalyptus camaldulensis* (Dehn.) under waterlogging. Various effects of waterlogging were seen as total biomass, net photosynthesis, maximum quantum yield and chlorophyll content of leaves. Four Eucalypt clones (2 months old) were exposed to waterlogging conditions for about 16 days. During the experiment various physiological parameters were observed at days 0, 8 and 16 under a plant growth incubator. Results showed that rate of transpiration, net photosynthetic rate and stomatal conductance were reduced dramatically in C2 and C4 clones after 16 days of waterlogging conditions. It was concluded that C2 and C4 clones performed well in waterlogging conditions.

Vellini *et al* (2008) evaluated the growth and physiological traits of eucalypt clones submitted to four irrigation regimes in a greenhouse. Observations were recorded for height, root, collar diameter, number of leaves, leaf area, stem and roots, root-shoot ratio, net photosynthesis, stomatal conductance, transpiration and leaf water potential. All the evaluated characters presented significant differences among genotypes and water regimes.

Bala *et al* (2008) studied the performance of *Eucalyptus camaldulensis* under different irrigation regimes. Irrigation schedule was maintained on the basis of IW/CPE ratio (Irrigation water/cumulative pan evaporation). Plant growth and biomass at 40 months age was high in I3 W2 treatment where 45/60 mm of water per irrigation was applied with a total of 1935 mm. Results of the study revealed that quantity of water added per irrigation is more important than the total irrigation input.

Kallarackal and Somen (2008) detected the water use characteristics of five important forest tree species such as *Acacia auriculiformis, Eucalyptus tereticornis, Anacardium occidentale*, *Tectona grandis* and *Eucalyptus grandis* on five different sites facing different microclimates and rainfall. A result indicates that the leaf area index *E. tereticornis* did not show the significant variation between the pre and post monsoon seasons. The five examined species indicated a significant variation in the rate of transpiration. It was seen by the observers that both species of *Eucalyptus* developed a large leaf areas and the plants transpired at high rates, when the atmospheric demand was high and free water was available in the soil.

Nasim *et al* (2009) reported the salinity effects on the growth of three species of *Eucalyptus* i.e *Eucalyptus tereticornis, Eucalyptus camaldulensis* (silverton and local) under salinity conditions. Such species were grown with control means no NaCl and salinity under hypoxic and non-hypoxic conditions in nutrient solution. In response to salinity and hypoxia *Eucalyptus* spp. showed different results. Significant decrease in the shoot dry matter of every species was caused by saline treatments at both nonhypoxic and hypoxic conditions. Absolute shoot dry matter was considerably better in *E. camaldulensis* (Silverton) in salinity and in *E. camaldulensis* (Local) in saline hypoxic usage. Plant height and collar diamter of all the species was reduced dramatically by salinity × hypoxia and salinity. *E. tereticornis* was noted as the most sensitive species to salinity as compared with the other two species. Sodium and chloride concentrations were expressively minor in *E. camaldulensis* (Local) in non-hypoxic saline treatment when related to the other two species. *E. camaldulensis* (Silverton) seems to have better tissue compartmentalization, whereas *E. camaldulensis* (local) appears to have better exclusion of sodium at the root level.

Cocozza *et al* (2010) studied the growth of poplar clones under various water levels. Two clones *Populus nigra* L. (Poli and 58-861) were examined in a controlled condition. Water stress condition led to reduce in plant size and predawn water potential in both clones under study. The control trees were recorded to be taller and they retained their leaves for longer period as compared to other treatments. Clone Poli did not show reduced stomatal activity during drought condition. Both the clones showed contrasting water transport strategies during drought. Clone 58–861 enabled water transport however clone Poli increased water conservation in the root cells. Results showed that there was significant difference between the performances of clones.

Feikema and Baker (2011) studied the effects of salinity on the *Eucalyptus* plantation. There were three species of Eucalyptus used for the experiment such as *E. globulus*, *E. grandis*, and *E. camaldulensis*. In the initial stages growth of trees were restricted in comparison to other species. *E. globulus* performed best in survival and growth of volume to the age of 10 years under slight to moderate salinity conditions as compared to other species. The overall performance of *E. grandis* was not so good during the experiment. On the other side *E. camaldulensis* performed well under the moderate to severe soil salinity. Results showed that there was significant difference between all the species.

Guo *et al* (2011) studied the effects of 30 day flooding on growth and physiology of 13 hybrid poplar clones. Stomatal conductance was not reduced in any of the plants during first few days of flooding. However, in tress of some clones, stomata opened and then closed as flooding was prolonged. Clones 58-280, DNP-34, 311-93, DN70, Simplot, R-419 and OP-367 were grouped into a cluster with high tolerance to flooding; clones 309, PC-1, DN-14273, 195-529, NE-353 and R-247 into a cluster with low tolerance to flooding.

Andrew *et al* (2013) studied the growth performance of three species of trees such as *Albizia ferruginea, Eucalyptus grandis*, and *Erythrina excels.* These species were treated at four moisture stages (12.5, 25, 50 and 100 %) of soil field capacity for six months. Water use efficiency, transpiration rate and evapotranspiration rate of all species were evaluated during this experiment. At 50 % soil moisture maximum growth was recorded. Results presented the minimum growth when seedlings were treated at 12.5 % soil moisture level. *E. grandis* and *Erythrina* seedlings performed well in 100 % soil moisture stage whereas total biomass of Albizia was recorded maximum in 50 % soil moisture level. Maximum rate of transpiration was recorded in *Erythrina excels.* Rate of evapotranspiration for the different tree seedlings was found to be non-significant.

Elobeid (2014) observed the physiological responses of *Eucalyptus camaldulensis* seedlings under the various water regimes. The main purpose of experiment was to know the response of seedlings under water deficit conditions. Observations like plant shoot height (cm), collar diameter (mm) were recorded once a week to check the growth of the seedlings. At shortest irrigation interval, the growth of the plants was healthy but when the plants were irrigated late by adopting longest irrigation interval, it was noticed that plant shoot height and collar diameter decreased dramatically. Results showed that root and shoot growth of the *E. camaldulensis* seedlings were badly affected, and it was concluded that the *E. camaldulensis* did not performed well and it is sensitive to the water deficit conditions.

Granda *et al* (2014) studied the differences among nine *Eucalyptus globulus* clones for drought responses. The plants were gradually subjected to severe drought stress. A total of 31 parameters, physiological, biochemical and hormonal were analysed. The C14 group (C14, C120, C405, C491, and C601) clones behaved as water savers. The C46 group (C46, C97, and C371) clones behaved as water spenders. The latter maintained the highest growth rate under the conditions tested. The method presented here could be used to identify appropriate *E. globulus* clones for drought environments.

Valadares *et al* (2014) evaluated five hybrids of *Eucalyptus grandis* × *E. urophylla* subjected to four irrigation regimes in the greenhouse. They evaluated photosynthetic rate, transpiration, stomatal conductance, leaf water potential, leaf relative water content, photochemical efficiency and chlorophyll content index. It was found that hybrid H3 was the most tolerant and H5 was the most sensitive to reduction in water availability in soil.

Gangwar *et al* (2015) studied three *Eucalyptus* clones viz. K25, K28 and A.P.10 under different edaphic conditions. These clones are introduced in Tarai and Bhabhar regions of Uttarakhand. The clonal plantation of A.P.10 at an age of 4 years showed an average diameter of 8 cm while in clonal testing area it showed an average diameter of 7 cm. K25 showed an average diameter of 7 cm and K28 8 cm under different soils.

Sánchez *et al* (2015) studied the effect of water stress and salinity on the clones of *Aruna donax* L. They conducted the experiment by using eight healthy clones. There were four different treatments in the experiment such as water stress with saline solution, well watered with non-saline solution, water stress with non-saline solution and well watered with saline solution. Biomass of plants was recorded to check the overall growth of clones. It was observed that the survival of *Aruna donax* L. clones were more in salinity levels as compared to water stress, but photosynthetic rate of plants was reduced in both treatments. 'Piccoplant' and 'Martinensis' clones were noted as the appropriate clones for growing under both stress environments.

Sixto *et al* (2016) evaluated the 4 *Eucalyptus* spp. and 4 *Populus* spp. under the salinity stress their capacity to grow in short rotation for biomass production. Along with Control treatment, two treatments of saline concentrations of NaCl such as moderate (50-55mM) and severe (125-30mM) were given to the plantation. Parameters such as growth, morphological and biochemical were considered in this experiment. Every *Eucalyptus* genotype showed a good response that is high survival rates under both severe and moderate saline concentrations. The poplar hybrids like 7171-B4 and Oudenberg exhibited medium-tolerance. These mechanisms were believed to have varying degrees of efficiency. A molecular approach acknowledged changes in the expression of genes linked to xylem differentiation, the more tolerant genotypes being those with lesser modifications.

2.2 Use of effluents for irrigating tree species

Myers *et al* (1996) reported that the *Eucalyptus grandis* when irrigated with either effluent or bore water, canopy closed in 24 months under different rates of water used. After 34 months mean dominant height was 12.1 m, stand collar area was 12.2 m^3 ha, leaf area index was 5.7 m and foliage mass was 6.5t/ha whereas pine had mean height 5.0 m, stand collar area 9.6m^2, LAI was 3.5 m and foliage mass 7.3t/ha. In the third year (when the eucalyptus had closed canopy), the *Eucalyptus* uses 22 per cent more water than the pines, but annually mean LAI of the *Eucalyptus* was three times greater than that of the pines.

Grieve and Shannon (1999) evaluated four clones of *E. camaldulensis* Dehn. (4543, 4544, 4573, and 4590) and one clone of *E. rudis* (4501) under controlled conditions with irrigation of saline drainage waters. Electrical conductivities of the solutions were 2, 12, and 28 $dS \cdot m^{-1}$. After treatment for 7 weeks, the clones could be separated into two distinct groups by significant differences in leaf-ion relations. Group 1 clones 4543, 4544, and 4573 accumulated less Na^+ and more Ca^{2+} and Cl^- in leaves than group 2 clones, 4501 and 4590. Leaf and stem Cl^- concentrations tended to be lower in all clones grown at 28 $dS \cdot m^{-1}$ than at 2 $dS \cdot m^{-1}$, despite increases in Cl^- concentration in the irrigation waters. Under saline conditions, K^+ and P were preferentially accumulated in the youngest leaves in the upper portion of the canopy, whereas Na^+, Ca^{2+}, and Mg^{2+} were retained in the older leaves.

Guo and Sims (2000) studied the effect of meatwork effluent on the seedlings of *Eucalyptus globulus* as well as on the soil. Observations like plant biomass, nutrient uptake were noted during the experiment. There were numerous temperatures (5°C, 15°C and 25°C) signifying various seasons in which seedlings were grown. Results concluded that at 5°C, the *E. globulus* saplings showed no reaction to effluent irrigation, but the soil pH was increased. The effects of effluent were dramatically influenced by temperature and irrigation rates. The positive effects of effluent irrigation on plants as well as on soil were seen as increased tree leaf area, increase in biomass production, maximum nutrient uptake, reduction in soil pH and enhanced soil nutrient concentrations. The most successful nutrient recovery happened at 15°C with approx. 60 % and 30 % nitrogen and phosphorus recovered respectively. Results showed that overall experience of effluent irrigation on *Eucalyptus* plantation was positive.

Heaton *et al* (2002) observed the effects of effluents on the root growth of *Salix viminalis* and *Eucalyptus nitens*. In this experiment, dairy pond wastes were used as an effluent. The dairy pond effluent was applied on the plantation at an interval of 14 days. *E. nitens* roots were observed by means of soil cores. Two treatments were given to the plantation via rate of application such as T1 (150 m^3ha^{-1}) and T2 (300 m^3ha^{-1}). The trees were planted in the plots and irrigated with the help of a micro sprinkler system. Results had shown that spatial distribution was influenced by the rate of effluent used. It was found that in the treatment number 2 that is 300 m^3ha^{-1} rate of application the growth of fine and course roots in the top soil horizons was positively affected by the effluent from dairy pond.

Bhati and Singh (2003) studied the effects of industrial effluents on growth of *Eucalyptus camaldulensis* seedlings. Different irrigation treatments were: T1: good water; T2: municipal effluent; T3: textile effluent; T4: steel effluent; T5: textile effluent + municipal effluent in 1:1 ratio; T6: steel effluent + municipal effluent in 1:2 ratio; T7: steel + textile + municipal effluent in 1:2:2 ratio; T8: steel + industrial effluent in 1:2 ratio. The survival was the lowest in case of T4 because of high concentration of heavy metals. The seedling of T3 produced the least growth and biomass, and improved growth was noticed in T5. In case of T6, T7 and T8 survival was relatively high.

Thwaites *et al* (2006) evaluated the near surface water content and water repellency of Blue gum (*Eucalyptus globulus*) under effluent irrigation. Such plantation is irrigated with sewage treated water. Three treatments were given to the plantation T1 (No irrigation), T2 (50 %) and T3 (100 %) irrigation. In first four months about 162 soil samples were collected in 3 rounds and their water content and degree of H_2O repellency checked. In T2 and T3 water repellency was reduced and soil is wetted up. A single peaky spreading of H_2O contents was detected in the soil samples, but the H_2O repellency distribution was dichotomous, with about

45 per cent tremendously water-repellent and approx. 36 % was wettable. At water contents with slight downward flux, the field was H_2O repellent and leaching through special flow paths is expected.

Livesley *et al* (2007) studied the different observations of *Eucalyptus globulus* under the effluent irrigation. Observations like accumulated soil N, NO3–N and NH4–N concentrations in soil water, gross ammonification, gross nitrification amounts were recorded. They examined the plantation with the separate and collaborating effects of drip and sprinkler irrigation, effluent and water irrigation, irrigation rate, and harvest residues retention. Results showed that NO3 rates of soil water were superior under effluent irrigation as compared to irrigation with normal water. NO3–N and NH4–N concentrations were approx. doubled when *E. globulus* plantation is irrigated with effluents by the means of drip irrigation.

Shah *et al* (2010) observed the effects of the industrial effluent of the Hudiara drain on the growth of *Eucalyptus camaldulensis* during initial ages of plants. Four treatments were given to the plants such as T0 (0 %), T1 (25 %), T2 (50 %), T3 (75 %) and T4 (100 %) effluent. In case of treatment (T2) maximum growth of plants was noted in the stem height, stem biomass, number of branches and seedling length. Maximum seeding collar diameter was recorded during initial stages in treatment number 3 (75 %) as compared to others. Though, the increase in effluent concentration decreased Potassium and Phosphorus in roots, and increased Iron in roots and stems, while in T1 and T2 increased Magnesium in stems. The results proposes that by mixing the wastewater of industrial effluent with tap water (50:50v/v) welfares the growth of *Eucalyptus camaldulensis*.

Rezende *et al* (2010) investigated the effects on the *Eucalyptus* plantation under the treated wastage of pulp mill effluent. There were three types of Brazilian soils in which *Eucalyptus* plants was raised under the effluent irrigation. The experiment was conducted in the controlled environment called as greenhouse. Two species of *Eucalyptus* were selected for the experiment such as *E. grandis* and *E. urophyla*. Rise in soil salinity and electrical conductivity was noticed after the six months of experiment planted. Growth of trees is observed by the means of total biomass production and tress performed well in the fine textured soils. Results concluded that the tolerance of the *Eucalyptus* plants to the effluent soil application was considered as satisfactory.

Piper *et al* (2011) reported that when two *Eucalyptus* spp. irrigated with industrial effluents, it leads to the mortality of coppice growth. Plantations of two species such as *E. moluccana* and *E. tereticornis* were irrigated with industrial effluent from an initial age-once the seedlings were evidently established. Both species grew fine and touched the height of eight to nine metre within 33 months. During this age random plots of *Eucalyptus* trees of both species were selected and felled to produce coppicing growth. After coppice growth appeared, irrigation with industrial effluents continued to coppice trees and uncut trees.

Within 8 months coppice growth failed and there was no bad effect seen on uncut trees. The key points of the failure of coppiced trees seemed to be a mixture of acid soils, high soil aluminium concentrations and high foliar manganese concentrations. In contrast uncut remained healthy when irrigated with industrial effluents. There was a lesser amount of waterlogging in the plots with uncut trees and these had lower foliar concentrations of potentially toxic elements.

Silva *et al* (2011) studied the growth and morphological characters of *Eucalyptus grandis* under the effects of sewerage sludge. There were two types of sludge viz. dry and wet sludge. Four different treatments were given to the plantation such as mineral fertilizer, no fertilizer application, dry and wet sewerage sludge. Observers also examined the nutrient cycling of *E. grandis* plantation. Biomass of plantation was increased dramatically in the both treatments of sewage sludges and as well as in mineral fertilizer treatment. Biomass of wood after the 36 months was similar in sludges treated plantation and mineral fertilizer treated plantation. Wood biomass was about 86 per cent lesser than the other treatments. *Eucalyptus* plantation was positively affected by the application of sewage sludge. Leaf litter production and increased nutrient transfer among the components of the ecosystem was noticed during the experiment.

CHAPTER-III

MATERIAL AND METHODS

The present investigation entitled, "Studying adaptability of Eucalypts clones to water logged and effluent irrigated environments**"** was carried out at different locations during 2016 to 2018. The details about the experimental sites, materials used, methodologies adopted and the observations recorded during the course of investigations are given in this chapter.

Experiment No. 3.1

3.1.1 Name of experiment

Performance of *Eucalyptus* clones irrigated with industrial effluents.

3.1.2 Location

The experiment was conducted at Liquor Factory Macchana, near Sangat Mandi, Punjab. Sangat Mandi is a suburb town of Bathinda city. It is located 25 km towards west from District headquarters of Bathinda. Sangat Mandi is situated at 30^0 3' 55.4" N latitude and 74^0 51' 18.6" E longitude at an elevation of about 202 m above mean sea level.

3.1.3 Climate

In general, the climate is sub-tropical with a long duration dry spell from October to mid-June and wet season from end of the June to mid-September. The area receives an average rainfall of about 421 mm per annum and 3/4th of total amount of rainfall is predictable during July to September with an average of about 31 rainy days.

3.1.4 Methodology:

Nine clones were used for the study. Six clones developed by PAU and three were commercial clones. The details of the clone are given Table 3.1. The plants of eight clones were raised in the Mist Chamber of the Department of Forestry and Natural Resources and one clone was procured from Prakriti clonal Agrotech, a leading supplier of clonal planting stock.

The plants of each clone were shifted to perforated polybags filled with silt and farmyard manure (1:1) and maintained in the nursery. The uniform size plants were used for the study. The plants were planted during March 2016. Each clone was replicated four times following with Randomized Block Design. One row of the non-experimental plants was planted around the trial. After planting, the irrigation was given. Regular irrigation, weeding and other plant protection measures were given as per the recommended practices (Anonymous 2012). The irrigation water was from the industrial effluent of the beverage industry.

Table 3.1 Details of the *Eucalyptus* clones used in the study

S.No.	Name	Origin of plus tree	Progeny number
1	C-411	ITC, Bhadrachalam paper mills	-
2	HC-2045	ITC, Bhadrachalam paper mills	-
3	C-413	ITC, Bhadrachalam paper mills	-
4	PE-1	PAU, Ludhiana	L-55
5	PE-7	HAU, Hisar	HS-6
6	PE-5	Orissa University of Agriculture and Technology, Bhubneshwar	OUAT,ET-10
7	PE-6	TNAU, Coimbatore	FC&RI, MTP/ET-5
8	PE-11	Australia Seed Centre	13547/JD1043
9	PE-8	Australia Seed Centre	16547/JD1572

3.1.5 Observations Recorded

3.1.5.1 Plant height (m)

Each plant was measured from the ground level to the tip of the main shoot with the help of calibrated measuring rod.

3.1.5.2 Diameter at breast height

Diameter at breast height of plants was measured by using digital vernier caliper at collar region and 1.37 m height above the ground level. Diameter was measured in millimeters (mm).

3.1.5.3 Survival percentage

From each replication, the plants which survived were counted and on the basis of this survival percentage was calculated.

$$\text{Survival (\%)} = \frac{\text{Number of survived plants}}{\text{Number of total plants}} \times 100$$

Table 3.2 Physical and chemical properties of soils used in the study

Sr No.	Soil properties	Values
1	Soil texture	Sandy loam
2	pH	8.3
3	EC (dS/m)	2.70
4	Organic carbon (%)	0.18
5	Available P (kg/acre)	10.2
6	Available K (kg/acre)	198
7	Available Zn (kg/acre)	0.82
8	Available Fe (kg/acre)	2.70
9	Available Mn (kg/acre)	2.00
10	Available Cu (kg/acre)	0.60

3.1.6 Irrigation Water Characteristics

The chemical properties of water used for the irrigation had the following characteristics (Table 3.3)

Table 3.3 Chemical properties of effluent water

Sr No.	Water properties	Values
1	pH	8.7
2	Carbonate (Meq/L)	2.0
3	Bicarbonate (Meq/L)	18.6
4	Chloride (Meq/L)	6.6
5	RSC (Residual Sodium carbonate Meq/L)	18.5
6	Conductance (Micromhos per cm)	2410

3.1.7 Statistical analysis

Statistical analysis was performed as per the procedure laid down for Randomized Block design (RBD). Analysis of variance, Least significant difference (LSD) and variance components were calculated for the interpretation of results of the study following Panse and Sukhatme (1989).

Experiment No 3. 2

3.2.1 Name of experiment

Screening of *Eucalyptus* clones under salt affected conditions.

3.2.2 Location of the site

The experiment was conducted at Experimental Area, Department of Forestry and NR, Punjab Agricultural University Ludhiana. Ludhiana located at about 247 meter above the mean sea level it lies between 30^0 90' N longitude and 75^0 81' E latitude, which signifies the central agro-climatic zone of the Punjab.

3.2.3 Climate

In general, the climate is sub-tropical with a long duration dry spell from October to mid-June and wet season from end of the June to mid-September. The area receives an average rainfall of about 730 mm per annum and 3/4th of total amount of rainfall is predictable during July to September with an average of about 38 rainy days.

3.2.4 Methodology:

Plants of seven clones were procured from Prakriti Biotechnologies and one clone (PE-11) used propagated in Mist Chamber at the Department of Forestry and Natural Resources. The details of the clones used in the present study given in the table number 3.4.

The clonal plants were planted on 15 December 2016 at the experimental area of the

Department of Forestry and Natural Resources. The clones were planted following Completely Randomized Design (CRD) with three soil types each having four replications. Three types of soils selected were normal soil, salt affected soil and mixed soil. Regular watering was given to all the treatments. Data on plant height and collar diameter were recorded three times at the age of 45, 110 and 140 days after planting. Number of leaves and branches were recorded after 110 days. The biomass was recorded at the end of the experiment.

Table 3.4 Details of the *Eucalyptus* clones used in the present study

S.No.	Name	Developed by
1	PE-1	PAU, Ludhiana
2	C-2169	ITC, Bhadrachalam
3	C-2013	ITC, Bhadrachalam
4	C-2135	ITC, Bhadrachalam
5	P-27	Pragati Biotechnologies, Hoshiarpur
6	P-23	Pragati Biotechnologies, Hoshiarpur
7	P-48	Pragati Biotechnologies, Hoshiarpur
8	C-405	ITC, Bhadrachalam

3.2.5 Observations recorded

Data on growth traits i.e. plant height, collar diameter etc. were recorded at age of 45, 120 and 140 days.

3.2.5.1 Plant height (cm)

The height of the plant was recorded in centimeters from the ground level to the tip of the shoot with the help of scale and calibrated measuring rod.

3.2.5.2 Collar diameter (mm)

Collar diameter was measured in millimeters at 2-3 cm above ground level with the help of digital vernier caliper in two directions perpendicular to each other and the average collar diameter was calculated.

3.2.5.3 Number of branches and leaves

Every small thin terminal branch of a plant was counted and similarly number of leaves from every plant was counted.

3.2.5.4 Root and shoot biomass

After uprooting the plants, fresh weight of root and shoot was weighed separately and afterwards air dried it following by oven dried and dry weight of root and shoot were measured.

3.2.5.5 Soil Characteristics

Table 3.5 Physical and chemical properties of soils used in the study

Soil properties	Normal soil	Salt affected soil	Mixed soil
Soil texture	Sandy loam	Loamy sand	Loamy sand
pH	7.3	8.3	7.9
EC (dS/m)	0.38	3.60	2.12
Organic carbon (%)	0.39	0.42	0.41
Available P (kg/acre)	28.6	13.7	19.2
Available K (kg/acre)	98	264	173.1
Available Zn (kg/acre)	1.96	2.16	2.08
Available Fe (kg/acre)	16.08	28.40	23.15
Available Mn (kg/acre)	5.28	2.20	3.19
Available Cu (kg/acre)	0.90	1.84	1.37

3.2.5 Statistical analysis

Statistical analysis was performed as per the procedure laid down for Completely Randomized design (CRD). Analysis of variance, Least significant difference (LSD) and variance components were calculated for the interpretation of results of the study following Panse and Sukhatme (1989).

Experiment No. 3.3

3.3.1 Name of experiment

Performance of Eucalyptus clones under simulated water conditions

3.3.2 Location of the site

The experiment was conducted at experimental area, Department of Forestry and NR, Punjab Agricultural University Ludhiana. Ludhiana is located at about 247 meter above the mean sea level it lies between 30^0 90' N longitude and 75^0 81' E latitude, which signifies the central agro-climatic zone of the Punjab.

3.3.3 Climate

In general, the climate is sub-tropical with a long duration dry spell from October to mid-June and wet season from end of the June to mid-September. The area receives an average rainfall of about 730 mm per annum and 3/4th of total amount of rainfall is predictable during July to September with an average of about 38 rainy days.

3.3.4 Methodology:

The clonal plants were planted on 05 March 2017 at the experimental area of the Department of Forestry and Natural Resources. The experiment involved two clones of

Plate 1: The simulated waterlogging trial involving two *Eucalyptus* clones with two levels of water depths.

Eucalyptus (C-413 and PE-1) of uniform height. The clones were planted following Completely Randomized Design (CRD). There were two water table depths 30 (cm) and 60 (cm). Water logging conditions were created by using big drums, fitted with plastic tubes from the base and drainage pipes were kept as per given heights (Plate 1). Recommended fertilizer and irrigation was applied.

3.3.5 Observations recorded

Data on growth traits i.e. plant height and collar diameter was recorded at age of 5.5, 7 and 12 months.

3.3.5.1 Plant height (m)

The height of the plant was recorded from the ground level to the tip of the shoot with the help of scale and calibrated measuring rod.

3.3.5.2 Collar diameter (mm)

Collar diameter was measured in millimeters at 2-3 cm above ground level with the help of digital vernier caliper in two directions perpendicular to each other and the average collar diameter was calculated.

CHAPTER-IV

RESULTS AND DISCUSSION

The present study entitled, "Studying adaptability of Eucalypts clones to water logged and effluent irrigated environments" was carried out at different locations of Punjab during 2016 to 2018. The results obtained are discussed under following headings in the light of appropriate reasoning and available literature. The relevant data has been presented in the tables and figures.

4.1 Performance of *Eucalyptus* clones irrigated with industrial effluents.

4.2 Screening of *Eucalyptus* clones under salt affected conditions.

4.3 Performance of Eucalyptus clones under simulated water conditions

4.1 Performance of *Eucalyptus* clones irrigated with industrial effluents.

In this experiment, nine different clones of *Eucalyptus* (C-411, C-2045, C-413, PE-5, PE-11, PE-1, PE-7, PE-8, and PE-6) were studied. The uniform size plants were used for the study. The observations on survival, height and diameter were taken at various ages.

4.1.1 Survival

The survival of clones varied from 95 to 100 per cent. Clones C-413, PE-11, PE-7 and PE-6 recorded 100 per cent survival, whereas C-411, C-2045, PE-5, PE-1 and PE-8 had exhibited 95 per cent survival. The details are given in Figure 4.1. The differences among clones were non-significant.

The pursued data showed that all the *Eucalyptus* clones established well at the site irrigated with effluent. Keeping in view the salinity conditions of the soil and irrigation water, the survival ranged from 95 to 100 per cent, which was exceptionally well. The role of the trees for remediation of such sites is well documented (Shah *et al* 2010, Singh *et al* 2010).

Piper *et al* (2011) also reported good establishment of seedlings of *Eucalyptus moluccana* and *E. tereticornis* irrigated with industrial effluents. Bhati and Singh (2003) studied the effects of industrial effluents on the growth of *Eucalyptus camaldulensis* seedlings. They found the good survival of seedlings under the steel and municipal effluents. In another study, the tolerance of two tree species *Eucalyptus grandis* and *E. urophylla* irrigated with pulp mill effluent was satisfactory (Rezende *et al* 2010). In the present study, the better survival may also be due to the light textured soil where the seepage was very fast.

4.1.2 Height and DBH

Data of growth traits of *Eucalyptus* clones at the age of 4.5 months are given in Table 4.1. Significant differences were observed among the clones for both the traits. At first look it was noticed that the performance of clone PE-1 in mean height was remarkable (203.7 cm) followed by PE-6 (187.4 cm), PE-11 (186.6 cm) and C-413 (184.6 cm). Clones PE-1, PE-6, PE-11 and C-411 were significantly superior from other clones.

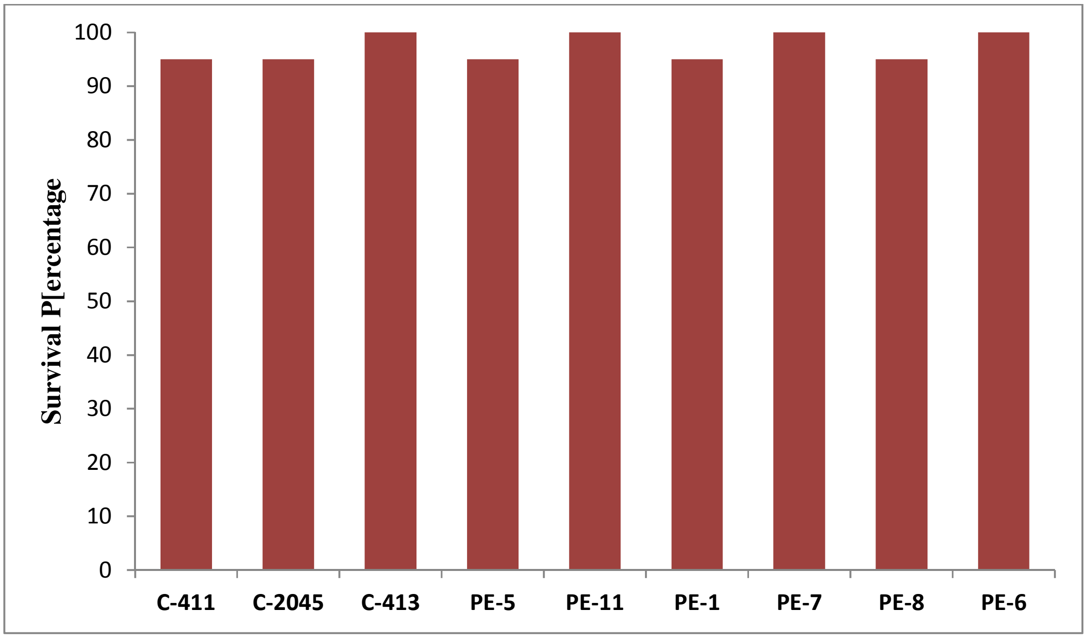

Fig. 4.1 Survival percentage of *Eucalyptus* clones irrigated with industrial effluents (Age 12 months)

Table 4.1 Growth traits of *Eucalyptus* clones irrigated with effluents (Age 4.5 months)

Clone	Plant Height (cm)		Collar Diameter	
	Mean	Relative ranking	Mean	Relative ranking
C-411	159.2	5	18.9	7
C-2045	157.4	6	16.9	9
C-413	184.6	4	21.1	4
PE-5	153.3	8	21.0	5
PE-11	186.6	3	22.3	3
PE-1	203.7	1	29.8	1
PE-7	155.0	7	20.3	6
PE-8	145.8	9	17.5	8
PE-6	187.1	2	24.7	2
Mean±SE	**170.3±6.75**		**21.04±1.31**	
LSD (P<0.05)	**25.4**		**3.49**	

Clone PE-8 registered as the lowest value (145.8 cm). The rankings of clones from maximum to minimum via mean height was observed as PE-1> PE-6> PE-11> C-413> C-411> C-2045 > PE-7> PE- 5> PE-8.

With respect to mean collar diameter, Clone PE-1 attained the maximum value (29.8 mm) and was significantly superior to other clones. The lowest mean diameter (16.9 mm) was registered by clone C-2045 which was at par with three other clones PE-8, C-411 and PE-7. The rankings of clones from the highest to the lowest for mean diameter was observed as PE-1> PE-6> PE-11> C-413> PE-5> PE-7> C-411> PE-8> C-2045. On the basis of overall performance of mean height and diameter it is found that clone PE-1 registered the first rank at the age of 4.5 months.

Table 4.2 presents the data on plant height and DBH of *Eucalyptus* clones irrigated with industrial effluents at age of 8 months. The significant differences among clones were noticed for both growth traits. With respect to mean height C-413 recorded the highest value (5.12 m) was statistically superior to other clones. It was followed by six clones i.e. PE-11, PE-1, C-2045, PE-6, PE-5 and C-411. The bottom rank was in case of PE-8.

The mean dbh of PE-1 (56.12 mm) was found to be maximum which was at par with C-413 (51.86 mm) but was significantly superior to other clones. The lowest value was registered by clone PE-8 (39.36 mm). The rankings of clones from maximum to minimum via mean diameter was noticed as PE-1> C-413> PE-6> PE- 5> PE-11> C-2045> PE-7> C-411> PE-8.

Table 4.2 Growth traits of Eucalyptus clones irrigated with effluents
(Age 8months)

Clone	**Plant Height**		**DBH**	
	Mean (m)	**Relative ranking**	**Mean (mm)**	**Relative ranking**
C-411	3.85	7	41.80	8
C-2045	4.22	3	42.18	6
C-413	5.12	1	51.86	2
PE-5	3.97	6	47.46	4
PE-11	4.24	2	45.12	5
PE-1	4.22	3	56.12	1
PE-7	3.71	8	42.10	7
PE-8	3.54	9	39.36	9
PE-6	4.22	3	50.29	3
Mean±SE	**4.13±0.33**		**46.25±1.78**	
LSD (5%)	**0.48**		**5.56**	

The growth traits data of *Eucalyptus* clones at age of 13 months are given in Table 4.3. Differences among the clones were found to be significant ($p<0.05$) for both the traits.

Plate 2: Variation in the *Euculyptus* clones irrigated with industrial effluent

Clone C-413 recorded the top rank for mean height with value of 7.23 (m) and was significantly superior to all the clones. It was followed by clones PE-5, PE-6 and C-2045. Clone PE-8 registered the lowest value (5.49 m). The rankings of clones for mean height was witnessed as C-413> PE-11> PE-6> C-2045> PE-11 > PE- 1> C-411> PE-7> PE-8.

With respect to mean DBH clone PE-5 attained the maximum value (79.91 mm) which was at par with C-413 (78.77 mm), PE-6 (78.57 mm) and PE-1 (76.43 mm) but was superior to other clones. The lowest mean diameter value was registered by clone PE-8 with an average value of 62.61 (mm). The rankings of clones was PE-5> C-413> PE-6> PE- 1> C-411> PE-7> C-2045 > PE-11> PE-8. On the basis of overall performance of mean height and DBH after 13 months it is concluded that clone C-413 and PE-5 are the most promising clones for height and diameter respectively.

Table 4.3 Growth traits of Eucalyptus clones irrigated with effluents (Age 13 months)

Treatment	Plant Height (m)		DBH (mm)	
	Mean (m)	**Relative ranking**	**Mean (mm)**	**Relative ranking**
C-411	6.06	7	69.02	5
C-2045	6.47	4	65.60	7
C-413	7.23	1	78.77	2
PE-5	6.60	2	79.91	1
PE-11	6.13	5	65.17	8
PE-1	6.11	6	76.43	4
PE-7	5.67	8	66.22	6
PE-8	5.49	9	62.61	9
PE-6	6.50	3	78.57	3
Mean±SE	**6.25±0.39**		**71.37±1.53**	
LSD (5%)	**0.52**		**6.68**	

The results of the present study showed the significant differences ($p<0.05$) among the clones for both the growth traits at all the three ages (Table 4.1, Table 4.2 and Table 4.3). The differential response of clones to any environment/abiotic stress may be due to their different genetic make-up. Grieves *et al* (1999) found the variation among clones of *E. camaldulensis* and *E. rudis* which were irrigated with saline water. *Eucalyptus* trees are effective for their ability to combat waterlogging, heavy water remediation and also provide biomass yields from such sites (Bilal *et al* 2014). Clone PE-1 performed better at the age of 4.5 months, but clone C-413 attained the top rank in height at age of 8 months and 13 months. The relative ranking of clones changed with time, which is often observed in the genetic trials of trees (Dhillon *et al* 2010).

4.2 Screening of *Eucalyptus* clones under salt affected conditions.

In a pot study of eight *Eucalyptus* clones (PE-11, C-2169, C-2013, C-2135, P-27, P-23, P-48, and C-405) were planted. Three types of soils were used (normal soil, salt affected soil and mixed soil). Observations in growth traits at various ages and biomass components were taken.

4.2.1 Growth traits

4.2.1.1 Measurements of height and collar diameter

Data of plant height of Eucalyptus clones after 45 days are given in Table 4.4. The difference among the clones was found to be significant ($p<0.05$). PE-11 was found to be significantly superior to other clones except with C-2135, C-2013 and P-23. C-2169 recorded the lowest value (31.67 cm). The relative ranking of clones was PE-11 > C-2135> C-2013 > P- 23> P-48> P- 27> C-405> C-2169. There were three soil types in which different clones were grown and normal soil recorded the highest mean height in the initial stages of growth but there were non-significant differences observed among the soil types.

Table 4.4 Plant height (cm) of *Eucalyptus* clones grown under different soil types (Age 45 days)

Clone	Soil Type			Mean
	Normal soil (S_1)	Salt affected soil (S_2)	Mixed soil (S_3)	
PE-11	40.75	38.75	44.25	41.25
C-2169	32.50	33.25	29.25	31.67
C-2013	40.50	37.00	37.75	38.42
C-2135	40.25	37.50	39.50	39.08
P-27	34.00	34.50	32.25	33.58
P-23	40.00	38.25	35.25	37.83
P-48	37.75	32.25	32.75	34.25
C-405	33.00	36.50	30.00	33.17
Mean	**37.34**	**36.00**	**35.13**	
LSD (5%) Clone= 4.01; Soil type= NS; Interaction= NS				

Second observation of plant height of *Eucalyptus* clones taken at 110 days after planting is given in Table 4.5. The analysis of data showed that differences among the clones were significant. Clone PE-11 performed very well in all soil types, with the average height of 91.25 cm that was significantly better than other clones. Clone P-48 got the second rank but was at par with P-27, C-2013, P-23 and C-2169. On the basis of performances the rankings of clones from maximum to minimum was observed as this PE-11 > P-48> P- 27>C-2013 > P-23> C-2169> C-405> C-2135. The effect of soil types was significant on plant height and the value was maximum in S_1 (82.19 cm) and was followed by S_2 (61.34 cm) and S_3 (56.63 cm).

Table 4.5 Plant heights (cm) of *Eucalyptus* clones grown under different soil types (Age 110 days)

Clone	Soil Type			Mean
	Normal soil (S_1)	Salt affected soil (S_2)	Mixed soil (S_3)	
PE-11	94.75	86.00	93.00	91.25
C-2169	83.50	47.75	50.75	60.67
C-2013	76.75	52.75	64.00	64.50
C-2135	64.75	51.75	60.50	59.00
P-27	83.00	57.75	56.00	65.58
P-23	85.25	56.75	49.50	63.83
P-48	94.75	48.25	65.50	69.50
C-405	74.75	52.00	51.50	59.42
Mean	**82.19**	**56.63**	**61.34**	
LSD (5%) Clone= 9.58;	Soil type= 5.87;		Interaction= NS	

Third observation on plant heights of *Eucalyptus* clones at age of 140 days is presented in Table 4.6. At the first blush, it was noticed that there were significant differences in the mean height among the soil types and clones. Clone PE-11 recorded the highest value (117.83 cm) and C-2135 recorded the lowest value (74.58 cm). The second rank was registered by clone P-27 by having a mean height of 93.08 cm. The ranking of clones by means of average height from maximum to minimum was noticed as PE-11 > P-27> C-2169> P- 48> P-23>C-2013 > C-405> C-2135. In conclusion, it was noticeable that the mean height of clone PE-11was significant superior in all soil types. The average growth of clones in normal soil was maximum (113.72 cm) which was significantly higher than that of mixed soil (81.66 cm). The plant height of salt affected soil (72.00 cm) was significantly lower than other two soil types. The lowest value (56.00 cm) was in case of C-2013 under the salt affected soils; whereas plants of C-2169 under normal soil attributed the maximum value

(125.5 cm). In case of salt affected soils, the mean height of clones from maximum to minimum was PE-11 > P-23> P-27> C-2169> C-405> C-2135> P- 48> C-2013. C-2013 recorded the lowest value in salt affected soil.

Table 4.6 Plant heights (cm) of *Eucalyptus* clones grown under different soil types (Age 140 days)

Clone	Soil Type			Mean
	Normal soil (S_1)	**Salt affected soil (S_2)**	**Mixed soil (S_3)**	
PE-11	125.00	112.25	116.25	117.83
C-2169	125.50	72.50	78.25	92.08
C-2013	115.50	56.00	75.25	82.25
C-2135	88.75	62.00	73.00	74.58
P-27	123.00	74.75	81.50	93.08
P-23	109.25	77.00	69.25	85.17
P-48	122.50	59.00	91.75	91.08
C-405	100.25	62.50	68.00	76.92
Mean	**113.72**	**72.00**	**81.65**	
LSD (5%) Clone= 9.82;	Soil type= 6.01;		Interaction= 17.00	

Table 4.7 shows the observations of collar diameter (mm) of Eucalyptus clones at age of 45 days. Both the treatments i.e clones and soil type had significant effect on the collar diameter. Prima facie it was noted that PE-11 attained significantly superior value (5.33 mm) and was followed by C-2013 (4.14 mm) and C-2135 (3.90 mm). The ranking of clones from maximum to minimum was PE-11> C-2013> C-2135> P- 48> P-23> C- 405> P-27> C-2169. C-2169 performed poor in collar diameter as well as in height. Soil type 1 (Normal soil) resulted the highest collar diameter growth (3.88 mm) which was however at par with that of mixed soil. It is clear that overall performance of clones in S_1 (Normal soil) was good and the lowest growth was in S_2 (salt affected soils).

Table 4.7 Collar diameter (mm) of *Eucalyptus* clones grown under different soil types (Age 45 days)

Clone	Soil Type			Mean
	Normal soil (S_1)	**Salt affected soil (S_2)**	**Mixed soil (S_3)**	
PE-11	5.45	4.77	5.76	5.33
C-2169	2.98	2.82	2.88	2.89
C-2013	4.70	3.68	4.04	4.14
C-2135	3.62	3.85	4.49	3.99
P-27	3.29	2.76	2.96	3.01
P-23	3.83	3.12	3.07	3.34
P-48	3.76	2.98	3.50	3.42
C-405	3.40	3.12	3.06	3.19
Mean	**3.88**	**3.39**	**3.72**	
LSD (5%) Clone= 0.44; Soil type= 0.27; Interaction= NS				

Second observation of collar diameter of eight *Eucalyptus* clones was observed at an age of 110 days and is given in the Table 4.8. The mean collar diameter values differed significantly among the clones. PE-11 maintained its top rank with value of 8.25 mm and was significantly superior to the other clones. C-405 got the next best value (5.28 mm) but was at par with five clones i.e P-23, P-48, C-2135, C-2013 and C-2169. The minimum value for collar diameter was noticed in clone P-27 (4.61 mm). With respect to soil types, there were significant variations among the clones thus normal soil types attained the highest mean (6.76 mm) and the rankings of soil types in clone means noticed as S_1 (6.76mm) > S_3 soil (5.28mm) > S_2 soil (4.16mm). PE-11 recorded the highest value (9.20mm) in the S_3 soil. It is clear that there were significant differences among the means of clones and the performance of clone PE-11 was outstanding as compared to other clones.

Table 4.8 Collar diameter (mm) of *Eucalyptus* clones grown under different soil types (Age 110 days)

Clone	Soil Type			Mean
	Normal soil (S_1)	Salt affected soil (S_2)	Mixed soil (S_3)	
PE-11	8.60	6.96	9.20	8.25
C-2169	6.52	3.75	4.34	4.87
C-2013	6.65	3.60	4.66	4.97
C-2135	5.98	3.86	5.28	5.04
P-27	5.90	3.74	4.19	4.61
P-23	7.13	4.03	4.21	5.12
P-48	6.47	3.45	5.26	5.06
C-405	6.82	3.89	5.14	5.28
Means	**6.76**	**4.16**	**5.28**	
LSD (5%) Clone= 0.43;	Soil type= 0.44;	Interaction= NS		

Table 4.9 shows the observations of collar diameter (mm) of Eucalyptus clones at age of 140 days grown under different soil types. There was significant variation among the clones and the ranking of clones from maximum to minimum was PE-11 > P- 48> C-2169> C- 405> C-2135 > P-23> P-27> C-2013. At first glance, it is noted that PE-11 attained the maximum collar diameter value 10.01 (mm) and was superior to other clones. The mean collar diameter in S_1 (normal soil) was significant superior with an average of 9.25 (mm) compared to S_2 and S_3. The lowest value was recorded in S_2 (salt affected soil). In case of salt affected soils, the mean collar diameter of clones from maximum to minimum was PE-11 > P-27> C-2169> C-2135> P-23> C-405> P- 48> C-2013. C-2013 recorded the lowest value (3.91 mm) and PE-11 registered the highest value (8.62 mm) in salt affected soil.

Data on growth trait of *Eucalyptus* clones under different type of soils showed significant difference among the clones and soil types ($p<0.05$). With respect to height and collar diameter PE-11 noticed as most promising clone under the each soil type (Table 4.4, Table 4.5, Table 4.6, Table 4.7, Table 4.8 and Table 4.9). The performances of clones under the normal soil (S_1) were found to be significantly superior to other soil types at all ages (45, 110 and 140 days). The Lowest values of clones were recorded in salt affected soil (S_2). It may be due to increased salt concentration in salt affected soil (Marcar *et al* 2002 b).

Morabito *et al* (1994) also reported that with increase in salt concentration, the growth of *Eucalyptus microtheca* clones was adversely affected. They studied the clonal variation of *Eucalyptus* clones in the salt affected soils. Height of clone 37 and 42 decreased in higher salt concentrations. Moreover, survival of the plants also decreased in high salinity treatments. The finding of Nasim et al (2009) was in conformity with the present study. Decreased growth of height and collar diameter of different *Eucalyptus* species under salinity conditions were observed by them. In another study, Nasim *et al* (2007) also observed the decreased DBH and plant height of *Eucalyptus camaldulensis* under increased salinity level. Moratibo *et al* (1996) reported the decreased shoot elongation of *Eucalyptus microtheca* plants under the increased level of salinity. Similarly, Singh *et al* (2010) reported the significant reduction in collar diameter and plant height under increased salinity levels.

Table 4.9 Diameter (mm) of *Eucalyptus* clones grown under different soil types (Age 140 days)

Clone	Soil Type			Mean
	Normal soil (S_1)	Salt affected soil (S_2)	Mixed soil (S_3)	
PE-11	11.34	8.62	10.08	10.01
C-2169	8.98	5.68	6.90	7.19
C-2013	8.74	3.91	6.68	6.44
C-2135	8.98	5.63	6.64	7.08
P-27	8.27	6.03	6.50	6.93
P-23	9.07	5.40	6.75	7.07
P-48	9.20	5.15	7.69	7.34
C-405	9.42	5.40	6.68	7.17
Mean	**9.25**	**5.73**	**7.24**	
LSD (5%) Clone= 0.84;	Soil type= 0.51;	Interaction= NS		

4.2.1.2 Number of leaves and branches

Table 4.10 presents the results regarding number of leaves of *Eucalyptus* clones grown under different types of soils. At first sight, it was noticed that there were a significant differences among the clones. On the other hand, the mean numbers of leaves, of different clones were significantly at par. The mean number of leaves value in clone PE 11 was 13.25. The ranking of clones from maximum to minimum was noticed as this PE-11> C-405> C-2013 > P- 27> P-48> P-23> C-2169> C-2135. It was observed that interaction between the clones and soil types was non-significant.

Table 4.10 Number of leaves of *Eucalyptus* clones grown under different soil types (Age 45 days)

Clone	Soil Type			Mean
	Normal soil (S_1)	**Salt affected soil (S_2)**	**Mixed soil (S_3)**	
PE-11	13.00	13.75	13.00	13.25
C-2169	7.25	5.50	4.25	5.67
C-2013	9.25	4.50	8.00	7.25
C-2135	3.75	3.75	6.25	4.58
P-27	8.25	6.25	7.00	7.17
P-23	7.50	7.00	5.50	6.66
P-48	7.75	7.00	6.50	7.08
C-405	9.00	7.75	7.75	8.17
Mean	**8.22**	**6.94**	**7.28**	
LSD (5%) Clone= 2.0;	Soil type= NS;		Interaction= NS	

The mean number of leaves in *Eucalyptus* clones after 110 days are given in Table 4.11. Both treatments i.e clone and soil type had significant effect on the number of leaves of the plants. Number of leaves in clone PE-11 was the highest (77.08) and in P-27 was the lowest (25.08). It had been clearly seen that the number of the leaves in normal soil was significantly higher (63.25) than those in mixed soil (32.84), whereas the lowest value was observed in salt affected soils (25.40). The interaction effect was found to be non-significant.

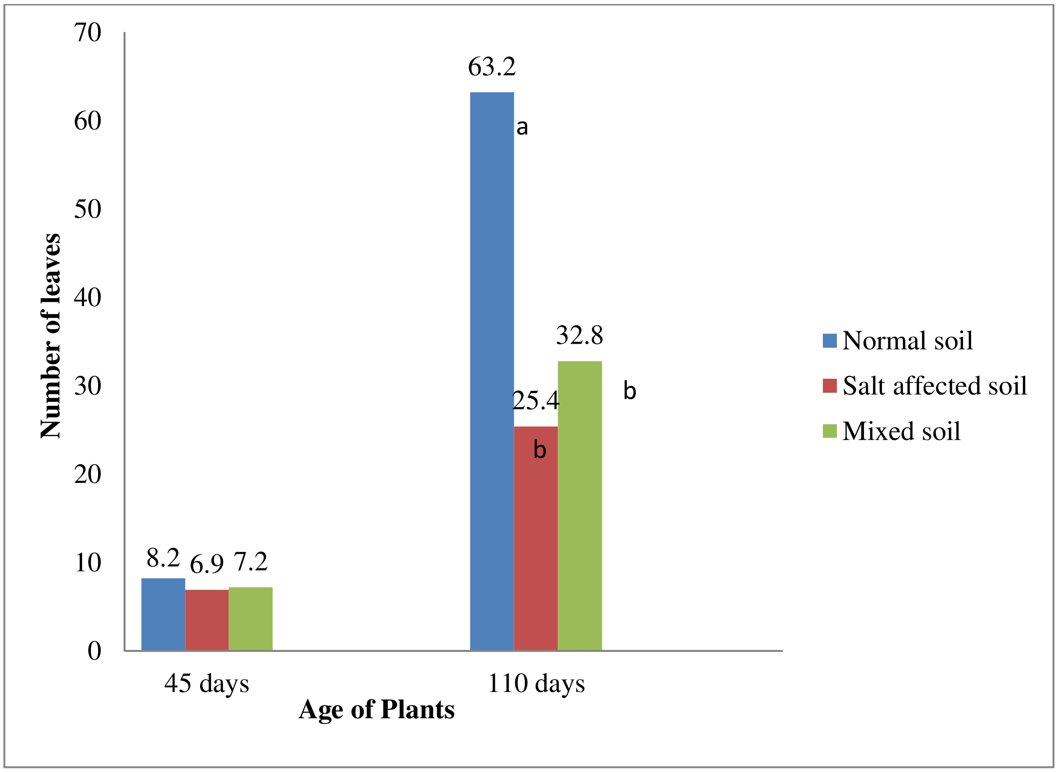

Figure 4.2 Number of leaves of Eucalyptus clones with respect to different soil types

Table 4.11 Number of leaves of *Eucalyptus* clones grown under different soil types (Age 110 days)

Clone	Soil Type			Mean
	Normal soil (S_1)	Salt affected soil (S_2)	Mixed soil (S_3)	
PE-11	101.75	68.75	60.75	77.08
C-2169	48.25	18.25	25.25	30.58
C-2013	56.75	16.25	28.50	33.83
C-2135	65.50	22.25	31.00	39.58
P-27	37.75	18.00	19.50	25.08
P-23	61.00	19.00	25.50	35.16
P-48	46.75	15.50	29.00	30.41
C-405	88.25	25.25	43.25	52.25
Mean	**63.25**	**25.40**	**32.84**	
LSD (5%) Clone= 13.69;	Soil type= 8.38;	Interaction= NS		

Number of branches per plant of different Eucalyptus clones under various soil types is given in the Table 4.12. Significant differences among the clones were noticed. The highest value (8.00) was found in case of C-405 and the lowest value (1.58) was registered by the clone C-2013. The relative ranking of clones with respect to number of branches was C-405 > PE-11> P- 23> C-2169> P-48> C-2135> P-27>C-2013. With respect to soil types, the differences among treatments were found to be significant. The interaction between the clone and soil type was found to be non-significant. It was observed that mean number of branches (2.50) of *Eucalyptus* clones in salt affected soils was the lowest, which was significantly lower than those in normal soil (7.68). In case of salt affected soils clone PE-11 attained the top rank in mean number of branches. The present study showed significant variation in the number of branches among the clones and soil types.

Table 4.12 Number of branches/plant of *Eucalyptus* clones grown under different soil types (Age 110 days)

Clone	**Soil Type**			**Mean**
	Normal soil (S_1)	**Salt affected soil (S_2)**	**Mixed soil (S_3)**	
PE-11	8.50	6.25	6.50	7.08
C-2169	9.50	2.25	2.25	4.66
C-2013	2.00	0.75	2.00	1.58
C-2135	6.25	1.25	2.50	3.33
P-27	6.00	1.50	1.75	3.08
P-23	8.50	0.00	1.75	5.12
P-48	7.75	1.50	1.25	3.50
C-405	13.00	4.00	7.00	8.00
Mean	**7.68**	**2.50**	**3.12**	
LSD (5%) Clone= 2.0;	Soil type= 1.28 ;		Interaction= NS	

In the present study the significant differences ($p<0.05$) among the clones was noticed at different age (45 and 110 days, Table 4.10 and Table 4.11). Clone PE-11 exhibited first rank and was significantly superior to the remaining clones. The findings of Sun and Dickinson (1993) are in conformity with the present study. They studied the 16 *Eucalyptus* species and found the significant variation between the performances of clones. The number of leaves in normal soil was higher as compared to salt affected soil (Figure 4.2). Singh *et al* (2010) reported the significant reduction number of leaves under increased salinity levels. Like number of leaves, the effect of clone and soil types were also significant on the number of branches per plant.

4.2.2 Shoot and Root biomass

After the completion of the experiment, the plants were uprooted from the pots and fresh and dry weights of plants were noted by partitioning of plants in three means as leaves and branches, stem and roots.

Table 4.13 presents the data of dry weights of Leaves and Branches of *Eucalyptus* clones grown under different soil types. In the mean dry weights of leaves and branches, significant differences among clones were observed. Maximum mean dry weight biomass was registered by clone PE-11 (46.56 g) in all soil types under study which was significantly superior to remaining seven clones .Minimum mean dry weight was registered by clone P-48 (22.63 g) .Mean dry weights in normal soil were found to be greater than other soil types and it was ranked maximum to minimum as Normal soil (49.59 g) > Mixed soil (19.33 g) > Salt affected soil (12.98g). It is concluded that the mean dry weights of mixed soil and salt affected soil was substantially lesser than normal soil and interaction effect was found to be non-significant. In case of salt affected soils, dry weight of clones from highest to lowest was PE-11 > P-27> P-23> C-2169> C-2135> C-405> P- 48> C-2013.

Table 4.13 Dry weights (g/plant) of leaves and branches of *Eucalyptus* clones grown under different soil types

Clone	Soil Types			Mean
	Normal soil (S_1)	**Salt affected soil (S_2)**	**Mixed soil (S_3)**	
PE-11	74.25	29.15	36.30	46.56
C-2169	44.15	11.60	17.13	24.29
C-2013	42.05	4.86	17.26	24.14
C-2135	49.15	10.60	16.66	25.47
P-27	41.15	12.40	16.65	23.40
P-23	53.00	11.80	15.85	26.88
P-48	41.70	8.45	17.75	22.63
C-405	51.30	10.60	17.05	33.30
Mean	**49.59**	**12.98**	**19.33**	
LSD (5%) Clone= 5.16; Soil type= 3.16; Interaction= NS				

Table 4.14 shows the results of stem dry weight of Eucalyptus clones grown under different soil types. At first glance it was noted that PE-11 attained the maximum mean dry stem biomass (25.39 g) and it was significantly superior from other clones. Similarly there was significant variations between the clones and the ranking of clones followed PE-11> P-27 > P- 48> C-2169> P-23> C-2013> C- 405> C-2135. Interaction effects were significant. The mean weight of dry stem in Normal soil was significantly superior (26.10 g) to other soil types. To put it into a nutshell it is clear to see that overall performance of clones in S_1 (normal soil) was maximum and S_2 (salt affected soils) was minimum. In case of salt affected soils clone PE-11 attained the top rank.

Table 4.14 Dry weights (g/plant) of Stem of *Eucalyptus* clones grown under different soil types

Clone	Soil Types			Mean
	Normal soil (S_1)	Salt affected soil (S_2)	Mixed soil (S_3)	
PE-11	42.75	15.65	17.77	25.39
C-2169	22.90	7.90	8.80	13.20
C-2013	28.15	3.33	6.45	12.64
C-2135	17.80	4.33	6.40	9.51
P 27	27.25	6.13	9.40	14.26
P 23	24.20	6.00	8.86	13.47
P 48	26.85	3.40	10.15	12.61
C-405	22.95	5.80	6.60	11.78
Mean	**26.10**	**6.56**	**9.30**	
LSD (5%) Clone= 2.25;	Soil type=1.37;		Interaction= 3.90	

Biomass of roots per plant is given in the Table 4.15. Maximum mean dry weight of roots was found in clone PE-11(27.50 g). The ranking of clones from highest to lowest values were recorded as PE-11> P-27> P-48> P-23 > C-2135 > C-2013> C- 405> C-2169. The mean dry weight of root in normal soil (28.64 g) was found to be significantly superior than mixed soil (15.90 g) and salt affected soil (8.29 g). Interaction effects between soil types and different clones were found significant. In case of salt affected soils, dry weight of clones from maximum to minimum was PE-11 > P-27> C-2135> C-2169> C-405> P-23> P- 48> C-

Normal soil

Salt affected soil

Mixed soil

Plate 3: Performance of *Eucalyptus* clone C-413 under different soil types.

2013. PE-11 attained the top rank and C-2013 registered the lowest value (4.40) in salt affected soils.

Table 4.15 Dry weights (g/plant) of Roots of *Eucalyptus* clones grown under different soil types

Clone	Soil Types			Mean
	Normal soil (S_1)	**Salt affected soil (S_2)**	**Mixed soil (S_3)**	
PE-11	39.45	18.25	24.80	27.50
C-2169	21.30	8.53	13.53	14.45
C-2013	25.75	4.40	14.53	14.89
C-2135	25.50	8.46	15.40	16.45
P-27	28.00	8.93	17.85	18.26
P-23	29.25	6.13	15.65	17.01
P-48	31.25	5.33	15.70	17.43
C-405	28.60	6.30	9.70	14.87
Mean	**28.64**	**8.29**	**15.90**	
LSD (5%) Clone= 3.20; Soil type= 2.32 **;** Interaction= 5.58				

Data on Biomass of leaves and branches, stem and roots were found to be significantly different under different soil types ($p<0.05$). Under normal soil (S_1) the performances of clones were observed as significantly superior to remaining soil types (Figure 4.3). The biomass of leaves and branches, stem and roots decreased under salt affected soil (S_2). The findings of Marcar *et al (*2002 b) are in conformity with the present study. They found reductions in shoot biomass of *Eucalyptus camaldulensis* plants due to increased salinity levels in pots. Similar study by Sánchez *et al* (2015) also reported the decreased biomass of *Aruna donax* L. plants in saline conditions. In the present study reduced growth in S_2 (Salt affected soil) may be due to decreased plant available water. Gangwar *et al* (2015) evaluated *Eucalyptus* clones at poor varying edaphic conditions, also found significant differences among clones for above ground biomass.

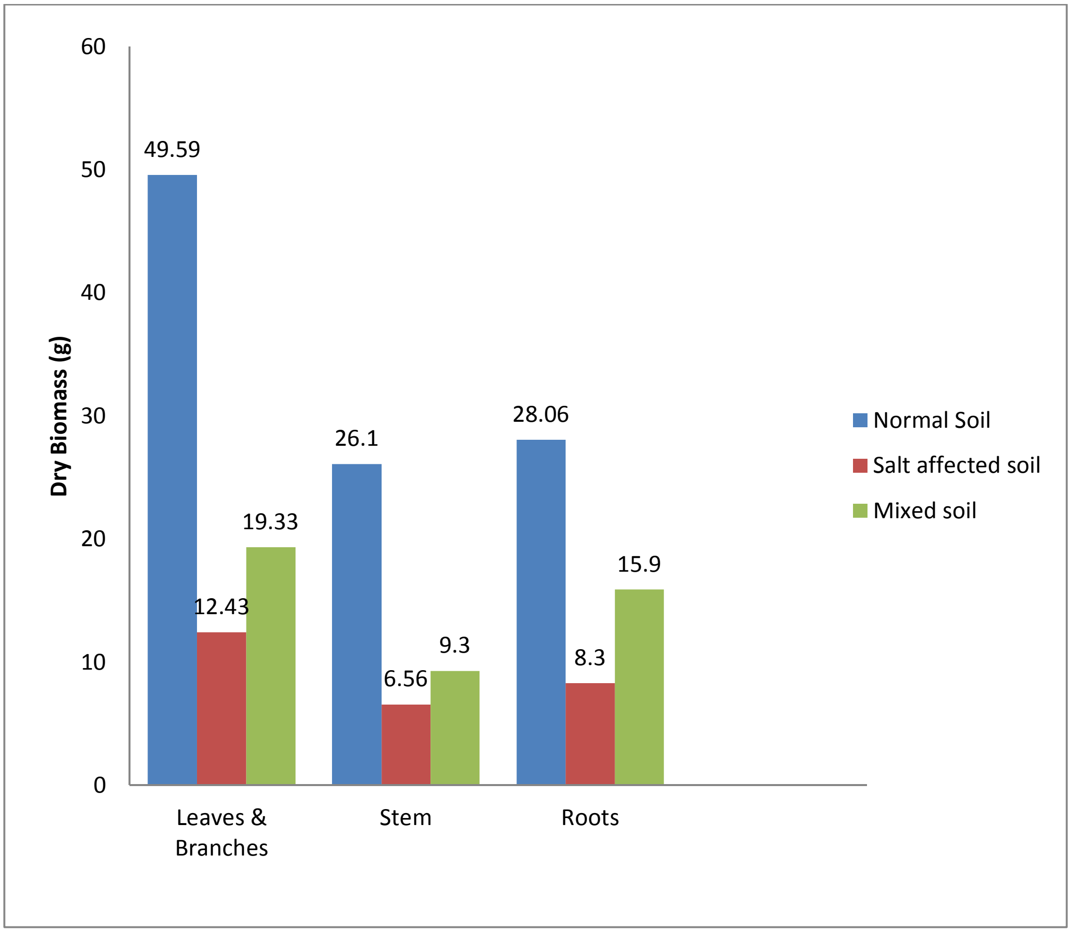

Figure 4.3 **Dry weights of leaves & branches, stem and roots of *Eucalyptus* clones grown under different soil types.**

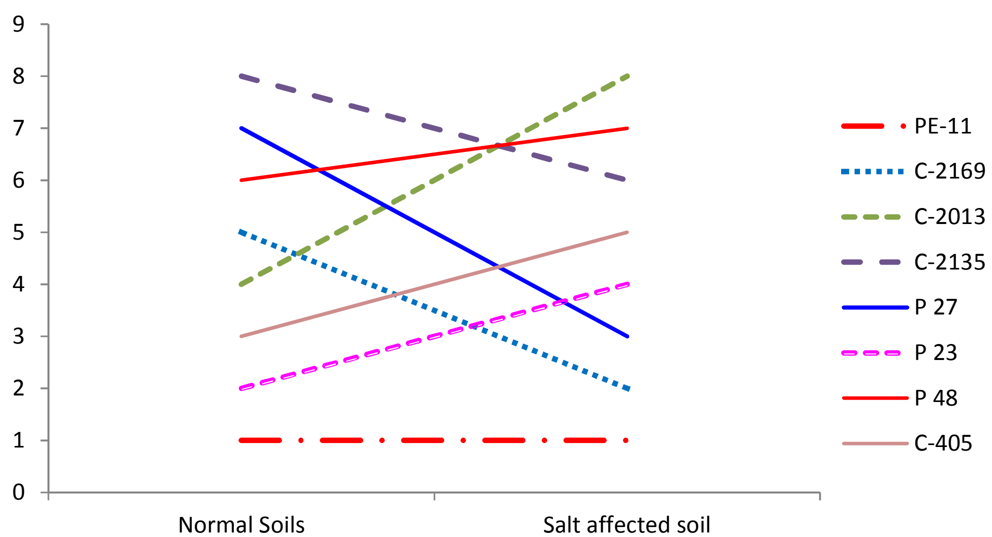

Figure 4.4 **Relative ranking of eight *Eucalyptus* clones for dry shoot biomass under two soil types**

The change in relative rank for dry shoot biomass of clones was noticed between normal and salt affected clones. Clones like PE-11 and P-48 were stable performances whereas clones like P-27, C-2169 and C-2013 experienced huge fluctuations in the relative ranks.

4.3 Performance of Eucalyptus clones under simulated water conditions

In this experiment, two clones (C-413 and PE-1) of Eucalyptus were planted in drums having two water table depths (30 cm and 60 cm). Observations in growth traits at various ages were recorded.

4.3.1 Height measurements

Figure 4.5 depicts the data of plant height of *Eucalyptus* with respect to clones during various ages (5.5, 7 and 12 months respectively). The significant differences between the clones were observed at age of 7 and 12 months. Mean height at 5.5 months was found to be non-significant. At age of 12 months clone C-413 attained the maximum height (4.5 m) and it was significantly superior than PE-1 (3.8 m). The mean height of C-413 and PE-1 was 3.2 m and 2.6 m respectively at age of 7 months.

Data of plant height of *Eucalyptus* clones with respect to level of waterlogging during various ages is shown in Figure 4.6. The significant differences were observed between the water table depths. At 60 cm waterlogging level the values were found to be maximum and significantly superior during all the ages. At age of 12 months, mean plant height of plants at 60 and 30 cm waterlogging level was recorded as 4.5 m and 3.8 m respectively.

4.3.2 Collar Diameter measurements

Results of collar diameter of *Eucalyptus* plants with respect to clones are display in Figure 4.7. At age of 5.5 months significant differences were recorded between the clones. Maximum value was registered of PE-1 (21 mm) and it was significantly superior than that of C-413. After 7 months, differences between the clones were non-significant. Maximum collar diameter at 12 months age was registered by C-413 (42 mm) and lowest value was recorded in case of PE-1 (40 mm).

Figure 4.8 displays the data of collar diameter of *Eucalyptus* plants with respect to level of waterlogging. Significant differences were found at all the ages and the values at 60 cm were significantly higher. At 12 month age, mean collar diameter at 60 cm water table depth was recorded maximum (44 mm) and minimum (37 mm) at 30 cm level of waterlogging.

Davidson and Tay (1985) attributed the poor growth in waterlogging conditions due to blockage of the vessels and decreased transpiration rate. Sandhu (2016) also found decreased growth of *Eucalyptus* clones under waterlogged conditions. The difference between the clones was also found to be significant ($p<0.05$) and the C-413 performed significantly higher at all ages.

The data of growth trait of Eucalyptus clones under simulated water conditions showed significant differences between the clones and level of waterlogging (30 cm and 60 cm). At 60 cm water table depth growth traits were found to be increased (Figure 4.6 and Figure 4.8) and C-413 performed better under both water table depths and registered the maximum value. The decreased growth of both clones at 30 cm water table depth may be attributed to decreased aeration in root zone. Florentine and Fox (2002) also observed the decreased growth in flooding conditions. Decreased stomatal conductance, transpiration and photosynthesis in plants under flooding environments were noticed by them. Reduced growth of *Eucalyptus camaldulensis* plants were found by Youngsukying and Nakasathien (2008) under waterlogged conditions. Rate of transpiration, net photosynthetic rate and stomatal were reduced in their study. In the present study height and collar diameter at 30 cm level of waterlogging, the values were minimum. This may attributed due to limited oxygen availability under waterlogged conditions (Dat *et al* 2004).

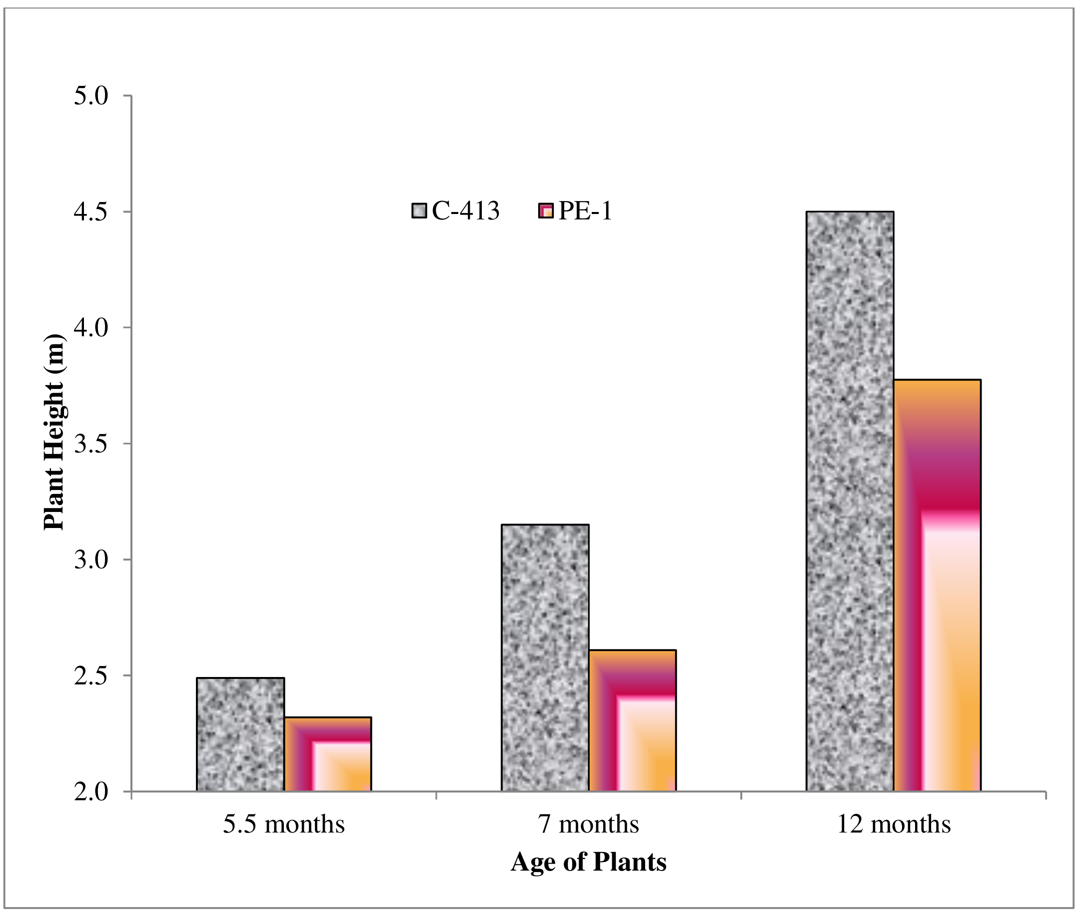

Figure 4.5 Plant height of *Eucalyptus* clones raised under simulated waterlogging conditions.

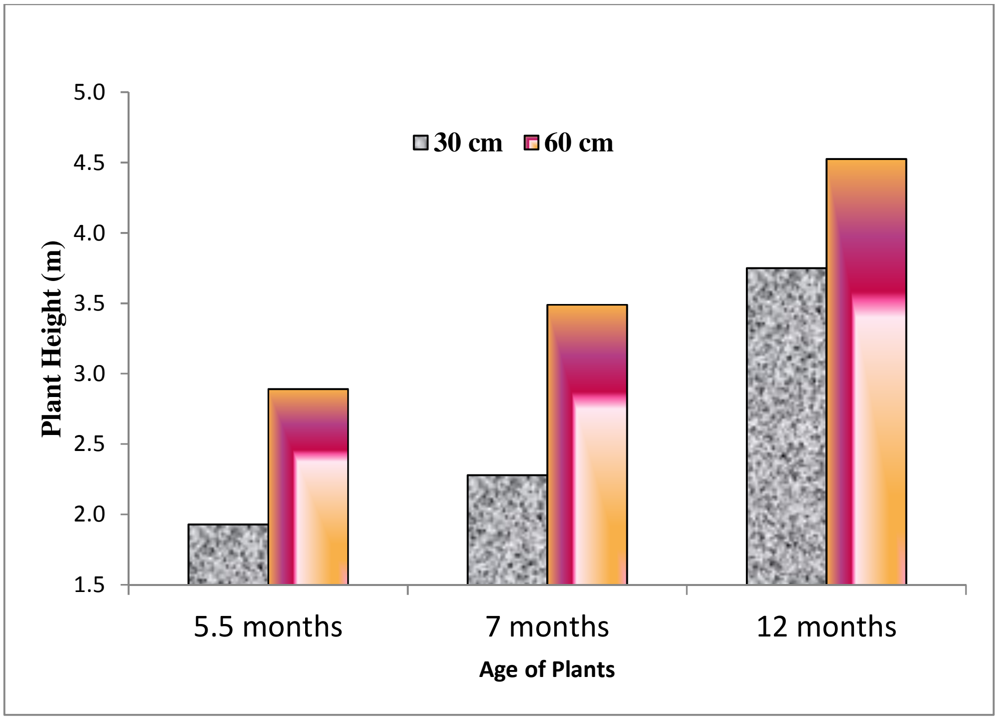

Figure 4.6 Plant height of *Eucalyptus* clones respect to level of water table.

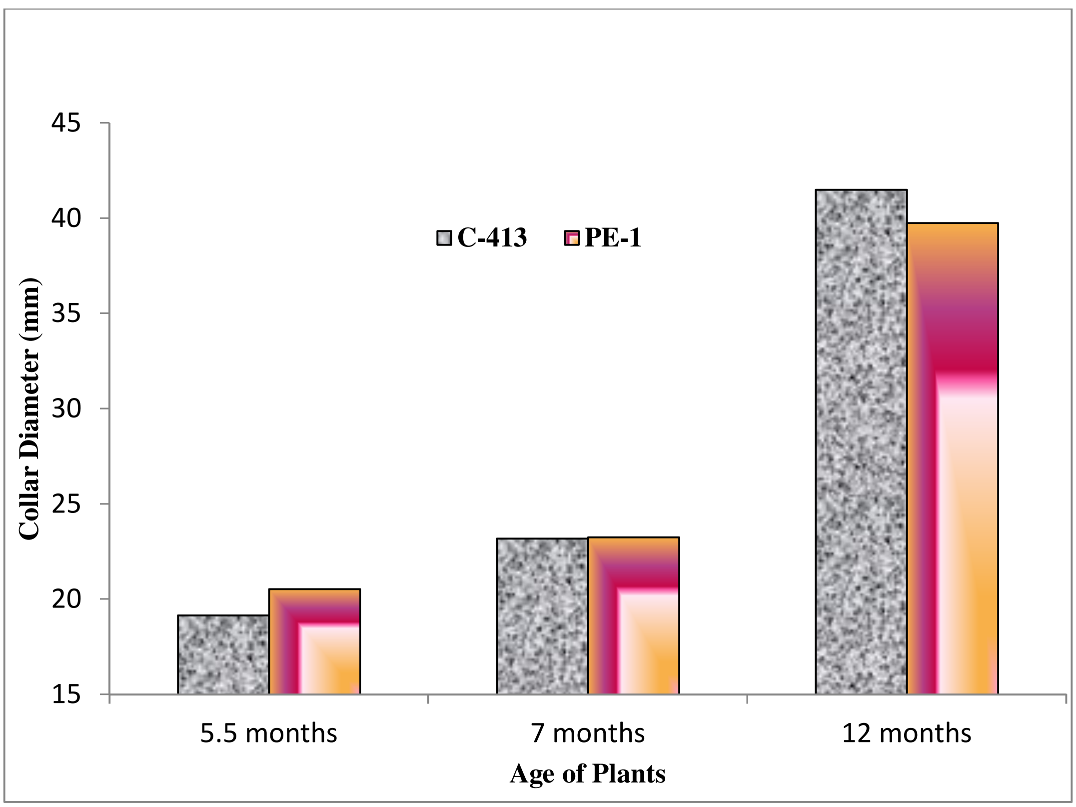

Figure 4.7 Collar diameter of *Eucalyptus* clones under simulated waterlogging conditions.

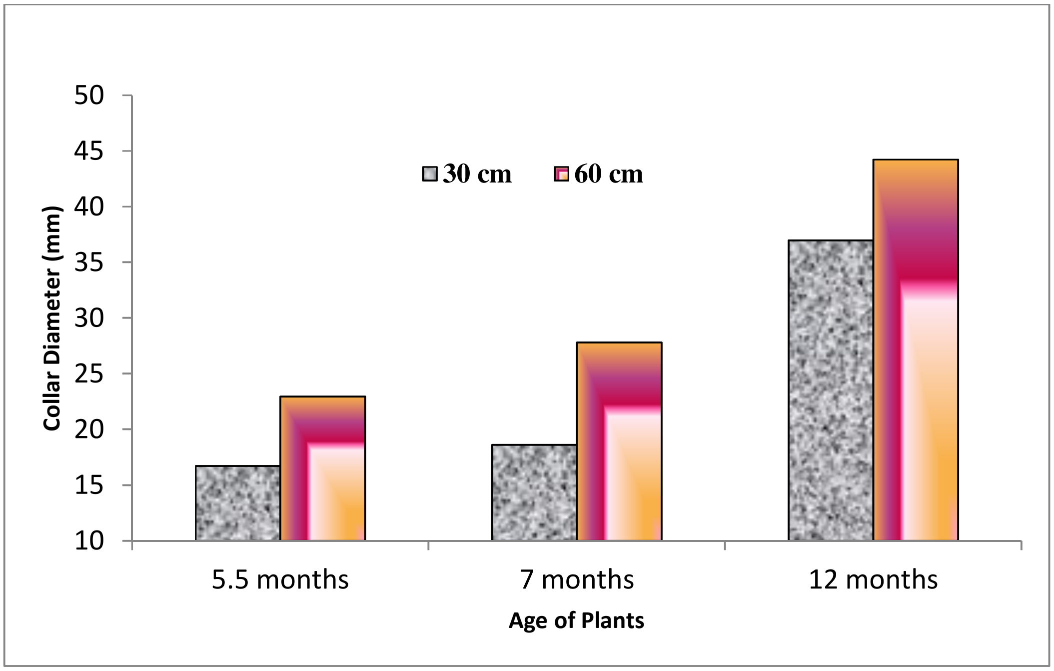

Figure 4.8 Collar diameter of Eucalyptus plants with respect to level of water table.

The present study showed that *Eucalyptus* clones established well under both the waterlogging levels. Earlier studies have also indicated the potential of *Eucalyptus* for bio drainage. Bilal *et al* (2014) reported that *Eucalyptus* based bio drainage techniques are more economical because it requires lower initial investment, provides good returns and sequester carbon in the timber. Chhabra and Thakur (1998) conducted a lysimeter study for four years and concluded that *Eucalyptus* had significantly higher bio drainage capacity at 1.5 metre than that of at 2 meter water table.

CHAPTER-V

SUMMARY

Eucalyptus is a versatile genus, belongs to Myrtaceae family. It can adapt to a varied range of edaphic and climatic conditions. It is a fast growing tree and grows well in a wide variety of soil conditions. *Eucalyptus* is native of Australia, and was introduced in India in the early 18^{th} century. In India, the majority of *Eucalyptus* plantations on government, forest, farm lands, community lands and along road / rail / canal strips are of seed origin. The most plantations are made to rejuvenate the denuded and barren hilly areas and replace low value natural forests. Most of the eucalypt plantations in India were raised during the time span of 1960 -1980. During this period the atmosphere for planting eucalypts was congenial as the foresters, scientists and workers advocated the concept that eucalypts are the adequate species for planting in degraded forests, barren lands and marginal private lands.

Tree breeding is the application of genetic principlesfor solving any productivity or tolerance objectives by using silvicultural practices. Considerable genetic diversity is found in *Eucalyptus* because of their high outcrossing nature and ability to hybridize naturally with other species of the genus. The high variation for tolerance to salt affected sites and marshy lands has been reported. These variations can be captured through selection of tolerant genotypes to abiotic stresses and by using planting stock originated from the tolerant trees. Several institutes of India had initiated the tree improvement programme on *Eucalyptus* and developed several clones. Punjab Agriculture University, Ludhiana has recently developed new clones on the basis of their growth and tolerance to insects and diseases.

The present investigations were carried out at two different locations i.e liquor factory, Machhana (Bathinda) and main experimental area of the Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana during 2016-2018. The entire study included three different experiments. In first experiment, nine *Eucalyptus* clones viz. C-413, PE-5, PE-6, C-2045, PE-11, PE- 1, C-411, PE-7and PE-8 were studied under effluent irrigated conditions. Survival percentage of the trees was counted and various parameters like tree height and DBH were recorded at three different ages (4.5, 8 and 12 months). Survival varied from 95 to 100 per cent and differences among clones were non-significant. With respect to height and DBH, significant differences were found among the clones. Clone C-413 was observed as most promising clone regarding mean height under effluent irrigation. The relative rankings of clones for mean height was witnessed as C-413> PE-5> PE-6> C-2045> PE-11 > PE- 1> C-411> PE-7> PE-8. The minimum value in mean height was registered by clone PE-8.In terms of DBH, PE-5 attained the highest and PE-8 got the lowest rank. The relative ranking with respect to DBH was PE-5> C-413> PE-6> PE- 1> C-411> PE-7> C-2045 > PE-11> PE-8.

In second Experiment eight Eucalyptus clones viz. PE-11, C-2169, C-2013, C-2135, P-27, P-23, P-48, and C-405 were studied under three different types of soil (normal soil, salt affected soil and mixed soil). Various observations like plant height, collar diameter, number of leaves and branches, dry biomass of leaves & branches, dry weight of shoot and dry weight of roots were recorded. PE-11 recorded the highest value and C-2135 recorded the lowest value with respect to mean plant height. The relative ranking regarding mean height was PE-11 > P-48> P- 27>C-2013 > P-23> C-2169> C-405> C-2135. Regarding various soil types, significant differences were recorded. Mean values in normal soils were maximum and in salt affected soils were minimum. In terms of collar diameter significant differences were observed among the clones and soil types. Clone PE-11 registered the highest value and P-27 recorded the lowest value regarding mean collar diameter. Data on number of leaves among clones as well as among soil types were found to be significant. Clone P-27 recorded the lowest value regarding number of leaves. PE-11 recorded the maximum number of leaves in each soil type. Number of branches among the clones as well as among soil types were found to be statistically different. The relative ranking of clones with respect to number of branches was C-405 > PE-11> P- 23> C-2169> P-48> C-2135> P-27>C-2013. Clone C-405 recorded the highest value. With respect to soil types, in normal soil plants attained the top rank and the lowest values were in case of salt affected soil in terms of number of branches. Dry weight of leaves and branches was found to be significant among clones as well as among soil types. PE-11 exhibited the maximum values and P-48 booked the minimum values. Interactions among the clones were found to be non-significant. With respect to dry weights of leaves and branches, normal soil registered the significantly highest values among the soil types. In terms of dry weight of stem and roots, significant differences among the clones as well as among the soil types were observed. Interactions among the clones were also found to be statistically different. PE-11 attained the highest rank in the dry weights of both stem and roots. With respect to soil types relative ranking was normal soil > mixed soil > salt affected soil. Lowest root biomass was observed in salt affected soils.

In third experiment, *Eucalyptus* clones were studied under simulated waterlogged conditions. It includes two water table depths viz. 30cm and 60 cm and two clones viz. C-413 and PE-1. The differences between the clones as well as between the water table depths were found to be significant. The performance of clone C-413 was found to be significant superior to PE-1 in terms of mean height. With respect to collar diameter non-significant differences between the clones were found. C-413 recorded the maximum collar diameter. In terms of water table depths (30 cm and 60 cm) significant differences were found. At 60 cm level of waterlogging, the performances of clones regarding height and collar diameter were maximum and minimum values found at 30 cm water table depth.

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