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# Growth and Carbon Storage Potential of Different Eucalyptus Clones Irrigated with Industrial Effluents

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**ABSTRACT: Forest ecology plays a vital role in mitigating climate change challenges through carbon sequestration. Anthropogenic activities per se industrialisation are the major contributor to pollution by producing greenhouse gases and releasing effluents in the environment. However, plantations producing higher biomass under effluent irrigated conditions like Eucalyptus plantations are considered effective but the growth and carbon sequestration performance of diverse clones under effluent irrigated conditions is scarce. Therefore, in the present study, nine *Eucalyptus* clones were evaluated for growth traits and carbon storage potential under distillery effluent irrigated conditions. A clonal trial was planted at the liquor factory Macchana, near Sangat Mandi, Punjab with nine clones replicated four times following RCBD design. The data were recorded on survival, growth traits, biomass, and carbon storage was worked out. Survival percentage varied from 85-95% with non-significant differences among the clones. Significant variation in growth traits and carbon biomass was observed among *Eucalyptus* clones except for tree survival. Clone C-316 was found superior among all the clones for diameter, volume, carbon biomass and carbon sequestration, whereas clone PE-7 recorded maximum height. Clone PE-6 exhibited bottom rank for all growth traits except height. Carbon storage varied from 30.37 to 56.01 kg/tree. The investigation revealed that clones C-316, C-411 and PE-7 were found excellent for planting at effluent irrigated condition sites and for higher carbon sequestration.**

**Keywords:** Biomass, carbon stock, Eucalyptus, clones, wood volume, distillery effluents.

## INTRODUCTION

Anthropogenic activity has significantly increased the amount of $CO_2$ and greenhouse gases (GHGs) concentration in the atmosphere and has altered the global carbon cycle, causing drastic changes in the climate and biodiversity of the world. Forest degradation, deforestation, land use and land use changes, fossil fuel burning, industrial and automobile emissions are the largest contributors of greenhouse gases. Climate change is a major concern for the world and getting main attention in the scientific communities. In addition, carbon dioxide is likely to double in the coming years, if the current rate of increase persists, leading to a worldwide temperature rise of up to 2-4° C and global sea level would increase by 28-98 cm (IPCC, 2014), due to the melting of polar ice. The impact of carbon climate change can be mitigated through forests and plantations, which sequester $CO_2$ from the atmosphere, and store carbon in wood, leaves, litter, roots and soil by acting as "carbon sinks". Increase in forest cover and plantation will maximize carbon sequestration and also increase ecological, environmental, social, and economic value. Overall, the world's forest ecosystems are estimated to store more carbon than the entire atmosphere (Singh *et al.*, 2023).

In India, forest cover is 21.71 % and tree outside forests are 2.91 % with a total growing stock of 56.60 $m^3$/ha (FSI, 2021). Demand for forest products mainly timber and fuel wood has grown in recent years. *Eucalyptus* is one of the fast-growing widely planted exotic hardwood genera in tropical and subtropical regions of the world known for its adaptability to a wide range of environmental conditions when grown within or outside its natural range. *Eucalyptus* is being used for its multipurpose benefits *viz.*, timber, solid wood, furniture, packaging cases, paper manufacture, doors, windows, pulpwood and fuel, shelter belts and honey trees. Apart from their economic value, *Eucalyptus* plays an important role in mitigating global environmental problems such as global warming and climate change by $CO_2$ sequestration, due to its rapid accumulation of large quantities of biomass within a short period of time (Ashish *et al.,* 2022).

The *Eucalyptus* clonal plantations have shown a rise in productivity from 25-30 $m^3$/ha/year to 35-45 $m^3$/ha/year in the last 30 years, owing to genetic improvement and better silvi cultural practices (Rezende, 2014). *Eucalyptus* hybrids and clones are now widely preferred for research and field plantations in the country to meet the present and future wood needs. Wide genetic diversity among *Eucalyptus* genomic groups and selection of different genotypes within these groups increase potential growth and establishment for diverse uses across heterogeneous sites and help optimize the production of *Eucalyptus* for improved biomass yields. Growth and biomass allocation in species depends on the availability of resources, type of management, stand age, soil chemical and physical properties, and climatic condition (Don *et al.,* 2011; Maquere *et al.,* 2008). In the present scenario *Eucalyptus* considered as one of the main industrial plantation species, with more than 20 million ha worldwide and it is managed by private authorities to meet their pulp and plywood requirements (Booth, 2013).

Several studies have been conducted to estimate the carbon stocks in *Eucalyptus* stands, but there is still a dearth of studies on considering variation among different *Eucalyptus* clones under distillery effluent irrigated conditions. The objective of this study was to evaluate the growth and carbon storage potential of nine *Eucalyptus* clones irrigated with distillery effluent.

## MATERIALS AND METHODS

*A. Site Description*

The research was conducted in a liquor factory at Macchana near Sangat Mandi, Bathinda, Punjab, India (30º3' 55.4" N latitude and 74º 51' 18.6" E longitude) with an elevation of about 202 m above mean sea level. 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 the total amount of rainfall is predictable during July to September with an average of about 31 rainy days.

*B. Plant materials and experiment details*

In this study, nine *Eucalyptus* clones were used (Table 1). Each clone was replicated four times with Randomized Block Design and plot size of 5 plants. One row of the non-experimental plants was planted around the trial. The plants were regularly irrigated with treated industrial effluent from the liquor factory.

**(i) Tree growth and biomass.** The growth traits i.e. diameter at breast height and tree height were recorded with the help of vernier's calliper and Ravi altimeter, respectively. Number of survived trees were counted for working out survival percentage. Four trees of each clone were harvested (one tree per plot from each of four replications) and logs of 3 m were made. Girth from both ends of each log was measured and used to calculate mean diameter. Volume of each log was calculated separately and volume of tree was calculated by adding four section of logs.

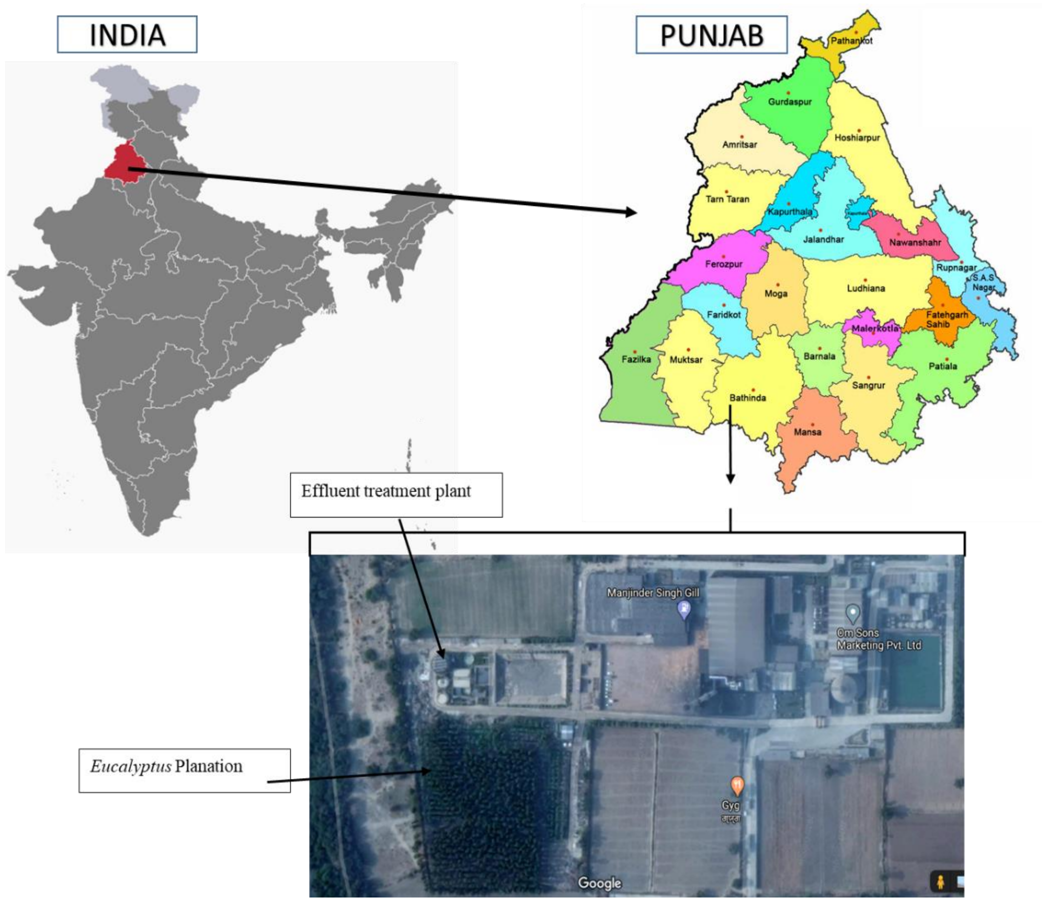


**Fig. 1.** Map of Experimental site.

**Table 1: Details of the *Eucalyptus* clones used in the study.**

| Sr. No. | Name | Origin of plus tree | Progeny/Provenance number |
|---|---|---|---|
| 1. | C-316 | FRI Dehradun | - |
| 2. | C-411 | ITC, Bhadrachalam paper mills | - |
| 3. | C-2045 | ITC, Bhadrachalam paper mills | - |
| 4. | PE-5* | Orissa University of Agriculture and Technology, Bhubaneshwar | OUAT, ET-10 |
| 5. | PE-6* | TNAU, Coimbatore | FC&RI, MTP/ET-5 |
| 6. | PE-7* | HAU, Hisar | HS-6 |
| 7. | PE-8* | Australia Seed Centre | 16547/JD1572 |
| 8. | PE-11* | Australia Seed Centre | 13547/JD1043 |
| 9. | C-413 | ITC, Bhadrachalam paper mills | - |

* These clones were developed by Punjab Agricultural University, Ludhiana

The biomass was separated into branches, stem and leaves. The fresh weight of biomass of different components of all the harvested *Eucalyptus* clones was recorded. Dry weight of wood biomass was estimated by wood samples collected from each clone and dried in oven at 75° to 80° C for 48 to 72 hours till the samples attained constant weight.

**(ii) Carbon storage.** Carbon storage was obtained by multiplying the biomass and the conversion coefficient of carbon content. Tree biomass was used to estimate carbon content of tree because 50 % of the biomass is composed of carbon. Carbon content was estimated with the following formula (Onrizal, 2004)

C= B× 0.5

Where

C = amount of carbon stock (t C/ha)

B = biomass (t/ha)

0.5 = carbon content

**(iii) Carbon sequestration.** Carbon sequestration (Co) was estimated with the following formula (Bismark*et al* 2008)

Sequestration of $CO_2$ = 3.67 × carbon content.

**(iv) Soil Organic Carbon.** Soil samples are collected at different depths i.e. 0-15, 15-30, 30-45 and 45-60 cm depth. Samples collected were transferred to the laboratory and were oven dried (70°C) until constant weight to determine water content. Samples were well-mixed, stones and plant residues (> 2mm) were removed. The carbon stock density of soil organic carbon was estimated (Pearson *et al.,* 2005):

SOC = rb × d × %C

Where,

SOC = soil organic carbon stock per unit area (t/ha)

rb = soil bulk density (g/cm$^3$) – Default value is 1.2

d = Total depth at which sample was taken (cm)

% C = carbon concentration (C must be expressed as a decimal fraction i.e. 2.2% C is expressed as 0.022)

*C. Statistical analysis*

Statistical analysis was performed as per the procedure laid down for Randomized Block design (RCBD). Analysis of variance, least significant difference (LSD 5%) and variance components were calculated for the interpretation of results of the study following Panse and Sukhatme (1989).

## RESULT AND DISCUSSION

*A. Survival and growth traits*

Survival of *Eucalyptus* clones ranged from 95 to 100 per cent and 90 to 95 per cent at age of one year and three year, respectively. Among nine clones three clones *viz*., C-316, C-411 and C-413 recorded the highest survival and there is no significant difference in survival among clones. Significant variation was recorded in growth traits (diameter, tree height and volume) among the nine *Eucalyptus* clones under study (Table 2). Diameter ranged from 9.98-13.01 cm and clone C-316 recorded the highest diameter and was statistically at par with clone C-411 and PE-7. Maximum height was recorded in clone PE-8 (17.16 m) and was statistically superior to all other clones. Per tree volume ranged from 0.122-0.066 m$^3$ amongst the different clones. Clone C-316 recorded a significantly higher volume and clone PE-6 recorded minimum diameter and volume whereas, clone PE-5 exhibited lowest height.

The high survival (90 to 95 %) showed that the clones had better adaptation to effluent irrigation site. Significant variation among the clones for all the growth traits, i.e. DBH, tree height and volume per tree at 3-year age was observed. Among all the clones, C 316, recorded significantly higher DBH and volume compared to the check clone (C-413). For tree height, clone PE-7 was statistically superior to rest of the clones and recorded higher values than check. Top four clones for volume were C-316>C-411>PE-7>PE-8. Variation in height, diameter and volume among *Eucalyptus* clones may be due to their different genetic makeup of individual clones as these were evaluated under uniform environmental condition. The similar findings were also recorded by (Singh *et al.,* 2020) in which the plantation was irrigated with industrial effluent and significant difference was observed among clones, which matches with our findings. The variation among genotypes/ clones irrigated with saline or effluents were earlier reported in *E. camaldulensis* (Grieve and Shannon 1999; Bhati and Singh 2003), hybrid *Eucalyptus* (Mughini *et al.,* 2013; Hopmans *et al.,* 1990), while studying inter-specific variation for growth, biomass and phytoremediation potential under municipal effluent irrigated area, also found variation in growth characteristics among 13 clones of *Eucalyptus* species.

*B. Tree biomass*

The differences among the clones were significant for all biomass components i.e. stem, branch and leaf biomass. Maximum fresh and dry stem biomass was recorded in clone C-316 (160.56 and 81.33 kg/tree) and statistically at par with C-411, PE-8, PE-7 and C-413 (Table 3).

**Table 2: Growth performance of 3 year old *Eucalyptus* clones irrigated with distillery effluent.**

| Clones | DBH (cm) | Height (m) | Volume ($m^3$) |
|---|---|---|---|
| **C-316** | 13.01* | 15.15 | 0.122* |
| **C-411** | 12.09 | 15.43 | 0.104 |
| **C-2045** | 10.88 | 15.22 | 0.084 |
| **PE-5** | 10.78 | 14.05 | 0.067 |
| **PE-6** | 9.98 | 14.09 | 0.066 |
| **PE-7** | 12.14 | 15.64 | 0.104 |
| **PE-8** | 10.9 | 17.16* | 0.098 |
| **PE-11** | 10.85 | 14.65 | 0.079 |
| **C-413 (Check)** | 11.10 | 14.78 | 0.082 |
| **Mean** | 11.31 | 15.07 | 0.089 |
| **CD (5%)** | 1.67 | 1.71 | 0.029 |

* indicates significant at 5 % level

Minimum biomass (fresh and dry weight) was observed in clone PE-6 (94.1kg/tree and 48.73 kg/tree, respectively). The maximum fresh branch biomass was recorded in clone C-316 which was significantly higher than those of clone C-2045, PE-5 and PE-6 and at par with other clones. The maximum value of dry branch biomass was again attained by C-316 which was statistically similar with those of PE-7, C-411, PE-8 and C-413. Minimum fresh and dry biomass was observed in clone PE-6 and PE-5, respectively. The leaf fresh and dry biomass was again maximum in clone C-316 (20.83 kg/tree and 7.94 kg/tree, respectively). In comparison to check clone (C-413), no clone reported significantly higher fresh and dry stem and branch biomass.

With respect to the above ground fresh biomass (stem + branch + leaves), clone C-316 was found to be superior clone, which is statistically significant than four clones PE-11, C-2045, PE-5, PE-6. The clones which are statistically at par with clone C-316 recorded numerically more values than mean biomass. Minimum biomass was recorded in clone PE-6 (122.17 kg/tree) followed by PE-5 with 136.27 kg/tree. The present study found significant differences among the *Eucalyptus* clones for all components of biomass i.e. stem, branch, leaf and root biomass. For all the components, the numerically highest value was in case of C-316. It was statistically at par with four clones (C-411, PE-7, PE-8, and C-413) with slight rank changes between them in different components. The biomass of a tree is a cumulative effect and depends upon growth traits (diameter, height), form factor and crown architecture. In this study clone PE-7 was at $5^{th}$ rank for diameter but recorded significantly higher tree height, and was among top four clones for all the dry biomass components. The biomass of clones was proportional to their growth (diameter and height) respectively which is in conformity with findings of Roy *et al.* (2006). Similar results were also found in earlier studies by Wang *et al.* (2013), who studied 30 five-year-old *Eucalyptus* clonal plantations to determine the variation of carbon storage of different clones and found variation in total biomass among clones. Huse *et al.* (2018) reported variation in 18 clones of *Eucalyptus* for growth and biomass at the age of four years.

**Table 3: Variation in tree biomass (kg/tree) among *Eucalyptus* clones irrigated with distillery effluent.**

| Clones | Stem | Branch | leaves | Total |
|---|---|---|---|---|
| **C-316** | 160.56* (81.33) | 42.97* (22.75) | 20.83* (7.94) | 224.36* (112.02) |
| **C-411** | 149.58* (64.11) | 33.60* (17.45) | 15.85 (5.95) | 199.03 (87.51) |
| **C-2045** | 109.17 (52.47) | 33.05* (14.30) | 12.15 (4.47) | 154.37 (71.24) |
| **PE-5** | 100.52 (47.32) | 24.15 11.94 | 11.60 4.25 | 136.27 63.51 |
| **PE-6** | 87.90 (45.61) | 24.94 (11.79) | 9.33 (3.34) | 122.17 (60.74) |
| **PE-7** | 132.28* (63.21) | 37.56* (18.33) | 15.73 (5.90) | 185.57 (87.44) |
| **PE-8** | 136.17* (63.37) | 35.91* (16.95) | 16.13 (6.06) | 188.21 (86.38) |
| **PE-11** | 113.78 (52.59) | 30.31 (14.58) | 15.70 (5.89) | 159.79 (73.06) |
| **C-413 (Check)** | 129.94* (63.00) | 34.07* (16.87) | 13.08 (4.84) | 177.09 (84.71) |
| **Mean** | 124.43 (59.22) | 32.95 (16.11) | 14.490 (5.40) | 171.87 (80.73) |
| **LSD (5%)** | 40.12 (20.71) | 12.07 (6.11) | 6.24 (2.5) | 54.3 (29.3) |

Dry weight in parenthesis
* indicates significant at 5 % level

*C. Carbon stock or carbon biomass*

The carbon biomass varied significantly among the clones and among the tree components. Statistical analysis revealed that clone C-316 had maximum carbon biomass in stem, branch and leaves *viz.*, 40.67, 11.38 and 3.97 kg/tree respectively (Fig. 3). These values were found to be statistically significant than all other clones except those of clone C-411, C-413, PE-7 and PE-8. No clone recorded significantly higher carbon stock in stem and branches than check clone C-413 but clone C-316 reported significantly higher carbon biomass in leaf. The percentage distribution of carbon biomass among individual clones was depicted in Fig 2. Stem carbon stock recorded maximum followed by branch carbon stock and leaf carbon biomass and there is not much variation in percentage distribution of carbon biomass observed among *Eucalyptus* clones.

Further, the relative performance for carbon storage per tree (Fig. 2) was similar as of biomass, as the latter were worked out by multiplying the biomass with uniform factor (0.5). Our present study result are in accordance with other studies in *Eucalyptus* (Kumar *et al.*, 2019) and in *Populus deltoides* (Pal *et al.*, 2009). The highest carbon stock was recorded in stem followed by branches and minimum in leaves because stem has highest biomass than branches and leaves. Similar results (stem > branches > root) were found by Rawat *et al.* (2012) in *Eucalyptus* spp. and Kaul *et al.* (2010) in *Eucalyptus tereticornis*, *Populus deltoides* and *Tectona grandis*.

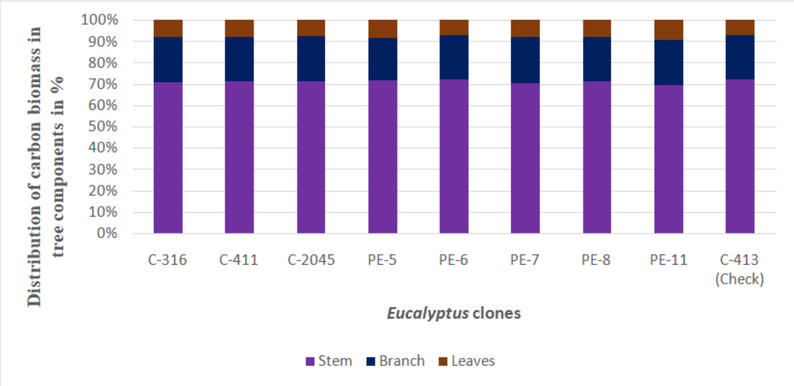


**Fig. 2.** Proportion contribution of C biomass in the individual components among *Eucalyptus* clones.

*D. Carbon Sequestration potential*

Carbon sequestration potential varied among *Eucalyptus* clones (205.56 – 111.46 kg/tree) and Clone C-316 recorded significantly highest carbon sequestration whereas, clone PE-6 recorded minimum. The mean carbon sequestration was 148.15 kg/tree and five clones recorded more than the mean value. Statistical analysis showed that clone 316 ranked first and was significantly superior to all other clones except with clones C-411. C-316, C-413, PE-7 and PE-8. Minimum was recorded in clone PE-6. In comparison to check C-413, only one clone C-316 recorded significantly higher carbon sequestration tree (Table 4).

Carbon sequestration differed among *Eucalyptus* clones with a range of 205.56-111.46 kg/tree. Similar results were reported by earlier studies, Latifah and Sulistiyono (2013) reported in 3 year old hybrid *Eucalyptus* plantation. Bijalwan (2016) conducted a study to evaluate the growth performance, biomass production and carbon sequestration of three energy plantation species *viz*., *Acacia auriculiformis, Cassia siamea* and *Eucalyptus* hybrid and recorded higher maximum carbon sequestration potential in *Eucalyptus* hybrid. Chauhan *et al.* (2019) in 10 year old plantations of four multipurpose trees and found variation in carbon sequestration among four species.

*E. Soil organic carbon*

Organic carbon under *Eucalyptus* plantation decreased with the increase in depth of the soil. It ranged from 0.56 -0.83 % under *Eucalyptus* plantation (Table 5). Carbon pool in the soil of *Eucalyptus* plantation recorded 14.94 t/ha at 15 cm, 13.15 t/ha at 30cm, 12.24 t/ha at 45cm and 10.08 at 60 cm depth of the soil. Per hectare soil organic carbon increased with soil depth while % of organic carbon decreased with soil depth. Soil organic carbon in the present study found maximum under *Eucalyptus* plantation is due to addition of litter, above ground biomass and recycling of organic matter (Singh and Sharma 2007). Higher organic carbon accumulation on the top soil surface layer under different species of tree could be attributed to regular litter accumulation (Swamy *et al.*, 2005).

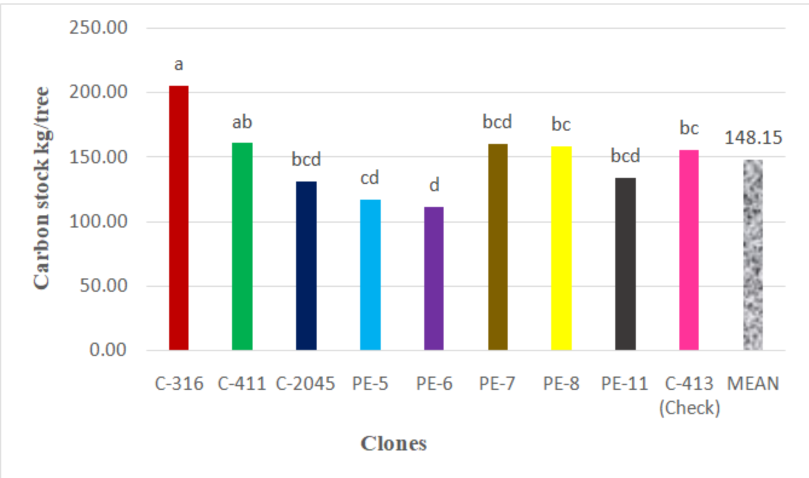


**Fig. 3.** Carbon stock (kg/tree) of *Eucalyptus* clones irrigated with effluents (age 3 year).

**Table 4: 11 Carbon sequestration (ton/ha) of 3 year old *Eucalyptus* plantation irrigated with liquor factor effluent.**

| Clones | Carbon sequestration kg/tree | Rank |
|---|---|---|
| **C-316** | 205.56 | 1 |
| **C-411** | 160.58 | 2 |
| **C-2045** | 130.73 | 6 |
| **PE-5** | 116.54 | 8 |
| **PE-6** | 111.46 | 9 |
| **PE-7** | 160.45 | 5 |
| **PE-8** | 158.51 | 4 |
| **PE-11** | 134.07 | 7 |
| **C-413 (Check)** | 155.44 | 3 |
| **Mean** | 148.15 | |
| **CD (5%)** | 96.72 | |

**Table 5: Soil organic carbon under Eucalyptus plantation.**

| Depth | OC% | SOC (tc/ha) |
|---|---|---|
| 0-15 | 0.83 | 14.94 |
| 15-30 | 0.75 | 13.15 |
| 30-45 | 0.68 | 12.24 |
| 45-60 | 0.56 | 10.08 |

## CONCLUSIONS

In general, all clones adapted well and relatively higher survival was recorded by clone C-316, C-413 and C-411. The study revealed significant variation among *Eucalyptus* clones in all growth traits and biomass. Diameter ranged 9.98-13.01 cm, height varied from 14.05-17.16m and volume ranged 0.122-0.066 $mm^3$. Clone C-316 recorded top rank for all traits except tree height, whereas clone PE-8 recorded maximum height and clone PE-6 found bottom rank. The relative ranking of clones for carbon sequestration was witnessed as C-316 > C-411 > C-413> PE-8 > PE-7 >C-2045 >PE11> PE-5 > PE-6. The present study revealed that clone C-316, C-411 and PE-7 found ideal and may be recommended for planting in effluent irrigated environments.

## FUTURE SCOPE

The promising clones identified in this study can be exploited commercially planation in industrial effluent irrigated sites.

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**Conflict of Interest.** None.

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