Research Article

Comparative Effect of Drought on *Eucalyptus camaldulensis* and *Tamarix aphylla* at Early Stages of Growth

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Abstract | All living organisms are affected by drought in terms of food and health. In the current scenario of drought and gradual change in climate that can result in water stress for terrestrial vegetation, drought-resistant plants should be sorted out. The objective of this study was to explore the growth behavior of *Eucalyptus camaldulensis* (recommended for waterlogged areas) and *Tamarix aphylla* (recommended for arid regions) under water stress. Therefore, a pot experiment was carried out with three treatments: Well-watered, 25% and 50 % drought to achieve said objective. It was found that drought negatively affected plant growth. The mean heights of E. *camaldulensis* and *T. aphylla* were maximum (38.16 and 34.7 cm, respectively) at control irrigation while minimum height was found (17.1 and 24.9 cm, respectively) at 50% drought. So, the reduction in plant height of *E. camaldulensis* was more (55.6%) as compared to *T. aphylla* (28.1%). The reduction in root length of both species was 19% and 9% respectively at 50 % drought. High drought stress (50%) resulted in a reduction of 49% and 38% dry matter in *E. camaldulensis* and *T. aphylla* respectively. The relative water contents (RWC) were more (71.5%) in *E. Camaldulensis* at the control level but significantly reduced (40%) at 50% stress while in T. aphylla less difference (52%-44%) was found in RWC. There was no significant difference found in diameter in both species. Though *E. Camaldulensis* could survive the periodic drought spells, however, the performance of *T. aphylla* was found better in this study. Consequently, research work is necessary to study *Eucalyptus camaldulensis* genetically and physiologically to bring modification in this plant that can make it less water demanding to conserve water.

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Introduction

Plant stress refers to any unfavorable condition or substance that affects a plant's metabolism, reproduction, root development, or growth. (Gaspar et al., 2002). There are various kinds of stresses like salt, drought, heat, cold and heavy metals stress. Among these drought stresses is one of the most threatening factors causes changes in the physiological, morphological, biochemical, and molecular mechanisms of the plants. It has been studied that drought stress is a very important limiting factor that affects both elongation and expansion of growth at the initial phase of plant growth and establishment (Anjum et al., 2003a; Bhatt and Srinivasa, 2005; Kusaka et al., 2005; Shao et al., 2008). Water stress is an important factor that needs to be addressed because the growth and productivity of plants are negatively affected by water

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shortage (Zlatev and Lidon, 2012).

Regular accessibility of water is necessary to cope demands of human beings in present as well as for the future, unfortunately, due to climatic changes, its scarcity is increasing gradually (Rosegrant and Cline, 2003). Weather changes are another factor, owing to which water availability is becoming low resulting in erratic conditions. This situation ultimately has long- lasting effects on the growth and productivity of plants (Harb et al., 2010). Water scarcity in soil affects on apical and lateral growth of plants and reduces biomass formation (Yordanov et al., 2000); (Zlatev and Lidon, 2012). Therefore, the yield losses of crops have reached up to 50% because of drought stress (Bray, 2000; Wang et al., 2003).

Pakistan is a thickly populated country and the population of Pakistan is 207.774 million with an average annual growth rate of 2.4% over the period of 1998–2017 (Pakistan Bureau of Statistics, 2018). So, current and predicted population pressure for wood and its products on its (Pakistan) rare forest resources (4.2 mha) is enormous (Rahim and Hasnain, 2010). Unfortunately, forests cover is very low (about 0.001 ha) per capita in Pakistan, while in the rest of the world it is about 1.00 ha per capita (Hosonuma et al., 2012). Furthermore, forests of Pakistan are gradually decreasing because of deforestation and human-induced activities (Khan et al., 1990).

Establishing new forests (Irrigated Plantations) in Pakistan is a big challenge due to water shortage. Pakistan has suffered severe drought conditions since 1998, which reduced wheat production and income of a farmer in the southern area of Sindh province (Faruqui, 2004). About 7.8 million ha of land in Pakistan is affected by water shortage which can be used for tree plantations by introducing drought-resistant species (Irshad et al., 2011).

Because of the severe water shortage in Pakistan, the land under forest cover can be increased by introducing only agroforestry systems. While these systems can be successfully established by introducing drought-resistant tree species (Nawaz et al., 2018). Agroforestry is the only hope which can reduce the pressure on existing forest cover and fulfill the wood demands of the community in Pakistan (Bartholome and Belward, 2005; Nawaz et al., 2016). The agroforestry practices not only cope with wood deficiency but also provides ecosystem services, improve degraded soils and mitigate microclimate of the area (Paul et al., 2017).

Growing drought-tolerant trees play a vital role in the agroforestry system to fulfill the deficiency of water (Bauer et al., 2013), because they adopt different mechanisms against drought stress, like osmotic adjustment, accumulation of solutes in cells and different morphological adoptions (Brock, 1994). The *Eucalyptus camaldulensis* is considered high water-consuming tree but throughout world it is one of the most important trees due to high growth rate, environmental adaptability and superior pulp properties (Stape et al., 2004). Being evergreen species, it absorbs more water at deeper depth as compared to other tree species (Baker et al., 2002). While *Tamarix aphylla* has adaptability against drought and salt stress due to its xerophytic and halophytic nature, respectively (Brock, 1994). *Tamarix aphylla* is native species of the Middle East, the Arabian Peninsula, and Pakistan. *Tamarix aphylla* is a drought-tolerant plant which can survive on less water availability in soil by adopting many physiological and morphological changes (El-Ghani, 2000).

Plants respond and adapt to and survive under drought stress by the induction of various morphological, biochemical and physiological responses. Plant drought tolerance involves changes at whole-plant, tissue, physiological and molecular levels. Manifestation of a single or a combination of inherent changes determines the ability of the plant to sustain itself under limited moisture supply (Farooq et al., 2009).

Focusing on water scarcity in Pakistan especially under arid and semi-arid climate there is a dire need to compare water use efficiency of the introduced and native species and discover the truth about *Eucalyptus camaldulensis* whether it can grow under water shortage or not as compare *Tamarix aphylla* for sustainable Agroforestry practices in Pakistan. Therefore, this study was designed to compare above-mentioned tree species through a pot experiment.

Materials and Methods

Soil analysis

Prior to experiment random soil samples were taken at 0-15 cm depth from the study area to analyze the chemical and physical properties of soil used in pots.

Samples were dried, ground, sieved, prepared and analyzed for electrical conductivity (dS [1]), pH, field capacity (%), saturation percentage (%) and organic matter by using the standard method of soil analysis in soil and water testing laboratory (Table 1).

Table 1: *Physico-chemical properties of soil used in pots.*

Parameters	Nursery soil
EC dSm^{-1}	1.00 ± 0.04
pH	8.2 ± 0.1
Sand (%)	59 ± 1
Silt (%)	22 ± 0.5
Clay (%)	19 ± 0.5

Plant materials and experimental design

The experiment was carried out at the research zone of the department of Forestry UAF. Two common tree species *Eucalyptus camaldulensis* (drought-sensitive) *and Tamarix aphylla* (drought-tolerant) were used under this study. Both species were grown in plastic bags (filled with clay and sand) with seeds and cutting respectively for the period of three (3) months, then transplanted into pots (filled with 4383.5g) sandy loam soil.

One month after transplanting, fifteen (15) plants per species were shifted to a green net house in order to protect from rainwater. Each specie was subjected to three treatments 100%, 75% and 50% field capacity in other words (control, 25% and 50% drought stress). Five replicates per treatment were used under complete randomized design (CRD) due to homogeneous experimental materials. After establishing plants in pots completely, water was given according to treatments (902 ml for 100%, 676 ml for 75% a and 451 ml for, 50% field capacity). Due to hot weather, water was given after an interval of 3 days by measuring each pot firstly then the required amount of water was given to each treatment. After completing 6 weeks of treatment, plants were harvested manually including roots and brought into laboratory for measurements and data analysis.

Data collection

Average monthly metrological data were collected from the Metrological Station that is permanently installed at just a few meters away from the experimental site. The summary of climatic conditions during experimental period (February 2014 to June 2014) is given in (Table 2)

Table 2: *Average monthly temperature and rainfall range during February 2014 to June 2014.*

Month	Temperature			R.H.	Rain fall	Pan evapo-ration
	MAX	MIN	Avg.			
	Avg. °C	Avg. °C	°C	%	Total (mm)	Avg. (mm)
February	20.0	08.9	14.4	65.0	14.3	01.7
March	24.7	13.6	19.2	60.1	41.7	03.0
April	32.2	18.6	25.4	52.2	28.2	05.3
May	38.7	24.9	31.8	27.5	17.0	07.6
June	40.9	28.1	34.5	33.5	07.1	08.4

Data for, morphological parameters, such as fresh and dry weight (g), root and shoot height (cm), and diameter (mm) of plants was taken). Root and shoot lengths (cm) were measured with measuring tape, and collar diameter (mm) was recorded by digital Vernier caliper. Fresh weight (g) was taken immediately after harvesting while dry weight (g) was taken after drying in an oven for 72 hours.

Relative water contents in plants leaves were calculated before harvesting the plants. To calculate (RWC), fresh leaves (0.5 g) of each plant were taken and dipped in distilled water, after four hours, leaves were taken out, and the surface water was removed with the help of tissue paper and then weighed to get the turgid weight (TW g). After getting TW, leaf samples were dried at 65 °C in the oven until the complete drying, after 72 hours the samples were again weighed, and the relative water contents were calculated by using formula (Jensen et al., 2019).

$$RWC= [(FW-DW)/ (TW-DW)]$$

Here FW is showing the fresh weight of the leaf in (g), TW is turgid weight in (g) measured after floating the leaf, and DW is the dry weight in (g) found by drying the leaf samples.

The percent growth reduction of each treatment was calculated by using following equation. First, % growth of each treatment was calculated, the growth of 100% field capacity (control) was kept 100%, after calculating % growth for both T1 and T2 treatments, the values were deducted from 100 (control) value. The resulted values are % growth reduction.

$$\% \text{ Growth} = \text{Control}/T1(100)$$
$$\% \text{ Reduction} = 100 - \% \text{ growth}$$

Statistical analysis
One-way analysis of variance (ANOVA) was used to test the effect of treatment using Stata SE 15. The difference among treatment was analyzes by using Tukey HSD test at P ≤ 0.05.

Results and Discussion

Effects of water stress on morphological characteristics of Eucalyptus camaldulensis and Tamrix aphylla
Results shows that a significant difference (LSD at P<0.05=6.64) occurred between treatment for plant height as showed in Figure 1a which shows that *Eucalyptus camaldulensis* and *Tamrix aphylla* gained up to 38.16 cm and 34.8 cm height, respectively at control conditions while at 25% (75% FC) drought, height of shoot was (31.96 cm and 31.22 cm) for *Eucalyptus camaldulensis* and *Tamarix aphylla,* respectively. The extreme drought (50%) caused maximum growth reduction in *Eucalyptus camaldulensis* and minimum in and *Tamarix aphylla* (17.14 cm, 24.94 cm respectively). The percent reduction (16.1% and 10%) in shoot length of *Eucalyptus camaldulensis* and *Tamarix aphylla* was found at 25% drought stress respectively while at 50% drought stress, shoot length was reduced (55% and 28%) respectively in both species.

Results in Figure 1b shows a significant difference (LSD at P<0.05=0.4980) between treatments for root length. It was found at well-watered, *Eucalyptus camaldulensis* gained 59.8 cm with increasing of water stress root length increased more up to 71.1 cm, at high drought stress root length started to decline and was measured 48.1 cm at 50% drought conditions. In the case of *Tamarix aphylla* the root length also significantly increased at 25% drought but decreased at 50% drought stress. Figure 1b shows that the root length of *Tamarix aphylla* was found 43.1 cm, 50.4 cm and 38.8 cm at control, 25 %, and 50% drought, respectively. The percent change in root length of *Eucalyptus camaldulensis* was found 18% higher at 25% drought as compared to well the water condition, while at 50% drought 20% reduction in root length was measured. In *Tamarix aphylla* percent increase and reduction in root length were 16.93% and 10% at 25% and 50% drought accordingly.

Effects of water stress on the biomass of Eucalyptus camaldulensis and Tamrix aphylla
Drought stress at different levels influenced significantly (LSD at P<0.05=8.790) the root shoot fresh weight (Biomass). Under well-watered conditions, *Eucalyptus camaldulensis* produced maximum biomass of 17.8 g, while 13.0 g and 8.03 g were found at 25% and 50% drought, respectively. In the case of *Tamarix aphylla*, it produced 16.1g fresh weight under well-watered conditions, while 14.1g and 11.4g biomasses were produced at 25% and 50% water stress. The percent comparison of both species shows that *Eucalyptus camaldulensis* reduced more fresh weight as compared to *Tamarix aphylla*. The percent loss in fresh weight of *Eucalyptus camaldulensis* at 25% and 50% drought stress was 27% and 55%, respectively while percent reduction in fresh weight of *Tamarix aphylla* was 13% and 31% at 25% and 50% drought respectively.

A significant reduction (LSD at P<0.05=6.40) in dry weight of both species was found. Under well-watered conditions, the total dry weight 10.8g was recorded in *Eucalyptus camaldulensis* while 8.9g and 5.03g dry weights were found at 25% and 50% water stress respectively. In the case of *Tamarix aphylla*, 12.17g dry weight under well-watered conditions, while 7.28g and 6.21g dry weights were recorded at 25% and 50% water stress respectively. The percent comparison of both species showed that *Eucalyptus camaldulensis* reduced more dry weight as compare to *Tamarix aphylla*. The percent loss in dry weight of *Eucalyptus camaldulensis* and *Tamarix aphylla* was recorded as 17%, 53% and 40%, 49% at 25% and 50% water stress, respectively. The water deficit soil inhibited the plant growth due to which the growth of root elongation and fresh weight decreased.

No significant differences were found in the diameters of both species at the early stages of growth therefore the diameters at different water regime for *Eucalyptus camaldulensis* were found 5mm, 4.8 mm and 2.5 mm at control, 25%, and 50% drought respectively. While diameters of *Tamarix aphylla* at different water level was recorded 6 mm, 5.5 mm and 4 mm at well-watered, 25%, and 50% drought, respectively.

Xerophytic plants effort to preserve high relative water content than that of sensitive ones by the osmotic adjustment which decrease their water potential in this way they absorb more water. *Tamarix aphylla* which is relatively drought-tolerant showed higher relative water content at drought conditions than *Eucalyptus camaldulensis* which is more sensitive to drought stress.

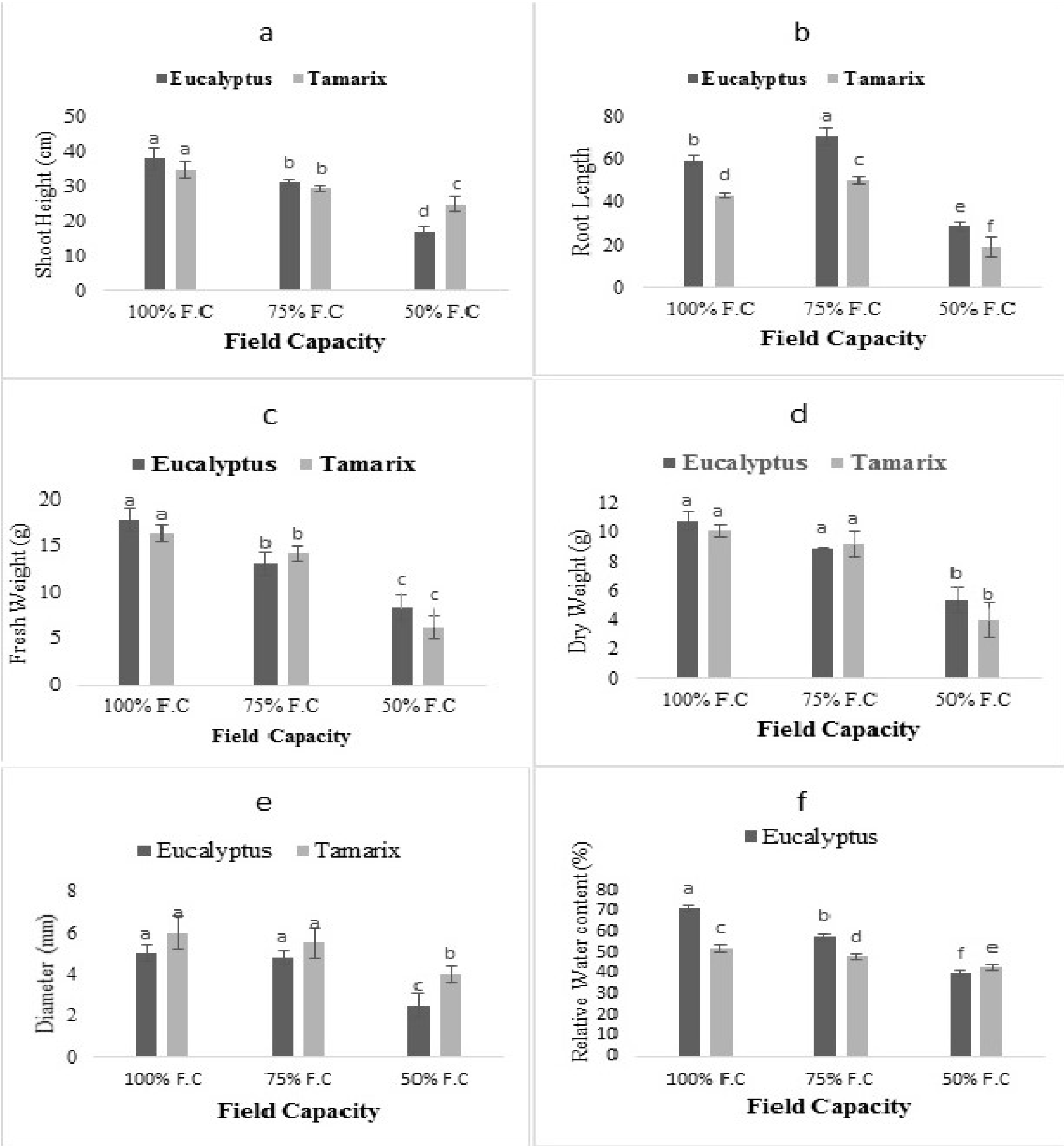

Figure 1: *Effect of drought stress (P<0.05) on root (a) and shoot lengths (b), fresh (c) and dry weights (d), stem diameter (e) and relative water contents (f) on eucalyptus and tamarix.*

A study was conducted to estimate the water use efficiency of both discussed species, the results showed that *Eucalyptus camaldulensis* utilized more water as compared to *Tamarix aphylla*. Planting of *Eucalyptus camaldulensis* on marginal (waterlogged) lands can convert them into productive lands (Afzal, 2018). Similar results were observed by (Cheng and Cheng, 2015) who stated when the irrigation interval increased, the plant height significantly decreased. Our results showed contrast with (Haworth et al., 2017) who stated that significant differences were not observed in the mean height of *Arundo donax*. It was questioned why root increased its length against drought stress, the answer found in previous studies was that when roots tips face stress their tips contained less water contents while the process of osmotic adjustments starts which increased level of soluble sugars and proline contents, therefore these sugars increase water content in root tips (Ji et al., 2014).

Similar results were reported by (McDonald and Davies, 1996) which indicate that enhanced biomass partitioning to roots may result from a drought-induced reduction in the sink strength of the above-ground plant tissues, making more assimilates available for root growth. Another research reported greater increases in the root length of *Eucalyptus camaldulensis* in the water-stress regime than in the well-watered regime (59% and 16%) respectively. whereas root growth ceased completely after week 5 in water-stressed (Silva et al., 2004). It was studied that cottonwood and willow forests flourish where groundwater is 3 m or less deep, yet *Tamarix aphylla* woodlands can survive where groundwater is 7 m deep or more(Stromberg and Chew, 2002). When drought stress occurs, it affects the yield and production by affecting the weight and number of branches (Nawaz et al., 2013).

According to one study, plant height, shoot weight, leaves area and plant biomass showed a decline in response of less-water conditions (Sirousmehr et al., 2014). Another study showed that leaf area index and plant dry matter significantly decreased when plants faced drought stress, while stem length showed less effect as compared to other root traits (Aranjuelo et al., 2010). Our results are also similar with (Allen et al., 2010) who discovered that the water deficit in soil inhibited the plant growth due to which the growth of root elongation and fresh weight decreased.

Our results correlate with (Elhadi et al., 2013) who indicated that no significant differences in tree collar diameter (mm) were observed among all irrigation frequencies at the early stages of growth. It was concluded by (Stoyanov, 2005) that drought-tolerant bean cultivars maintained high relative water content under limited water availability. According to (Ramoliya and Pandey, 2003) high relative water content of leaves indicated to be an adaptation under xerophytic habitat.

Conclusions and Recommendations

In this study, overall % growth at well-watered was found better for *Eucalyptus camaldulensis,* as it is fast growing and water loving tree, however, under drought conditions, growth of Tamarix *aphylla* was found better than *Eucalyptus camaldulensis* as *amarix aphylla* is drought resistant plant. The percentage reduction in growth parameters was minimum in *Tamarix aphylla* as compared to *Eucalyptus camaldulensis* at high drought stress at their early stages of growth that decides the adaptability of a tree species in arid conditions. At high stress the growth parameter and biomass were started to more decline especially in *Eucalyptus camaldulensis* as compared to even wilting of plants.

Pakistan is facing water shortage therefore, it is recommended that less water consuming, and drought-tolerant species should be recommended, so, *Tamarix aphylla* is a better specie for agroforestry practices under the semi-arid climate of Pakistan due to drought tolerance ability. However, research work is necessary to study (genetically and physiologically) to various tree species, especially *Eucalyptus camaldulensis* that is fast-growing but more water demanding to bring modification in it that can make it more drought-tolerant plant, so that the deficiency of water can be minimized to produce more forests in Pakistan.

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Novelty Statement

Planting of eucalyptus in Pakistan especially in areas having low water availability is under miss conceptions. It is the need of hours to compare its water use efficiency and resistance against drought. Therefore, this study was designed to compare its performance against water stress with a tree that is drought resistant, so that its recommendations for agroforestry could be made successful.

Author's Contributions

MSH performed research trial and preparations of the first manuscript draft, MFN supervised the study, gave the idea and designed the study. MAT provided help in data analysis, manuscript improvement and corrections. NEH played a vital role in editing, data entry and in manuscript revisions. All authors read and approved the final manuscript.

Conflict of interest

There is no conflict of interests regarding the publication of this article.

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