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Morphological, physiological and biochemical performance of *Tectona grandis* and *Gmelina arborea* under drought stress conditions

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Abstract

Drought is one of the most widespread global environmental problems leading to low water availability for plants, which causes a significant loss in growth, productivity and finally their yields. In the present study, the effect of drought stress on growth characteristics, physiological and biochemical parameters of *Tectona grandis* and *Gmelina arborea* at seedling stage under nursery conditions have been discussed.

Pot culture experiments were conducted in RBD design to observe the effect of moderate drought (MD) and severe drought (SD) stress on the selected seedling sunder nursery conditions for one year. Moderate and severe drought conditions were artificially created with the help of CPE (Cumulative Pan Evaporation) values and PWP (Permanent Wilting Point). The amount of water equal to the calculated field capacity was provided to each polybag at the interval of calculated CPE. Physiological parameters *viz.* photosynthetic rate, stomatal conductance and transpiration rate of the seedlings were measured. Total Chlorophyll and Proline content were estimated for biochemical analysis.

The outcome of the experiment showed that with the increasing age of the seedling, the effect of drought become more pronounced till the end of the experiment in terms of growth characteristics. Also, the severe drought condition was more lethal to the selected species seedlings. Further, the decreasing biomass, physiological parameters and chlorophyll content were found along with increased proline content with the severity of drought stress confirm the result. However, *G. arborea* found to be more affected than *T. grandis*. Hence, it can be concluded that the *T. grandis* species is better for plantation in an area with the moderate drought and can be maintained in severe drought climatic conditions. The plantations of suitable tree species in drought-prone areas will be helpful in sustainable forest management and resilient the forest ecosystem to climate change.

Keywords: Drought, nursery, CPE, PWP, field capacity, parameters, species

Introduction

The Earth's surface is covered by 70% of water (Siddique and Bramley, 2014) [27] out of which only 2.5% is freshwater (Gleick and Palaniappan, 2010) [10]. The freshwater is required for drinking and various domestic purposes. Inspite of the fact that majority of this freshwater is trapped in glaciers, permanent snow, or aquifers (Siva kumar, 2011) [29], there is enough freshwater available on this planet for seven billion people. But the water is distributed unevenly, too much wasted, polluted and unsustainably managed by anthropogenic activities (UN-Water, FAO, 2007) [6]. The rate of such activities has been increased with the growing rate of population in the last century (UN-Water, FAO, 2007) [6]. Also, the erratic rainfall patterns due to global warming and changing climatic conditions, deforestation and increasing urbanization, all are adding in the production of drought-affected areas (Satendra and Kaushik, 2014) [25].

Around 1.2 billion people live in areas of physical scarcity of water including 500 million people approaching this situation. Another 1.6 billion people face economic water shortage (where countries lack the necessary infrastructure to take water from rivers and aquifers) (UN-Water, FAO, 2007) [6]. India is also affected by drought stress which covers about 32.55% of its total geographic area, spreading over in several states like Andhra Pradesh, Bihar, Gujarat, Haryana, Jammu and Kashmir, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal (Nagarajan, 2003) [19]. Drought stress condition arises when there is the scarcity of water in the soil than its optimum requirement and the atmospheric conditions cause continuous loss of water by transpiration or evaporation (Jaleel *et al*., 2009) [13]. Plants are unable to receive oxygen due to lack/insufficient amount amount of water in the rhizosphere, building an anaerobic situation which in turn creates drought stress conditions (Jaleel *et al*., 2009) [13]. The increasing impact of drought stress in forestry like dying of trees in the southern parts of Europe due to elevated temperature (Bigler *et al*., 2006), increased mortality rates of trees in temperate and boreal forests of western North America (van Mantgem *et al*., 2009) [32] and about 10 million hectares of land have been affected in various forest types due to widespread death of many tree species since 1997 (Raffa *et al*., 2008) [22] are some of the recent drought affected events from across the world.

Drought stress leads to many physiological, biochemical and molecular changes in the plants (Akhtar and Nazir, 2013) [1]. Physiological responses include reduction of leaf water potential, loss of turgor and osmotic adjustment, decrease in stomatal conductance, decline in nutrients and water uptake and finally decline in net photosynthesis and reduction in growth of the plants. Biochemical responses include transient decrease in photochemical efficiency, decreased efficiency of Ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco), accumulation of stress metabolites like Malate dehydrogenase (MDHA), Glutathione, Proline, Glycine betaine, Polyamines and alpha-tocopherol, increase in antioxidative enzymes like Superoxide dismutase (SOD), Catalase (CAT), Ascorbate peroxidase (APX), Peroxidase (POD), Glutathione reductase (GR) and Monodehydro ascorbate reductase (MDHAR) and finally reduction in Reactive oxygen species (ROS) accumulation. At a molecular level, found stress-responsive gene expression, increased expression in Abscisic acid (ABA) biosynthetic genes, synthesis of specific proteins like Late embryogenesis abundant(LEA*)*,Desiccation stress protein (DSP) and dehydrins in response to water stress tolerance. (Shao *et al*., 2008; Amarjit *et al*., 2005; Reddy *et al*., 2004) [26, 2, 24].

The *Tectona grandis* (Teak) and *Gmelina arborea* (Khamer) are the two species selected keeping in view their economic importance and regeneration capability, accounted in several Regenerative indexes (RI) of forest tree species in order to perform the drought experiment. The plantation of these species are raised for commercial purpose as well as reclaiming degraded lands. Teak is widely used as a plantation species on sites with a seasonal tropical climate. It is often grown in agroforestry systems and is one of the most versatile timber species used for heavy and light construction work, house building, carpentry, wood carvings etc (GRIN, 2007) [9]. Various parts of the tree including the wood are accounted for medicinal properties. The wood of the tree is partially resistant to fire and drought (Rao *et al*., 2008) [23]. Khamer is primarily used for pulpwood production because of its relatively high yield of kraft pulp and low chlorine requirement. Its wood is sawn for general carpentry, joinery, furniture components, musical instruments, boat decking and other household fixtures. It can also be used as fuel wood (Florido and Cornejo, 2002) [8]. Under flooded conditions, seedlings of *Gmelina arborea* produce more adventitious roots, an adaptation to survive in flooding condition (Osundina and Osonubi, 1989) [21].

The severity of drought is unpredictable as it depends on many factors such as occurrence and distribution of rainfall, evaporative demands and moisture storing capacity of soils (Jaleel *et al*., 2009) [13]. Therefore, the emphasis should be given on afforestation practice in such areas and for that, the cultivation and plantation of drought specific species with economic importance in order to enhance the value of drought-affected land should be performed. The main objective of the present study was to observe the performance of *Tectona grandis* and *Gmelina arborea* under drought stress in terms of selected morphological, physiological and biochemical parameters in nursery conditions. Also, to screen the species for their tolerance behaviour in different levels of drought stress which is necessary in order to raise the plantations of such species in nursery conditions and in drought-affected sites.

Material and Methods

1. Experimental site and Plant material

Pot culture experiments were conducted in the nursery of Tropical Forest Research Institute (TFRI), Jabalpur (M.P.) for one year. The location of experimental sites in the nursery was specified as $23^0$5’57.2” N latitude, $79^0$59’2” E longitude and 394 m altitude above the sea level according to Global Positioning System (GPS). Two tree species *viz: Tectona grandis* (Teak) and *Gmelina arborea* (Khamer) were selected for the study. The seeds were collected from TFRI campus during March to May and sown in the nursery beds in June, just before first shower of rainfall, which is favourable for normal and healthy germination process.

2. Growth condition and Experimental design

The size of nursery mother beds was fixed to be 10m x 1m and the sowing medium was sand which provided sterile conditions for germination of seeds. Pre-sowing treatment was given to *Tectona grandis* and *Gmelina arborea* (Family – Lamiaceae) seeds in a pit filled with water and cow dung for 1 week. Germination period for the selected species varied as, *Tectona grandis*10-15 days and *Gmelina arborea* 12-15 days. After the germination of seeds, the seedlings having 2-3 leaves were transferred to transparent polythene bags of standard size (15 cm x 23 cm) filled with soil, sand and farm yard manure (FYM) in 2:1:1 ratio. The polythene bags were initially placed under shade for one month to protect the seedlings from direct sunlight and then kept in open area for another one month in order to acclimatize them with the prevailing conditions.

Complete Randomized Block Design (CRBD) was adopted to conduct pot culture experiments in order to observe the effects of drought stress. After acclimatizing seedlings in polythene bags for a month in open areas, three water treatments (W1-Control, W2 - Moderate drought and W3 - Severe drought) were provided to seedlings. Each treatment consisted of nine seedlings and the experiment was replicated thrice.

3. Drought treatment

Drought experiments in the seedlings planted in polybags under nursery condition were conducted according to the experimental design mentioned above. The amount of water equal to the field capacity [Soil moisture at field capacity (%) = (WW-DW) x 100/DW, where, WW - Wet Weight of soil + plant (g) and DW - Dry Weight of soil + plant (g), adopted by Tyree *et al*. (2002)]was given to polybags at the interval of calculated Cumulative Pan Evaporation [CPE = Sum of evaporation values, adopted by Eliades, (1988) & Savva and Frenken, (2002)] values by Open Pan Evaporimeter. Moisture content in the soil was measured at permanent wilting point [Soil moisture at permanent wilting point (%) = (WW-DW) x 100/DW, where, WW - Wet Weight of soil + plant (g) and

DW - Dry Weight of soil + plant (g), adopted by Savva and Frenken, (2002)]. Severe drought (SD) conditions were created with the help of time interval counted on the basis of CPE values calculated till the species specific permanent wilting point (PWP) while Moderate drought (MD) conditions were created with half of the CPE values calculated for severe drought conditions. Frequency of watering to polybags varied in different seasons, which was high during summer and low during winter. The transparent polythene shade was provided to the whole experimental design including Open Pan Evaporimeter in order to maintain uniformity during rainy season.

At Wilting Point, CPE values for *Tectona grandis* were calculated to be 120 and 60 mm for severe (SD) and moderate drought (MD), which were attained in 50 and 24days during winter and 25 and 13 days during summer respectively. The seedlings kept under drought conditions were irrigated after 23 days (W2) and 49 days (W3) in winter and 12 days (W2) and 24 days (W3) in summer. At Wilting point, the soil moisture content was found to be 6.42%.

CPE values for *Gmelina arborea* were calculated to be 40 and 20 mm for SD and MD, which were attained in 14 and 7 days in winter and 5 and 3 days in summer respectively. The seedlings kept under drought conditions were irrigated after 6 days (W2) and 13 days (W3) in winter and 2 days (W2) and 4 days (W3) in summer. At Wilting point, the soil moisture content was found to be 8.61%.

4. Morphological parameters

The growth measurements of seedlings planted in polybags like height, collar diameter and size of leaves were taken at pre-treatment stage and thereafter every three months for one year. Height and collar diameter were measured by scale/ inch tape and vernier caliper ctively (Husen, 2009) [12].Total Biomass of seedlings was estimated by destructive method at the end of experiment. Leaves of different maturity were plucked and size was measured using Systronics make Leaf Area Meter.

5. Physiological parameters

Physiological parameters *viz.* photosynthetic rate, stomatal conductance and transpiration rate of the seedlings of selected species were measured in six months interval (January and August 2016) between 8:00 AM to 10:00 AM using CID make Photosynthetic System. All the measurements were taken for one year. Leaves were placed in the leaf chamber of the instrument. Three leaves taken per treatment and replicated thrice (Husen, 2009) [12].

6. Biochemical parameters

Biochemical parameters like Chlorophyll and Proline were estimated at the end of experiment. Chlorophyll was estimated following Arnon's method (1949). Weighed 0.1g of fresh leaf sample, finely cut and well crushed to fine pulp in pestle mortar with the addition of 5ml of 80% acetone. Centrifuged at 5000 rpm for 5min and transferred the supernatant in a test tube. Vortexed the residue with the addition of 5ml of 80% acetone and again centrifuged it for 5 min in 5000 rpm. The supernatant was collected in the same test tube. Mixed and read the absorbance of the solution at 645, 663 and 470 nm against the solvent (80% acetone) blank.

Calculation

The amount of extracted chlorophyll was calculated in the mg chlorophyll/g tissue by following formula:

Chlorophyll a (mg g-1) = $[(12.7 \times A663) - (2.6 \times A645)] \times V/1000 \text{ x } W$

Chlorophyll b (mg g-1) = $[(22.9 \times A645) - (4.68 \times A663)] \times V/1000 \text{ x } W$

Total Chlorophyll = $[(20.2\times A645) + (8.02\times A663)] \times V/1000 \text{ x } W$

Proline content in the leaves was quantified by the spectrophotometric method followed by Bates *et al*., (1973). Extract 0.1g of dried leaf sample by homogenizing in 5ml of 3% aqueous sulphosalicyclic acid. Centrifuged at 3000 rpm for 25 min and homogenate was filtered through What man No. 2 filter paper. 2ml of filterate, glacial acetic acid and acid ninhydrin were taken in a test tube and heated it in the boiling water bath for 1hour. Terminated the reaction by placing the tube in ice bath. Added 4ml toluene to the reaction mixture and stirred well for 20-30 seconds. Separated the toluene layer and warmed to room temperature. Measured the red colour intensity at 520 nm. Ran a series of standard with pure proline in a similar way and prepare a standard curve. Toluene was taken as a blank for both sample and standard. Found out the amount of proline in the test sample from the standard curve.

Calculation

The proline content was expressed as follows:

$$\mu \text{ moles per g tissue} = \frac{\mu\text{g proline/ml x ml toluene}}{115.5} \text{ x } \frac{5}{\text{g sample}}$$

Where, 115.5 is the molecular weight of proline

7. Statistical Analysis

The data were statistically analysed using SX software. Analysis of Variance (ANOVA) table was drawn and significant variation among different treatments was observed by comparing calculated F values with tabulated F values. Pairwise comparison among the selected treatments was done after calculating critical difference (CD) at 5% significance levels.The correlation was established among different parameters at 5% and 1% significant level.

Results

1. Morphological parameters

Significant ($P<0.05$) difference in height, collar diameter and size of leaves of *T. grandis* and *G. arborea* seedlings were found among the selected treatments (Fig. 1-6). Height of *T. grandis* and *G. arborea* seedlings continuously increased with age. In *T. grandis*, sharp increase took place after rainy season in August 2016 in control, moderate and severe drought conditions. In *G. arborea* the control seedlings survived from start of experiment till end of experiment, while under MD and SD, the seedlings survived till May 2016 only. Height increased to 164.38%in control, 142.56% in MD and 84.45% in SD treatments after one year experiment in *T. grandis* while in *G. arborea* height increased to 23.32% in control and 8.83% and 5.01% in MD and SD respectively till their survival time (May 16).

Collar diameter (CD) of *T. grandis* seedlings also showed the similar trend as that of height, which is increased with age and decreased with severity of drought stress. CD increased by 4 times in control, 4.83 times in MD and 3.41 times in SD treatments with age. In *G. arborea*, CD increased to 85.36% in control, 58.82% in MD and 59.45% in SD treatments.

Average leaf size of *T. grandis* decreased from August15 (21.65 cm^2) till next February16 (3.62 cm^2) and then increased after emergence of new leaves in April16 (35.03 cm^2) in the control treatment. Size of leaves in MD and SD continuously decreased with age of the seedlings. Average leaf size of *G. arborea* decreased from August 15 (5.8 cm^2) till next February 16 (3.07 cm^2) and then increased after emergence of new leaves in April 16 (4.97 cm^2) and reached to the maximum in next august 16 (15.18) in the control treatment. In MD and SD, size of leaves continuously decreased with age of the seedlings up to February and then become absent.

Significant ($P<0.05$) difference in total biomass was observed among the selected tree species under different treatments at the end of experiment (Table 1).Drought stress in polybags reduced the biomass in the seedlings of selected species and this reduction increased with severity of stress from MD to SD.Under MD treatment, maximum reduction in biomass was found in *G. arborea* (49.57%) and minimum in *T. grandis* (26.58%), while under SD, maximum reduction was observed in *G. arborea* (51.33%) and minimum in *T. grandis* (48.06%), when compared with control conditions.

Table 1: Effect of drought stress on biomass in the seedlings of selected species.

Treatment	Total Biomass (TB) (g)
T. grandis	
Control	9.03
Moderate	6.63
Severe	4.69
CD$_{0.05}$ SE$\pm$	1.247 0.309
G. arborea	
Control	23.32
Moderate	11.76
Severe	11.35
CD$_{0.05}$ SE$\pm$	2.071 0.514

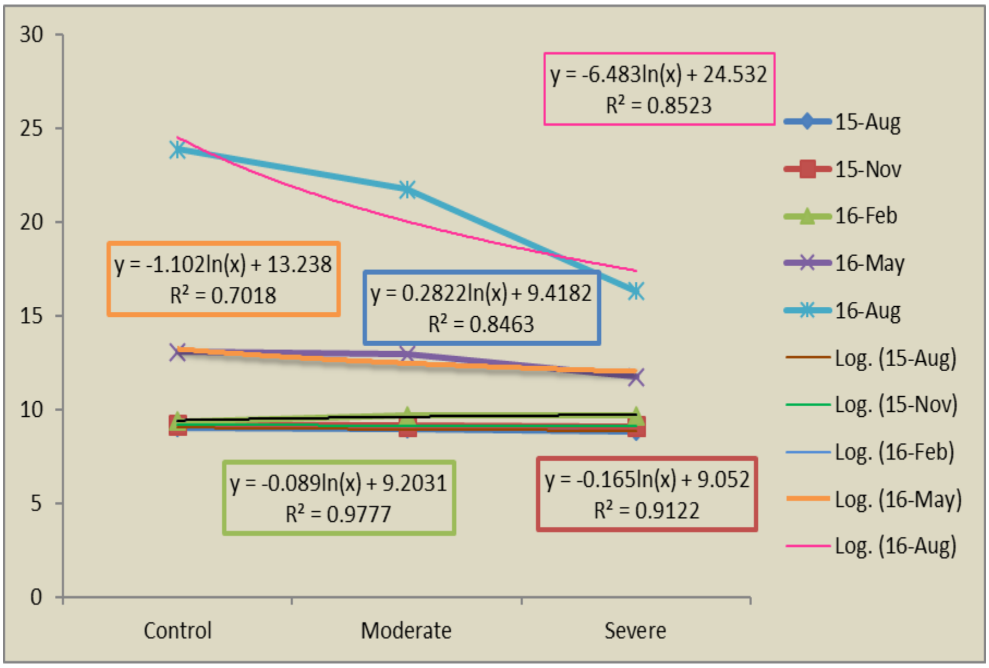

Fig. 1: Effect of drought on height of *T. grandis* showing trendline and regression graph with R^{2}value.

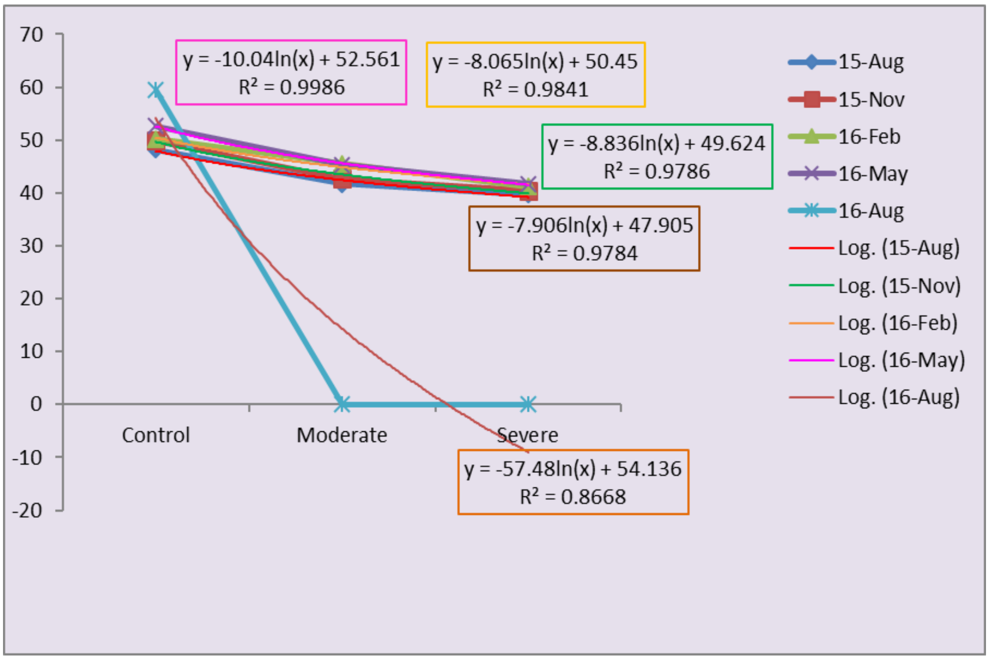

Fig 2: Effect of drought on height of *G. arborea* showing trendline and regression graph with R^{2}value.

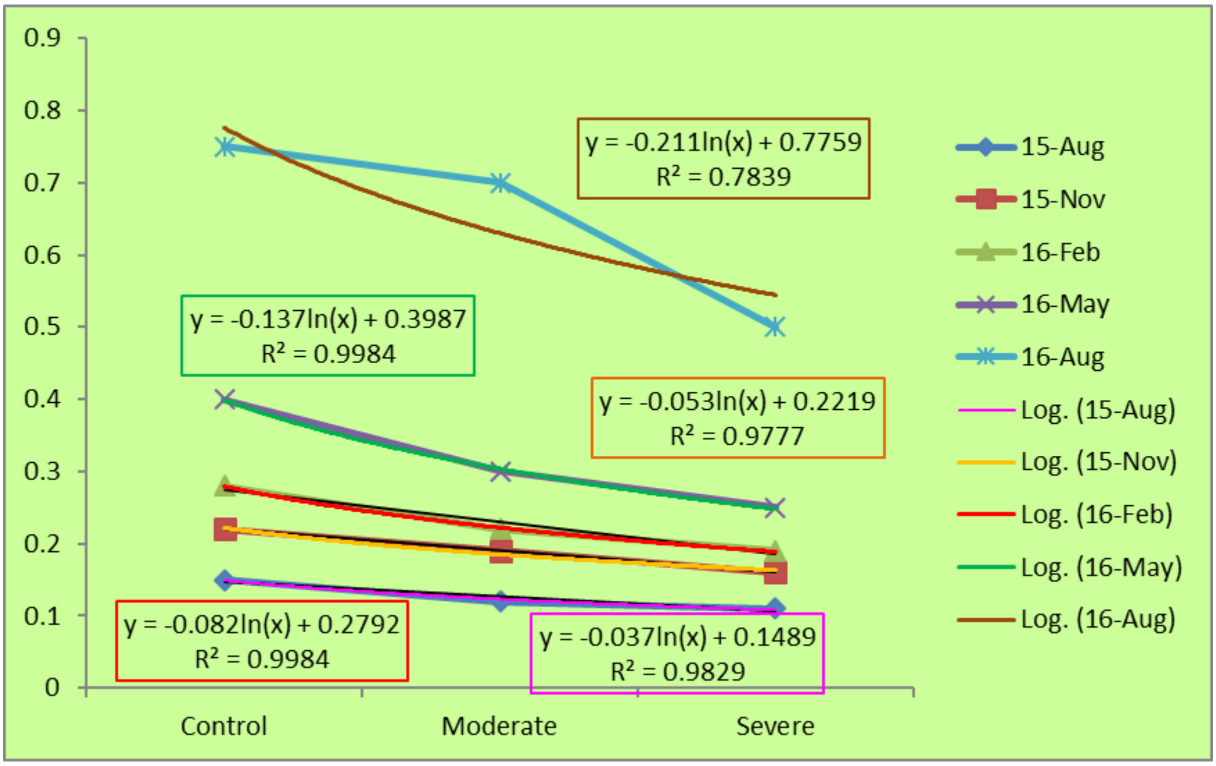

Fig 3: Effect of drought on collar diameter of *T. grandis* showing trendline and regression graph with R^2value.

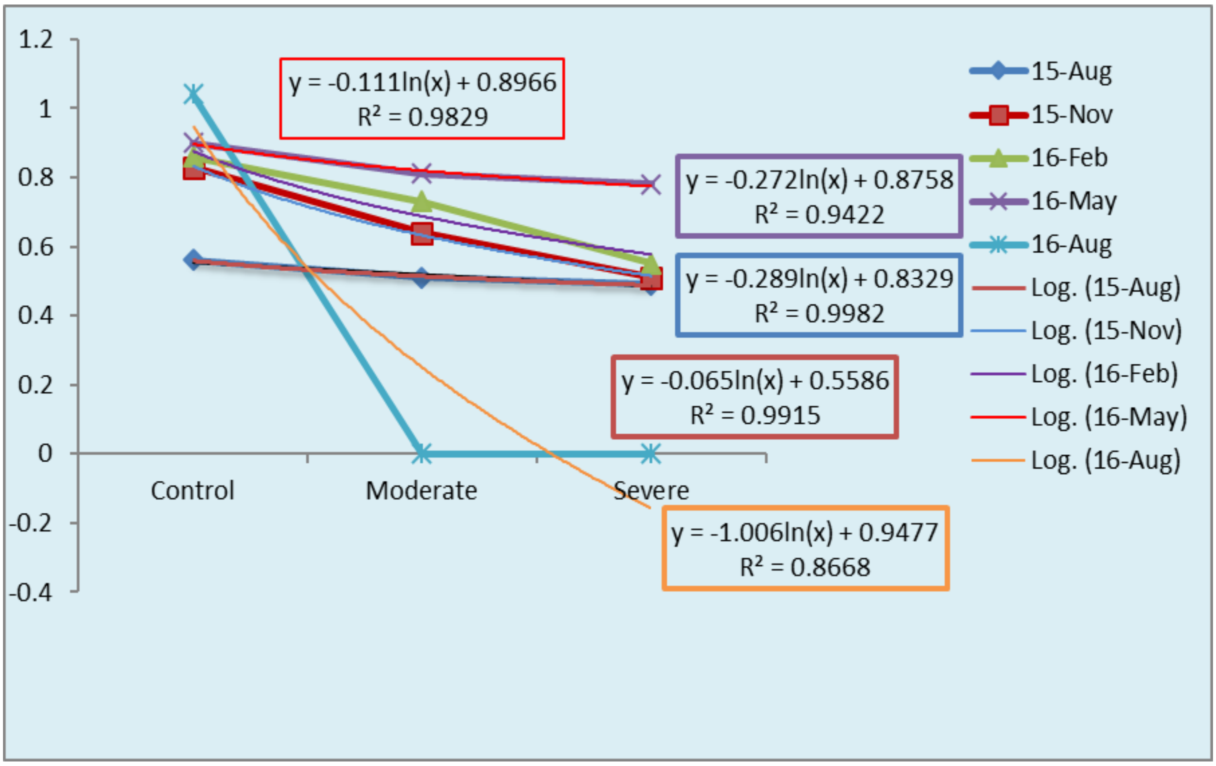

Fig 4: Effect of drought on collar diameter of *G. arborea* showing trendline and regression graph with R^2value.

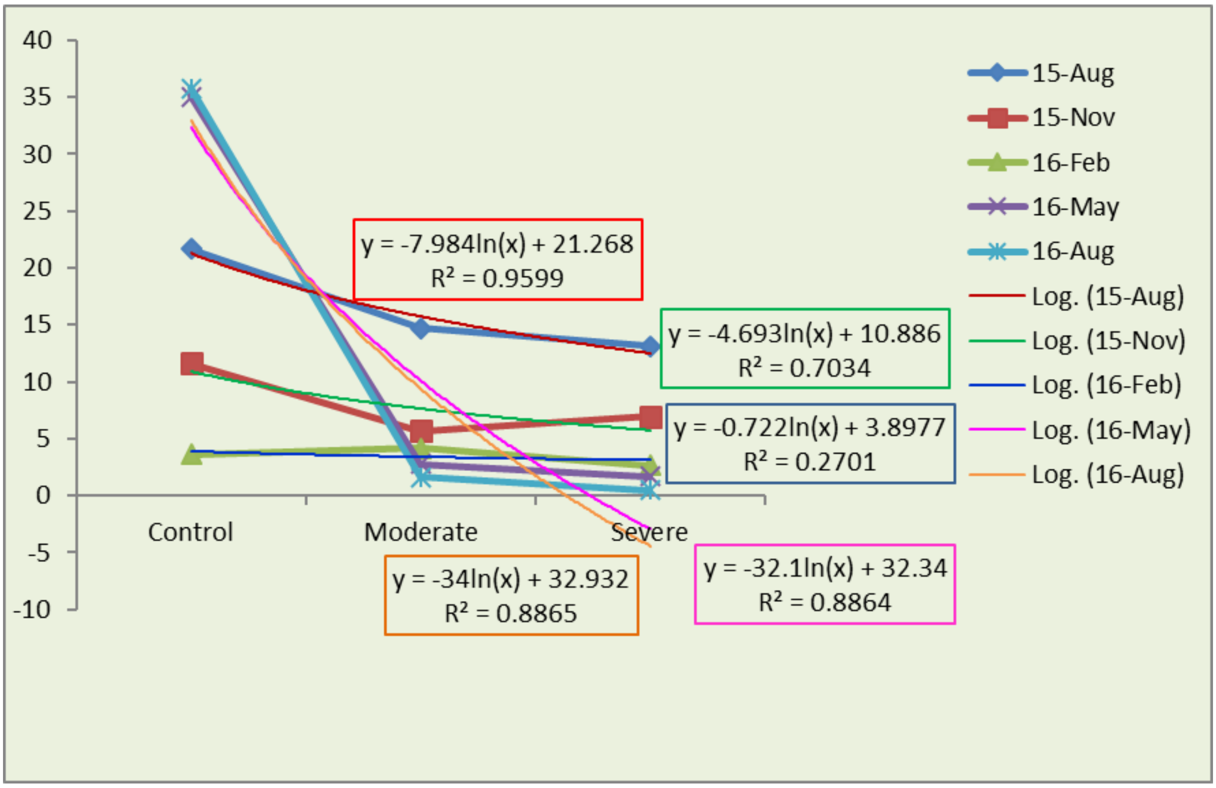

Fig 5: Effect of drought on size of leaves of *T. grandis* showing trendline and regression graph with R^2value.

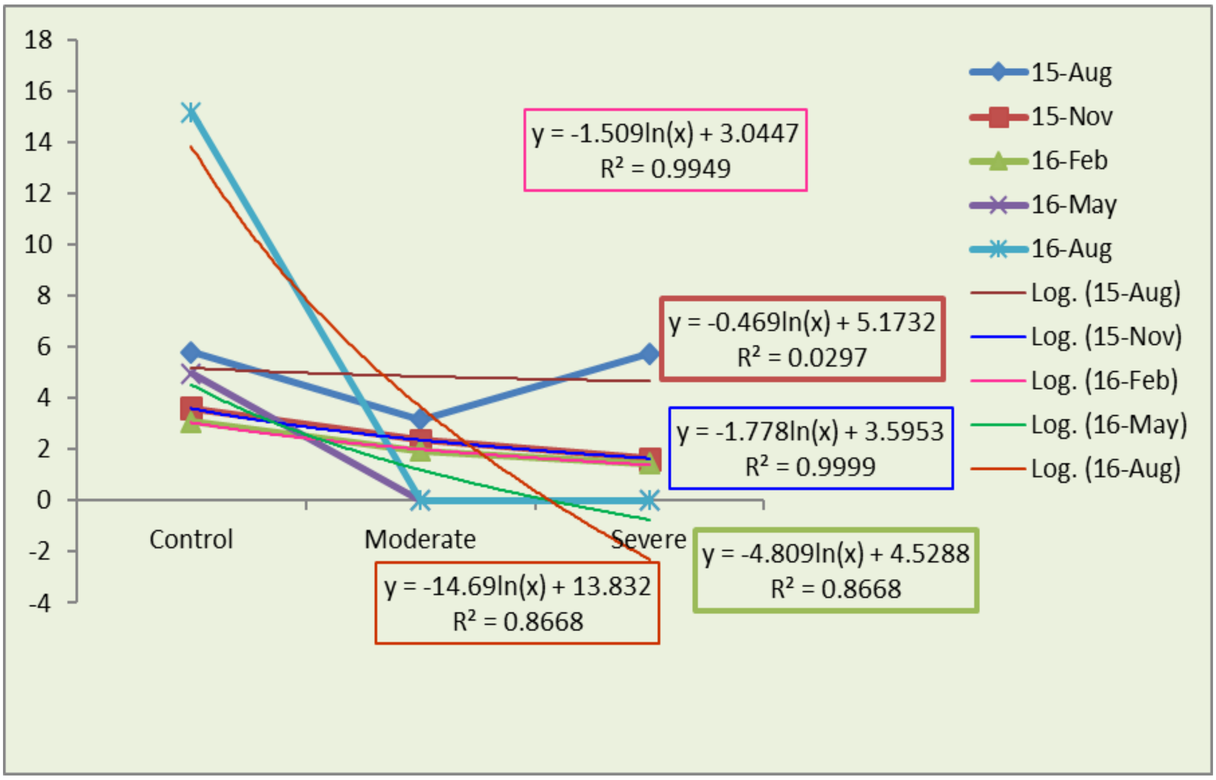

Fig 6: Effect of drought on size of leaves of *G. arborea* showing trendline and regression graph with R^2value.

2. Physiological parameters

Physiological parameters *viz.* Photosynthetic rate (Pn), Stomatal conductance (C) and Transpiration rate (E) were recorded half yearly for one year (Table 2). The observations in July 16 in *G. arborea* (MD and SD) was not taken due to absence of leaves. Photosynthetic rate followed the similar trend as that of biomass content of the seedlings. Under control conditions, maximum photosynthetic rate was found in *G. arborea*, followed by *T. grandis* while under drought treatments, maximum photosynthetic rate was recorded in *T. grandis*, followed by *G. arborea*. Stomatal conductance and transpiration rate were recorded maximum in *G. arborea* followed by *T. grandis* under control and drought treatments. Maximum Photosynthetic rate, Stomatal conductance and Transpiration rate were found in July 16 followed by January 16 in all the selected treatments of *T. grandis* and control treatment of *G. arborea* seedlings. Photosynthetic rate, Stomatal conductance and Transpiration rate decreased with increase in severity of drought. Sharp decline in photosynthetic rate was observed in *G. arborea.*

Table 2: Effect of drought stress on physiological parameters of the selected species.

Treatment	**Photosynthetic Rate (Pn) (µmol/m^2/s)**		**Stomatal Conductance (C) (mmol/m^2/s)**		**Transpiration Rate (E) (mmol/m^2/s)**	
Tectona grandis						
	January 16	July 16	January 16	July 16	January 16	July 16
Control	2.00	2.50	12.00	12.18	0.92	0.99
Moderate	2.02	2.10	9.77	10.02	0.57	0.67
Severe	0.94	1.00	8.69	9.07	0.30	0.52
Gmelina arborea						
Control	2.60	3.40	45.02	45.78	5.03	6.56
Moderate	0.40	-	10.62	-	2.21	-
Severe	0.35	-	7.69	-	0.97	-

3. Biochemical parameters

After completion of drought experiment, biochemical parameters including chlorophyll and proline were analysed. Significant (*P*<0.05) difference in foliar bio-chemicals of the selected tree species was observed (Fig. 7-8). Maximum total chlorophyll content was found in *G. arborea* (6.04 mg/g) followed by *T. grandis*. Chlorophyll content decreased with increase in drought stress in both the selected tree species. Proline increased with increase in drought stress and found maximum in *T. grandis* and minimum in *G. arborea.*

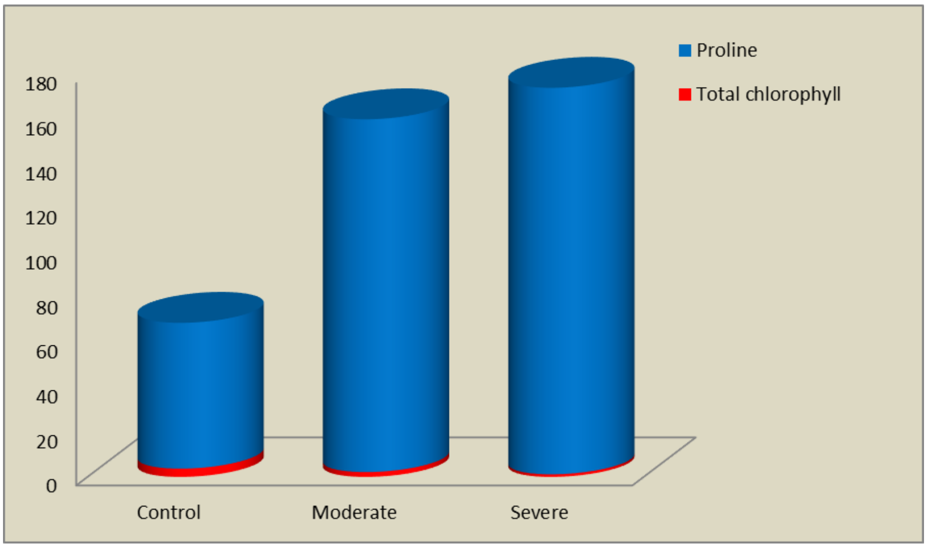

Fig 7: Effect of drought on foliar biochemicals of *Tectona grandis.*

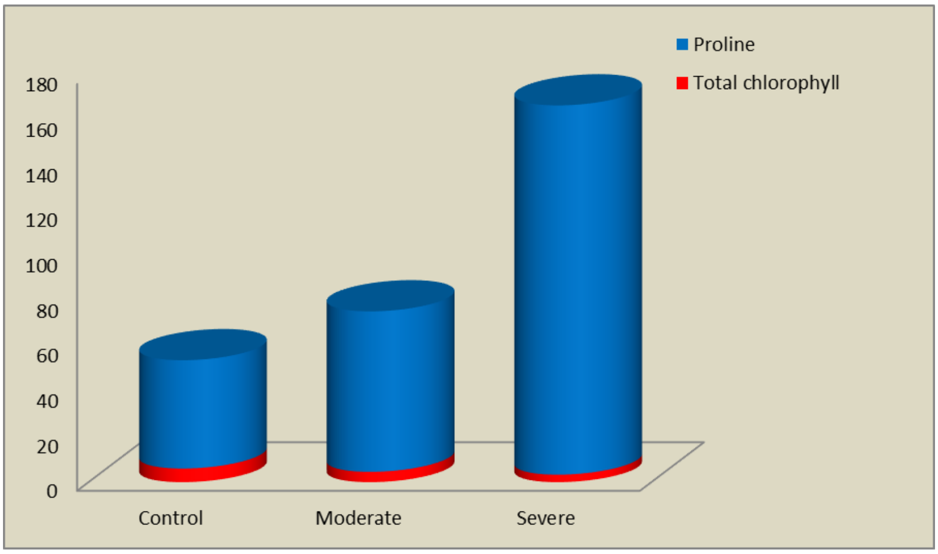

Fig 8: Effect of drought on foliar biochemicals of *Gmelina arborea.*

4. Correlation Studies

Significant positive correlation (*P*<0.05 to *P*>0.01) was observed between growth traits and physiological parameters (Table 3-4). Significant positive correlation (*P*<0.05 to *P*<0.01) among chlorophyll content, growth traits and physiological parameters was found in the selected tree species. Negative significant (*P*<0.05 to *P*<0.01) correlation was found between proline content and growth traits and physiological parameters.

Table 3: Correlation among growth traits, physiological characteristics and biochemical parameters in *T. grandis* under drought stress.

		Growth traits				**Physiological characteristics**			**Biochemical parameters**	
		HT	**CD**	**SOL**	**TB**	**PR**	**SC**	**TR**	**TC**	**PL**
Growth traits	HT	1								
	CD	0.426	1							
	SOL	0.651	0.628	1						
	TB	0.761*	0.702*	0.833**	1					
Physiological characteristics	PR	0.798**	0.776*	0.661	0.794*	1				
	SC	0.804**	0.686*	0.959**	0.878**	0.804**	1			
	TR	0.830**	0.678*	0.915**	0.912**	0.740*	0.961**	1		
Biochemical parameters	TC	0.700*	0.835**	0.838**	0.799**	0.831**	0.875**	0.851**	1	
	PL	-0.657	-0.546	-0.940**	-0.733*	-0.688*	-0.934**	-0.833**	-0.806**	1

HT - Height, CD - Collar Diameter, SOL - Size of leaves, TB – Total Biomass, PR - Photosynthetic rate, SC – Stomatal Conductance, TR - Transpiration rate, TC - Total Chlorophyll and PL – Proline.

Table 4: Correlation among growth traits, physiological characteristics and biochemical parameters in *G. arborea* under drought stress.

		Growth traits				**Physiological characteristics**			**Biochemical parameters**	
		HT	**CD**	**SOL**	**TB**	**PR**	**SC**	**TR**	**TC**	**PL**
Growth traits	HT	1								
	CD	0.813**	1							
	SOL	0.681*	0.645	1						
	TB	0.730*	0.661	0.928**	1					
Physiological characteristics	PR	0.716*	0.642	0.979**	0.927**	1				
	SC	0.743*	0.670*	0.964**	0.963**	0.987**	1			
	TR	0.720*	0.675*	0.957**	0.891**	0.970**	0.959**	1		
Biochemical parameters	TC	0.475	0.431	0.749*	0.789*	0.777*	0.823**	0.839**	1	
	PL	-0.685*	-0.575	-0.567	-0.652	-0.644	-0.695*	-0.759*	-0.818**	1

HT - Height, CD - Collar Diameter, SOL - Size of leaves, TB – Total Biomass, PR - Photosynthetic rate, SC - Stomatal Conductance, TR - Transpiration rate, TC - Total Chlorophyll and PL – Proline.

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Discussions

Environmental stresses affect many aspects of tree physiology and metabolism, and can negatively impact tree growth, development and distribution (Harfouche *et al*., 2014) [11]. Drought is one of the most widespread global environmental problem leading to low water availability for plants, which causes significant loss in growth, productivity and finally their yields (Ludlow and Muchow, 1990) [16]. Global climate change will likely make water scarcity an extreme greater limitation to plant productivity across increasing amount of land. It is widely known that drought affects morphological, physiochemical and molecular processes in plants resulting growth inhibition, stomata closure with consecutive reduction of transpiration, decrease in chlorophyll content and inhibition of photosynthesis, protein changes and differential responses of antioxidative enzyme (Xiao *et al*., 2008, Chave *et al*., 2009) [33, 5]. Stress responses and tolerance mechanisms involve the prevention or alleviation of cellular damage, the re-establishment of homeostasis and growth resumption. Because forest trees are sessile and continue to develop over many growing seasons, mechanisms have evolved that allow trees to respond to changes in environmental conditions (Harfouche *et al*., 2014) [11]. The forest trees behave differently in the presence of drought stress environments. Mechanisms that permit stress survival are termed as resistance, which allow an organism to tolerate or avoid stress.

In the present study, height and collar diameter found to be significantly increased with age of the seedlings but showed decreasing trend with increasing severity of drought. The effect of drought was more pronounced on *Gmelina arborea* seedlings while *Tectona grandis* seedlings shown resistance behavior and able to maintain their growth till the end of experiment. The findings corroborate with the studies conducted in *Tectona grandis*, where reduction in plant growth occurred when subjected to drought conditions (Husen, 2009; Sneha, 2012) [12, 30]. Similar studies were conducted on other tree species *viz. Albizzia lebbek*, *Leucaena leucocephala* and *Shorea robusta* in the Tarai region of Uttarakhand during 2002-2004 (Rao *et al*., 2008) [23]. Ashraf (2004) [3] also observed significant reduction in height and stem diameter of *Dalbergia sissoo* and *D. latifolia* plants, when subjected to water deficit conditions and later was found superior in tolerating drought stress than former species.

The selected tree species are deciduous in nature. In *Tectona grandis* and *Gmelina arborea* leaf fall starts from November to February and new leaves appear in April-May of next year. Absence of leaves during May onwards under drought could be because new leaves did not emerge after leaf fall due to less availability of water to the *Gmelina arborea* seedlings. Under drought treatments size of leaves decreased with age of the seedlings and severity of drought. Smaller size of leaves in drought treatments might be due to limited photosynthesis under the conditions of less availability of water to the seedlings. The reduced rate of leaf expansion may be beneficial to plants under drought stress, as it reduces the area for transpiration (Mahajan and Tuteja 2005) [17]. *Melia azedarach* adapted to drought stress by reducing total leaf area, thus prevented water loss more efficiently (Jhou *et al*., 2017) [14].

The biomass declined with increase in drought stress and differed significantly among the selected treatments. Similar observations were found in *Albizzia lebbek*, *Leucaena* *leucocephala* and *Shorea robusta* in the Tarai region of Uttarakhand (Rao *et al*., 2008) [23] and *Pongamia pinnata* (Swapna and Rajendrudu, 2015) [31]. Drought stress appears to be governed by a functional balance between water uptake by the roots and photosynthesis by the shoots and this balance is affected by water stress (Rao *et al*., 2008) [23].

Physiological parameters like photosynthetic rate, transpiration rate and stomatal conductance decreased under drought stress in the selected species. The results are in agreement with the studies conducted on 4.5 years old teak clones by Husen (2009) [12] and on *Melia azedarach* and *Swietenia macrophylla* by Jhou *et al*. (2017) [14]. Ashraf *et al*. (2004) [3] also observed that drought stress caused a significant reduction in net photosynthetic rate (*P*N), transpiration rate (*E*), and stomatal conductance (*g*s) in *Dalbergia sissoo* and *D. latifolia*.

The foliar biochemical of the selected tree species were observed to be differ significantly. Chlorophyll content decreased with increase in drought stress in both the selected tree species. Photo inhibition seemed to have played some role in the reduction of chlorophyll content (Chaudhry, 2006) [4]. Chlorophyll loss is a negative consequence of stress and is also considered as an adaptive feature, which reduces light harvesting and hence the possibility of further damage to the photosynthetic machinery (Munne´-Bosch and Alegre, 2000) [18]. Nautiyal *et al*. (1996) [20] observed reduction in chlorophyll a, b and total chlorophyll in the leaves of *Pongamia pinnata* (L) Pierre under controlled laboratory conditions resulting less photosynthesis and low growth. Teak seedlings under the drought treatments IW/ET= 0 and 0.3 showed a significant reduction in relative chlorophyll content (Sneha *et al*., 2012) [30]. Proline content increased with severity of drought stress. In abiotic stress, proline accumulation serves as a means of osmotic adjustment and also play protective role in plants (Xiao *et al*., 2008) [33].

Significant correlation between growth traits and physiological parameters observed as optimal growth and biomass is always due to the higher and good photosynthetic rate and osmoregulation processes, which declines under drought stress in order to prevent water loss thus affecting the production and growth of plant (Larson and Funk, 2015) [15]. Similar results have also been found in *Salix* species under normal (Singh *et al*., 2012) [28] and in *T. grandis* under drought conditions (Husen, 2009) [12]. The positive correlations among chlorophyll content, growth traits and physiological parameters also found in other species like *Alstonia macrophylla, Acacia auriculiformis, Artocarpus heterophyllus, Terminalia arjuna* and *Azadiracta indica* under drought stress conditions (De Costa and Rozana, 2000) [7].

Conclusion

The current elevating drought situation, has imposed the huge damage to agriculture and forestry, giving rise to barren and degraded areas in this constantly growing population period. In the present study, the various changes were observed in terms of growth, physiological and biochemical analysis as the effect of drought in selected *Tectona grandis* and *Gmelina arborea* species seedlings. It was found that the effect of drought stresses had great negative impact on physiological parameters and total chlorophyll content due to which the selected growth traits were greatly affected in terms of reduction whereas the proline content found to be elevated. This clearly depicts the close relationship of species morphology with its physiological and biochemical condition and also shows the strong defensive response for protection and survival. The correlation analysis makes the above conclusion strong. Further, the survivability of *T. grandis* (MD and SD) till the end of year indicates its capability and level of tolerating the drought stress which is very necessary to know for any of the plant species in order to have an idea for plantations in such sites. Forest tree species are the most long-living organisms with the numerous tangible and intangible benefits. Hence, in order to protect the environment and livelihood from the harmful effects of drought stress and to fulfill the resource requirement of increasing population there is need of plantations of forest tree species with economically importance attributes which should be suitable for such areas.

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