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Impact of water logging condition on seedling of five timber tree species

Abstract

Under natural conditions, plants are frequently exposed to transient or permanent soil waterlogging. Flooding of the soil with water with poor drainage drastically influences the soil physico-chemical properties, most notably soil oxidation-reduction potential, pH and O_2 level. Thus, conditions of hypoxia or anoxia are commonly encountered by plant root systems. These O_2 restrictive conditions dramatically have an effect on plant growth, development and survival. One in every of the simplest characterized plant responses to soil waterlogging is that the metabolic switch from aerobic respiration to anaerobic fermentation. In this study the effects of waterlogged were examined on seedling growth, metabolic, physiological and morphological responses of five species of timber trees (*Casuarina cunninghamiana,* C. *glauca, Eucalyptus rostrata*, *Cupressus sempevirens* and *E. citrodora*). The results indicated a wide variation among these timber tree species in their response to water logging. *Casuarina cunninghamiana* and C. *glauca* were more tolerant to waterlogging than the other species, followed by *Eucalyptus rostrata* then *Cupres sussempevirens. E. citrodora* was the least tolerant waterlogging species.

Waterlogging treatment decreased the seedling growth and the leaf contents from carbohydrates, total and free phenols, chlorophylls and carotenoids as well as N, P and K contents in the leaves. On the other hand, waterlogging treatment increased both epinastic leaf angles, contents of total indoles, total free amino acids, chloride, sodium, calcium and magnesium in the leaves. Moreover, total free amino acids, total indoles, carbohydrates, total and free phenols contents were also increased in stems and roots of waterlogged seedlings.

Volume 6 Issue 1 - 2022

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Received: February 15, 2022 | **Published:** February 24, 2022

Introduction

Stress tolerant tree also called resistance or susceptible stress tree is one type of tree mechanism to respond in stress conditions.[1] The reaction involved changes whether it inhibits or stimulates tree growth either in hormone, structure or physiological changes. As known, woody trees were the best selections in tolerating stress resulting by planted in high risky areas such as along highway. Subsequently, these urban tree areas were facing with critical environment stress every day. One of common stress was waterlogging stress occurred when excessive water is supplied to the trees.[2,3]

Waterlogging does not necessarily occur only when the soil is inundated. Soil waterlogging has long been identified as a major abiotic stress and the constraints it imposes on roots have marked effects on plant growth and development. When such events take place in the spring, they can greatly reduce seed germination and seedling establishment. Thus, soil waterlogging is an important factor affecting the growth, development and survival of numerous plant species, not only in natural ecosystems but also in agricultural and horticultural systems.[4,5] Waterlogging occurs when water fills a critical proportion of the soil air spaces, depending on the plant species of plant involved. During waterlogging, inhibition of root respiration and subsequent to the root tissue has been suggested as cause of flooding stress.[6] As water saturates the soil, air spaces are filled, leading to the modification of several soilphysico-chemical characteristics.[7,8] The first event that takes place is in fact the increased presence of H_2O: soil water saturation characterises flooding. Nevertheless, the mechanisms which trigger a plant response are often presumed by-products of root zone flooding (i.e. changes in soil redox and pH; a decline in O_2 level…). Alternatively, toxic effects of the production of anaerobic respiration have been suggested as a mechanism of root damage in both herbaceous and tree species.[9,10] The 0_2 diffusion system from the aerial parts to the roots is limited and varies in mesophytes depending on waterlogging tolerance.[11-13] Adventitious root formation and increasing root porosity are however a temporary feature to case or help recover from waterlogging damage.[14,15]

Plant species differ in tolerance to root zone waterlogging.[16-18] and these differences are important for selecting plants adapted to these conditions.[19] The existence of genetic variability for waterlogging tolerance is known[19,20] and screening plants for increased tolerance to waterlogging was reported.[19,21]

The purpose of this study was to evaluate the relative waterlogging tolerance of some timber seedling tree species. Also, to examine the effects of waterlogging on growth, elemental contents, and endogenous hormones in seedlings of some timber tree species.

Materials and methods

The present investigation was carried out in two successive seasons of 1999 and 2000 on seedlings of five timber trees species *(Casuarina cunninghamiana*, *C. glauca, Eucalyptus rostrata, E. citrodora and Cupres sussempervirens).*

Seeds of each timber tree species were germinated in sand in the greenhouse. After germination, newly emerged seedlings with the first two leaves were chosen and transferred into washed sand in plastic containers of 30 cm diameter at the base, 50 cm at the top and 30 cm deep. The plants were irrigated with a dilute nutrient solution,[22] until starting the waterlogging treatment, where the seedlings were grown for 6 months. The plants were then selected for uniformity on the basis of plant length within each cultivar. Plants were grown in containers, each contained 20 plants.

Waterlogging was initiated by closing the drainage system of plastic containers and adding tap water to the containers. Water was maintained about 5 cm above the sand level through the experimental period. Non waterlogged plants were served as control and irrigated and drained daily.

More details on the experimental technique are described elsewhere.[23]

Time of appearance of waterlogging symptoms and percentage of survived seedlings were recorded and the affected seedlings were daily removed.

Samples were taken from waterlogging seedlings as well as from the control (freely drainage) for growth measurements. The seedlings were separated to roots and shoots. The root system was washed to be free from sand. Fresh weight of roots and tops was recorded.

Leaves or phylloclades (casuarinaspieces), stems and roots samples were collected for determination of potassium, sodium[24] chloride,[25] nitrogen,[26] phosphorus,[27] calcium, magnesium,[28] total indols[29] and the modification of Selim et al,[30] freephenols,[31] total phenols,[32] total carbohydrates[33] total sugars,[31] and total free amino acids.[34] Moreover chlorophyll and careteniods were determined in leaves/phylloclade according to Welburn and Lichtenthaler.[35]

The values presented in the tables are based on the means of the two seasons.

The experimental design for all studied treatments was the complete randomized block design with three replicates and data were statistically analyzed according to the method of Duncan.[36] Data were subjected to an analysis of variance. Significant differences among means were determined using least significant differences ($p < 0.05$) comparison.

Results and discussion

Symptoms of waterlogging injury on the seedlings were chlorosis and abscission of leaves, in addition to wilting of leaves and shoot, which are considered the main indicators for plant damage.

Survival

A great variability existed among the timber tree species in their tolerance to waterlogging (Table 1). The time required for each population to reach certain level of survival differed from specie to another. The survival percentage declined as a function of time of waterlogging treatment.

It can be noticed that E. rostrata appeared to be least tolerant species to waterlogging; however, *C. cunningharniana* was the most waterlogging tolerant species. The relative tolerance had been found in an ascending order as *Casuarina cunninghamiana, C. glauca, Eucalyptus rostrata, Cupres sussempervirens* and E. *citrodora.* Variation between species and strains in their tolerant to waterloging had been reported.[6,16] Plant tolerance may be adapted to the reduced oxygen levels by either reducing their demand for oxygen by metabolic change or by increasing oxygen supply to root through the modification of root anatomy.[8,37-40] The extent of injury is dependent on the duration of oxygen deficiency and can range from stoppage of growth to death of plants.[4,41]

Seedling growth

The waterlogging treatment decreased seedling growth in terms of fresh weight (Table 2) of all timber tree species under this study, compared with un-waterlogging control. The reduction in growth was associated with the tolerant to waterlogging. The lowest reduction in seedling growth 3.1% and 7.9% for root and shoot respectively was found for the most tolerant species *(C. cunningharniana)* which showed the least effect by water logging. However, the great reduction in growth (67.6% and 51%for root and shoot, respectively was found in the seedlings of the least waterlogging tolerant (E. *cetrodora).*

Table 1 Times (days) at which percentage of seedlings reached specified levels of survival during waterlogging treatment mean of the two seasons, 1999-2000

Species	Time needed to reach levels of survival (days)			
	Survival %			
	2000		1999	
	50%	80%	50%	80%
E. rostrata	54	45	45	38
E. citrodora	27	23	11	4
C. cunninghamiana	172	140	168	130
C. glauca	168	125	160	122
C. sempervirens	32	31	18	15
$LSD_{0.05}$	2.9	3.9	2.1	3.5

Table 2 Effect of water logging on seedlings growth (measured as fresh weight when 50% survival was reached) of five timber tree species (mean of the two seasons, 1999-2000)

Species	Seedlings weight (g)		Growth reduction %
	Control	Waterlogged	
Shoots			
E. rostrata	1.96	2.92	32.9
E. citrodora	1.52	3.1	51
E. cunninghamiana	1.16	1.26	7.9
E. glauca	1.51	1.64	7.9
E. sempervirens	0.54	0.98	44.9
$LSD_{0.05}$	0.42	0.19	
Roots			
E. rostrata	0.94	1.66	43.4
E. citrodora	0.6	1.58	67.6
E. cunninghamiana	0.94	0.97	3.1
E. glauca	1.19	1.26	3.6
E. sempervirens	0.27	0.67	59.7
$LSD_{0.05}$	0.16	0.11	

Similar growth reduction was found in citrus,[16] olive,[18] Birch rootstocks[17] and in other tree species.[3-5,10] Such decrease in growth can by oxygen deficiency could be possibly due to reduction of photosynthesis.[4,42] and nutrient uptake by active absorption.[43] In this connection, Parent et al.[2] reported that, adaptations to waterlogging include morphological changes which comprise the formation of hypertrophied lenticels, the initiation of adventitious roots and/or the development of aerenchyma. Our knowledge of the basic adaptive mechanisms of plants to soil waterlogging has benefited from large scale genomic and proteomic approaches, however, the diversity of the adaptive responses involved underlines the difficulty when studying this stress.

Leaf angle (epinasty)

Waterlogging increased leaf epinasty (Table 3). The epinastic movement of the leaves has been caused by more rapid expansion of cell on the upper side of the petiole compared to the cell on the lower side.[44] It is known that ethylene will induced epinasty even at very low concentration,[41] thus waterlogged plants have similarly appeared to the plants which have been gassed with ethylene.[44] In this respect, Irfan et al., (2010) reported that other plant response to waterlogging is to produce ethylene, which signals various adaptive functions to plant survival, such as increased number of adventitious roots, and formation of aerenchyma in such environment. Different apple genotypes present variable response to hypoxia due to genetic variability. The main responses in apple rootstocks to waterlogging are reduction of new adventitious root growth, leaf senescence and reduced dry weight accumulation.[45]

Table 3 Effect of waterlogging on leaf/phylloclade epinasty of some timber tree species (mean of the two seasons, 1999-2000)

Species	Leaf or phylloclade angle (degree)		
	% of control	Waterlogged	Control
E. rostrata	166.6	55	33
E. citrodora	181.3	58	32
E. cunninghamiana	140	28	20
E. glauca	154.2	37	24
E. sempervirens	182.4	62	34
$LSD_{0.05}$		3.8	2.1

Various studies have established that the ethylene levels in waterlogged plants exceeded those of the control plants.[46] The ethylene production and epinasty were observed in shoots under anaerobic conditions, this is true when the root of tomato plants growing in nutrient solution were made anaerobic, increased ethylene production and epinasty were observed in the shoot.[47] Auxin and ethylene concentration increased in waterlogged plants.[23,41]

However, the effect of waterlogging on epinastic leaf angle differed with specie (Table 3). Seedling of *C.cunninghamiana* which was the most tolerant species to waterlogging had the lowest effect of waterlogging on epinastic leaf angle, However epinastic leaf angle *of E. citrodora***,** the least waterlogging tolerance was the most influenced by waterlogging. Accordingly', the waterlogging tolerance of Casuarina species have been linked with their ability to minimize ethanol production by the maintenance of low respiration rates and the production of other non-toxic and proportion such as oxygen transport from the shoot to the root.[38]

Sodium, chloride, calcium and magnesium

Waterlogging increased the concentration of Na^+, Cl^-, Ca^{++} and Mg^{++} in the leaves, stems and roots of all timber tree species under this study (Table 4). This increase of both Na^+ and Cl^- that occurred with waterlogging were the result of increase in the uptake of Na^+ and Cl^-.[48] The more tolerant Casuarina species *(C.cunninghamiana* and, *C. glauca)* as shown in Table 1, had the lowest increases of both Na^+ and Cl^-. Oncontrary the least tolerant specie E. *citrodora* had the highest increases of Na^+ and Cl^-.

This increment in both Na and Cl were correlated with the reduction in root and shoot growth (Table 2). The higher tolerance species to waterlogging had the lower reduction in die growth of shoots and roots as well as the lower increase in both Na^+ and Cl^- concentration. These results possibility indicate that waterlogging increases the potential salt toxicity.

Table 4 Effect of waterlogging on sodium, chloride, calcium and magnesium concentration in seedling parts of some timber tree species (mean of the two seasons, 1999-2000)

Species	Sodium %					
	Roots		Stems		Leaves or phylloclade	
	Waterlogged	Control	Waterlogged	Control	Waterlogged	Control
E. rostrata	0.69	0.39	0.59	0.29	0.45	0.4
E. citrodora	0.75	0.42	0.7	0.3	0.51	0.43
E. cunninghamiana	0.64	0.44	0.66	0.49	0.57	0.54
E. glauca	0.68	0.39	0.69	0.43	0.55	0.51
E. sempervirens	0.79	0.52	0.68	0.2	0.61	0.55
$LSD_{0.05}$	0.1	0.12	0.1	0.13	0.08	0.1
	Chloride %					
E. rostrata	1.18	0.98	0.72	0.59	0.25	0.18
E. citrodora	1.19	0.86	0.65	0.47	0.27	0.18
E. cunninghamiana	1.2	0.74	0.59	0.53	0.17	0.16
E. glauca	1.15	0.78	0.58	0.54	0.17	0.15
E. sempervirens	0.88	0.17	0.23	0.18	0.28	0.19
$LSD_{0.05}$	0.19	0.06	0.08	0.08	0.08	N.S.

Citation: El-Yazel MAS, El-Shewy AA, Matter FMA. Impact of water logging condition on seedling of five timber tree species. *Horticult Int J.* 2022;6(1):37–45. DOI: 10.15406/hij.2022.06.00240

Table Continued...

Species	Sodium %					
	Roots		Stems		Leaves or phylloclade	
	Waterlogged	Control	Waterlogged	Control	Waterlogged	Control
	Calcium %					
E. rostrata	0.51	0.35	0.53	0.63	0.98	0.53
E. citrodora	0.52	0.39	0.61	0.59	0.91	0.66
E. cunninghamiana	0.41	0.23	0.61	0.27	0.57	0.53
E. glauca	0.39	0.24	0.55	0.34	0.61	0.57
E. sempervirens	0.53	0.53	0.63	0.67	0.87	0.63
$LSD_{0.05}$	0.06	0.08	0.06	0.07	0.06	0.09
	Magnesium %					
E. rostrata	0.65	0.61	0.51	0.45	0.69	0.39
E. citrodora	0.68	0.59	0.56	0.51	0.66	0.42
E. cunninghamiana	0.95	0.61	0.76	0.21	0.53	0.51
E. glauca	0.86	0.67	0.66	0.33	0.51	0.57
E. sempervirens	0.51	0.43	0.29	0.27	0.59	0.15
$LSD_{0.05}$	0.1	0.09	0.09	0.07	0.09	0.09

In this respect Gadallah[49] indicated that waterlogging and salinity together increased Na^+ $Ca^{++}$and Cl^- accumulation in shoot tissues and decreased the stability of leaf membranes to dehydration.

Nitrogen, phosphorus and potassium

The waterlogging treatment decreased the concentration of N, P and K in the leaves, stem and roots of the studied all timber tree species (Table 5). In this respect Pearson et al.[50] Nasr et al.[51] reported that the waterlogging treatment had no influence on N, P and K concentrations in different plant parts. A reduction in mineral uptake in waterlogged plants might be attributed to the dieback of the absorbing roots during flooding. This causes a declining content of nutrients in plants with increased age. In addition, possible decrease in 0_2 in the soil with increasing waterlogging may have reduced the uptake of N, P and K by the plants.

Table 5 Effect of waterlogging on the concentration of nitrogen, phosphorus and potassium in seedling parts of some timber tree species (mean of the two seasons, 1999-2000)

Species	Roots	Stems			Leaves or phylloclade	
	Waterlogged	Control	Waterlogged	Control	Waterlogged	Control
	Nitrogen %					
E. rostrata	1.2	1.4	1	1.1	1.9	1.9
E. citrodora	1.3	1.4	1.2	1.3	1.8	1.9
E. cunninghamiana	1.2	1.3	1	1.1	1.6	1.6
E. glauca	1.2	1.3	1.1	1.2	1.7	1.8
E. sempervirens	1.1	1.2	1.1	1.3	2	2.1
$LSD_{0.05}$	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	Phosphorus %					
E. rostrata	0.03	0.05	0.03	0.05	0.18	0.27
E. citrodora	0.05	0.07	0.06	0.09	0.19	0.24
E. cunninghamiana	0.08	0.1	0.1	0.13	0.2	0.31
E. glauca	0.09	0.09	0.1	0.1	0.22	0.32
E. sempervirens	0.31	0.15	0.08	0.15	0.25	0.26
$LSD_{0.05}$	0.06	N.S.	N.S.	N.S.	N.S.	N.S.

Citation: El-Yazel MAS, El-Shewy AA, Matter FMA. Impact of water logging condition on seedling of five timber tree species. *Horticult Int J.* 2022;6(1):37–45.
DOI: 10.15406/hij.2022.06.00240

Table Continued...

Species	Roots	Stems			Leaves or phylloclade	
	Waterlogged	Control	Waterlogged	Control	Waterlogged	Control
	Potassium %					
E. rostrata	0.41	0.44	41	0.44	0.67	1.44
E. citrodora	0.43	0.47	0.45	0.48	0.7	1.38
E. cunninghamiana	0.42	0.44	0.51	0.54	0.79	1.1
E. glauca	0.43	0.46	0.52	0.56	0.75	1.12
E. sempervirens	0.55	0.66	0.71	0.74	0.78	1.44
$LSD_{0.05}$	0.05	0.12	0.09	0.08	0.03	0.16

Also, Gadallah[49] reported that die waterlogging was the dominant factor affecting K^+ content.

Total free amino acids

Data in Table 6 show that leaves or phylloclade of waterlogged seedlings of timber trees contained more free amino acids than un-waterlogged seedlings. The same trend also was noted with both stems and roots of waterlogged seedlings. From the same Table 6 it could be nosed that both survived of E. *rostrata* and *E. citrodora* contained the highest values of total free amino acids in their leaves, stems and roots. Moreover, the two species have higher sensitivity to waterlogging treatment (Table 1). This result may explain that amino acids increased in tissue of survived seedlings.

Table 6 Effect of waterlogging on the concentration of total free amino acid in seedling parts of some timber tree species (mean of the two seasons, 1999-2000)

Species	Total free amino acid as mg/g D.W.					
	Roots		Stems		Leaves or phylloclade	
	Waterlogged	Control	Waterlogged	Control	Waterlogged	Control
E. rostrata	5.91	3.08	5.26	2.87	12.41	11.86
E. citrodora	6.05	3.33	5.66	3.01	12.99	11.25
E. cunninghamiana	5.52	2.93	4.39	2.26	8.52	8.16
E. glauca	5.88	3.02	3.99	2.33	9.95	8.15
E. sempervirens	5.39	3.43	4.39	2.26	9.4	9.28
$LSD_{0.05}$	0.12	0.11	0.14	0.31	1.08	1.17

In this respect Slatyer[52] reported that the increase in total free amino acids may be due to the interruption of protein synthes and proteolysis which occurs in plants under stress. Bradford and Young[53] noted that ethylene release from many plant species in response to flooding due to amino acid (1-aminocyclo-propan-1-carboxylic acid (ACC)), the intermediate precursor of ethylene. Moreover, Parent et al,[2] reported that, most proteins induced during hypoxic conditions are enzymes involved in the establishment of this fermentative pathway. Because the plant cells need to keep a continuous ATP supply, the use of alternative electron acceptors and/or alternative pathways may be key elements of survival under soil waterlogging.

Total and free phenols

The waterlogging treatment Table 7 decreased the total and free phenols in the leaves or phylloclade of all timber tree compared with the control. In this connection Leopold[54] classified the phenols compounds as growth inhibitors. Moreover, Kefeli and Kutacek,[55] suggested that, plant phenols may be divided into three groups, promotive, Inhibitors and inactive.

On the other hand, the total and free phenols in both stems and roots of all timber tree species were increased compared with the control. This increasing effect may be attributed to that phenolic compounds constitute a part of cellular solutes and provide a reducing environment that could be an adaptive mechanism for scavenging oxygen free radicals during stress.

Total indoles

The leaves or phylloclade, stem and roots of waterlogged seedlings of timber trees contained high values of total indoles (IAA) compared with non-waterlogged seedlings.

Yamamoto and Kozlowski[56] on *Acer negundo* seedlings indicated that auxin accumulation at or above the flooding are essential for AR initiation and development. However, apparent auxin effects actually might be mediated by ethylene (C_2H_4) action, since auxin accumulation stimulates C_2H_4 biosynthesis.

Steven et al[57] suggested that auxin was accumulated at or above the flood line of tomatoplant. They added that auxin is essential for the initiation of adventitious root primordial (ARP).

Total soluble sugars and carbohydrates

A progressive reduction in both sugar and total carbohydrate contents (Table 9) were observed in seedling leaves of timber trees as a result of waterlogging treatments. Such reduction in growth which caused by oxygen deficiency due to waterlogging could be possibly due to reduction of photosynthes, Loustalat[42] and nutrient uptake by active absorption roots.[43]

Table 7 Effect of waterlogging on total phenols and free phenols concentration in seedling parts of some timber tree species (mean of the two seasons, 1999-2000)

Species	Roots		Stems		Leaves or phylloclade	
	Waterlogged	Control	Waterlogged	Control	Waterlogged	Control
	Total phenols mg/g D.W.					
E. rostrata	62.05	38.92	61.83	19.99	52.6	61.49
E. citrodora	55.15	35.15	56.1	23.2	43.15	59.2
E. cunninghamiana	58.53	29.02	60.86	29.02	57.77	84.56
E. glauca	59.1	33.15	55.1	33.2	52.2	81.13
E. sempervirens	49.4	27.89	27.26	20.79	31.44	38.68
$LSD_{0.05}$	2.45	2.5	3.5	2.23	2.23	2.58
	Free phenols as mg/g D.W.					
E. rostrata	40.09	32.59	16.06	9.52	26.83	35.26
E. citrodora	30.25	20.2	18.25	8.25	33.15	41.15
E. cunninghamiana	33.89	24.02	21.5	9.08	39.23	57.52
E. glauca	29.15	19.11	19.25	11.12	39.2	49.13
E. sempervirens	34.6	11.83	23.68	8.52	15.39	16.05
$LSD_{0.05}$	2.45	3.05	2.19	1.4	2.69	3.54

Table 8 Effect of waterlogging on total indols concentration in seedling parts of some timber tree species. (mean of the two seasons, 1999-2000)

Species	Total indols as mg/g D.W.					
	Roots		Stems		Leaves or phylloclade	
	Waterlogged	Control	Waterlogged	Control	Waterlogged	Control
E. rostrata	0.636	0.589	0.59	0.311	1.571	0.534
E. citrodora	0.713	0.666	0.62	0.34	1.34	0.571
E. cunninghamiana	0.809	0.319	1.333	1.114	1.135	0.637
E. glauca	0.73	0.455	1.389	1.202	1.95	0.84
E. sempervirens	1.597	0.743	0.957	0.889	1.49	0.9
$LSD_{0.05}$	0.1	0.02	0.28	0.11	0.27	0.08

Table 9 Effect of waterlogging on total soluble sugars and total carbohydrates concentration in seedling parts of some timber tree species (mean of the two seasons, 1999-2000)

Species	Roots		Stems		Leaves or phylloclade	
	Waterlogged	Control	Waterlogged	Control	Waterlogged	Control
	Total soluble sugars as mg/g D.W.					
E. rostrata	23.44	9.21	15.97	8.6	15.84	37.36
E. citrodora	29.17	19.11	17.15	9.2	19.2	36.37
E. cunninghamiana	40.03	16.66	32.39	18.33	17.33	26.39
E. glauca	35.15	18.99	36.11	19.99	19.2	29.5
E. sempervirens	24.98	16.86	23.41	7.59	18.3	31.75
$LSD_{0.05}$	3.6	2.75	3.8	3.2	2.53	2.81
	Total soluble carbohydrates as mg/g D.W.					
E. rostrata	56.65	18.51	21.99	11.45	51.9	56.38
E. citrodora	45.2	25.11	24.14	13.44	50.09	54.11
E. cunninghamiana	63.33	30.1	67.5	19	50.08	60.85
E. glauca	44.1	32.11	51.1	22.5	48.14	55.2
E. sempervirens	41.85	22.8	50.68	17.25	23.36	50.9
$LSD_{0.05}$	3.54	2.68	5.92	1.79	2.44	1.29

Citation: El-Yazel MAS, El-Shewy AA, Matter FMA. Impact of water logging condition on seedling of five timber tree species. *Horticult Int J.* 2022;6(1):37–45. DOI: 10.15406/hij.2022.06.00240

The plant response may also include a reduction in stomatal conductance and photosynthesis, as well as root hydraulic conductivity. These physiological modifications may in turn affect carbohydrate reserves and translocation. In fact, efficient use of carbohydrates may discriminate between tolerant and intolerant species.[2]

On the other hand, total soluble sugars and total carbohydrates in both stem and roots of all timber tree species were increased compared with the control. Blake and Reid[58] compared three species of Eucalyptus, and found that ethylene production was high in the flood-tolerant species in response to flooding, and that the ethylene caused tissue hypertrophy (opening channels for air movement to the roots) and basal stem thickening.

Chlorophyll content

Data in Table 10 showed a progressive reduction in chlorophyll A, B and carotenoids contents in leaves of timber trees grown under waterlogging condition.

Gadalla[49] and our results indicated that waterlogging increased the concentration of Na and Cl in leaves. This increase of both Na and Cl were the result of increase in the uptake of Na and Cl.[48] Moreover, Muller and Santarius[59] reported that NaCl accumulated in the leaf cells and affected lipid-synthesizing enzymes such as galactosyltransferase and cylase which are attached to the chloroplast envelop.

From the results of this study, it could be noticed that, plants that can withstand waterlogging are characterized by the following:

I. Increased auxin content in plant roots, which inhibit the growth of the main root and induced the growth of many adventitious roots, causing an increased area of oxygen absorption from the soil by plant roots.

II. Increased ethylene content of both stems and roots which facilitates opening of air passage between roots and stems, thus increasing the oxygen supply to the roots.

III. The selective permeability of plants, as they reduce the uptake, of Na and Cl ions from the soil and its translocation and deposits in plant organs, thus avoiding the toxic effects of such elements to the plants, and increasing its survival under waterlogging conditions.[60-64]

Table 10 Effect of waterlogging on chlorophyll content in the leaves/phylloclade of some timber tree species (mean of the two seasons, 1999-2000)

Species	Carotenoid		Chlorophyll as mg/g F.W.			
			A		B	
	Waterlogged	Control	Waterlogged	Control	Waterlogged	Control
E. rostrata	0.852	1.295	1.377	2.001	0.763	1.268
E. citrodora	0.703	1.402	1.23	1.8	0.624	1.074
E. cunninghamiana	0.123	0.686	0.546	1.072	0.077	0.577
E. glauca	0.24	0.84	0.67	1.24	0.13	0.72
E. sempervirens	0.347	0.692	1.077	1.319	0.47	0.815
$LSD_{0.05}$	0.11	0.08	0.14	0.11	0.08	0.15

Conclusion

It is clear from this study that there are wide variations among these timber tree species in their response to waterlogging. *Casuarina cunninghamiana* and C. *glauca* were more tolerant to waterlogging than the other species, followed by *Eucalyptus rostrata* then *Cupres sussempevirens*. *E. citrodora* was the least tolerant waterlogging species.

In general, it is recommended that, under areas where water table is high, especially in the newly reclaimed lands that needs to plant timber trees as a fences, to plant *Casuarina* plants, as they can tolerate high water table which causes suffocation of plant roots, and consequently death of plants.

Acknowledgments

None.

Conflicts of interest

The author declares there is no conflict of interest.

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Citation: El-Yazel MAS, El-Shewy AA, Matter FMA. Impact of water logging condition on seedling of five timber tree species. *Horticult Int J.* 2022;6(1):37–45.
DOI: 10.15406/hij.2022.06.00240

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Citation: El-Yazel MAS, El-Shewy AA, Matter FMA. Impact of water logging condition on seedling of five timber tree species. *Horticult Int J.* 2022;6(1):37–45. DOI: 10.15406/hij.2022.06.00240