EFFECT OF PROLONGED WATERLOGGING ON GROWTH AND MINERAL CONTENT OF SOME FOREST TREE SPECIES

Khamis, M. H. 1* and Hariri M. F. 2

ABSTRACT

An experiment was conducted at Horticulture Research Station of Sabaheia- Alexandria to investigate the ability of Albizia lebbeck, Melia azedarach, Morus nigra, Pongamia pinnata, Salix mucronata and Taxodium distictum, seedlings to prolonged waterlogging conditions for 32 months. Growth characteristics and biomasses were measured periodically at 8, 16, 24 and 32 months and mineral contents at the end of study for both the waterlogging and drain phases. The species were found to vary considerably in their ability to tolerate permanent waterlogging. Complete mortality was recorded for Albizia through the first 8 months of waterlogging whereas, Melia and Morus seedlings, that stressed under prolonged waterlogging, were died between the 9th and 16th months. Generally, waterlogging suppressed the root and shoot growth in all experimental species except, stem and roots biomasses of Salix and Taxodium and leaves biomasses of Taxodium that increased under waterlogged conditions. Foliar N, P, K and Mg concentrations of Pongamia, Salix and Taxodium were decreased in waterlogging than drain treatment. Concentration of foliar Mn at the end of study was increased in Salix and Taxodium seedlings but, it decreased in Pongamia as a result of waterlogging. Na and Cl concentrations of waterlogged seedlings of Pongamia, Salix and Taxodium were increased higher than the concentrations in drained seedling.

Keywords: waterlogging, timber trees, biomass, mineral content, Albizia, Melia, Morus, Pongamia, Salix, Taxodium

INTRODUCTION

Waterlogging condition (hypoxia) is the major threat to the sustainability of most irrigated agriculture lands in Egypt. About 40% of the cultivated area is affected to some extent by waterlogging and soil salinity as solely elements or together (Mohamedin et al., 2010). Waterlogging causes a condition of low oxygen concentrations in soils, because of the low solubility of oxygen in water (0.28 mol m⁻³ at 20 °C), the low diffusivity of oxygen in water-filled pores (about 10 000 fold slower than through gas-filled soil pores (Grable, 1966), and the rapid use of dissolved oxygen by bacteria and roots. In addition, waterlogging can cause the accumulation of ethylene and products of root and bacterial anaerobic metabolism (carbon dioxide, ethanol, lactate, etc.). In the longer-term, under the influence of anaerobic organisms, there is a possibility of reduction of NO³⁻, Mn⁴⁺, FeⅢ and SO₄²⁻ at successivity lower redox potentials. Waterlogging (hypoxia) has a series of effects on plants where it rapidly decreases growth, initial of

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roots and shoots (Barrett-Lennard et al., 1986), and it increases the senescence of roots, beginning at the tips (Barrett-Lennard et al., 1988). Also, it affects processes associated with flux movement across membranes, such as the uptake of inorganic nutrients (Buwalda et al., 1988), and the efflux of internal cell constituents such as K⁺, Cl⁻, organic and amino acids, and 'basic and acidic metabolites'. Moreover, it can decrease stomatal conductance and/or leaf water potentials (Moezel et al., 1989; Huang et al., 1995 and Else et al., 2001). Flooding is assumed to cause an energy crisis in plants because due to a lack of O₂ mitochondrial respiration is replaced by alcoholic fermentation which yields considerably less energy equivalents (Ferner et al., 2012).

The response of plants to waterlogging is highly variable among species. The capacity for the formation of roots of high porosity, including aerenchymatous (Drew, 1992) and adventitious roots (Visser et al., 1995), can determine the level of tolerance of a given plant species to waterlogging (Laan et al., 1991). Restricted of water uptake lead to reduce leaf water potential (Else et al., 2001), stomatal conductance and carbon assimilation. Long-term effects of waterlogging can include reducing of plant growth (Olivella et al., 2000) and a shift in resource allocation from above- to below-ground biomass (Naidoo and Naidoo, 1992). Waterlogging also results in profound physiological disturbances including an increase in CO₂ content in the soil solution and a decrease in O₂ supply (anaerobiosis) (Else et al., 1995 and Dell’Amico et al., 2001).

Therefore, it is recommended to introduce new plant species having high capability to consume water (biological drainage) to encounter this serious problem. No doubt drains will have a similar hydrological impact to trees thus, in some cases, trees are known to lower water tables up to 3 km from the plantation, and more commonly their impact is between 10 and 30 m (George, et al., 1999 and NSW DPI, 2009). These trees act like pumps to draw large volumes of water. The trees use some of this water and the rest returns to the atmosphere through transpiration. By pumping water the trees act to regulate the height of the water table. Albizia lebbeck (L.) Benth. (Lebbeck) is a species of family Fabaceae native to tropical southern Asia, and widely cultivated in other tropical and subtropical regions. A nitrogen-fixing tree, proposed as forage in more acid soils. Also, Melia azedarach (L.) is a medium-sized tree of Meliaceae that is native to Southeast Asia and Australia. It is deciduous or semi-evergreen trees and is adapted to a wide range of soil moisture conditions. Additionally, Morus nigra L. (black mulberry) is a small deciduous tree of Moraceae that grow to about 10-13 meters in height. Pongamia pinnata (L.) Pierre (Indian Beech), is a species of Fabaceae, native in tropical and temperate Asia. It is a legume tree that grows to about 15–25 m in height with a large canopy which spreads equally wide. It may be deciduous for short periods and it can grow in a wide range of conditions. Typically it is found in coastal areas, along the edges of mangrove forests, tidal streams and rivers.
Moreover, *Salix mucronata* Thunb (synonym: *Salix Safsaf* Forsk. ex Trautv.) (safsaf willow) is a species of *Salicaceae*, is a deciduous broad-leaved tree and is a colonizing floodplain genus characterized by vigorous growth rate and production of a massive root system that can rapidly stabilize stream bank sediments. It also occurs in ditches and on the edges of swamps, lakeshores and other wetland habitats. Safsaf willow has been cultivated for an agricultural crop to many purposes, such as for bioenergy, making baskets and some medical uses (Foster and Duke, 1990). Also, *Taxodium distichum* (L.) Rich. (Baldcypress) is a deciduous conifer tree of *Taxodiaceae* that grows on saturated and seasonally inundated soils ranging from well-drained to 3 m of flooding for the entire growing season. Normally, baldcypress is found on intermittently flooded and very poorly drained phases of Spodosols and it helps to maintain high regional water tables, and they can also be used to provide advanced wastewater treatment for small communities (Ewel, 1990).

The objective of this study is to investigate the resistance of *Albizia lebbeck* (L.), *Melia azedarach* (L.), *Morus nigra* (L.), *Pongamia pinnata* (L.), *Salix mucronata* Thunb, and *Taxodium distichum* (L.) Rich. seedlings to prolonged waterlogging.

**MATERIALS AND METHODS**

**Site and Materials**

An experiment of applying permanent waterlogging upon one-year-old seedlings of six tree species was conducted within 32 months from March, 2011 to October, 2013 at the nursery of Horticulture Research Station of Sabahia- Alexandria. All seedlings were transplanted in first March, 2011 in plastic pots containing a constant weight of soil. Waterlogging was imposed by dipping the plastic pot in plastic tub that water level was maintained at 3 cm above the soil surface while the drain treatment was watered to the field capacity. Plastic tubes were drained and water replaced periodically, with 8, 16 and 24 months to prevent salt accumulation. The potted soil had sandy clay texture, where its chemical analysis is shown in Table (a).

**Table (a): Chemical analysis of the planting soil**

<table>
<thead>
<tr>
<th>E.C. dS m⁻¹</th>
<th>Soluble cations (meq l⁻¹)</th>
<th>Soluble anions (meq l⁻¹)</th>
<th>CaC₀³⁻ (% )</th>
</tr>
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<tbody>
<tr>
<td>pH</td>
<td>K⁺</td>
<td>Mg⁺</td>
<td>Ca⁺</td>
</tr>
<tr>
<td>7.8</td>
<td>1.8</td>
<td>0.26</td>
<td>5.6</td>
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<table>
<thead>
<tr>
<th>CaC₀³⁻</th>
<th>2.6</th>
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Tree species and Treatments
Tree species were: Albizia lebbeck (L.) Benth., Melia azedarach (L.), Morus nigra (L.), Pongamia pinnata (L.), Salix mucronata Thunb and Taxodium disticum (L.) Rich. On the other hand, waterlogging treatments were: prolonged waterlogging and drain-free (control) through four durations (8, 16, 24 and 32 months from transplanted).

Measurements
Three seedlings were harvested from each treatment at 8, 16, 24 and 32 months then blotted dry and were divided into leaves, stem and roots. Stem height and diameter, leaf area and both fresh and dry weights of all parts were measured. Leaf area sampling, was on a fresh sub-sample of 10 leaves per seedling, placed uniformly on a glass tray and were scanned by Beng, 4300 scanner. The scanner resolution was set at 300 dpi (dot per inch). The scale was set at 100%, and images were recorded as black-and-white line drawings and saved in an uncompressed, tagged image file format (TIFF) to make the images compatible with the image analysis software. Afterward, image files were imported into Scion Image software for windows version 4.0.2 to analyze and detect the mean leaf area. Subsequently, they were oven-dried at 60 °C for 48 hours, weighted. Dry leaves were ground with a tissue grinder and stored in sealed paper bags for chemical analysis after digestion according to Evenhuis and Dewaard (1980). Total (N, P, K and Mg and Na in plant tissue samples were determined according to FAO (1980). Chloride concentration was determined by potentiometric titration method according to (Brown and Jackson, 1955). An Orion Model 401 Specific Ion Meter was used for the potentiometric determination of chloride in plant tissue. An Orion 94-17 Solid State Chloride Electrode and 90-01 Single Junction Reference Electrode were used for this determination according to La Croix et al. (1970). Free proline was determined spectrophotometrically following the ninhydrin method which described by Bates et al. (1973) who used L-proline as a standard curve for calculated the proline concentration on a fresh weight basis (µ mol g⁻¹ D.W.).

Statistical Analysis
The experimental design was a 4 x 2 factorial with four waterlogging durations (8, 16, 24 and 32 months from transplanted) and two levels of inundation (waterlogging and drain) for the six tree species. Three replicates for each combination of duration and treatment and 3 pots per replicate were done. Mean values of replicates of each parameter were compared for only the three survived species (Pongamia, Salix and Taxodium) by two ways analysis of variance (ANOVA) following a randomized complete blocks design (RCBD) by using CoStat Statistic Software and means were compared by Duncan's Multiple Range Test since it is good performance in detecting true differences (Carmer and Swanson, 1973).
RESULTS AND DISCUSSIONS

Mortality
Complete mortality was recorded for Albizia through the first 8 months of waterlogging whereas, Melia and Morus seedlings, that stressed under prolonged waterlogging, were died between the 9th and 16th months. The mortality of these species may be explained by their sensitivity to anaerobiosis condition of waterlogging treatment. Muller et al. (1994) concluded that increasing water uptake resistances at the soil/root transition also cause water deficits on leaves during periods of high evaporative demand. These resistances are supposed to be caused not only by drought but also by anoxic conditions during periods of waterlogging due to energy limitations in plasma membrane transport processes.

Growth
Pongamia pinnata progressively increased stem height with increase the waterlogging duration, and this increase was doubled in compare with drained seedlings at the end of study. Where diameter of all Pongamia seedlings increased with increase the waterlogging duration but waterlogged seedlings were thinner than drained (Fig. 1). Leaf area was negatively affected after 16 months of waterlogging and obviously, the deterioration was more on waterlogged seedlings than drained therefore, the waterlogged seedlings totally shedding their leaves at the last duration.

Stem height of Salix under waterlogging treatment was nearby 2-fold longer than drained seedlings after 32 months. Conversely, the drained seedlings had more thickness stem diameter than waterlogged seedlings and significantly, the diameter increased with increasing waterlogging duration with a constant variation (Fig. 2). Leaf area of waterlogged salix was smaller than drained seedlings and leaf area significantly was not affected with increase the waterlogging duration. Taxodium was resistance to prolonged waterlogging where after 32 months of prolonged waterlogging, the stem height and diameter increased by 2.5 and 2-fold, respectively more than well-drained seedlings. On the other hand, leaf area decreased by 3-fold less than well-drained seedlings whereas, the leaf area of drained seedlings progressively, raised with increase the waterlogging duration (Fig. 3).

These results are complemented with Dat et al. (2004) and Glenz et al. (2006) that waterlogging of soil adversely affects shoot growth of many species by inhibiting the formation and expansion of leaves, reducing internode elongation, and inducing chlorosis, leaf senescence, and abscission. Also, waterlogging may increase or decrease the diameter growth of woody plants.
Figure (1): Interaction effects of waterlogging and duration on stem height, stem diameter, leaf area and S/R ratio of *Pongamia pinnata* seedlings as affected by prolonged waterlogging for 32 months. Means ± standard errors (S.E.) are shown in error bars (≤ 0.05). There is no data for leaf area of waterlogged seedlings at 32 month because *Pongamia* is shedding all leaves.

Figure (2): Interaction effects of waterlogging and duration on stem height, stem diameter, leaf area and S/R ratio of *Salix mucronata* seedlings as affected by prolonged waterlogging for 32 months. Means ± standard errors (S.E.) are shown in error bars (≤ 0.05). There is no data at 24 month because salix is deciduous on March.
Figure (3): Interaction effects of waterlogging and duration on stem height, stem diameter, leaf area and S/R ratio of Taxodium distichum seedlings as affected by prolonged waterlogging for 32 months. Means ± standard errors (S.E.) are shown in error bars (≤ 0.05).

Figure (4): Interaction effects of waterlogging and duration on different fresh and dry weights (leaves, stem and roots) of Pongamia pinnata seedlings as affected by prolonged waterlogging for 32 months. Means ± standard errors (S.E.) are shown in error bars (≤ 0.05). There is no data for leaf area of waterlogged seedlings at 32
The decrease of stem diameter and leaf area may be clarified by the decrease of photosynthesis as Jennifer et al. (2006) concluded that net photosynthesis decreased significantly over time in the NaCl waterlogged treatment, in both *Melaleuca cuticularis* and *Casuarina obesa*, and was approx. 50% lower than initial values in both species. Also, Muller (2000) explained that severely physiological stress caused by anoxic conditions in the rooting environment may be expected to inhibit nutrient and water uptake by roots which at least leads to the reduction of transpiring surfaces via leaf shedding. Water limitation does not obviously lead directly to drought damage on leaves but may indirectly trigger leaf-shedding, e.g. by hormone signals. Therefore, Talbot et al. (1987) the reduction in specific leaf area of *Salix caprea* was probably mediated by reduced turgidity and failure of leaf tissue to expand fully. Roots which become totally submerged or waterlogged for long periods will suffer from lack of oxygen. This leads to
slow growth, senescence or abscission of leaves and adventitious rooting of stems (Jackson, 1980).

Biomass

*Pongamia pinnata* appeared less tolerant to prolonged waterlogging than *Salix* and *Taxodium* as fresh and dry (leaves, stem and roots) biomasses of waterlogged plants were less significantly in compare with drain plants. As well as, leaves, stem and roots biomasses of *Pongamia pinnata* seedlings declined with increasing the waterlogging duration (Fig. 4). Also, shoot/root ratio of *Pongamia* was decreased with increasing the waterlogging duration as a result of shedding the leaves completely and deterioration of stem biomass comparing to roots biomass (Fig. 1).

Furthermore, the fresh and dry leaves biomasses of *Salix mucronata* were decline with increasing the waterlogging duration but, fresh and dry biomasses of stem and roots were increased (Fig. 5). On the other hand, fresh and dry biomasses of leaves, stem and roots of *Taxodium disticum* seedlings were increased with increasing the waterlogging duration (Fig. 6). There was no obvious trend of S/R ratio for both salix and taxodium probably because they are deciduous and semi-deciduous trees and the third duration (at 24 month) was on March where the seedlings of salix not initiate leaves yet and taxodium lost a lot of leaves in the last autumn (Fig. 2 and 3). These results indicate that the tolerance of *Pongamia* to waterlogging is not as high as *Salix* and *Taxodium*.

Decline the growth of shoots and roots of *Pongamia* seedlings in waterlogging conditions was matched with Karen et al. (2001) who they found that waterlogging suppressed root and shoot growth in all experimental tree species when tested their ability to grow new roots under waterlogged conditions. The decrease in leaves biomasses explained by Muller et al. (1994) who mentioned that, increasing water uptake resistances at the soil/root transition cause water deficits on leaves during periods of high evaporative demand. These resistances are supposed to be caused not only by drought but also by anoxic conditions during periods of waterlogging due to energy limitations in plasma membrane transport processes. Also, Muller (2000) revealed that, severely physiological stress caused by anoxic conditions in the rooting environment may supposed to inhibit nutrient and water uptake by roots which at least leads to the reduction of transpiring surfaces via leaf shedding.
Mineral content

Foliar N, P, K and Mg concentrations of *Pongamia*, *Salix* and *Taxodium* on a dry weight basis were decreased in waterlogging than drain treatment. Whereas, the concentration of foliar Mn at the end of study was increased for *Salix* and *Taxodium* seedlings but, it decreased for *Pongamia* as a result of waterlogging (Fig. 7, 8 and 9). On the other hand, foliar Na and Cl concentrations of waterlogged seedlings of *Pongamia*, *Salix* and *Taxodium* were increased higher than the foliar concentrations in drained seedlings, demonstrating that the above mentioned species has a poor ability to eliminate these ions from its leaves.

Dat *et al.* (2004) declared that waterlogging reduced water and nutrient uptake and metabolism and the response of seedlings to waterlogging reflect species habitats and growth patterns (Sakio, 2005). These results are matched with Gimeno *et al.* (2012) that flooding increased iron and manganese concentrations but decreased nitrogen and potassium concentrations of lemon trees. Also, Talbot *et al.* (1987) detected that magnesium content of leaves was significantly reduced in *Salix caprea*. On the other hand, Jennifer *et al.* (2006) proved that concentrations of Na, Cl
and proline of *Melaleuca cuticularis* and *Casuarina obese* increased on a dry weight basis, particularly in waterlogged plants. Reduced forms of

Figure (7): Interaction effects of waterlogging and duration on leaves mineral content of *Pongamia pinnata* seedlings as affected by prolonged waterlogging for 32 months. Means ± standard errors (S.E.) are shown with error bars (≤ 0.05). There is no data for leaf area of waterlogged seedlings at 32 month because Pongamia shedding all leaves.
Figure (8): Interaction effects of waterlogging and duration on leaves mineral content of Salix mucronata seedlings as affected by prolonged waterlogging for 32 months. Means ± standard errors (S.E.) are shown in error bars (≤ 0.05). There is no data at 24 month because salix is deciduous on March.

Figure (9): Interaction effects of waterlogging and duration on leaves mineral content of Taxodium disticum seedlings as affected by prolonged waterlogging for 32 months. Means ± standard errors (S.E.) are shown in error bars (≤ 0.05).
iron and manganese can be passively absorbed into roots and then transported to the shoot (Jones and Etherington, 1970). During prolonged flooding, ferric and manganic forms are reduced to ferrous and manganous forms that are soluble (Ponnampерuma, 1972). Even though flood tolerant species can immobilize these ions within the root system (Mckevlin et al., 1995) and baldcypress can partially exclude them (Pezeshki et al., 1999) thus tissue Mn and Fe concentrations may be greater than found in plants under aerated conditions (Tanaka and Yoshida, 1970).

RECOMMENDATION

Survival of Taxodium disticum and Salix mucronata for 32 months is indicative of a high inherent tolerance to conditions of prolonged waterlogging and having high capability to consume water (biological drainage) therefore, we recommend using both species in the persistent waterlogged soils. Also if waterlogging is partially up to 24 months, Pongamia pinnata could be joined with both. Therefore, it is recommended to study another tree species having high capability to consume water (biological drainage) to encounter this serious problem in Egypt.

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تأثير التشبع بالمياه لفترات طويلة على النمو والمحصول المحسني لبعض أنواع أشجار الغابات

محمد هشام خمص و محمد فاروق الحربي

أجريت التجربة في محطة بحوث البساتين بالصحبة لدراسة التكيفات لارتفاع شتلات أشجار البيج، الزنيلخت، الشروق، الودود، البنجابيا، المفتوحات، اللقاح، والثعالث. تم تشغيل التشبع بالمياه لفترات طويلة لعدم الشيخ. ثم قياس الثمار، الوزن، الكثافة الحيوية، ونسبة النجاح عند 8 و 16 و 24 شهر من بداية التربة، وتحدير المحصول من العناصر المعدنية في نهاية التربة فقط (عدد 27 شهر). كانت أعم المتاح لها:

1. الأنواع تختلف اختلافاً كبيراً في قدرتها على تحمل الخفقات الدائرية. فقلت متوسط مقتل لشتلات البيج خلال 8 أشهر الأولى من التشبع بالمياه.
2. شتلات الزنيلخت والثعالث و المفتوحات خلال الفترات ما بين 8 - 16 شهر من بدء التربة.
3. النمو والثعالث.(دراسة في جميع الأنواع) وكاش من الأغذية والثعالث و المفتوحات.
4. الحيوية لثعالث وثعالث المفتوحات والثعالث المفتوحات.(دراسة في جميع الأنواع) وكاش من الأغذية والثعالث و المفتوحات.
5. ازداد تركز القرباني والثعالث المفتوحات في الشتلات المفتوحات. والثعالث المفتوحات بعملة الأغذية و الثعالث المفتوحات.
6. ازداد تركز القرباني والثعالث المفتوحات في الشتلات المفتوحات. والثعالث المفتوحات بعملة الأغذية و الثعالث المفتوحات.
7. يخضع القرباني والثعالث المفتوحات للخفقات الدائرية لعدم الشيخ. وأيضاً القرباني المفتوحات في استهلاك المياه (الجذب البيولوجي)، لذا فإنها تتميز باستخدام كلا النوعين في التربة المشهورة بالمياه. أيضاً إذا الخفقات (يصل إلى 24 شهر). فيمكن استخدام البنجابيا مع كلا النوعين السابقين من المستحيل دراسة أنواع أخرى من الأشجار لاستهلاك المياه (الجذب البيولوجي) لمعرفة هذه المشكلة الخطيرة في مصر.