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Growth and morpho-physiology of *Tectona philippinensis* under different water stress and soil conditions

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Abstract. *Hernandez JO, Tolentino CA, Quiñones LAE, Villancio GB, Maldia LSJ, Combalicer MS. 2021. Growth and morpho-physiology of Tectona philippinensis under different water stress and soil conditions. Biodiversitas 23: 507-513.* Plants exhibit adaptive mechanisms to respond to fluctuating amounts of soil moisture and poor soil properties; however, these mechanisms remain largely unknown in many forest tree species growing in dry and limestone areas in the Philippines, such as the endemic and endangered *Tectona philippinensis* Benth & Hook.f. This study investigated the growth and morpho-physiological responses of *T. philippinensis* wildlings to water stress and soil types. One-year-old wildlings were subjected to two watering treatments, i.e., well-watered and water-stressed, and three different soil types, i.e., Lobo, Batangas, Mt. Makiling Forest Reserve, and UP-Laguna-Quezon Land Grant. The root collar diameter, height, biomass allocations, and morpho-physiological traits (photosynthesis, stomatal conductance, transpiration, relative water content, specific leaf area, and stem green density) were measured. Overall, the growth performance of the wildlings was improved significantly when grown in soil from the natural habitat under WW conditions. Therefore, the recommended conservation approach potentially suitable for *T. philippinensis* is in-situ, particularly in riparian areas, when artificial irrigation is not possible and practical. The present study's findings provide us with a better understanding of the growth and ecophysiology of *T. philippinensis* under water-deficient conditions for its effective in-situ conservation.

Keywords: Drought stress, endemic species, in-situ conservation, Lamiaceae

Abbreviations: ANOVA: analysis of variance, BMB: Biodiversity Management Bureau, CFNR: College of Forestry and Natural Resources, FM: fresh mass, DENR: Department of Environment and Natural Resources, GV: green volume, GW: green weight, CON: Lobo, Batangas, UP LAG: Laguna-Quezon Land Grant, MAK: Mt. Makiling Forest Reserve, AN: photosynthetic rate, RWC: relative water content, RCD: root collar diameter, RGI relative growth increment, SLA: specific leaf area, stem green, SGD: density, g_s: stomatal conductance, E: transpiration rate, TM: turgid mass, DFBS: Department of Forest Biological Sciences, UPLB University of the Philippines Los Baños, WS: water-stressed, WW: well-watered

INTRODUCTION

Two of the most important environmental factors controlling plant growth and distribution are moisture availability and soil types and their interactions. For example, water stress affects most of the physiological activities of plants, including carbon assimilation, chlorophyll synthesis, biomass allocation, relative water content, and stomatal conductance (Miftahudin et al. 2020; Wang et al. 2021). The interacting effects of water shortage and poor soil properties limit plant growth and productivity, particularly in dry areas (Byambadorj et al. 2021; El-Mageed et al. 2018). The previous experimental results showed that both soil nutrients and moisture amounts influenced the increase in chlorophyll content of plants under water-deficient conditions (Wang et al. 2021). Contrarily, the low amount of water had resulted in higher growth performance, several new shoots, chlorophyll content, and leaf soluble sugar compared with high amounts of water treatments (Guo et al. 2021). Further, Basal and Szabo (2020) reported that irrigation regimes significantly altered the morpho-physiological traits. Plants have adaptive mechanisms to respond to fluctuating amounts of soil moisture and poor or contrasting soil properties, including plasticity development, cell turgidity, and osmoregulation even at more negative water potentials (Guyot et al. 2012; Maréchaux et al. 2015). However, these adaptive mechanisms have remained largely unknown in many forest tree species growing in dry and limestone ridges in the Philippines, such as *Tectona philippinensis* Benth. & Hook.f.

Tectona philippinensis is one of the only three species in the genus *Tectona* L.f. (Lamiaceae). The species is commonly called Philippine teak but is also known locally by the vernacular names malabayabas and bunglas. It is known only to be distributed in Ilin Island in Occidental Mindoro and Batangas Province in Luzon Island, usually along dry hills and exposed limestone ridges along the coasts, and is also a deciduous species (Caringal et al. 2015). With such conditions of the habitat and limited natural distribution in the Philippines, Hernandez et al. (2016) reported that the species must have adaptive mechanisms typical of plants in drylands or xerophytes. *T. philippinensis* is regarded as a critically endangered species

(IUCN and DAO 2017-11), which may be attributed to habitat destruction through land conversion and development and its natural habitat's physical condition. For more than a decade, several conservation-related studies about the species, e.g., *ex-situ* conservation areas for the Philippine teak of the Biodiversity Management Bureau (BMB) and in-situ conservation spearheaded by non-government organizations (Caringal et al. 2021), have already been conducted. However, the present populations of *T. philippinensis* in Ilin Island and Batangas Province remain fragmented. Thus, future conservation efforts will be effective if basic information on how *T. philippinensis* respond to water stress and different soil types are made available to better understand the growth and ecophysiology of the species.

This study investigated the growth and morpho-physiological responses of *T. philippinensis* to watering regimes and soil types. Due to the very limited geographical distribution of the species, particularly in dry hill and exposed limestone substrate, it was hypothesized that the growth and morpho-physiological traits of *T. philippinensis* are significantly higher in water-stressed (WS) and soil from natural habitat compared with well-watered treatment (WW) and other soil types. The present study's findings provide us with a better understanding of the growth and ecophysiology of *T. philippinensis* for its effective conservation.

MATERIALS AND METHODS

Study site

Sampling was conducted in Brgys. Sawang and Sulok, Lobo, Batangas (13º38'45.641" N and 121º14'40.295" E) and in Brgys. Katayungan and Baclayon, San Jose, Occidental Mindoro (Ilin Island) (12º13'21.215" N and 121º5'18" E) (Figure 1). In 2018, both water stress and soil experiments were conducted in the nursery located at the Department of Forest Biological Sciences (DFBS), College of Forestry and Natural Resources (CFNR), University of the Philippines Los Baños (UPLB), Laguna, Philippines. The nursery's mean annual temperature and precipitation were 27°C and 915 mm, respectively.

Experimental materials and design

Approximately 2.5-7.0 cm high wildlings collected from a forest floor in Barangay Soloc, Lobo, Batangas were used for the water stress and soil experiments. Roots were pruned to make their lengths uniform (ca., 7 cm) in all treatments before planting. Wildlings were first acclimatized for 2-3 weeks, in which all seedlings were watered every two days at runoff conditions. The wildlings were transplanted to polythene pots (5 L in volume). The soil used, with pH from 5.27-5.86, was air-dried for five days, pulverized, and sieved to ensure that soil in every pot has equal permeability.

A preliminary watering experiment was first done to determine the intensity of water stress used in the study. The treatments for the preliminary experiment were; (a) every two days (control), and intervals of 4, 6, and 8 days watering using 250 mL tap water. In the final experiment, two treatments were employed, namely: (i) well-watered (WW), water was supplied every two days at 8:00 AM, and (ii) water stress (WS), water was supplied every six days at 8:00 AM using a fine mist sprinkler system for 30 minutes. The WW has soil moisture of approximately 45-50% after two days, whereas WS has soil moisture of less than 15% after six days. The soil moisture content of the soil in the pots for each treatment was measured only at the beginning of the initial and final experiments.

In the soil experiment, soils from Lobo, Batangas (control), Mount Makiling Forest Reserve (MAK), and UP-Laguna-Quezon Land Grant (LAG) were used. The soils' physical and chemical properties were analyzed (Table 1). Specifically, soil samples were collected from 15-25 cm deep, excluding litterfall. Each treatment was replicated three times in the final experiment with ten wildlings per replicate. A total of 45 seedlings (3 levels of soils × 3 replicates × 5 wildlings) were used for the soil experiment. Pots were positioned following a 0.2 m distance between seedlings and a 0.5 m distance between rows. Replacement of dead and inferior quality wildlings was done before treatment imposition. Regular weeding and monitoring of the changes in the overall appearance of each wildling were also done.

Measurement of growth and morpho-physiological traits

The wildlings' total height and root collar diameter (RCD) growths were measured weekly using a digital caliper and ruler, respectively. Relative growth increments (RGI) in RCD and height, following the formula:

$$RGIRCD\ or\ RGITH = \frac{Final\ measurement}{Initial\ measurement} x\ 100$$

The biomass growth and allocation were measured at the end of the experiment (i.e., December 2019). Wildlings were harvested and separated into different plant components, that is, root, stem, and leaf) and oven-dried at 65 °C to a constant weight. Roots were washed carefully to remove the soil and avoid damage to fine roots. We measured only the RGIs for the soil experiment due to technical and logistical concerns.

Table 1. Soil pH and texture of soil used in the soil experiment of the present study

Soil properties	CON	MAK	LAG
pH	4.95-5.00	5.70-5.80	5.20-5.30
Texture	Sandy clay loam	Sandy clay loam	Clay loam

Note: CON: soils from Lobo, Batangas (control), MAK: soils from Mount Makiling Forest Reserve, LAG: soils from UP-Laguna-Quezon Land Grant

Figure 1. Sampling sites in Lobo, Batangas and Ilin Island, San Jose, Occidental Mindoro, Philippines

5-7 fully expanded and healthy leaves were collected from each wildling to measure the specific leaf area (SLA) between watering treatments at the end of the experiment. SLA was computed by dividing the leaf areas, measured using the grid method, to the oven-dry mass of the leaves (dried at 65°C for 48 hours). Two to three stem samples (5 cm long) were also cut from the RCD for the determination of stem green density (SGD) using the water displacement method and the formula (Pérez-Harguindeguy et al. 2013):

$$SGD = \frac{Green\ weight, GW}{Green\ volume, GV}$$

The photosynthetic rate (AN, µmol m^{-2} s^{-1}), stomatal conductance (gs, mol m^{-2} s^{-1}), transpiration rate (E, mmol H_2O $m^{-2}s^{-1}$) were measured using a portable photosynthesis system (LI-6400XT, LI-COR Inc., Lincoln, USA). Measurements were conducted between 9:00 AM and 04:00 PM with saturating light (1500-2000 µmol m^{-2} s^{-1}), 400 µmol CO_2 mol^{-1}, 1.0 stomata ratio, 60-70% chamber relative humidity, and 28 °C leaf temperature. Lastly, 3-4 leaves were collected at the end of the experiment to determine leaf relative water content (RWC), following Jimenez et al.'s (2013) procedures. Leaves were immediately weighed to obtain the fresh mass (FM), petioles were immersed in water overnight, reweighed to obtain turgid mass (TM), and oven-dried at 65°C for 48 hours to obtain the oven-dry mass (DM). The RWC was then computed using the formula (Hernandez et al. 2021):

$$RWC = \frac{FM - DM}{TM - DM} x\ 100$$

Statistical analysis

One-way analysis of variance (ANOVA) followed by post hoc multiple comparison tests was employed to analyze the effects of water stress and different soil types on the growth and morpho-physiological traits of *T. philippinensis*. All the statistical analyses were run in R statistical software (version R-3.5.1) at a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

Results

Effects of watering and different soil types on the growth and biomass of Tectona philippinensis

In this study, water stress (WS) as the main factor significantly affected the height and biomass increase of *T. philippinensis* (Figure 2). The relative growth increment in RCD was statistically similar between treatments but varied significantly in the case of height, such that the WS treatment resulted in a significantly lower height growth compared with the WW treatment.

The RCD and height growth responses of *T. philippinensis* varied significantly across soil treatments (Figure 3). Generally, wildlings that were grown using the Lobo soil (CON) resulted in a significantly greater mean RCD (1.84±0.21) and mean height (56.91±6.36) than those grown in other soils. Further, there was a significant treatment effect on the biomass growth of *T. philippinensis* seedlings (Figure 4).

Effects of water stress on the morpho-physiological traits of Tectona philippinensis

The morpho-physiological traits measured in this study varied considerably between WW and WS treatments (Figure 5). Here, the photosynthesis rate, stomatal conductance, and RWC were significantly higher in WW than in the WS-treated seedlings. In this study, there was a significant increase in the transpiration rate of WS-treated seedlings compared with the well-watered ones (Figure 5). Lastly, the wildlings' stem green density (SGD) was significantly higher in WW than in WS treatment (Figure 5).

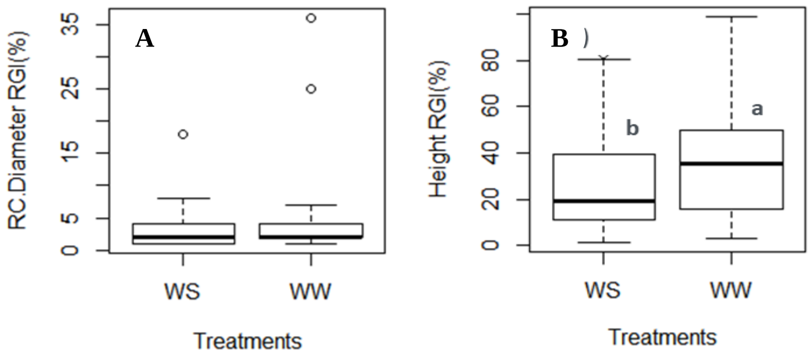

Figure 2. Relative growth increments in A. RCD and B. H of *Tectona philippinensis* in water stress (WS) and well-watered (WW) conditions. Different lowercase letters indicate significant differences between treatments at α = 0.05

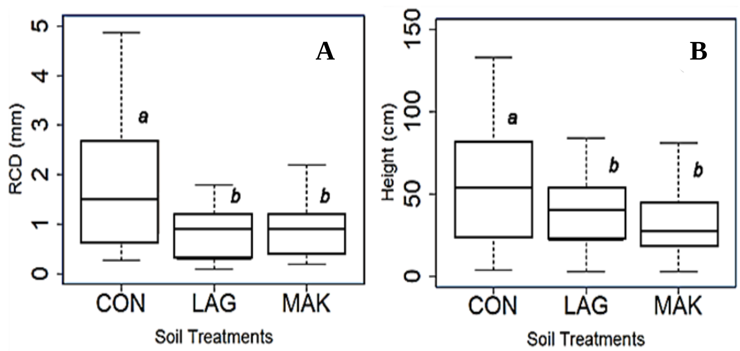

Figure 3. A. Root collar diameter and B. height growth responses of *Tectona philippinensis* wildlings to different soils from Lobo soil (CON), Mt. Makiling Forest Reserve soil (MAK), and UP-Laguna-Quezon Land Grant soil (LAG). Different lowercase letters indicate significant variations between the two treatments

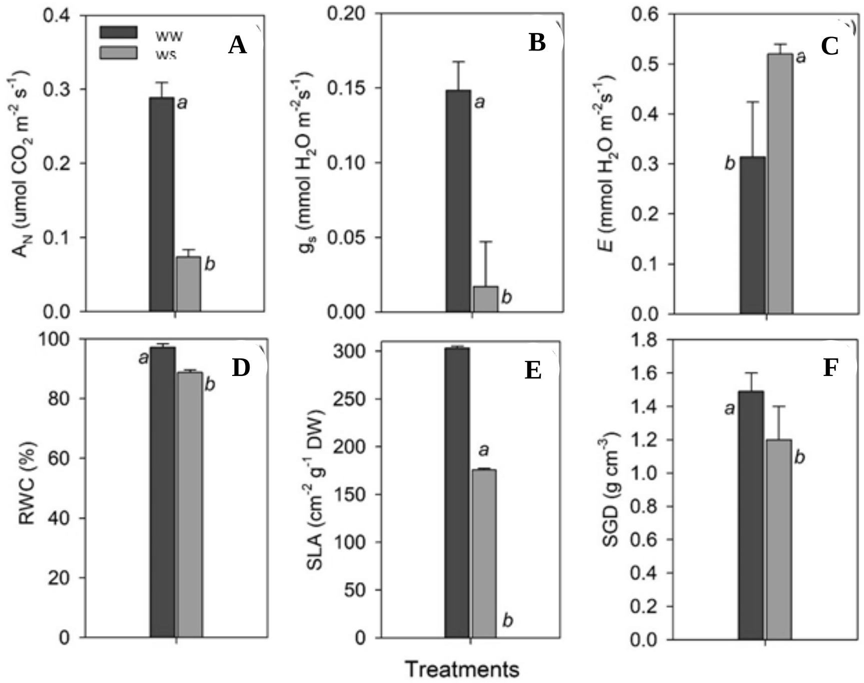

Figure 5. Effects of water stress on: A. photosynthesis-A_N; B. stomatal conductance – gs; C. transpiration; D. relative water content (RWC); E. Specific leaf area-SLA; F. stem green density-(SGD) of *Tectona philippinensis*. Different lowercase letters indicate significant variations between the two treatments (One-way ANOVA at α = 0.05). Vertical bars indicate standard errors (N= 5)

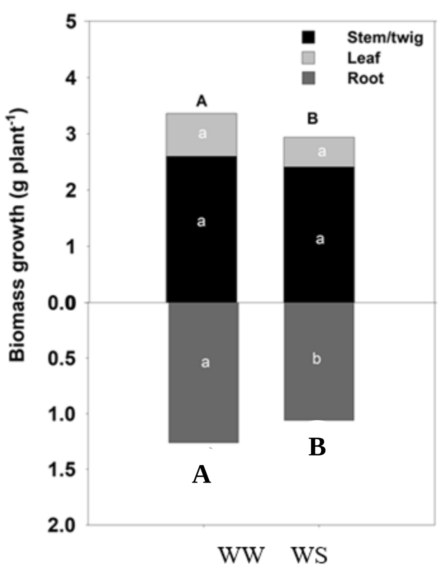

Figure 4. Biomass growth of *Tectona philippinensis* in WW (well-watered) and WS (water-stressed) treatment. Different uppercase and lowercase letters indicate significant variations in total biomass and biomass by plant component between treatments, respectively (One-way ANOVA at α = 0.05)

Discussion

Effects of watering and different soil types on the growth and biomass of Tectona philippinensis

Results are consistent with Byambadorj et al.'s (2021) finding, who reported that the 4 and/or 8 L h^{-1} watering treatments had lower annual height growth than 12 L h^{-1} in all *Populus* species tested. The observed decrease in the height of *T. philippinensis* under water stress can be attributed to water resource limitation, which controls the carbon assimilation in plants. However, the survival rate of the species remained high (> 90%) towards the end of the experiment, confirming the results in Ferreira et al. (2015). Water-stressed wildlings may have efficiently conserved limiting water supply, resulting in a high survival rate at the expense of vegetative growth. These wildlings may have also invested more biomass and energy on the storage and mechanical functions under water stress rather than carbon for height growth. The decline in height growth can be considered an adaptive trait of the species because low height/shoot growth requires less water and carbon, thereby minimizing water loss via transpiration. This further explains the observed high survival rate of water stress-treated wildlings even at the end of the experiment. Greater mean RCD and height imply that *T. philippinensis* can achieve the highest growth potential in the soil in the natural habitat.

WS treatment resulted in a significantly lower total biomass than the control. Verelst et al. (2012) also reported that even a mild water stress treatment resulted in a significant decrease in biomass production as an adaptation response. Here, root biomass allocation significantly decreased at water stress treatment. Allocation to stem and leaf did not vary significantly between the WW and WS treatments, in line with the study conducted by Samanhudi et al. (2017) on *Rauvolfia serpentina*. As to the total biomass, our result generally conforms with the findings reported in many studies, which reported significant tradeoffs among leaves, stems, and roots biomass as influenced by water stress (e.g., Dolezal et al. 2020; Li et al. 2020; Zhang et al. 2015). However, we found a contrasting result on root biomass allocation. Most studies reported that water deficit conditions increased root to shoot proportion, which is considered an important strategy for plants to enhance water balance and foraging soil resources from the ground (Bardgett et al. 2014; Salazar et al. 2015). Besides resource limitation, this contrasting result can be attributed to the sustained stem/shoot biomass allocations even under water stress. Wildlings of *T. philippinensis* may have invested their carbon more in maintaining stem/shoot growth rather than root growth. This partially reflects its presence in sandy soil, dry limestone substrate in the Philippines. This type of substrate does not necessarily need a longer or higher root growth to survive a dry condition. Under deficit conditions, the species may have behaved similarly to that in the natural habitat. However, further belowground phenology studies are necessary to explain further the root growth of the species under water stress. Moreover, the result of the present study can be explained by life-history theory, i.e., plants that are well-adapted to the low-resource environment tend to exhibit low phenotypic plasticity and grow slowly. This is because they redirect or reallocate limiting resources to other important functions, such as storage and defense for survival.

Effects of water stress on the morpho-physiological traits of Tectona philippinensis

Other studies showed that water stress decreased photosynthetic activity, regardless of stomatal conductance and intercellular CO_2 concentration (Ashraf and Harris 2013; Maréchaux et al. 2015). Although the RWC decreased at WS treatment compared with WW, wildlings under this treatment were still able to maintain high RWC (i.e., >70%), which is still within the range considered normal to keep the physiological processes functioning under water stress (Jimenez et al. 2013; Lugojan and Ciulca 2011; Soltys-Kalina et al. 2016). Studies have shown that when the RWC falls below 70%, there will be some negative impacts on the physiological processes in plants, including turgor loss, stomatal closure, and decrease in intercellular CO_2 concentration, and all of which can lead to impairment of photosynthetic machinery (Lugojan and Ciulca 2011; Singh and Reddy 2011; Soltys-Kalina et al. 2016).

An increase in transpiration rate can be attributed to the observed high RWC even under water stress conditions because high RWC improves water status or the balance between water supply to the leaf tissue and transpiration rate in plants. Further, a decrease in *gs* increases osmotic stress, leading to excessive water loss via evapotranspiration. This further explains the observed lower height growth and lower SLA in WS than WW. Smaller leaf areas of the water-stress wildlings may also be treated as an adaptive trait for reducing water loss via transpiration. This is because smaller leaves may have fewer stomata per unit leaf area. Our result is consistent with the pattern observed in the other water stress experiments. The leaves of well-watered seedlings expand at a much faster rate than those seedlings under water stress (e.g., Urban and Restrepo-Diaz 2017). High-SLA leaves, however, could mean lower biomass allocation to thicker leaves or mechanical leaf tissues (Byambadorj et al. 2021). Thus, we could say that high-SLA leaves of water-stressed seedlings of *T. philippinensis* may have higher biomass allocation to dense or thicker leaves for mechanical support.

For high SG, a study by Krishnan et al. (2019) concluded that dry-forest tree species with low stem specific density showed a greater survival rate under drought conditions. Similarly, the growth of some plants was positively related to stem density but faced a tradeoff between structural support (Haworth et al. 2017). Thus, our result suggests that although the seedlings of *T. philippinensis* had a significantly lower biomass growth at water stress conditions than WW, they may have higher structural support than the well-watered ones. This explains the presence/endemism of the species in dry limestone substrate in Mindoro and Batangas, Philippines. Further, Hernandez et al. (2016) also found the xerophytic characteristics of *T. philippinensis* in its leaf and stem anatomy; for example, thick layers of sclerenchymatous cells have extensively been associated with mechanical/ structural support (Leroux 2012).

The present study revealed that water stress and different soil types significantly affected the height, biomass allocation, and morpho-physiological traits of *T. philippinensis*. Here, height growth and biomass allocations to aboveground and belowground components of the wildlings were significantly higher in WW treatment compared with WS. The RCD and height growth performance were also generally higher in soil obtained from the natural habitat of the species (i.e., Lobo soil) compared with those from other soil types (i.e., MAK and LAG soils). Overall, the growth performance of the species was better when wildlings were grown using soil from the natural habitat with well-watered conditions. Although the growth and most of the morpho-physiological traits were significantly lower in WS-treated wildlings, their RWCs were still within a normal range (i.e., >70%), and their survival rate under water stress was high. This indicates drought tolerance in *T. philippinensis*, and such tolerance may have created a tradeoff between growth investment and survival or defense against water stress. Therefore, the recommended conservation approach for *T. philippinensis* is in-situ, particularly in riparian areas where water is abundant. Planting may also be done during the rainy season. Water stress, exacerbated by a dry environment in the species' natural habitat, can be mitigated by soil, water, and planting management strategies. Additional studies (e.g., belowground phonological studies) are highly recommended to understand the growth performance of the wildlings better.

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