Evaluation of Drought Tolerance in Seven Native Tree Species with Landscape Potential: A Biometric Approach

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Abstract Nursery-grown native trees, established from seed, require an extended length of time and water to develop into a marketable plant. The objective was to determine how much water it took for seven native trees with landscape potential to reach an appropriate size for outplanting and how plant biomass is allocated when subjected to three different watering intensities. Trees were grown in a greenhouse from seed and firmly established as young trees before being assigned and subjected to a three watering treatment; field capacity, 2/3 field capacity and 1/3 field capacity. Tree heights were measured weekly for 22 weeks and harvested to determine root, stem, and leaf weights. All species stayed alive under the different watering regimes but had different responses in both height growth and biomass allocation. Only one species, *Andira inermis*, if subjected to abundant watering reached outplanting height by the end of 22 weeks. *Plumeria alba* growth did not respond positively to increasing water and field capacity was wasteful of water. In terms of biomass allocation, some species particularly *A. inermis* and *Tabebuia heterophylla* were plastic in their allocation of biomass by dedicating more biomass to roots while under water stress and dedicating more biomass to stem wood when watered at field capacity. Other species, in particular, *Bucida bucera* did not change biomass allocation in response to watering levels. The results indicate that Virgin Island nursery managers can save water during growing of these species by controlling watering levels and still obtain marketable local trees.

Keywords: drought tolerance, landscape plantings, native tree species, tropical dry forest, field capacity, pore space, soil water

Disclaimer:

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Introduction

Seven tree species native to the US Virgin Islands and Puerto Rico with potential for landscape plantings were grown in a greenhouse from seed and subjected to 3 different watering intensities. According to the American Nursery Growers Association, the minimum size of a tree for planting in a landscape setting is 4 to 5 feet tall (120 to 150 cm) and 0.5 inches or (12.5 mm diameter) measured 6 inches (15 cm) above the root collar for land scape planting. Since water is at a premium in the semiarid environment of the USVI determining the water requirements needed to grow a marketable tree for landscape planting needed to be determined. Determining the biomass and its allocation to leaves, stems and roots for seven different species and three watering regimes would be an asset to nursery growers and landscapers. Where plant biomass is allocated (stem, leaves, roots) suggest a plant species' water saving strategy.

Methodology

Five of the species were planted in 3 gallon pots (11,400 cm^3), they were: *Andira inermis (*W. Wright) Kunth ex DC, *Bucera bucida* L, *Jacquinia arborea* Vahl, *Pimenta racemosa* (Mill.) J. W. Moore, and *Plumeria alba* L. One species, *Tabebuia heterophylla* (DC.) Britton, was planted in "12 gallon" pots (45,000 cm^3) while the final species, *Guaiacum officinale* L was planted in 1000 cm^3 pots. The black plastic potting pots were made by Custom ™Containers and purchased from Hummert International, a horticultural supply company.

Each species was assigned a watering regime based on the relative amounts of water received: field capacity, 2/3 field capacity and 1/3 field capacity. In addition, the pots were color coded blue, green, and yellow to avoid confusion while watering and symbolize a gradient from abundant watering through drought. Referencing the plants by field capacity or its proportion of field capacity instead of the amount of water received, allows one to make comparisons between different sized plants. The color coding is also convenient shorthand to refer to the treatments while discussing and graphing results. Macro and micronutrients were supplied to the plants via a water soluble 12-48-8 Sol-U-Gro™ fertilizer.

Field capacity refers to the state when pore space in the soil is equally divided between air and water. The macrospores are filled with air and the micropores are filled with water. Gravity causes the excess water to drain from the macropores; water for the plants to use is held within the micropores via capillary action (Brady and Weil, 2002).

We determined soil field capacity two different ways. The first way is theoretical. Since the ideal soil consists of 50% soil particles, be they of mineral or organic origin, and 50 % pore space, the volume of the pots was divided by 2. The results were divided by 2 again because pore space was estimated to be evenly divided between macropores and micropores. For example, a 3 gallon pot has 11,400 cm^3. So 5,700 cm^3 would be pore space. Therefore a moist soil at field capacity would hold 2,850 cm^3. This is in an ideal soil. However the potting mix used were 2 parts sphagnum moss, 1 part river sand and 1 part top soil.

Next, the field capacity of our pots filled with potting mix was determined in an experimental fashion. The theoretical estimate of field capacity for 3 “gallons” of potting mix was corroborated by allowing potted plants to wilt, thus indicating dry soils, and weighing the dry pots. The potting mix was watered until water ran out the bottom of the pots. We waited an hour, until all the gravitational water had drained out of the macropores. The moist pots were weighed. Subtracting the weights of the dry pots, from the wet pots determined the amount of water being held in the micropores of the potting mix. On average it was 3kg, which is equivalent to 3 liters of water. This is close enough to the estimated field capacity value of 2,850 cm^3 for an ideal soil.

The plants in 3 gallon pots received 3.8 L of water a week in the field capacity treatment because 3 L is field capacity and the pitchers we used to water the plants were gallon sized (3.8 L). By watering the plants with 3.8 L we more than ensure the plant would receive the necessary water for a plant to achieve field capacity, and we can see excess water drain from the bottom of the pot. Plants assigned the watering regime of 2/3 field capacity received 2 L, and those trees assigned the watering regime of 1/3 field capacity" received 1 L.

In a previous but similar experiment, the watering treatments were field capacity (3 L), ½ field capacity (1.5 L), and 1/3 field capacity (1 L) but we found that there was no increase in plant growth when watering was increased from 1/3 to ½ field capacity. By bumping up the watering amount to 2 L from 1.5L we increased the amount of water in the soil from 50% of field capacity to 66% of field capacity, all the while still conserving water. A nursery manager wants to save water while promoting plant growth.

Each week, height and stem diameter was measured and recorded. As per the guidelines for land scape planting, stem diameters were measured at 6" (15 cm) above the root collar. At the end of the experiment, 9 plants of each species were harvested, dried in an oven for 3 days at 50˚ C (Ostertag et al., 2008), separated into its components and weighed.

The data was statistically analyzed using JMP. Graphs were generated in Excel. We calculated descriptive statistics and then performed an ANOVA to see if there were differences amongst the treatments. If there was a statistical difference between treatments for a particular species, a Dunnet's test was performed. Kalunda Cuffy, a second year undergraduate in the computer science program helped with plant care, data collection and entry, photo documentation, along with making graphics.

Principal Findings and Significance by Species

Results for all species are summarized in tables 1 and 2 and then graphically displayed by species.

Andira inermis:

Trees grew best when they received 3.8 L of water a week. With the 3.8 L treatment, trees reached 4 feet (120 cm) and 0.5 inches (12.5mm) by 22 weeks from a starting height of 44 cm. Trees watered with 2 L kept growing but at a slower rate. They reached 107 cm from 44 cm by the end of the experiment. Trees watered with 1 L a week grew from 44 cm at the start of the experiment, until they reached 63 cm and then stopped growing. (Figure 1) Total Biomass was significantly different for all three treatments ($p = 0.0002$).

Interestingly enough, *A. inermis* dedicates more significantly more biomass to roots (43%, versus 34% green and 31%) when under water stress in an effort to capture more water. The proportion of leaf biomass stayed the same for all 3 treatments and under the “blue” treatment instead of dedicating 43% of its biomass to roots as under the yellow treatment, these trees dedicated 43% of the biomass to stem wood. During the course of this experiment, the trees concentrated all above ground woody growth upon a single stem and did not produce lateral branches. Total biomass produced by *A. inermis* was different for all three treatments. This species is often found along stream sides, but tolerates a wide range of sites, hence the differing allocations of biomass in response to site conditions (Little and Wadsworth, 1974). (Figure 2).

***Bucida buceras*:**

Trees need 3.8 L of water a week. This species does not respond well to water stress. By the end of the week all the plants, particularly the 2 L and 1 L plants were wilting and obviously under water stress. This is curious because *B. buceras* is often found growing close very close to the ocean shore on the drier east end of St Croix. One would think it is a drought tolerant tree. By the end of 15 weeks, no tree was ready to be sold under any treatment. This is a very thirsty species. No growth unless the soil is at field capacity. 1 L and 2 L of water barely keep the trees alive. Maybe watering the trees twice a week with at least 2 L would keep the trees not stressed and growing (Figure 3).

Unlike *A. inermis*, biomass allocation in *B. buceras* is not plastic. Trees subjected to different watering treatments allocated their biomass the same way. Over half of the biomass was dedicated to stems and branches, and the rest of the biomass was more or less equally divided between roots and leaves (Figure 4).

B. bucida is a very branchy tree with many lateral branches the form of a pagoda or a series of parasols that get smaller as they ascend the tree. Branches in young trees are kept close to the ground. Maybe this is an attempt by the plant to reduce evaporation of soil water by shading the soil in its root zone. There are two other trees that share this pagoda like growth form: *Terminalia catappa* L. and *Tabebuia bilbergii* (But & K.Schum) Standl ssp *ampla* A Gentry. The first tree, *T. catappa* is a now pan tropical tree species, that goes by the common names of Sea Almond and West Indian Almond. It often grows close to the shoreline where it tolerates sandy soils and salt from the wind and in the soil. The second tree, *T. bilbergii* grows in the very dry tropical forests or tropical thorn scrub of the Ecuadorian and Peruvian Coast. According to the Holdridge Life Zone region classification system, tropical very dry forest receives less than 1,000 mm of rain a year, whereas tropical thorn scrub receives between 500 mm and 250 mm of rain a year (Holdridge, 1978).

A note on the biomass data for *B. bucera*, the trees in the field capacity treatment dedicated 16% of their biomass to foliage. This is an underestimate. We discovered that this species is very sensitive to the insecticide Malathion™. We were spraying the greenhouse for white flies and the "field capacity treatment lost their leaves because they were closest to the spray. They had not fully recovered at the time of the experiments end. We believe that a more reasonable estimate of the foliage allocation is 25% of biomass for the field capacity treatment trees.

Guaiacum officinale

These trees were grown in 1000 cm^3 pots rather than 3 gallon pots. The three watering treatments were 500 ml, 250 ml and 125 ml per week, which translates to field capacity, 2/3 field capacity, and 1/3 field capacity. They did not grow fast enough in time for the experiment to be transplanted to 3 gallon pots. To grow plants 8 cm tall in 3 gallon pots would be considered over-potting and probably wouldn't be done nursery context. After 15 weeks of growth, the trees are not ready for out planting, but maybe ready to be transferred in 3 gallon pots.

There is a significant difference between treatments for both tree height ($p = 0.0028$) and biomass ($p = 0.0001$). Trees grew best with the field capacity treatment. Trees did not respond well when subjected to the subjected to the treatment. In fact, ½ of the trees died. This mortality of the trees in the 1/3 field capacity treatment negatively affected the statistical analysis of the result for tree subjected to this treatment but not for the trees in the field capacity or 2/3 field capacity treatments.

Trees that received 500 ml of water a week had an average height of 20 cm versus 13 cm for those trees in the 2/3 field capacity treatment that received 250 ml a week (Figure 5). Dried biomass produced was 6 g in the field capacity treatment versus 3 g in the 2/3 field capacity treatment. Most of the biomass, ≥ 50%, was dedicated to leaves (Figure 7). It appears that this species is very susceptible to drought stress while very young, although generally this tree is considered resistant to drought and salt (Jones, 1995, Daley and Zimmerman, 2007).

Jacquinia arborea

This tree grew the same whether subjected to the field capacity treatment or the 2/3 field capacity treatment (39 cm versus 41 cm versus 30 cm). Trees subjected to the 1/3 field capacity treatment grew the least (P= 0.024).Therefore, we recommend watering with 2L per week instead of 3L in order to save water (Figure 8).

There was no difference between treatments for total biomass but there were differences in the biomass allocation (Figure 9). For all three treatments, most of the biomass was dedicated to tough leathery leaves instead of roots; in particular the trees subjected to drought in the 1/3 field capacity treatment dedicated 55% of their biomass to leaves. Leathery leaves are water conservation strategy. The dedication of more biomass to roots as demonstrated by *A. inermis* and *T. heterophylla* is another strategy to capture the limiting resource of water.

Pimenta racemosa

Trees subjected to the 2/3 field capacity treatment (77 cm) grew the most in height, followed by the field capacity treatment (74 cm) and then the 1/3 field capacity treatment (66 cm) (Figure 10). As expected, the field capacity treatment produced the most biomass (92 g), followed by the 2/3 field capacity (67 g), and1/3 field capacity treatment (50 g) (Figure 11). There was no statistical difference between treatments for both height growth and biomass.

We noticed that early on in the experiment, watering the trees with 3.8 L of water appeared excessive; the plants looked sickly and grew slower, yet towards the end of the experiment, as the trees grew bigger, they looked healthier and what was once "excessive" water was no longer excessive but just abundant.

According to Jones, 1995, *P. racemosa* is moderately drought tolerant, so that plants watered to field capacity should not be problematic. No other tree species reacted this way to watering, most of the time they responded positively or not at all, but never negatively, not even trees that grow on arid sites like *P. alba* and *J. arborea.*

We also observed an unusual phenomenon. As of yet, the cause is unknown. Often times, the main stem would fall over, and lateral the lateral branches on the (now) superior side of the stem would become the new terminal leaders or apices. What was supposed to be a tree now becomes a bush. This happened to some trees regardless of watering regime. The reason for this is unknown and not all trees took on this bush like form. However, this might explain why total biomass is the field capacity treatment, yet tree heights are marginally higher in the 2/3 field capacity treatment. However, as mentioned earlier there are no statistical differences amongst treatments.

Trees in all 3 treatments devoted roughly the same proportion of biomass to leaves and roots, (40% and 37%) but the trees in the field capacity treatment dedicated a statistically significant proportion of biomass to stem (25%) probably because some of them were so branchy.

Our recommendation is to water with 2 L once a week, rather than 3.8 L, at least for the first 10 weeks. Once the trees reach 45-50 cm, they are big enough to use more water.

Plumeria alba

P. alba was the experiment's most drought tolerant species. Average growth was 0.7 cm per week for the trees that got 2 L water and 0.5 cm for those that got 1 L and 3.8 L of water (Figure 12). But there was no statistical difference. In order to optimize growth, one should water one a week with 2L, but 1 L per week is acceptable. To water with 3.8 L weekly just wastes water.

This species not subjected to biomass harvest due to rarity of the species. However the growth for of the species is such that there is much more biomass dedicated to stem rather than leaves Roughly 90% of the above ground portion of the tree is stem, with just a few leaves at the top of the stem.

Tabebuia heterophylla

These trees were in "12 gallon" pots (45,000 cm^3) because they had a bigger starting size. The amount of water to apply was determined by subtracting the dry weight of the pots from the wet weight. In this case the trees received 10 L in the field capacity treatment, 5 L in the 2/3 field capacity treatment and 2.5 L in the yellow treatment. Trees in the green treatment grew best.

There were no statistically differences amongst treatments at the beginning of the experiment but there was at the end of the experiment in regards to height ($p = 0.0121$) but not biomass (Figure

13). What is interesting is the allocation of biomass. The trees subjected to the drought or 1/3 field capacity treatment dedicated 60% of their biomass to roots ($p = 0.05$) versus some 38% for the field capacity treatment and 45% for the 2/3 field capacity treatment (Figure 14).

Conclusions

With the exception of the *G. officinale* trees subjected to the 1/3 field capacity treatment, all the studied tree species tolerate low levels of irrigation. None of the trees lost their leaves during the course of the experiment, although there were differences in growth and biomass allocation. Irrigation in this case was performed by a hose and a bucket in the greenhouse, but by extension could be considered as substitute for rainfall, if the trees were planted outside. This study has implications for tree nursery managers. Ideally, they want to produce trees ready for landscape planting in the least amount of time possible with the least amount of water.   It would be worthwhile to continue this study with other tree species, and with the same species transferred into bigger pots. What was learned here can be improved and built upon. For example, increasing the sample size slightly will hopefully increase the significance of the results. With the experiences gained from the study, the techniques employed can be further refined.

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List of Presentations:

Cuffy, K., M. Morgan, T.W.Zimmerman, (2013) Evaluation of Drought Tolerance in 3 Native Tree Species with Landscape Potential, a Biometric Approach. Poster Presented at UVI Student Science Symposium (March 23, 2013).

Morgan, M., K. Cuffy, and T.W. Zimmerman. (2013) Evaluation of Drought Tolerance in 4 Native Tree Species Suitable for Landscaping: A Soil Water& Biometric Approach. Poster presented at UVI Research Day (April 6, 2013).

Article submitted to the peer reviewed journal Tree Planters Notes, (October 2013).

Student Participation:

Kalunda Cuffy, a second year undergraduate in the computer science program helped with plant care, data collection and entry, along with making graphics.

TABLES AND GRAPHICS

Table 1. Tree heights by species and treatments at the beginning and end of the experiment.

Species	**Treatment**	**Initial Height (cm)**	**Final Height (cm)**	**Statistical Importance**
Andira inermis	field capacity	44 ± 4	126 ± 12	0.0001 A
A. inermis	2/3 field capacity	44 ± 3	107 ± 12	B
A. inermis	1/3 field capacity	44 ± 4	63 ± 9	C
Bucida bucera	field capacity	36 ±6	88 ± 7	0.0004 A
B. bucera	2/3 field capacity	33 ±4	51 ± 3	B
B. bucera	1/3 field capacity	36 ±8	50 ± 6	B
Guaiacum officinale	field capacity	8 ± 2	20 ± 6	0.0005 A
G. officinale	2/3 field capacity	8 ± 2	15 ± 2	A
G. officinale	1/3 field capacity	8 ± 2	8 ± 4	B
Jacquinia arborea	field capacity	20 ± 7	39 ± 3	0.002 A
J. arborea	2/3 field capacity	21 ±4	41 ± 2	A
J. arborea	1/3 field capacity	20 ± 5	30 ± 2	B
Pimienta racemosa	field capacity	19 ± 1	74 ± 13	NS A
P. racemosa	2/3 field capacity	21 ± 2	77 ± 7	A
P. racemosa	1/3 field capacity	20 ± 2	66 ± 5	A
Plumeria alba	field capacity	84 ±4	92 ± 5	NS A
P. alba	2/3 field capacity	80 ±2	91 ±4	A
P. alba	1/3 field capacity	89 ±4	96 ± 5	A
Tabebuia heterophylla	field capacity	92 ± 5	137 ± 6	0.012 A
T. heterophylla	2/3 field capacity	97 ±4	144 ± 9	A
T. heterophylla	1/3 field capacity	96 ± 5	109 ± 3	B

Table 2. Total tree biomass and allocation by species and treatment. Biomass allocation is written as a proportion.

SPECIES	TREATMENT	Root Biomass	Stem Biomass	Leaf Biomass	Total Biomass (g)	Root Shoot Ratio
Andira inermis	field capacity	0.43	0.31	0.26	84.1	0.8
A. inermis	2/3 field capacity	0.34	0.40	0.26	174.1	0.5
A. inermis	1/3 field capacity	0.31	0.42	0.26	247.0	0.5
Bucida bucera	field capacity	0.25	0.53	0.21	81.7	0.5
B. bucera	2/3 field capacity	0.27	0.46	0.27	162.7	0.6
B. bucera	1/3 field capacity	0.31	0.53	0.16	220.3	0.6
Guaiacum officinale	field capacity	0.31	0.19	0.50	6.13	0.47
G. officinale	2/3 field capacity	0.26	0.18	0.56	3.09	0.37
G. officinale	1/3 field capacity	0.16	0.20	0.64	1.45	0.20
Jacquinia arborea	field capacity	0.29	0.18	0.53	40.9	0.4
J. arborea	2/3 field capacity	0.33	0.21	0.46	54.1	0.5
J. arborea	1/3 field capacity	0.28	0.23	0.49	59.7	0.4
Pimienta racemosa	field capacity	0.42	0.18	0.40	50.1	0.7
P. racemosa	2/3 field capacity	0.39	0.21	0.40	66.8	0.6
P. racemosa	1/3 field capacity	0.35	0.26	0.39	92.2	0.6
Tabebuia heterophylla	field capacity	0.38	0.44	0.18	642.3	0.63
T. heterophylla	2/3 field capacity	0.45	0.40	0.15	683.9	0.85
T. heterophylla	1/3 field capacity	0.60	0.30	0.10	592.5	1.63

Figure1. Heights of *A. inermis* subjected to 3 different watering treatments.

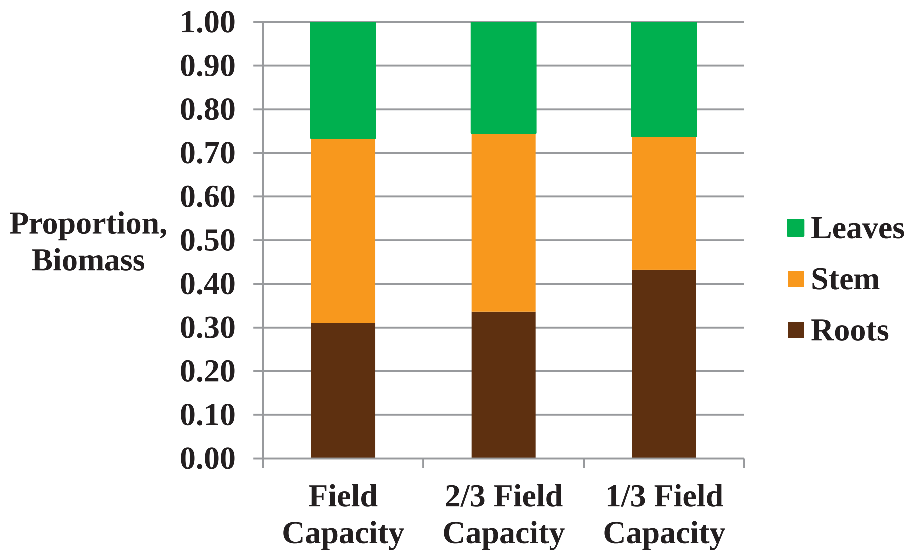

Figure 2. Allocation of Biomass in response to watering levels by *A. inermis*.

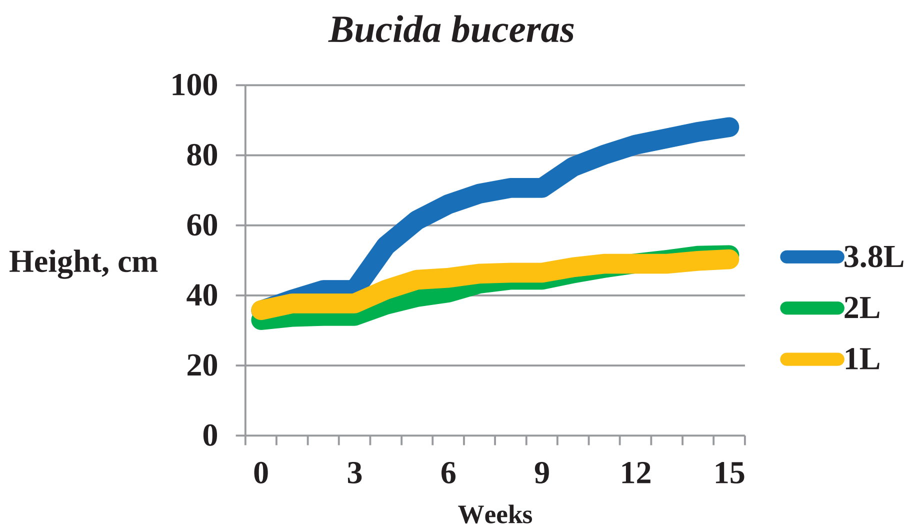

Figure 3. Heights of *B. buceras* by treatment plotted over time.

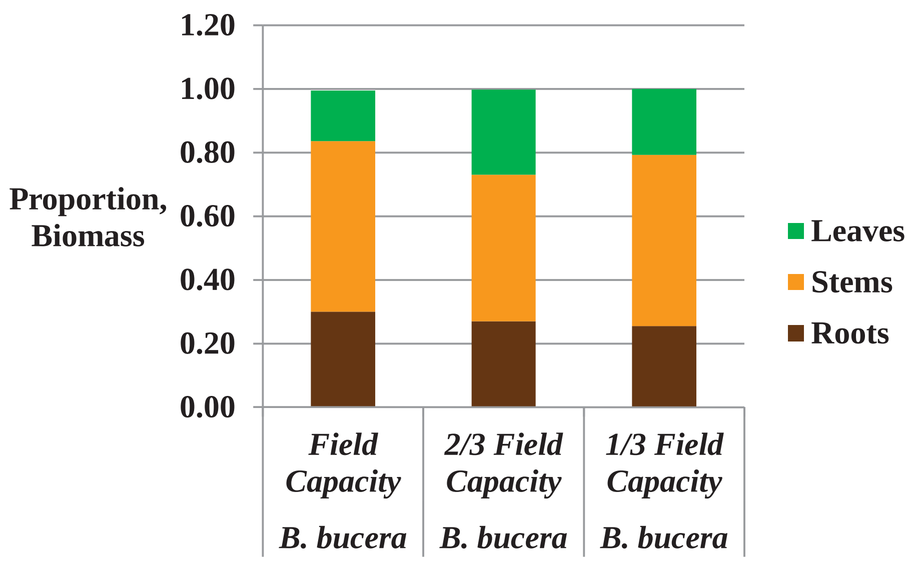

Figure 4. Biomass allocation of *B. buceras* represented as a proportion .

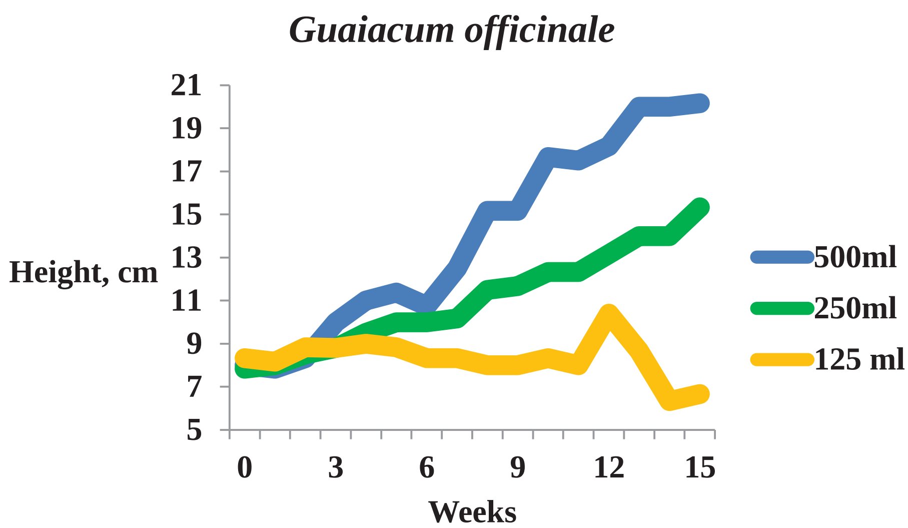

Figure 5: Heights of *G. officinale* subjected to 3 different watering treatments plotted over time.

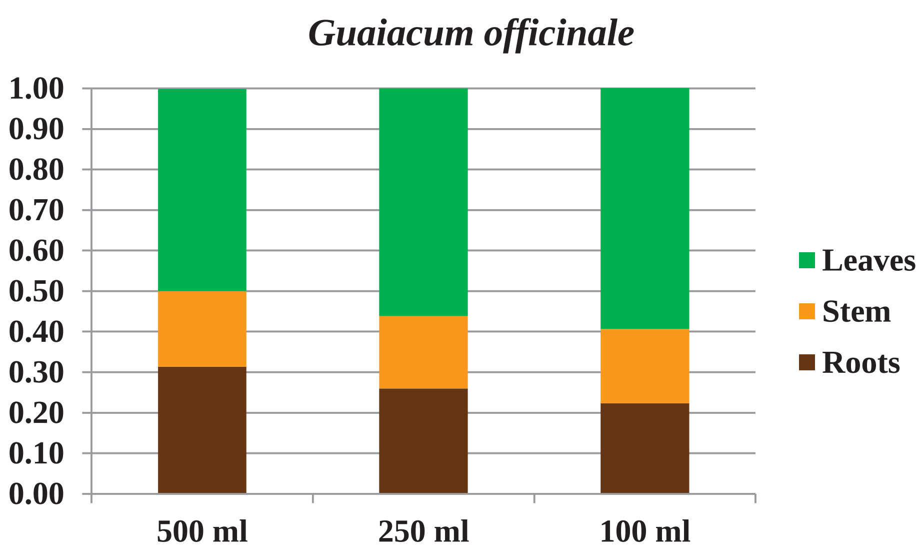

Figure 6. Biomass allocation by proportion; *G. officinale.*

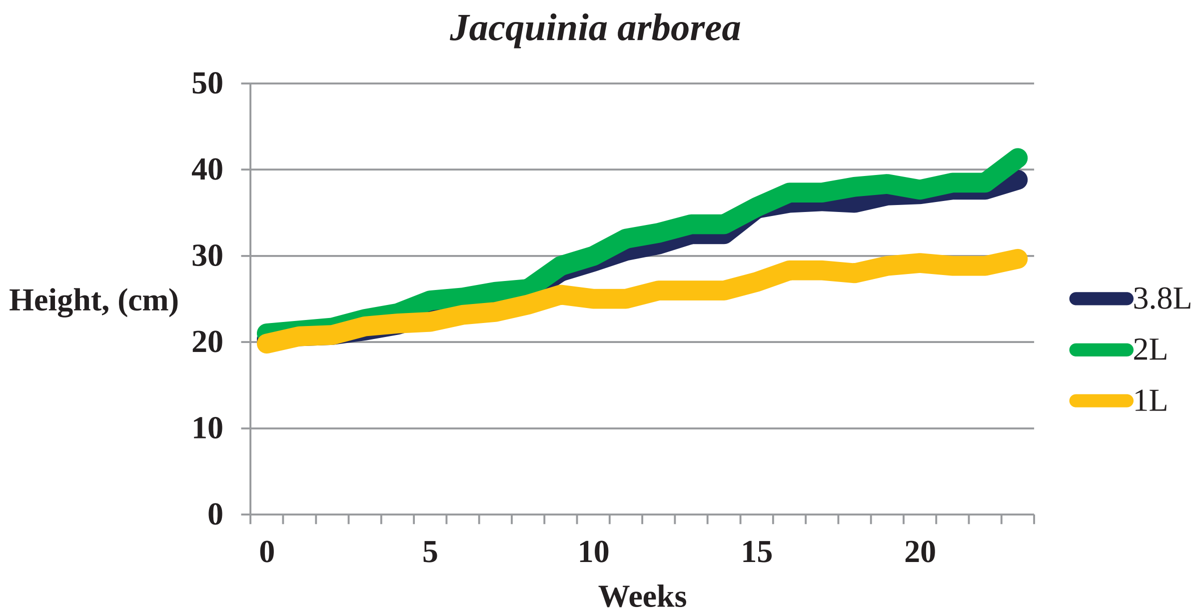

Figure 7. Tree heights of *J. arborea* by treatment plotted over time.

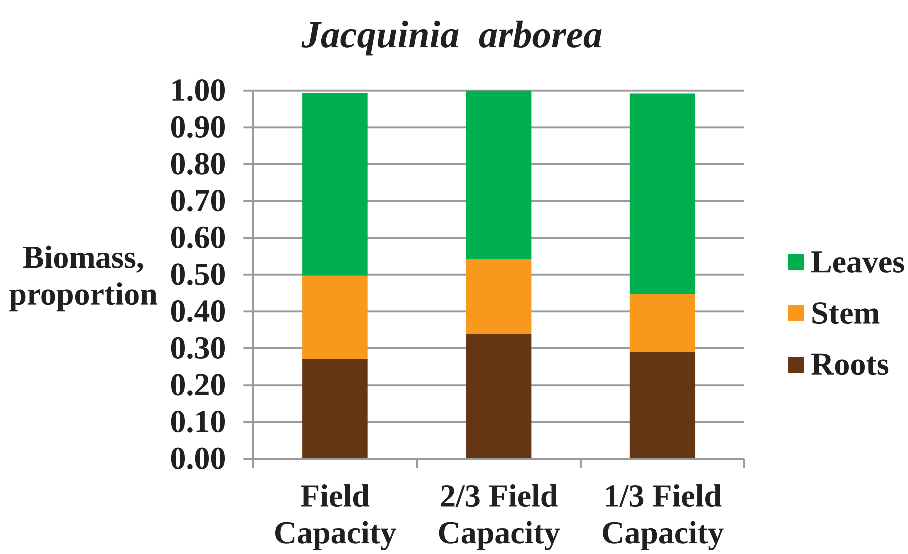

Figure 8. Biomass allocation of *J. arborea* by treatment.

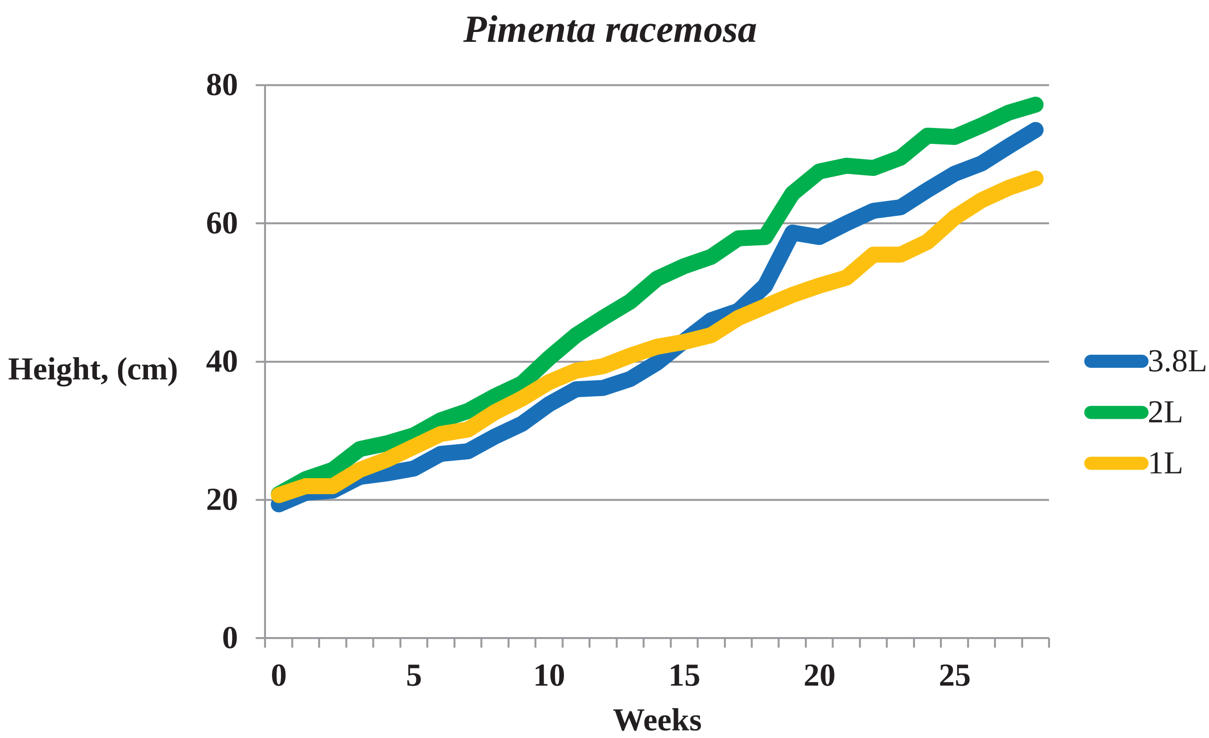

Figure 9. Tree heights plotted over time for *P. racemosa* seedlings subjected to 3 watering levels.

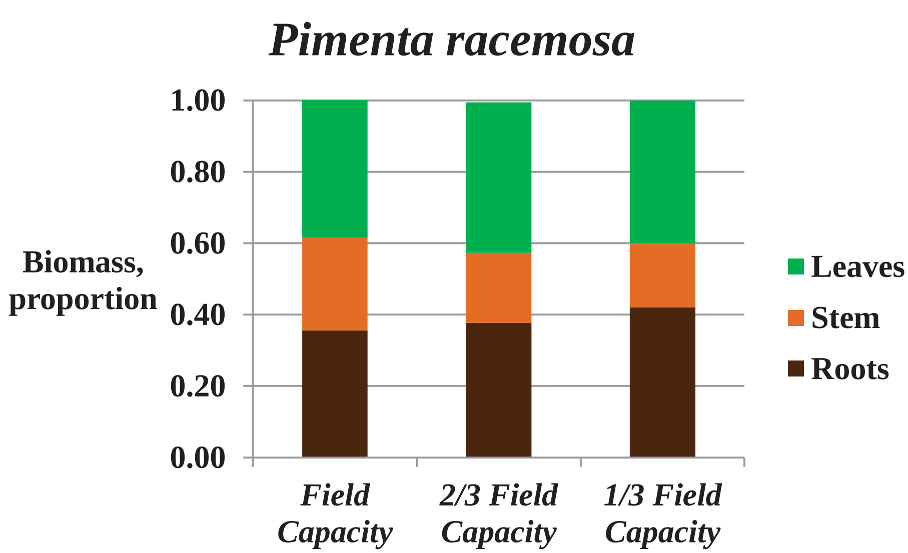

Figure 10. Allocation of biomass by *P. racemosa* seedlings subjected to 3 watering different levels.

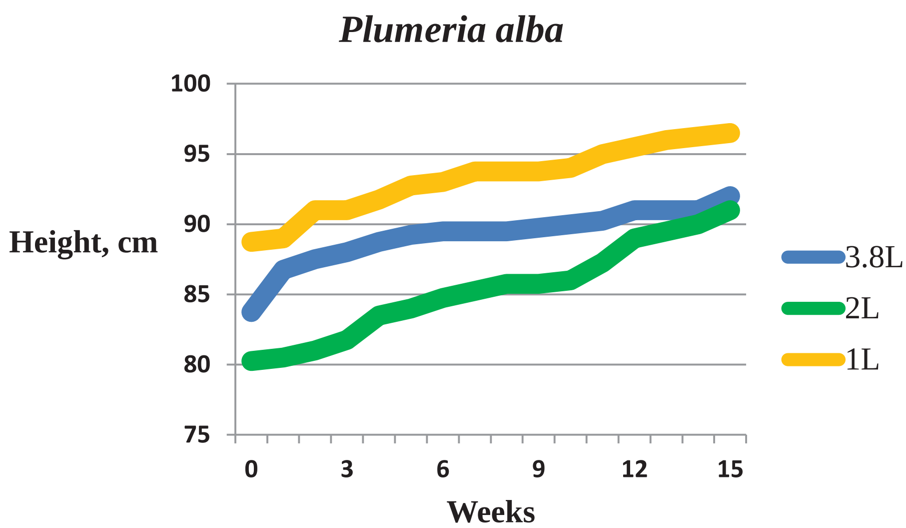

Figure 11. Heights of *P. alba* seedlings plotted over time subjected to 3 watering different levels.

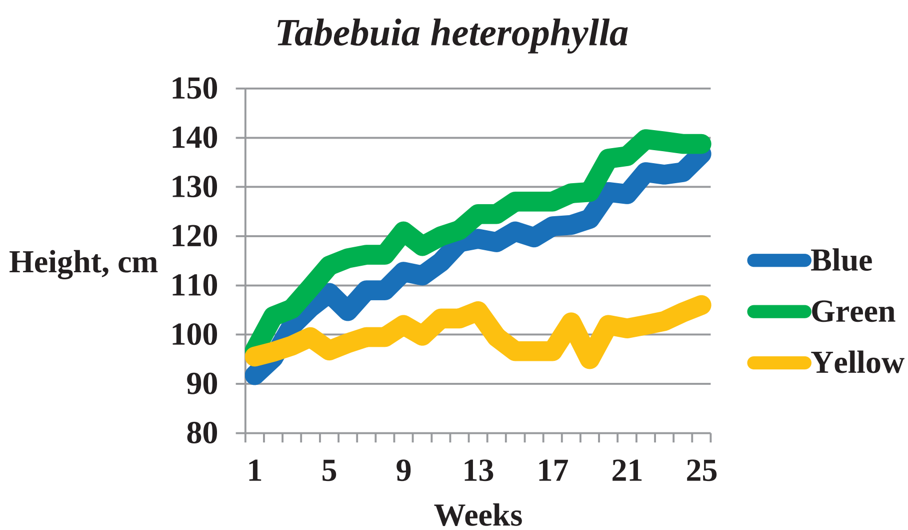

Figure 12. Heights of *T. heterophylla* saplings subjected to 3 watering treatments, plotted over time.

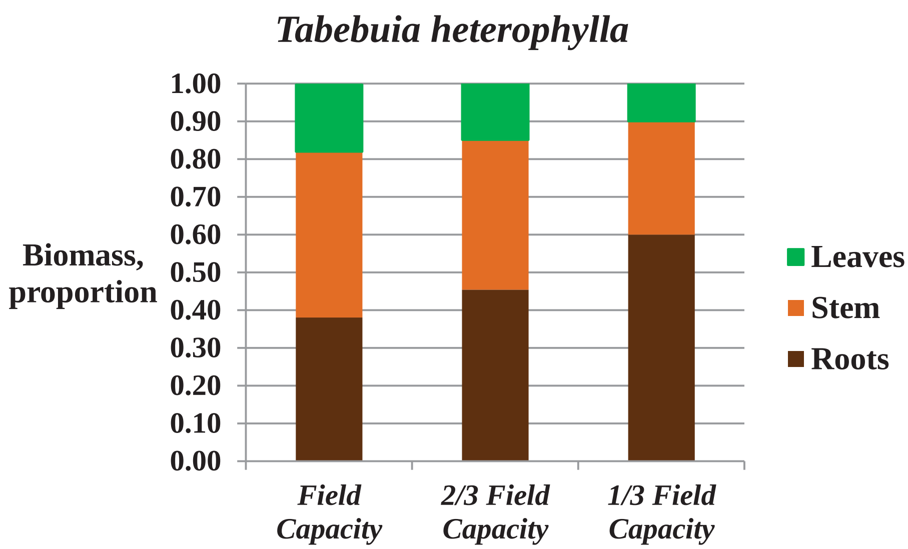

Figure 13. Biomass allocation of *T. heterophylla* saplings subjected to 3 watering treatments.