Improved Precision Irrigation of Trees in Planning and Managing Florida Friendly Landscapes

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ABSTRACT

Increased water use from a growing population is straining Florida's limited water supplies. Florida-Friendly Landscaping^{TM} (FFL) can reduce the strain with the right plant in the right place. Water demand of FFL plants during drought, particularly valuables trees, is largely unknown. The purpose of this research is to quantify minimum water demand by comparing two signature landscape trees, southern magnolia and live oak, with and without water stress grown in containers using a sophisticated weighing lysimeter system. A second study tracked canopy and root growth of water stressed trees in large containers. Finally, a model was derived for water use strategies and risk of water stress in these two species in order to predict the probability of seasonal irrigation needs of a FFL. We found that southern magnolia and live oak have different strategies to cope with water stress. Southern magnolia appeared to be the conservative species, minimizing water use by closing stomata, and maintaining thriving roots in the shallow soil profile to accommodate water replenishment schedule. In contrast, live oak sustained water use by keeping stomata open to the point of shedding their leaves to reduce projected conductance and protect them from hydraulic failure. Live oak invested in a deep root system, which included more fine roots to explore the water resource in the deeper soil layer. Live oak required more water (50-55% of the optimum demand) to stay green, compared to magnolia (35-40%), However, tree size will be reduced significantly in magnolia under severe deficit irrigation and it will affect the values of this tree species in the landscape even though the leaves remain green.

OBJECTIVES

This study consists of three different parts using the two most popular landscape tree species in Florida: anisohydric live oak (*Quercus virginiana)* and isohydric southern magnolia (*Magnolia grandiflora*), with the aim to:

- ✓ Study the behavior of stomatal conductance (related to transpiration), photosynthesis, and predawn leaf water potential (how tightly water is held) of these two species under progressive water stress
- ✓ Study above-ground growth and root growth (root depth, number of fine roots, ratio of root/shoot) under deficit irrigation conditions (defined as 30% of well-watered irrigation)
- ✓ Apply the results of research on oak and magnolia by analyzing in the context of changes in reference transpiration (ETo) and the frequency of dry periods in central Florida in recent decades.

METHODS

Part 1. Three progressive dry-downs were conducted from 2019 to 2020 in early and late dry seasons using a weighing lysimeter system that precisely measured changes in tree-container weight due to transpiration. Six trees of each species were suspended from a 2-m high tripod lysimeter in a metal basket holding the container from an electronic load cell sensor that measured weight changes. Load cells were wired to a data logger system that measured lysimeter weight every half hour for irrigation data. The data logger calculated water loss from the previous day’~~s~~ (ET_A), which was relayed to solenoid~~s~~ valves for durations of irrigation and replaced water loss. For water stressed live oak trees, the datalogger replaced only 90% of water loss, imposing a slow dry down. For water stressed magnolia trees, the amount of water replaced was adjusted within a range of 90% to 20% to speed up the stress levels when necessary because magnolia uses less water than live oak, leading to a slower dry down process. A dry down was finished when measures of water stress (reduced transpiration, increased xylem water tension, and visual quality) and daily water use was about 40% of the well-watered trees. There were three dry-downs for each species: two in early dry and one in late dry season. New sets of trees were used in each dry-down. After each dry-down, trees were removed from the lysimeter baskets and well-irrigated. Growth was measured at the end of four to six months to assess long-term impact on each species.

Part 2. The root study experiment ran for 14 months, concurrent with the three dry-down studies described in Part 1. Eight trees, four for well-watered four for drought of each species were grown in meatal barrels (85cm height, 58cm diameter) to allow root growth more representative of an in-ground landscape setting. Five trees of each species were assigned to a water stress treatment where they were being deficit irrigated at 30% of the control, well-watered trees were irrigated at full replacement of local evapotranspiration. Impact of water stress was measured every three weeks by changes in photosynthesis, transpiration, internal water tension and growth (height, trunk diameter). At the end of the experiment, measurements of total leaf area, shoot elongation, and trunk growth were recorded. To assess the ability of the root systems to exploit soil water, maximum root traits such as total root length, root diameter, root volume, total fine root length, root dry weight by depth, and functional root traits such as root length density and specific root length were recorded. The results will compare how the two species, differ anisohydric versus isohydric water use strategy, allocate carbon between root growth and top growth in response to drought.

Part 3. Historical daily rainfall and evapotranspiration (ETo) data from 1970 were collected from four weather stations from north, central and south Florida. I will analyze these data for length and intensity (rainfall minus ETo) of dry periods, both during the drier winter and wet summer seasons, through a machine learning-based approach. Machine learning has become a powerful tool to handle large climate data sets to determine the scale of potential drought, and potential changes over time. I will then link results from the previous two studies on tree water use with contrasting water use strategies (isohydric magnolia and anisohydric oak) under water stress to analyze the risk of dry periods across a scale of duration and intensity on tree growth. This analysis can improve both planning and management of water in Florida Friendly Landscapes.

RESULTS

R1. Behavior of stomatal conductance, photosynthesis and predawn leaf water potential of these two species under progressive water stress

Magnolia's stomatal conductance (gs) readings were significantly lower than that in live oak. Generally, magnolia's gs decreased throughout the day, highest in the mid-morning and lowest in the mid-afternoon; the values of gs at noon and mid-afternoon were very close and significantly different from that in the morning in both dry-downs. The difference between mid-morning stomatal conductance and noon, and/or mid-afternoon were much higher in magnolia water stressed trees compared to that in well-watered trees. Meanwhile, live oak's gs did not show this pattern, except in the second dry-down (2020-2021) in water-stressed trees. Live oak's gs mid-morning and mid-noon were almost similar, even mid-noon gs were higher than mid-morning gs in well-watered trees.

In magnolias, gs of water-stressed trees quickly declined in comparison to that of well-watered trees, as soon as water reduction started. The difference in gs in between the two treatments gradually increased along with the progressive dry-down (figure 1-A). This trend was translated and reflected in water use/transpiration of this species.

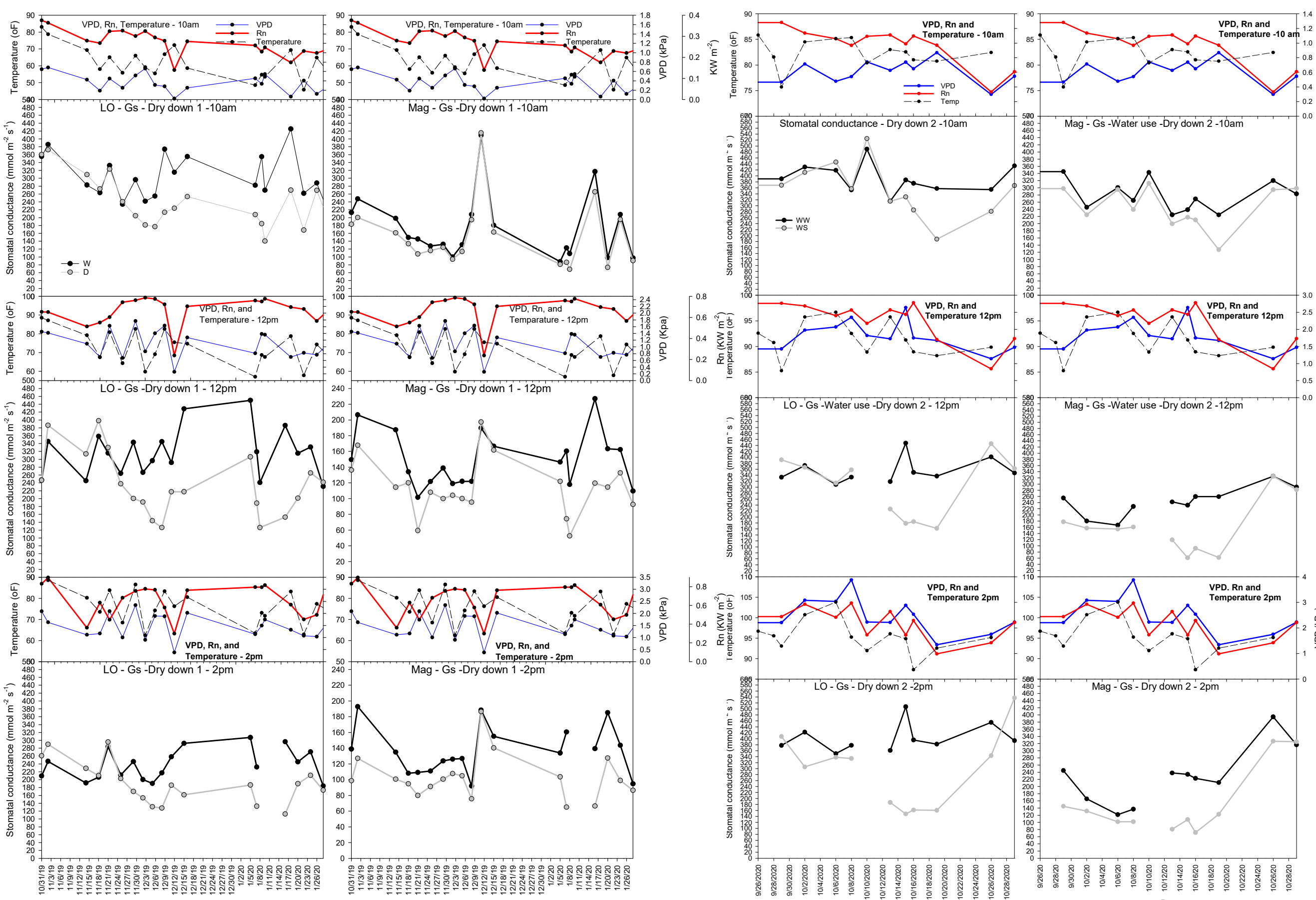

Figure 1. A-left. Stomatal conductance and microclimate data (VPD, Rn, Temperature) mid morning, mid noon, and mid afternoon in dry down 1-right. Stomatal conductance and microclimate data mid morning, mid noon, and mid afternoon (VPD, Rn, Temperature) in dry down 2

Daily water use was reduced in water-stressed trees right after the onset of the dry-down, and progressively declined throughout the dry-down. Water stressed live oaks' gs, in contrast, did not decline compared to the well-watered live oaks, and even increased on the first weeks of the dry down until leaf water potential (LWP) reached around -4 Mpa. Gs decreased a great deal suddenly in both dry-downs. Together with the sudden decrease in gs, some leaves started to turn brown and dropped, which is a typical characteristic reported in most deciduous trees;

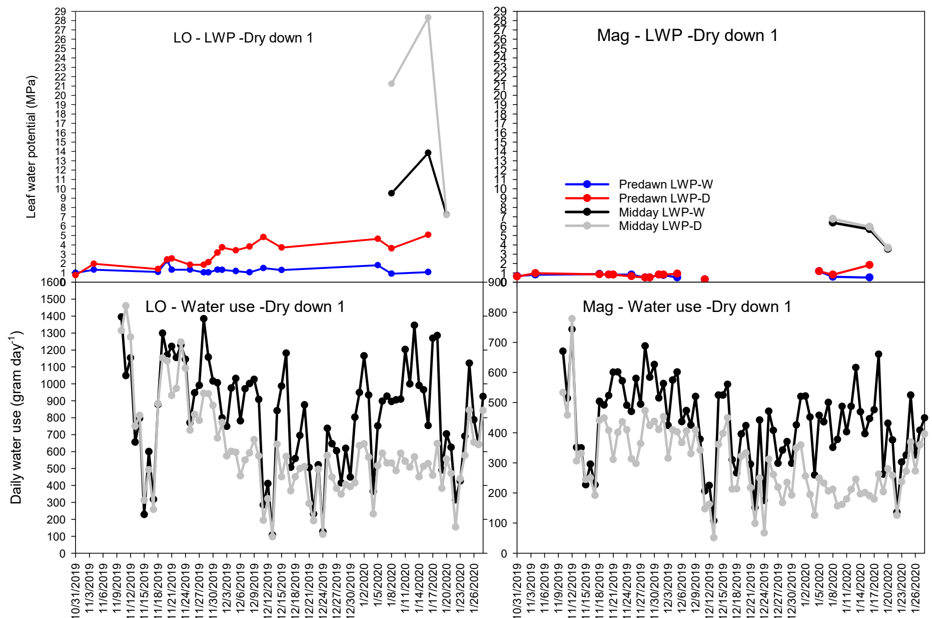

Figure 2. A. Predawn, midday leaf water potential, and daily water use of live and magnolia in dry down 1.

stress – shedding the part that loses water as a trade-off with photosynthesis. With live oak, shedding leaves is also a mechanism to reduce projected losses in conductance; thus, has the potential to improve tree hydraulic failure. This gs change pattern was also translated into daily water use in this species in two dry-downs (figure …).

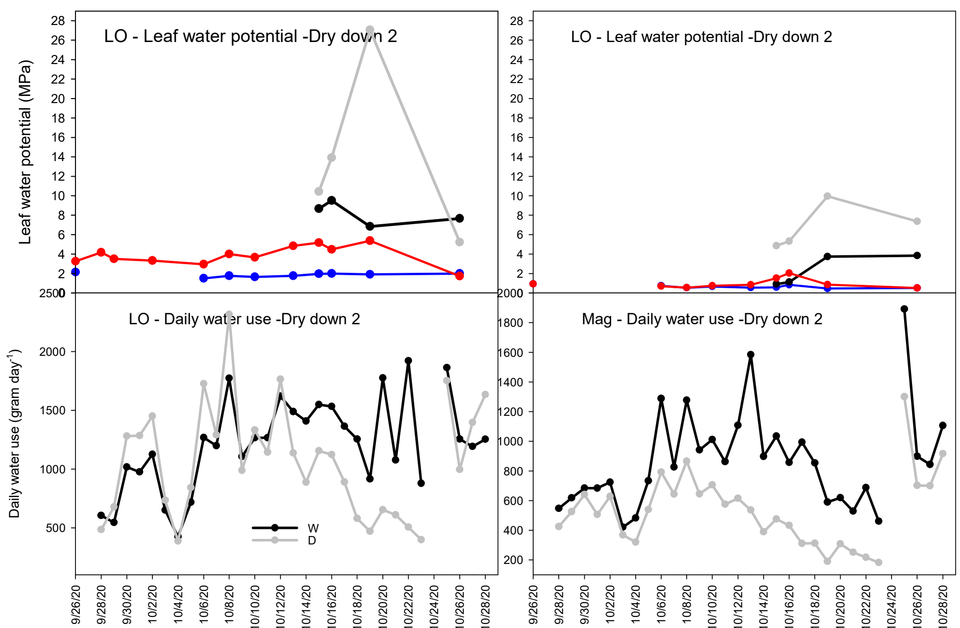

Figure 2. B. Predawn, midday leaf water potential, and daily water use of live oak and magnolia in dry down 2.

Changes in gs in these two species were opposite with the changes in predawn leaf water potential (LWP). As soon as irrigation was reduced, predawn LWP in live oaks went more negative and progressed over time of the dry-down; meanwhile, predawn LWP in water-stressed magnolia stayed at the same level as the well-watered trees for a much longer time, then gradually became more negative with the progress of the dry-downs. In the third dry-down (2021), in late dry season, we managed to adjust the amount of water irrigated back to the pots so that the very similar predawn LWP were achieved in both species. In this case, the same pattern in water use was shown. Even though gs was not measured in this dry down, it is likely that gs would have the same pattern with the two previous dry-downs in both species. Mid-day LWP in magnolia were much lower than that in live oak, with the similar values of predawn LWP. These values tell us that live oak represents very isohydric traits, meanwhile, magnolia showed more of the anisohydric characteristics.

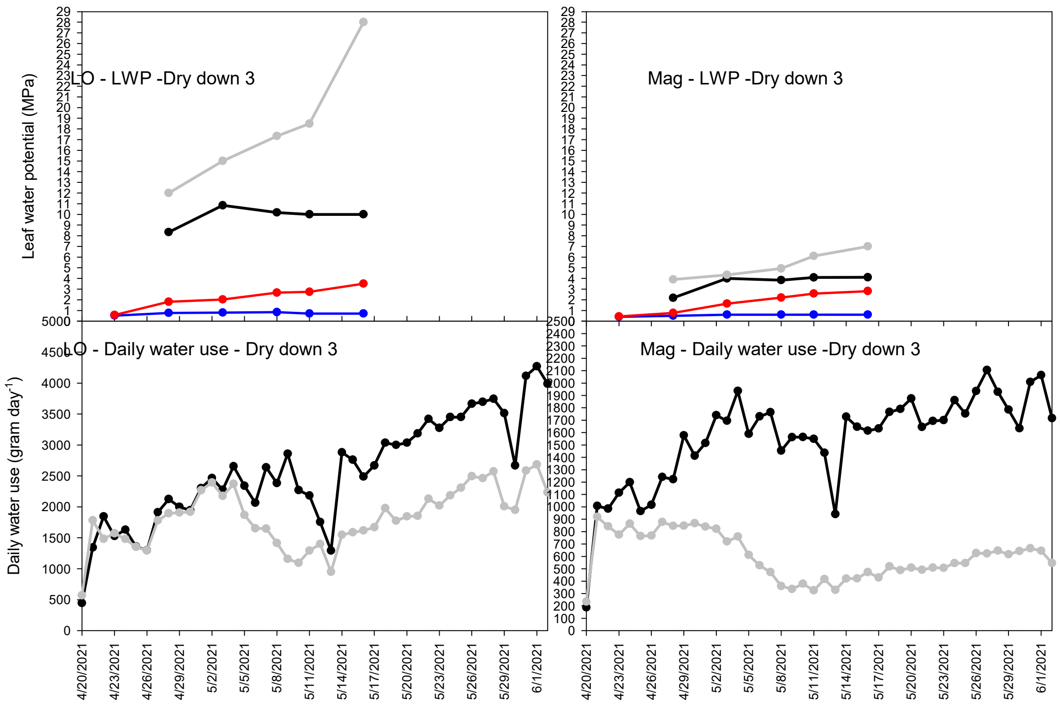

Figure 2. C. Predawn, midday leaf water potential, and daily water use of live oak and magnolia in dry down 3.

Growth subsequences during water stress and after being well-watered under progressive dry down

During the dry down, growth in projected canopy area (PCA), and trunk crossed sectional area (TCSA), and height were not affected by drought for both species in early dry season, which is the time of the year that trees' growth almost ceased. However, growth was apparently affected by drought in late dry season (April – May) in both species (figure 3). Months after being well-watered, PCA and TCSA of water-stressed grew more slowly in the previous drought of exposed trees compared to those in well-watered trees in both species. Height and growth, however, were in contrast. Subsequent growth in height in WS live oak were similar to that in well-watered trees, even grew taller in water-stressed magnolia in the first two dry-downs conducted in early dry season. In the third dry down, in late dry season, all trees' growth parameters declined during the dry down in both species. In comparison with live oak, water-stressed magnolias' growth was much more significantly decreased. However, watered-stressed magnolia showed faster subsequent growth rate than that in well-watered trees, almost reaching the same height, the same PCA and TCSA with the well-watered trees.

Gas exchange and Fluoresence

Non-photochemical quenching (NPQ) is a photoprotective process that removes excess excitation energy within chlorophyll-containing complexes and prevents the likelihood of formation of damaging free radicals. “This type of quenching competes with both fluorescence and photochemical quenching, and acts as a ‘safe’ mechanism for dissipating substantial levels of chlorophyll excitation energy, depending on the prevailing conditions and species” (Demmig-Adams and Adams, 2006). Our results showed that NPQ measured at the end the first two dry-downs in magnolia were always higher than that of live oak. At PAR 1400 μmol m^{-2} s^{-1}, NPQ increased from 3.3 to 4.6 with the increase of PAR from 1200 to 1400 μmol m^{-2} s^{-1} in magnolia on average on both well-watered and water-stressed plants. Meanwhile, the difference in this parameter in live oak was much lower and had contrasting results between well-watered and stressed plants: NPQ decreased from 3.1 to 2.9 in well-watered plants and increased from 2.8 to 3.4 in water-stressed plants. This could be the explanation for the faster growth rate in WS magnolia after being well-watered, compared to live oak.

Table 1. Non photochemical quenching in live and magnolia

Non photochemical quenching

Species	*Water treatment*	*Light intensity (PAR) (μmol m^{-2})*	
		1200	***1400***
Magnolia	W	3.37	4.56
	D	3.33	4.77*
Live oak	W	3.07	2.85
	D	2.80	3.39*

R2. Study root growth (root depth, number of fine roots, ratio of root/shoot) under deficit irrigation conditions (defined as 30% of well-watered irrigation)

Tree growth

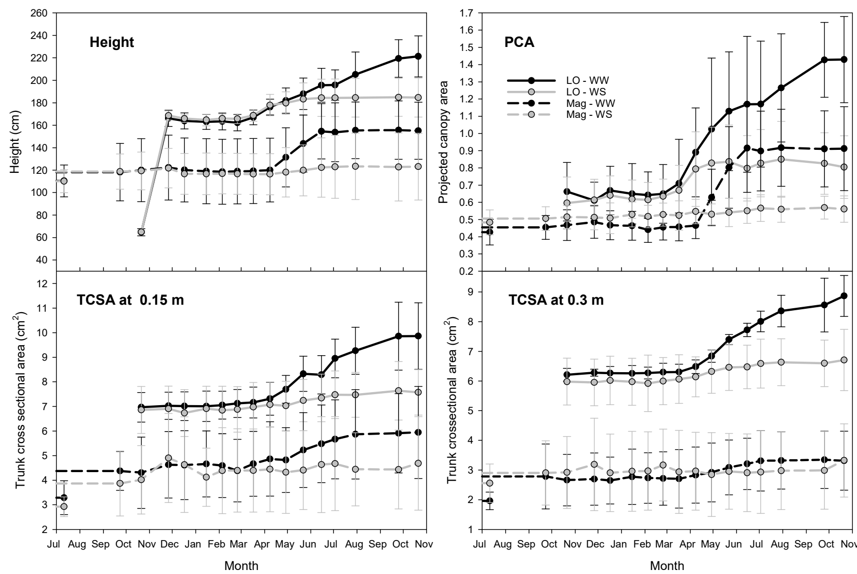

Figure 3. Height, projected canopy, trunk crossed sectional area at 0.15m and 0.3m of live oak and magnolia under long term soil water deficit

Long-term drought had great impact on reducing tree sizes in both species in terms of height, PCA and TCSA at 0.15m. There was no growth in water-stressed magnolia; however, there was still growth in water-stressed live oak from April to June in height and from April to May in PCA compared to well-watered trees (figure 3).

Root traits

Live oak's root diameter was much smaller than magnolia's root (Fig. 4-D). Root diameter decreased under water stress in all soil layers in live oak, but did not change for the top soil layer in magnolia. Total root surface area decreased in water-stressed live oak in all soil layers, in contrast, root surface layer did not change in water-stressed magnolia compared to the well-watered trees. Total root length decreased throughout the soil profile in live oak under deficit irrigation. Total root length of magnolia decreased under deficit irrigation in the middle and bottom layer; however, remained the same as in well-watered conditions. Root length per volume soil stayed the same in the top layer in magnolia and decreased in the next two layers under deficit conditions. In contrast, it remained the same in the bottom layer, but decreased in the top two layers under deficit irrigation in live oak. Very fine root ratio (VFR) at the bottom layer remained the same under drought conditions in live oak (22% and 21% in well-watered and water-stressed trees, respectively). Meanwhile, VFR decreased from 18% to 15% in magnolia under drought conditions.

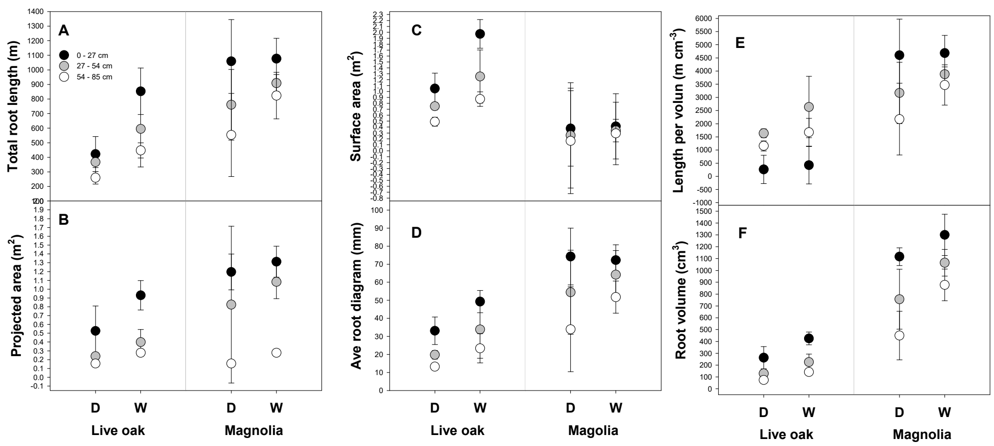

Figure 4. A-F: A. Total root length, B. Projected root area, C. root surface area, D. Average root diagram, E. Total root length per volume, F. Root volume of live oak and magnolia under long-term soil water deficit

Live oak with small mean root diameter and higher specific root length (SRL) associated with strategies for fast acquisition because they allow fine soil exploration for water without high carbon investment per unit of root length. The root tissue (RTD) increases in the deeper soil layer in live oak, most likely due to tissue reinforcement. Florian Fort et al., (2017) reported that this increase was coupled with a decrease in aerenchyma percentage that could allow live oak to survive under water shortage by the production of dense and protected root tissues (Hacke et al., 2001). Deeper roots in live oak trees provided a mechanism of dehydration avoidance, together with light decrease in stomatal conductance, sufficient to maintain leaf turgor. Meanwhile, the

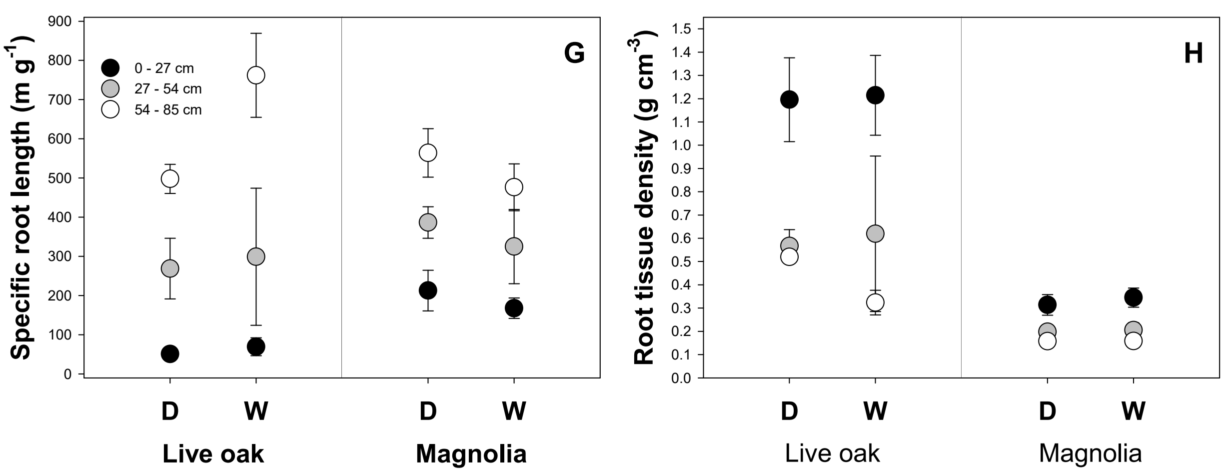

Figure 4 G_H.: G. Specific root length, H. Root tissue density of live oak and magnolia under long-term soil water deficit

major mechanism to avoid dehydration in magnolia is the focus on shallow root, and strong closure of stomata that will keep the tree alive; however, in the long run, the plant will likely stop growing, similar to the bonsai effect (figure 4).

R3. Intensity and frequency of dry periods analysis in central Florida in recent decades will include these two contrast trees in terms of water use in this climate context. Currently we are working on this part and planning on completing it in January 2022.

CONCLUSION

Under drought, the main regulation mechanism that limits water loss and buildup of excessive xylem tension in magnolia is through rapid closure of stomata with the cost of limiting carbon assimilation, thus, reducing plant growth a great deal along with the progress of soil water deficit and the length of the drought. Together with early and rapidly closing stomata, magnolia showed the ability to protect its leaves from the likelihood of formation of damaging free radicals by increasing non-photochemical quenching (NPQ), which is a photoprotective process that removes excess excitation energy within chlorophyll-containing complexes, especially under abiotic stresses such as drought. Magnolia appears to be water conservative, consuming the water resource slowly and minimizing water stress over long periods of time. And/however with opportunistic strategies, which focus more on developing roots on more shallow soil profiles, thus relying on shallow water and maximizing transpiration and growth after water was replenished.

On the other hand, live oak appeared to process fast water resource acquisition with more fine and deep roots under soil water deficit. Under soil water stress, live oak stomata remain open, which results in more negative leaf water potential, and potentially risking the excessive xylem tension and loss of turgor. Therefore, live oak rapidly sheds leaves to reduce projected loss of conductance.