

Assessing benefits of irrigation and nutrient management practices on a southeast Florida royal palm (*Roystonea elata*) field nursery

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Abstract Many of the best management practices (BMPs) that are recommended for agricultural producers have not been scientifically evaluated for their conservation benefits considering the soil, climate, and hydrology of the proposed application location. The goal of this study was to compare royal palm (*Roystonea elata*) production in south Florida, USA, using tensiometer automated irrigation and reduced soil applications of nitrogen (N) and phosphorus (P), to that of traditional grower practices considering water savings, nutrient inputs, crop yield, crop nutrient status, soil nutrient status, and economic analyses. The study consisted of six treatments: (1) control (i.e., a grower irrigation rate and N and P fertilizer rates); (2) irrigation system automated to irrigate when soil water suction exceeded 5 kPa and the

grower N and P rates; (3) irrigation system automated to irrigate when soil water suction exceeded 15 kPa and the grower N and P rates; (4) irrigation system automated to irrigate when soil water suction exceeded 15 kPa and 50% of the grower N and P rates; (5) the grower irrigation rate and 75% of the grower N and P rates; and (6) the grower irrigation rate and 50% of the grower N and P rates. Irrigation water volume applied, plant diameters, and plant heights were measured periodically throughout the study and plant tissue samples and soil samples were collected periodically for analysis of N and P content. Significant differences among treatments were only observed for the irrigation water volume applied. Automating the irrigation system to irrigate at soil suction exceeding 5 and 15 kPa resulted in 75 and 96% less water applied, respectively, than traditional irrigation scheduling practices used by a grower. Economic analyses suggested that all treatments would result in financial savings ranging from 7 to 34% per ha considering a 5-year, 2 ha investment. Thus, automating irrigation based on soil water suction for palm production in southern Florida, USA and similar locations will result in more sustainable agricultural production systems by benefiting the environment (less nutrients and water applied) and the grower (lower cost).

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Introduction

The availability of water supplies to meet all water needs is a growing challenge throughout the world (Shiklomanov 2000; Oki and Kanai 2006), particularly in locations experiencing rapid growth and development. One such area is Miami-Dade County in south Florida, USA (Fig. 1). The rapid growth of Miami-Dade County can be appreciated by a population increase from 2.2 million in 2000 to an estimated 2.4 million in 2006 (US Census Bureau 2007). Considering

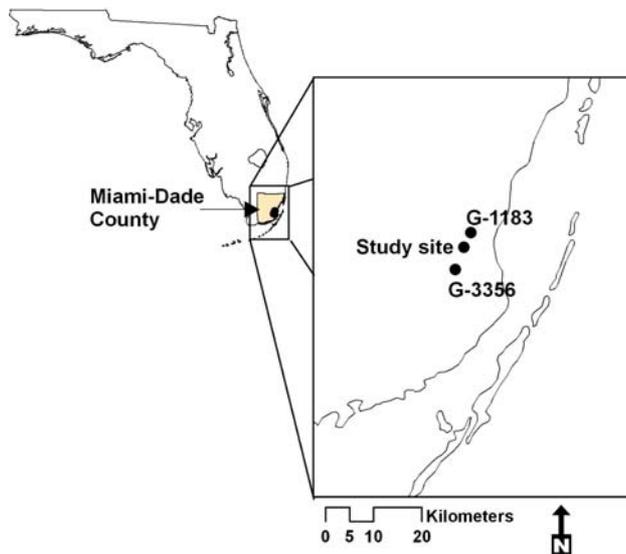


Fig. 1 Location of Miami-Dade County, the study site, and two groundwater monitoring wells within close proximity to the study site in Florida, USA

that the average person uses 0.662 m³/day of water in Florida, this translates into an increased water demand of more than 132,000 m³/day due solely to the population growth between 2000 and 2006 (SFWMD 2007). Population growth is not the only increasing demand on water supplies in southeastern Florida; restoration and preservation efforts of national parks (e.g., the federally and state mandated Comprehensive Everglades Restoration Project) and agriculture production also require portions of the water supply.

The stress being placed on water resources by the many different users has initiated many water conservation programs in Florida. One such program, designed for agriculture, is the Florida Best Management Practice (BMP) program [more information on the Florida BMP program can be found through the Florida Department of Agriculture and Consumer Services, Office of Agricultural Water Policy (FDACS 2007)]. This program identifies a list of practices that have resulted in water conservation when implemented in agricultural production systems. However, many of these practices have not been scientifically evaluated for their water conservation benefits considering the soil, climate, and hydrology of south Florida's agricultural area, nor have the economic implications been considered. The latter aspect is important because technology to be adopted must not only be technically feasible but must also be profitable relative to current practices.

A BMP that has shown substantial water quality and quantity benefits in many locations with various production systems is the use of soil moisture sensors, such as tensiometers, to schedule irrigation. Tensiometers are widely used due to their simplicity in design and implementation and physical nature. A study conducted on a citrus grove with

sandy soil in Highlands County, FL, USA, suggested that tensiometers placed at multiple depths could be used to determine irrigation needs to minimize leaching of agrochemicals below the root zone (Paramasivam et al. 2000). Tensiometers were used to initiate irrigation in the citrus study when soil water potential was greater than 10 kPa (January–June) and 15 kPa (July–December). In addition to water quality benefits, water quantity benefits have also been reported with irrigation systems automated through tensiometer measurements (Steele et al. 2000). Steele et al. (2000) indicated that using tensiometers (as well as other low water volume irrigation scheduling) resulted in approximately 5% higher yields and 30% lower irrigation volumes compared to typical corn irrigation practices in North Dakota, USA (Steele et al. 2000).

In south Florida, irrigation based on tensiometers was investigated for tomato production (Wang et al. 2004; Muñoz-Carpena et al. 2005a). Wang et al. (2004) studied tensiometer use for tomatoes on calcareous gravelly soils of south Florida and found that irrigation based on manual reading of tensiometers at 10, 20, and 30 kPa significantly improved yields of marketable, large and extra-large fruit as compared to local grower practices of time-based irrigation scheduling. Muñoz-Carpena et al. (2005a) reported that application of automated switching tensiometers reduced water irrigation volumes by 73% for tomato production on shallow sandy soil in south Florida with no significant difference in total marketable fruit yield. Similar results were obtained with switching tensiometers for tomatoes grown on gravelly-loam soil (Krome-series) in the same area (Muñoz-Carpena et al. 2008).

Although tensiometer based irrigation scheduling approaches have been shown to reduce leaching of agrochemicals (Paramasivam et al. 2000), reduce water volumes applied (Steele et al. 2000; Muñoz-Carpena et al. 2005a), and not hinder crop yields (Steele et al. 2000; Muñoz-Carpena et al. 2005a); the tensiometer based irrigation scheduling approaches have not been tested or commonly implemented (as evident by lack of refereed publications) in field nursery production in south Florida.

The nursery industry has continued to grow in south Florida, particularly in Miami-Dade County over recent years. Specifically, employment in the nursery and greenhouse industry has increased from 1,035 jobs in 2001 to 4,297 jobs in 2006. Therefore it is not surprising that industry output has also increased from US \$138.3 million in 2001 to US \$447.6 million in 2006 (Hodges and Haydu 2006; Minnesota IMPLAN Group, Inc. 2007). Total area of nursery production has also increased (as reported by the Miami-Dade County Extension Service) from 2,718 ha in 1998 to 5,081 ha in 2002. As this industry grows, so does the amount of water needed for irrigation. It is crucial to improve irrigation management that result in water conser-

vation to maintain adequate water resources and to sustain the growing nursery industry.

The goal of this study was to compare royal palm (*Roystonea elata*) production using tensiometer automated irrigation and reduced nitrogen (N) and phosphorus (P) nutrients to that of traditional grower practices considering water delivered, soil nutrient concentration, plant tissue nutrient concentration, crop yield, and economic analyses. Royal palms were selected because they are a fast growing palm, an expensive and profitable ornamental crop, and are generally found in tree and palm nurseries in southeastern Florida.

Material and methods

Study site

The study was conducted in a commercial field nursery in Homestead, FL, USA (latitude: 25°27'39"N, longitude: 80°24'35"W) (Fig. 1). Nursery production in south Florida occurs year-round with trees or palms often grown several years before being sold.

The soil at the site is classified as Biscayne (soil series) marl (USDA texture) with an available water capacity of 0.38–0.51 cm per cm of soil (USDA-NRCS 1996). Mineralogical analyses indicated that marl is predominantly composed of calcite minerals that precipitated from water saturated with calcium bicarbonate. Organic carbon in natural marl soils range from 10 to 30% and marl soils are characterized by poor to very poor drainage (Li 2001). Marl soils have been further characterized by a soil water characteristic curve presented by Muñoz-Carpena et al. (2005b) that showed large water holding capacity at high suction values (Fig. 2).

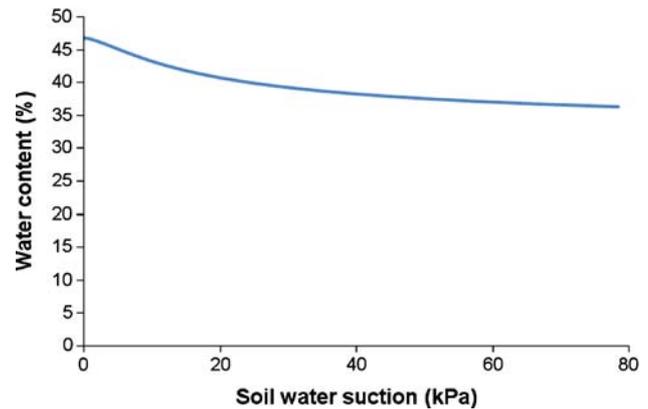


Fig. 2 Soil water characteristic curve modified from Muñoz-Carpena et al. (2005a, b) for marl soil, Homestead, FL

Homestead, FL is characterized by a marine tropical/sub-tropical climate that includes a dry season (November through mid-May) and a wet season (mid-May through October). Average monthly temperatures range from 15 to 28°C and average annual rainfall is approximately 1,399 mm (considering available data from 1998 to 2006 for Homestead, FL, from the Florida Automated Weather Network, <http://www.fawn.ifas.ufl>). Average monthly rainfall and reference evapotranspiration (ET) values for Homestead are reported in Table 1.

The groundwater table at the study site is fairly shallow. The US Geological Survey (USGS) measures groundwater levels throughout south Florida and has a monitoring site approximately 5 km south-southwest of the study site (G-3356, USGS ID 252502080253901). For this USGS monitoring site, groundwater levels during the study period ranged from approximately 1.0 to 0.6 m below the ground surface. It is expected that similar groundwater levels were

Table 1 Rainfall and reference ET data from FAWN (1998–2007)

Month	Reference ET for 2006 (mm/day)	Reference ET for 2007 (mm/day)	Average ET ^a (mm/day)	Rainfall for 2006 (mm)	Rainfall for 2007 (mm)	Average rainfall ^a (mm)
January	2.38	2.32	2.07	13.97	41.40	35.98
February	2.80	2.41	2.47	87.88	49.28	52.74
March	3.61	3.77	3.34	15.49	41.66	51.72
April	4.25	4.19	4.01	69.85	34.29	50.98
May	4.21	4.23	4.08	86.87	77.98	114.97
June	3.95	4.02	3.69	122.68	232.66	220.31
July	3.62	3.18	3.82	332.49	218.95	195.67
August	3.85	3.40	3.36	273.05	47.50	261.16
September	3.19	2.17	2.87	183.13	223.77	228.39
October	3.37	3.25	2.93	53.34	197.10	174.34
November	2.36	2.92	2.37	42.16	17.27	65.86
December	2.20	2.59	2.01	45.21	16.76	32.88

^a Data from FAWN weather station, 1998–2007

present at the study site due to the flat topography. In fact, the average difference between maximum daily groundwater levels between the above mentioned monitoring site and another USGS monitoring site (G-1183, USGS ID 252918080234201) located approximately 8.4 km to the northeast for October 2006 through September 2007 was 0.08 m (Fig. 1).

The grower used drip tube irrigation (0.0023 m³/h per emitter, 61 cm emitter spacing) with an automatic timer and solenoid valve to irrigate the field nursery prior to the start of our study. Operating pressure of the irrigation system was 207 kPa. The royal palms were purchased by the grower and planted in the field. At onset of our study, the palms were considered established in the field. Palm establishment was considered to be achieved when palm root systems had adapted to function in their new environment so that the palms showed no signs of drought stress with adequate water.

Experimental design

The study consisted of six treatments: (1) control (i.e., a grower irrigation rate and N and P fertilizer rates); (2) irrigation system automated to irrigate when soil water suction

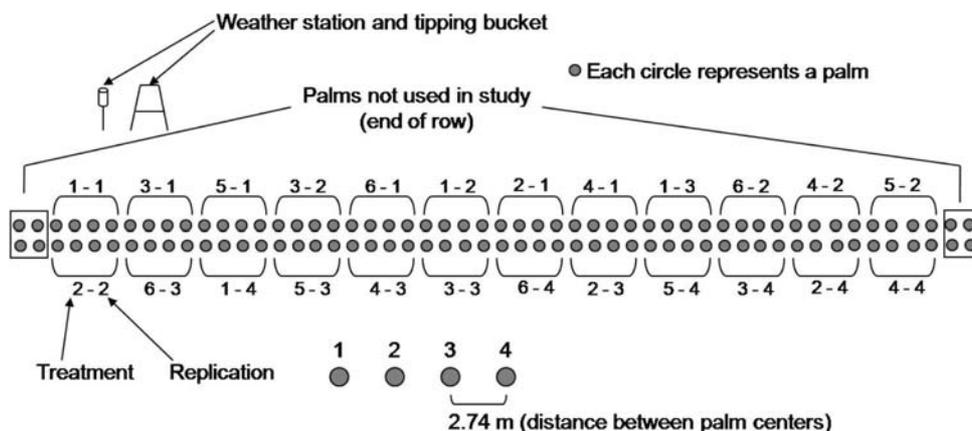
exceeded 5 kPa and a grower N and P rates; (3) irrigation system automated to irrigate when soil water suction exceeded 15 kPa and the grower N and P rates; (4) irrigation system automated to irrigate when soil water suction exceeded 15 kPa and 50% of the grower N and P rates; (5) the grower irrigation rate and 75% of the grower N and P rates; and (6) the grower irrigation rate and 50% of the grower N and P rates (Table 2). Each treatment was replicated four times, with each replicate consisting of four palms. Thus, 96 palms were used in the study (6 treatments × 4 replications × 4 palms/replication). The palms used in this study were planted in two rows, approximately 175 m long with 2.7 m between palm centers and 4.3 m between rows. Treatments were arranged in a completely random design with the two palms on the row ends not included in the experiment to minimize end-of-row influences on collected data. The treatment layout is depicted in Fig. 3. Palms were identified by treatment number, replication, and palm number (e.g., 1, 2, 3, or 4).

Irrigation monitoring and control equipment was installed in the experimental plots in January and February of 2006. Water meters (DLJ Epoxy Coated Bronze Water Meters, Daniel L. Jerman Co., Hackensack, NJ, USA) were installed to measure water volume delivered by treatments.

Table 2 Description of treatments used in the study

Treatment number	Irrigation management for treatment	Nutrient management for treatment
1	Grower irrigation rate	Grower N and P fertilizer rate
2	Tensiometer automated irrigation when soil suction exceeded 5 kPa	Grower N and P fertilizer rate
3	Tensiometer automated irrigation when soil suction exceeded 15 kPa	Grower N and P fertilizer rate
4	Tensiometer automated irrigation when soil suction exceeded 15 kPa	50% of grower N and P fertilizer rate
5	Grower irrigation rate	75% of grower N and P fertilizer rate
6	Grower irrigation rate	50% of grower N and P fertilizer rate

Fig. 3 Overview of palm planting including rows used in the study



For the soil water suction treatments (i.e., treatments 2, 3, and 4), solenoid valves (LR Nelson Corp., Peoria, IL, USA) and switching tensiometers (RA model, Irrrometer Co.[®], Riverside, CA, USA) were installed in line with the water meter. The solenoid valves were used in conjunction with the switching tensiometers to regulate irrigation based on the setting of the switching tensiometer. The switch was positioned on the tensiometer to the soil water suction setting at which irrigation was initiated when exceeded. Irrigation would occur when the grower timer initiated irrigation. We were limited to the grower time settings for irrigation because this study was in the grower production field. Hence, if the soil water suction was greater than the tensiometer setting, irrigation would occur for the period allocated by the grower. Typically, the grower irrigated for 20 min during dry season and 5 min during wet season although this rate would be modified if additional irrigation was needed due to weather or soil conditions. All treatments received irrigation through drip irrigation tubes which were the same as that used by the grower.

Tensiometer settings of 5 and 15 kPa were selected after initial investigation at the study site. Irrigation occurred in the morning and oftentimes the soil water suction readings were relatively low at this time. In addition, as depicted in Fig. 2, the soil water retention curve for marl soil is characterized by the greatest change between 0 and 20 kPa. Based on these two factors, the two tensiometer settings were selected. These settings are similar to those used effectively by the authors to irrigate other crops.

Granular fertilizer was used by the grower. To ensure that only N and P were different among treatments, a special fertilizer blend was purchased that included potassium and micronutrients. Granular fertilizer was manually applied to each palm according to the treatment. Grower fertilizer was Palm Special #7216 (12-4-12) from Atlantic Fertilizer (Homestead, FL). Grower N and P treatments were 278 and 40 kg per ha, respectively, per year divided into four fertilization events. Atlantic Fertilizer made a special blend for treatments that corresponded to the lower N and P rates without changing the other nutrients in the fertilizer [the N and P fertilizer treatments varied: grower rate, 50% of grower rate, and 75% of grower rate (Table 2)].

A weather station (HOBO[®] Weather Station, Onset, Bourne, MA, USA) was installed at the study site that included sensors for measuring wind speed, barometric pressure, temperature, relative humidity, and radiation. A tipping bucket (RG2-M Onset data logging rain gauge, Bourne, MA, USA) was also installed to estimate precipitation. Reference ET was measured using data collected from the weather station and the FAO Penman–Monteith method (Allen et al. 1998). Royal palm ET crop coefficients for southern Florida were not available so the actual ET was not estimated.

Data collection

Data were collected from 3 March 2006 to 5 October 2007. Data collection was halted due to palms reaching marketable size and being sold by the grower.

Water meter and tensiometer data were manually recorded approximately weekly for each replication of each treatment to determine water volume delivered and to identify any irrigation problems.

Plant height and diameters (at 30.5 and 61.0 cm above the soil surface) were measured every 2 months. These measurements are an assessment of ‘palm yield’, as palms are sold based on their size. Height and diameters were measured for two plants [palm 2 and palm 3 (Fig. 3)], for each treatment and replication. Hence, height and diameters were collected from two palms in each replication.

Soil samples were collected every 4 months. Soil samples were divided so that the top 25.4 cm was considered sample ‘a’ and the portion of soil sample between 25.4 and 45.7 cm was considered sample ‘b’. Soil samples were dried in a drying oven at 75°C until negligible water loss occurred. Soil samples were analyzed for total phosphorus (TP) (EPA method 365.1), inorganic carbon (IC) (Dionex Ion Chromatograph, Dionex Corporation, USA), total carbon (TC) (combustion, Elemental CNS Analyzer, Elementar Analysensysteme GmbH, Germany), and total nitrogen (TN) (combustion, Elemental CNS Analyzer, Elementar Analysensysteme GmbH, Germany) once a year. All soil samples were analyzed for ammonium–nitrogen (NH₄–N) (EPA method 350.12) and nitrate–nitrogen (NO₃–N) (EPA method 353.2) (three times annually).

Plant tissue samples were collected every 4 months. Leaflets for plant tissue analysis were collected from the newest fully matured fronds; two leaflets were collected from each palm and combined to form one sample. Tissue samples were washed in detergent, acid washed, rinsed with deionizer water, and dried in an oven at 75°C. Plant tissue samples were analyzed for TP (EPA method 365.1), TC (combustion, Elemental CNS Analyzer, Elementar Analysensysteme GmbH, Germany), and TN (combustion, Elemental CNS Analyzer, Elementar Analysensysteme GmbH, Germany).

Statistical analyses were performed using SAS 9.1 statistical software package (SAS Institute, Cary, NC, USA). Irrigation water applied was evaluated by one-way analysis of variance (ANOVA) and treatment means were separated with a Waller–Duncan Test ($\alpha = 0.05$). To compare only differences in irrigation, irrigation water application was evaluated using all treatments. Treatments 1, 5, and 6 were the same (based on grower irrigation rate) and therefore were not evaluated separately. Significant differences in palm heights and diameters were evaluated considering growth occurring after the first sampling date using the

repeated measures two-way ANOVA procedure and treatment means were compared by a least significant difference (LSD) test. Soil and tissue nutrient data were evaluated for interactions (e.g., date, sample location, and treatment) by two-way ANOVA and treatment means were compared with a Waller–Duncan Test.

Economic analyses

Economic analyses were performed to determine the profitability of the proposed practices. Partial budgeting technique was used to compare the “costs that change” from one treatment to the other. Since some of the practices involved upfront expenditures on equipment and installation (treatments 2, 3, and 4) while generating a stream of benefits over time, the technique of net present value was used to determine the profitability of each of the practices relative to that of the grower practice. In other words, the analyses considered the additional costs and benefits (in the form reduced spending) if the proposed practices were to be adopted in place of the grower current practice. Given that, in some cases the investment associated with the proposed practices had a life span of approximately 5 years, the analysis was scaled up and conducted for a 2-ha farm (considered the minimum viable unit) over a period of 5 years. On this basis, a practice was considered to be more profitable than the grower current practice if the present value of the net benefit (calculated as the difference between expected savings due to the grower switching management practices and the extra cost incurred) over the 5-year period was positive. A discount rate of 5% per annum was used in the analysis. This rate was chosen to reflect the opportunity cost of capital. The break-even year for the investment, that is, the number of years it would take for the discounted benefits to equal the investment cost, was also determined. Table 3 shows the costs of inputs used in the study. For treatments with tensiometers, five tensiometers were considered in the economic analyses to be sufficient for a 2-ha planting. The annual maintenance was estimated to cost US

Table 3 Input costs considered in economic analyses for the different treatments

Item (unit)	US\$
Fertilizer (12-4-12) (\$/kg)	1.25
Fertilizer (6-2-12) (\$/kg)	1.05
Fertilizer (8-3-12) (\$/kg)	1.13
Timer (\$/unit)	60
Tensiometer (\$/unit)	115
Irrigation (pumping cost) ^a (\$/m ³)	0.18
Installation (\$/ha)	400

^a Pumping using diesel power

\$50/ha based on field conditions at the study site. The investment cost for treatments 2, 3, and 4 for a 2-ha unit included one timer (US\$60), five tensiometers (US\$575), and installation charges (US\$800).

Results and discussion

Average daily water volumes applied throughout the year and during the wet season and dry season are presented in Fig. 4. There were significant differences in water volumes applied among different irrigation methods [i.e., control (treatments 1, 5, and 6), 5 kPa tensiometer setting (treatment 2), and 15 kPa tensiometer setting (treatments 3 and 4)] for all data, wet season data only, and dry season data only. On average, the 5 kPa setting resulted in 75% less water volume applied as compared to the control treatment and the 15 kPa setting resulted in even greater water savings compared to the control treatment with 96% less water volume applied.

Water savings with the tensiometer automated irrigation systems were found to be significant in this study, similar to water savings reported for tomato production using tensiometer automated irrigation (Muñoz-Carpena et al. 2005a). The water savings were particularly noteworthy since no differences were observed among treatments for the change in palm size (i.e., diameters and heights), which was a direct indication of crop yield. The minimal amount of water volume applied by the 15-kPa tensiometer treatment suggests that the palms may be receiving water from sources other than rainfall and irrigation.

Due to the shallow groundwater table at the study site, one additional potential source of water available to the palms could be water from capillary rise of groundwater. A small study (aside from the project reported in this manuscript) was pursued to answer this question and is reported in

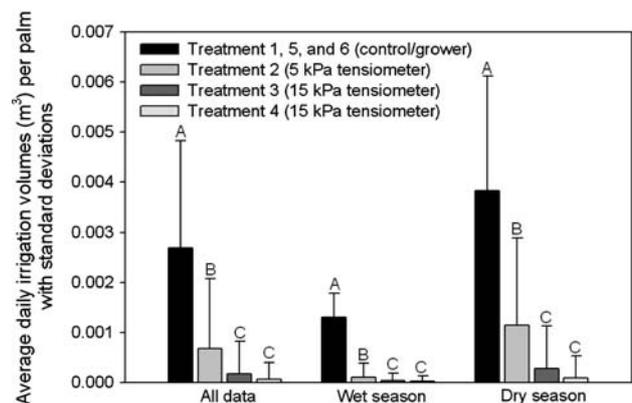


Fig. 4 Irrigation volumes collected from 3 March 2006 to 5 October 2007 presented for treatments with Waller–Duncan test ($P = 0.05$) significant differences denoted (by A, B, and C) considering all data, wet season data only, and dry season data only

Migliaccio et al. (2008). This study consisted of measuring soil moisture at multiple depths (15.2, 30.5, and 45.7 cm) at a continual interval of 15 min. Results suggest that capillary rise was contributing to the water available for palm uptake. Others (e.g., Benz et al. 1984; Ayars and Schoneman 1986; Kahlow et al. 2005; Sepaskhah and Karimi-Goghari 2005) have also documented capillary rise in shallow groundwater conditions that contributed to crop water needs.

Results from the three different irrigation treatments were compared to the daily average reference ET and precipitation (from the weather station at the study site) on a monthly basis (Fig. 5). Since no historical daily weather data were available at the study site, available data from the University of Florida FAWN station was retrieved for comparison between previous years and the time period of this study (Table 1). Average annual rainfall for the FAWN station (1998–2007) is 1,485 mm, whereas annual rainfalls for 2006 and 2007 were 1,326 and 1,199 mm, respectively. Reference ET for years 2006 (1,211 mm) and 2007 (1,171 mm) was greater than the average for the period of record (1,128 mm). Therefore, rainfall was less during our study period than average and reference ET was greater during our study period than average.

Plotting average daily water applied for the three irrigation methods [i.e., control (treatments 1, 5, and 6), 5 kPa tensiometer setting (treatment 2), and 15 kPa tensiometer setting (Treatments 3 and 4)], rainfall, and reference ET (from the study site weather station) (Fig. 5) illustrates that tensiometer automated irrigation treatments predominantly were activated to irrigate during the dry season (March–May) when reference ET started to increase. However, as rainfall increased (which likely was reflected in a rising groundwater table), fewer irrigation events were initiated

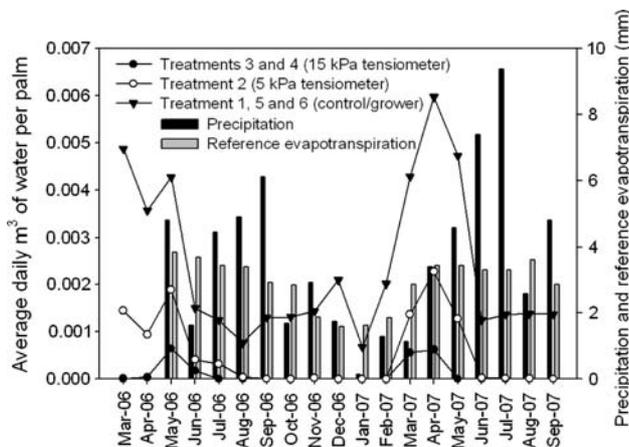


Fig. 5 Average daily water delivered by irrigation treatments on a monthly basis presented with average daily precipitation and reference evapotranspiration (ET) rates for the study site (note that precipitation and ET rates were not available at this site for March 2006 and April 2006)

by the tensiometer automated irrigation treatments. Another approach is to consider reference ET values as compared to irrigation plus rainfall values (Fig. 6). Figure 6 suggests that reference ET is generally lower than the irrigation plus rainfall values at the study site. Reference ET appears to increase from January to April, stabilize until August, and then decrease until January. Irrigation plus rainfall follows a more sporadic pattern. However, tensiometer treatments plus rainfall appear more stable and values are generally closer to those of reference ET than that to the control treatments plus rainfall. Since a cropping coefficient was not available, the actual ET was not calculated and therefore comparison of reference ET should be completed with this consideration.

Although reference ET demands are almost always met by irrigation and rainfall (Table 6), it is likely that actual ET will be greater than reference ET and therefore there would be periods when the irrigation and rainfall amounts were not sufficient to meet crop water needs. During these periods, it is thought that capillary rise from the groundwater table maybe contributing to palm water requirements (Migliaccio et al. 2008).

During this study, south Florida also experienced a substantial drought (as illustrated by the data in Table 1). Hence, results of this study reflect an unusually dry year. This suggests that water savings may be greater in years of normal to above normal precipitation. Greater water savings are expected in wetter years as the tensiometers only allow for irrigation when soil water is above specified soil water suction. Therefore, during wet years less irrigation will be initiated by the tensiometers, resulting in even greater water savings. An analogous phenomenon occurs when considering the dry and wet seasons. Water savings during the wet season using the 15 kPa treatments and the 5 kPa treatment resulted in 98 and 92% water savings, whereas less water savings were documented during the dry

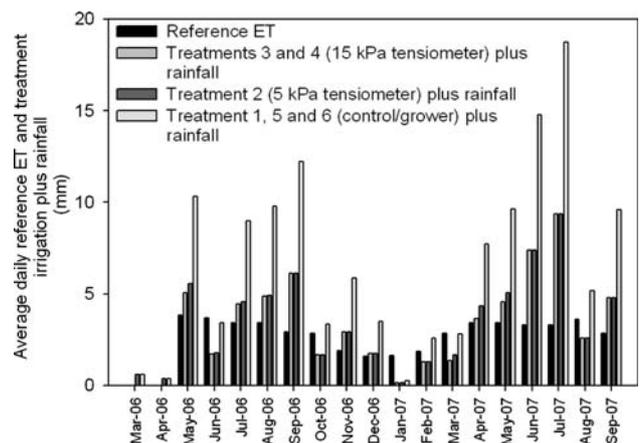


Fig. 6 Average daily values for reference ET and treatments plus rainfall at the study site for the period of study

season (only 95 and 70% water savings, respectively) (Fig. 4).

Irrigation savings were evaluated with respect to production yields as determined by palm diameter and height measurements. There were no significant statistical interactions between measurement date and treatment for plant height or diameter. Mean initial values and mean final values for diameters and heights are presented with standard deviations in Table 4. No significant differences were observed among treatments considering the change in plant diameter or height from initial to final values (Table 5).

Soil sample nutrient results are presented in Tables 6 and 7. Interactions between soil depth and treatment and between soil collection date and treatment were not significant; therefore data were pooled for evaluation. No significant differences were observed among treatments for soil IC, TC, TN, TP, $\text{NH}_4\text{-N}$, and $\text{NO}_3\text{-N}$ concentrations. Likewise, there was no significant interaction between sampling date and treatment interaction for leaf nutrient concentrations. Therefore data from all dates were pooled for statistical comparison of leaf nutrient element content. No significant differences were observed in leaf tissue C, N, or P content among treatments (Table 8).

The lack of any significant differences among treatments for palm size, soil nutrient element content and leaf nutrient element content implies that modification of irrigation and nutrient practices to reduce inputs of water, N, and P had no significant impact on crop production. The comparable changes in palm growth among treatments suggest that nutrients are likely applied in excess in the grower treatment. The lack of significant differences among treatments for soil nutrient element content and leaf nutrient element content implies that the excess nutrients are transported from the system, by hydrologic (groundwater leaching) or atmospheric (wind or volatilization) pathways. Also, irrigation occurred daily, whereas soil samples were taken every 4 months. Thus, differences in soil N and P concentrations may have occurred immediately following fertilization but receded to similar levels after daily irrigation and natural rainfall events. All soil samples were taken at least 1-month following a fertilization event.

Table 4 Royal Palm (*Roystonea elata*) initial and final measurements for diameters and heights presented as means with standard deviations for each treatment

Treatment	Initial diameter at 30.5 cm (cm)	Initial diameter at 61.0 cm (cm)	Initial height (cm)	Final diameter at 30.5 cm (cm)	Final diameter at 61.0 cm (cm)	Final height (cm)
1	17.0 ± 3.3	13.6 ± 2.4	159.5 ± 23.4	68.4 ± 8.7	54.5 ± 9.8	478.2 ± 28.9
2	16.3 ± 4.0	12.8 ± 2.2	160.5 ± 24.6	66.7 ± 13.7	53.9 ± 13.3	462.9 ± 61.5
3	17.5 ± 3.2	13.2 ± 2.0	155.9 ± 21.8	71.2 ± 6.7	56.7 ± 6.8	467.7 ± 33.3
4	15.5 ± 2.4	12.2 ± 1.3	151.3 ± 18.9	66.8 ± 6.2	53.9 ± 6.8	465.2 ± 30.6
5	17.6 ± 1.7	13.4 ± 1.4	170.4 ± 10.4	70.4 ± 4.2	57.2 ± 5.2	483.3 ± 34.9
6	14.8 ± 2.5	11.9 ± 2.0	143.1 ± 19.9	68.1 ± 7.7	57.4 ± 9.3	453.2 ± 30.0

Table 5 Royal Palm (*Roystonea elata*) average mean differences between initial and final values with LSD evaluated at the 0.05 significance level

Treatment	Diameter at 30.5 cm (cm)	Diameter at 61.0 cm (cm)	Height (cm)
1	51.4	41.0	318.6
2	50.5	41.1	302.4
3	53.7	43.5	311.8
4	51.3	41.7	313.9
5	52.9	43.8	312.8
6	53.4	45.6	310.1
LSD	8.59	9.81	41.0

Table 6 Inorganic carbon (IC), total carbon (TC), and total phosphorus (TP) soil concentration means and standard deviations for each treatment

Treatment ^a	IC with standard deviation (kg/kg) ^b	TC with standard deviation (kg/kg)	TP with standard deviation (mg/kg)
1	0.096 ± 0.006	0.128 ± 0.001	2145 ± 1526
2	0.097 ± 0.004	0.128 ± 0.004	2248 ± 748
3	0.097 ± 0.004	0.128 ± 0.001	2561 ± 1066
4	0.097 ± 0.003	0.128 ± 0.001	2180 ± 1088
5	0.100 ± 0.004	0.128 ± 0.001	2346 ± 1287
6	0.098 ± 0.003	0.128 ± 0.001	2792 ± 134
MSD ^c	0.005	0.00128	1707

^a No significant differences were found among treatments using Waller–Duncan Test ($\alpha = 0.05$)

^b (kg/kg) refers to kg of IC per kg of dried soil

^c Minimum significant difference value

Table 9 compares the “costs that change” for each of the six management practices and shows the potential savings relative to the grower practice. Treatment 1, representing the grower practice, had the highest cost of US \$1,756 per ha while treatment 4 representing a 50% reduction in current use of N and P content in fertilizer and irrigating at 15 kPa, had the lowest cost of US \$1,165 per ha. This implies that if growers were to adopt any of the five proposed management practices (treatments 2–6), they would realize cost

Table 7 Total nitrogen (TN), ammonium–nitrogen (NH₄–N), and nitrate–nitrogen (NO₃–N) soil concentration means and standard deviations for each treatment

Treatment ^a	TN with standard deviation (g/kg) ^b	NH ₄ –N with standard deviation (mg/kg)	NO ₃ –N with standard deviation (mg/kg)
1	2.22 ± 0.41	3.17 ± 1.08	147 ± 182
2	2.20 ± 0.23	3.14 ± 1.56	194 ± 137
3	2.41 ± 0.50	3.33 ± 1.52	176 ± 203
4	2.25 ± 0.34	3.32 ± 1.33	139 ± 139
5	2.20 ± 0.27	3.26 ± 0.86	152 ± 204
6	2.22 ± 0.24	3.70 ± 1.22	114 ± 151
MSD ^c	0.437	1.03	134

^a No significant differences were found among treatments using Waller–Duncan Test ($\alpha = 0.05$)

^b (g/kg) refers to g of TN per kg of dried soil

^c Minimum significant difference value

Table 8 Total carbon (TC), total nitrogen (TN), and total phosphorus (TP) tissue concentration means and standard deviations for each treatment

Treatment ^a	TC with standard deviation (kg/kg) ^b	TN with standard deviation (g/kg)	TP with standard deviation (mg/kg)
1	0.445 ± 0.008	18.52 ± 2.02	1,380 ± 294
2	0.442 ± 0.006	19.26 ± 1.53	1,467 ± 223
3	0.444 ± 0.006	19.99 ± 3.32	1,439 ± 206
4	0.445 ± 0.005	18.04 ± 2.25	1,411 ± 145
5	0.446 ± 0.005	19.49 ± 1.57	1,397 ± 156
6	0.444 ± 0.008	18.26 ± 1.83	1,454 ± 206
MSD ^c	0.008	2.26	285

^a No significant differences were found among treatments using Waller–Duncan Test ($\alpha = 0.05$)

^b (kg/kg) refers to kg of TC per kg of dried plant tissue

^c Minimum significant difference value

Table 9 Costs that vary and potential savings per hectare

Treatment	Quantity		Cost			Total \$/ha	Savings per ha ^a	
	Water used (m ³ /ha)	Fertilizer (kg/ha)	Pumping (\$/ha)	Fertilizer (\$/ha)	Labor ^b (\$/ha)		\$/ha	%
1	832	2,317	447	1,309		1,756	0	0
2	208	2,317	112	1,309	50	1,471	285	16
3	35	2,317	19	1,309	50	1,378	378	22
4	35	2,317	19	1,096	50	1,165	592	34
5	832	2,317	447	1,189		1,636	120	7
6	832	2,317	447	1,1096		1,543	213	12

^a Savings calculated relative to grower practice (treatment 1)

^b Labor for maintaining tensiometers

reductions (savings) ranging from US \$120 to US \$592 per ha. This translates into potential savings of between 7 and 34% per ha compared to the grower practice. Of importance to this study was the fact, that all treatments in which tensiometers were used out performed those in which the technology was not employed. As can be seen in Table 9, treatment 4 resulted in the greatest per ha savings of US \$592 (34%), followed by treatments 2 and 3 with savings of US \$285 (16%) and US \$378 (22%), respectively. Of the five treatments, treatment 5 resulted is the least potential savings with US \$120 (7%) per ha. No savings are reported for treatment 1 since this was the baseline value used.

Since treatments 2, 3, and 4 had greater initial costs associate with purchasing and installing the tensiometers (US\$ 1,435) and annual maintenance (US \$50/ha), the technique of net present value (discussed earlier) was used to better assess the profitability of each of the proposed management practices relative to the grower practice. Table 10 summarizes the results of the analyses and shows that all of the improved management practices had a positive net present value indicating that they would influence the grower's current level of profitability in a positive manner. The results also confirm earlier results and suggest that treatment 4 was the most profitable with the highest net present value (US \$3,756) followed by treatment 3 (US \$1,910). The break even analysis revealed that for the three practices incurring the higher initial cost, it would only take 2 years for treatments 3 and 4 and 3 years for treatment 2 to completely offset the extra cost.

Thus, implementation of the tensiometer automated irrigation and the lower N and P fertilizer rates are economical for the grower. Tensiometer automated irrigation is also environmentally advantageous as it results in reduced water volumes pumped, which conserves water in the aquifer and minimizes the potential for agrochemical leaching. Application of reduced N and P fertilizer rates is also environmentally advantageous by reducing the N and P inputs into

Table 10 Net present value of benefits of proposed management practices for 2-ha unit

Treatment	Net present value ^a (US \$)	Break even year
1	–	–
2	1,105	3
3	1,910	2
4	3,756	2
5	1,043	–
6	1,846	–

^a Discount rate of 5%

the watershed. Use of such practices in southern Florida and similar locations will result in more sustainable agricultural production systems.

Conclusion

This study compared royal palm production using tensiometer automated irrigation and reduced N and P fertilization to that of traditional grower practices. Significant differences were observed among the irrigation treatments, with the greatest water savings occurring in the 15 kPa tensiometer treatment. These results were particularly meaningful since no significant differences were found among the treatments for palm growth, nutrient element concentration in soil, or leaf nutrient element content in palm tissue. Hence, lower irrigation rates and lower N and P fertilizer rates resulted in no significant change in palm production. Use of less water and nutrients is clearly an environmental benefit. However, economic analyses also indicated that these practices would provide a monetary savings to the grower. While this study focused on royal palm production in south Florida, results are expected to be relevant to many other ornamental plant species under similar environmental conditions.

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