HortScience 33(6):995–998. 1998.

Root and Shoot Growth Patterns in Four Palm Species and Their Relationships with Air and Soil Temperatures

Timothy K. Broschat
University of Florida, Ft. Lauderdale Research and Education Center, 3205 College Avenue, Ft. Lauderdale, FL 33314

Additional index words. rhizotron, *Roystonea regia, Cocos nucifera, Syagrus romanzoffiana, Phoenix roebelenii,* royal palm, queen palm, coconut palm, pygmy date palm

Abstract. **Royal palms [*Roystonea regia* (HBK.) O.F. Cook], coconut palms (*Cocos nucifera* L. 'Malayan Dwarf'), queen palms [*Syagrus romanzoffiana* (Chamisso) Glassman], and pygmy date palms (*Phoenix roebelenii* O'Brien) were grown in a rhizotron to determine the patterns of root and shoot growth over a 2-year period. Roots and shoots of all four species of palms grew throughout the year, but both root and shoot growth rates were positively correlated with air and soil temperature for all but the pygmy date palms. Growth of primary roots in all four species was finite for these juvenile palms and lasted for only 5 weeks in royal palms, but ≈7 weeks in the other three species. Elongation of secondary roots lasted for only 9 weeks for coconut palms and less than half of that time for the other three species. Primary root growth rate varied from 16 mm·week^{-1} for coconut and pygmy date palms to 31 mm·week^{-1} for royal palms, while secondary root growth rates were close to 10 mm·week^{-1} for all species. About 25% of the total number of primary roots in these palms grew in contact with the rhizotron window, allowing the prediction of the total root number and length from the sample of roots visible in the rhizotron. Results indicated that there is no obvious season when palms should not be transplanted in southern Florida because of root inactivity.**

Studies on the relationships between tree growth and environmental variables have typically dealt only with the aboveground portions of the tree. However, plant root and shoot growth periodicity and rates often differ and may respond to different environmental factors. Although root structure and dry mass at a single point in time can easily be determined using pot culture, root growth rates over time are usually determined by using a rhizotron or underground window through which roots can be directly observed (Huck and Taylor, 1982). An understanding of root and shoot growth patterns can be useful in optimizing transplanting success.

Although rhizotron construction does not have to be complicated or expensive, relatively few studies of tree root growth have been published. Most of these have been on temperate trees (Cripps, 1970; Harris et al., 1995; Langlois et al., 1983; Reich et al., 1980). The few tropical or subtropical trees thus studied have been important fruit species such as *Citrus sinensis* L. (Bevington and Castle, 1985), *Persea americana* Mill. (Ploetz et al., 1991), *Litchi chinensis* Sonn. (Marler and Willis, 1996), and *Mangifera indica* L. (Willis and Marler, 1993). The only palm species whose root growth has been studied is the African oil palm (*Elaeis guineensis* Jacq.) (Jourdan and Rey, 1997).

Palm roots differ greatly from those of dicot trees in morphology and architecture. They lack the secondary thickening that is characteristic of woody dicot roots, and up to 70% of the volume of primary palm roots is composed of aerenchyma cells (Jourdan and Rey, 1997; Tomlinson, 1990). All primary roots in palms except for the seedling radicle are adventitious and originate from the base of the palm stem. The radicle and early primary roots in African oil palm have a finite growth pattern, whereas growth of primary roots on mature palms is indefinite (Jourdan and Rey, 1997). Palm secondary roots arise from the radicle and from primary roots and normally have finite growth. Primary and secondary roots in woody dicots have indefinite growth. The purpose of this study was to determine the patterns of root and shoot growth rates and their relationships with several environmental variables in four species of palms grown as landscape ornamentals.

Received for publication 26 Jan. 1998. Accepted for publication 15 May 1998. Florida Agricultural Experiment Station Journal Series No. R-06132. I thank Susan Thor for her assistance in this study. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

Materials and Methods

A trench 1 m wide × 10 m long and 1 m deep was excavated in a Margate Fine Sand soil in Fort Lauderdale, Fla., in Aug. 1995. This trench was lined along its length with 6.3-mm-thick × 60-cm-wide polycarbonate plastic sheets supported by a timber frame in a manner similar to that described by Harris et al. (1995). This rhizotron was covered with 12-mm-thick plywood doors to exclude light and the floor was covered with 10 cm of gravel. Gaps between the trench wall and the plastic were backfilled with soil of the appropriate horizon.

Four replicate container-grown royal palms, Malayan Dwarf coconut palms, queen palms, and pygmy date palms were planted 1.3 m apart along the length of the rhizotron. The edge of the rootball was placed ≈4 cm from the rhizotron wall. The royal palms were 1 year old at planting and averaged 120 cm in total height, the coconuts were 1 year old and 84 cm tall, the queen palms were 2 years old and 101 cm tall, and the pygmy date palms were 2 years old and 53 cm tall. The trees were arranged in the rhizotron in a randomized complete-block design.

Although there were no plates separating the root systems of the palms in this study, there was never any question about the identity or origin of a particular root. Roots of these four species differed greatly from each other in color, thickness, and texture. Because of the finite growth and generally downward orientation of primary roots in juvenile palms, <2% of the primary roots in this study ever approached the edge of an observation window. These few roots were then excluded from further measurements.

A type T thermocouple probe was buried in the soil at a depth of 20 cm near the roots of one palm, and a second probe was used to monitor air temperature in the shade. These were connected to a scanning digital thermocouple thermometer (Cole-Parmer Instruments, Vernon Hills, Ill.) that recorded temperatures hourly. All palms received irrigation or natural rainfall daily and were fertilized every 6 months with 100 g of Nutricote Total 13N–5.6P–10.8K, Type 270 (Florikan Corp., Sarasota, Fla.), per palm.

Root length extension was measured for up to eight primary and eight secondary roots per tree on a weekly basis. Individual roots were identified and the weekly position of each root tip was indicated by marking on the plastic with a wax pencil. Shoot growth rate was also measured weekly by subtracting the height of the tip of the spear leaf for a given week from that measured the following week. For pygmy date palms, which had multiple spear leaves at one time, plant height to the tip of the longest leaf was substituted for height to the tip of the spear leaf. Since the stems of juvenile palms do not elongate vertically until the palm canopy has reached its mature size, true stem elongation comparable to that reported for dicot trees could not be measured in this study. At the end of 2 years, all palms were removed from the rhizotron. All primary roots were cut off flush with the trunk and the number of primary roots in contact with the window, as well as the total number of primary roots on each palm, were counted. All other data were derived from living palms in the rhizotron.

Data were analyzed by analysis of variance, and Pearson product moment correlations were calculated to show relationships between plant growth variables and environmental variables. Statistical analyses were performed using the CORR, GLM, and MEANS procedures of SAS (SAS Institute, Cary, N.C.).

Results and Discussion

Primary roots of all four palm species grew relatively straight and were oriented at angles between 130° and 230° (0° = straight up). The duration of primary root elongation in these juvenile palms was finite and ranged from a low of ≈5 weeks for royal palm to ≈7 weeks for the other three species (Table 1). During this time, these roots attained lengths ranging from 19.1 cm for pygmy date palms to 26.5 cm for royal palms. Jourdan and Rey (1997) reported that primary roots of 5- to 12-month-old African oil palm seedlings grew at an average rate of 71 mm·week^{-1} in Cote d'Ivoire and attained a maximum length of ≈180 cm. They also found that vertical primary roots of mature (10-year-old) African oil palms grew to a maximum length of 600 cm at a rate of ≈21 mm·week^{-1}. Our palms ranged from 1 to 4 years of age during this 2-year study and had average primary root growth rates ranging from 16 mm·week^{-1} for coconut and pygmy date palm to 31 mm·week^{-1} for royal palm. These rates are more typical of primary roots of 10-year-old oil palms than of the <1-year-old juvenile palms they studied. Comparable primary root growth rates for 1- to 4-year-old African oil palms are not known.

With respect to the number of new primary roots produced each year, royal palms produced >94 roots per palm per year, compared with ≈51 for coconut, 45 for queen, and 31 for pygmy date palms (Table 1). Royal palms also produced the most new primary roots per leaf and pygmy date palms the fewest.

Secondary roots in all four species grew perpendicular to the primary roots from which they emerged and were also finite in their growth. Secondary roots of pygmy date palms attained a final length of only 44 mm, whereas those of coconut averaged 141 mm (Table 1). Jourdan and Rey (1997) reported that horizontal secondary roots (equivalent to the secondary roots in this study) in mature African oil palms grew at a rate of 14 mm·week^{-1} and attained a maximum length of 20 cm, slightly longer than that measured for juvenile coconut palms in this study. All primary and secondary roots of these four species appeared to remain alive and functional during the 2-year study period. Palm roots have a limited life and are continually being replaced, but the functional lifespan of the roots observed in our study could not be determined.

Palms normally produce third- or fourth-order roots, in addition to the primary and secondary roots monitored in this study (Tomlinson, 1990). All four species in this study produced third-order roots, but these never exceeded 1 cm in length. Tomlinson (1990) suggests that the finest (third- and fourth-order) absorbing roots are found in the surface leaf litter zone of the soil. Since the top 10 cm of the soil profile was obstructed by our rhizotron frame, we were unable to determine if fourth-order roots were present in this zone or not.

Shoot growth rates for royal, coconut, and queen palms were similar to each other and averaged between 147 and 161 mm·week^{-1} (Table 1). These species produced between six and 10 leaves per palm per year. In contrast, pygmy date palms produced nearly 35 leaves per palm per year, but shoot height increased by only 4 mm·week^{-1}. The annual rate of leaf production may or may not differ between juvenile and mature (i.e., palms with trunks and fruits) palms. The rate of leaf production for mature 'Malayan Dwarf' coconut palms at this location averaged 9.5 leaves per year in another study (Broschat, 1997), compared with 10.0 in this study. However, annual leaf production rate is known to increase with increasing age in African oil palms until flowering and fruiting begin at 3 to 6 years of age. Leaf production rate then decreases slightly and becomes stable after 7 to 8 years (Hartley, 1988). There are no comparable leaf production rate data for mature royal, queen, and pygmy date palms.

Primary and secondary root growth and shoot growth rates were positively intercorrelated for all species except pygmy date palms (Table 2). For that species, only primary and secondary root growth rates were positively correlated.

Root and shoot growth occurred throughout the year for all species of palms (Fig. 1). However, weekly growth rates for both roots and shoots were generally lower during the cooler winter months. Primary root growth

Table 1. Root and shoot growth data for four species of palms growing in a rhizotron. Data are means for each species ± SE.

Variable	Royal palm	Coconut palm	Queen palm	Pygmy date palm
Length of roots (cm)[z]				
Primary	26.5 ± 1.8	24.5 ± 1.4	24.5 ± 2.0	19.1 ± 1.6
Secondary	7.1 ± 0.8	14.1 ± 1.4	5.2 ± 1.2	4.4 ± 0.9
Duration of root growth (weeks)[z]				
Primary roots	4.9 ± 0.3	7.0 ± 0.6	7.3 ± 0.5	7.1 ± 0.5
Secondary roots	3.1 ± 0.1	8.7 ± 1.3	2.5 ± 0.3	3.8 ± 0.8
Growth rate (mm·week^{-1})[z]				
Primary roots	31 ± 2	16 ± 1	26 ± 1	16 ± 1
Secondary roots	11 ± 1	8 ± 1	9 ± 1	8 ± 1
Shoot	147 ± 7	149 ± 9	161 ± 9	4 ± 1
No. new organs/year				
Primary roots	94 ± 16	51 ± 9	45 ± 3	31 ± 1
Leaves	6 ± 0	10 ± 0	7 ± 0	35 ± 2
No. roots/leaf[z]	14.9 ± 2.0	5.0 ± 0.7	6.6 ± 0.3	0.9 ± 0.2
Total no. primary roots[y]	196 ± 32	112 ± 17	105 ± 7	70 ± 2
No. primary roots in contact with window[y]	50 ± 8	29 ± 4	26 ± 3	19 ± 1

[z]From living palms in rhizotron.
[y]From excavated palms.

Table 2. Correlations among palm growth rates and environmental variables. Data are Pearson product moment correlations (r). Correlation coefficients followed by the letter "a" are significant at $P < 0.0001$, those followed by "b" at $P < 0.01$, those followed by "c" at $P < 0.05$, and those followed by "NS" are nonsignificant. All correlations are based on n = 102 observations.

	Growth rate of											
	Royal palm			Coconut palm			Queen palm			Pygmy date palm		
Variable	Shoots	Primary roots	Secondary roots	Shoots	Primary roots	Secondary roots	Shoots	Primary roots	Secondary roots	Shoots	Primary roots	Secondary roots
Shoot growth	---	0.767 a	0.809 a	---	0.799 a	0.464 a	---	0.373 a	0.332 b	---	0.057^{NS}	0.008^{NS}
Root growth												
Primary	0.767 a	---	0.740 a	0.799 a	---	0.448 a	0.373 a	---	0.493 a	0.056^{NS}	---	0.429 a
Secondary	0.809 a	0.740 a	---	0.464 a	0.448 a	---	0.332 b	0.493 a	---	0.008^{NS}	0.429 a	---
Air Temperature												
Mean	0.785 a	0.693 a	0.641 a	0.699 a	0.687 a	0.191 c	0.668 a	0.557 a	0.439 a	0.132^{NS}	0.345 a	–0.03^{NS}
Minimum	0.758 a	0.660 a	0.608 a	0.758 a	0.688 a	0.356 a	0.674 a	0.535 a	0.427 a	0.186^{NS}	0.321 b	–0.014^{NS}
Maximum	0.651 a	0.546 a	0.590 a	0.543 a	0.590 a	0.022^{NS}	0.527 a	0.488 a	0.451 a	–0.034^{NS}	0.140^{NS}	–0.161^{NS}
Soil Temperature												
Mean	0.736 a	0.696 a	0.666 a	0.658 a	0.697 a	0.173^{NS}	0.615 a	0.542 a	0.497 a	0.076^{NS}	0.354 a	–0.059^{NS}
Minimum	0.719 a	0.695 a	0.630 a	0.682 a	0.701 a	0.240 c	0.609 a	0.518 a	0.460 a	0.102^{NS}	0.373 a	–0.013^{NS}
Maximum	0.693 a	0.645 a	0.659 a	0.644 a	0.697 a	0.191 c	0.565 a	0.552 a	0.479 a	0.019^{NS}	0.285 b	–0.092^{NS}
Daylength	0.685 a	0.532 a	0.580 a	0.514 a	0.516 a	–0.025^{NS}	0.663 a	0.448 a	0.468 a	0.034^{NS}	-0.142^{NS}	–0.237 c

was positively correlated with mean and minimum air and soil temperatures and maximum soil temperature for all species, and with maximum air temperature for all species except pygmy date palms (Table 2). Secondary root growth was also positively correlated with mean, minimum, and maximum air and soil temperatures for royal and queen palms, but minimum air and soil temperatures in coconut palm. Coconut palms are the least cold hardy of the four species in this study and their growth might be expected to be limited by cool temperatures. For pygmy date palms, primary root growth was positively correlated with mean and minimum air temperature and mean, minimum, and maximum soil temperatures. Correlations between secondary root growth in pygmy date palms and all temperature variables were negative, though nonsignificant. Shoot growth rates were positively correlated with all temperature variables as well as daylength for all species except pygmy date palms. Growth rates in most plants are a function of temperature (Taiz and Zeiger, 1991) and palms are no exception.

Since air and soil temperatures in southern Florida are related to daylength (Fig. 2), it is not surprising that root and shoot growth rates are also highly correlated with daylength for most palm species (Table 2). Because temperatures could not be held constant, this experiment did not establish what effect, if any, daylength had on palm root and shoot growth rates. In some species of tropical dicot trees, all growth ceases in response to short days (Broschat and Donselman, 1983a, 1983b, 1986). Since some growth occurred throughout the year in this study, daylength does not appear to trigger cessation or resumption of growth in palms as it can in dicot trees. On the other hand, cumulative daily solar radiation could potentially influence palm growth rates. Since this variable was also strongly correlated with daylength and temperature, its effects cannot be determined from these data.

Since all palms in this study received irrigation and/or rainfall daily, water stress was probably never a major growth-limiting factor. On the other hand, heavy rainfall resulted in very high water tables (within 30 cm of the soil surface) on several occasions. The reaction of palm roots to saturated soil conditions varied among the four species. Under these high soil moisture conditions, royal palm primary roots rapidly elongated downward into the water. In contrast, queen palm primary roots changed their orientation from downward to lateral and then upward away from the water. The rate of growth for queen palm primary roots and all royal palm roots was significantly higher during one 3-week period of high water tables than during a period of similar temperatures when water tables were >1 m from the surface (Table 3). Pygmy date palm primary roots and all coconut palm roots did not change their direction or rate of growth in response to superabundant soil water, but secondary root growth of pygmy date palm was greatly inhibited by high soil moisture.

This rhizotron provided an effective means of monitoring root growth of palms growing in natural soils. When the palms were removed from the rhizotron at the end of the study, the total numbers of primary roots on each palm were counted. The percentage of all primary roots in contact with the rhizotron window ranged from 25.1% to 26.5% for these four species of palms (Table 1). There was also little variability in this percentage among individuals within a species (standard errors ranged from 0.015 to 0.029). Thus, the total number and lengths of roots of the entire root system for juvenile palms planted in this manner can be accurately estimated from the sample of roots in contact with the rhizotron window.

These results indicate that palm root and shoot growth differs from that of tropical broadleaf trees. Root growth flushes, alternating with periods of active stem elongation, have

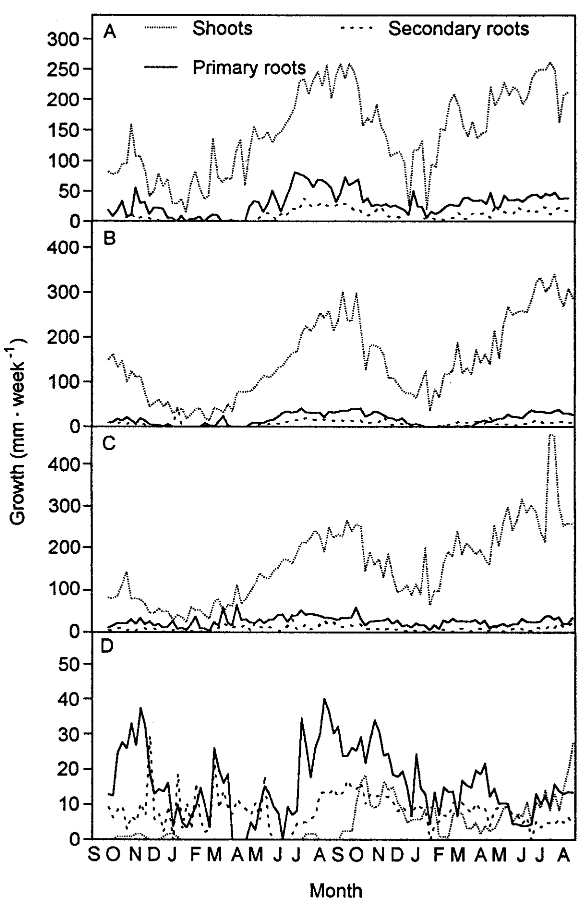

Fig. 1. Weekly root and shoot elongation for four species of palms grown in a rhizotron from Aug. 1995 through Aug. 1997. Data are means for each species based on four replicate trees per species. Note that Y-axis ranges differ among species. (**A**) royal palm; (**B**) coconut palm; (**C**) queen palm; and (**D**) pygmy date palm.

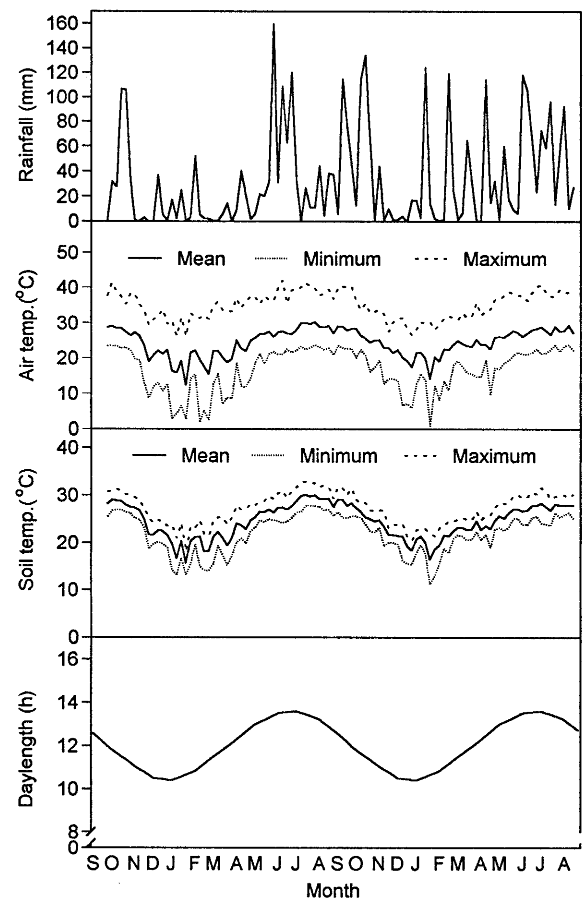

Fig. 2. Weekly rainfall, air and soil temperatures, and daylength from Aug. 1995 through Aug. 1997.

Table 3. Comparison of palm root growth rates during a 3-week period of high water table (within 30 to 60 cm of the soil surface) in late June 1997 and a 3-week period of similar temperature, but normal (>1 m in depth) water table in late May and early June 1997.

		Growth rate (mm·week^{-1})	
Species	Water table	Primary roots	Secondary roots
Royal palm	High	48	21
	Normal	29	9
P[z]		0.009	0.002
Coconut palm	High	20	2
	Normal	8	1
P		NS	NS
Queen palm	High	18	1
	Normal	4	1
P		0.0002	NS
Pygmy date palm	High	1	1
	Normal	1	7
P		NS	0.04

[z]Based on ANOVA within each species and root type.

been reported for avocado (Ploetz et al., 1991) and citrus (Bevington and Castle, 1985), but root growth was generally continuous for mango (Willis and Marler, 1993) and lychee (Marler and Willis, 1996) despite periodic growth flushing by the stems. Palm root and shoot growth occurred throughout the year, but growth rates varied in response to temperature. Root growth rates for avocado and citrus were also positively correlated with soil temperature (Bevington and Castle, 1985; Ploetz et al., 1991). Mean root growth rate reported by Ploetz et al. (1991) for avocado (18 to 19 mm·week^{-1}) are similar to those measured for coconut and pygmy date palms in this study.

Because root and shoot growth in these four palms occurred throughout the year, there are no obvious seasons when palms should not be transplanted due to root inactivity. Reduced root growth rates occur during cooler weather, but transpiration is also lower under such conditions.

Literature Cited

Bevington, K.B. and W.S. Castle. 1985. Annual root growth pattern of young citrus trees in relation to shoot growth, soil temperature, and soil water content. J. Amer. Soc. Hort. Sci. 110:840–845.

Broschat, T.K. 1997. Nutrient distribution, dynamics, and sampling in coconut and Canary Island date palms. J. Amer. Soc. Hort. Sci. 122:884–890.

Broschat, T.K. and H. Donselman. 1983a. Effect of photoperiod on growth of West Indian mahogany. HortScience 18:206–207.

Broschat, T.K. and H. Donselman. 1983b. Growth of 10 species of ornamental tree seedlings exposed to different photoperiods. J. Amer. Soc. Hort. Sci. 108:992–996.

Broschat, T.K. and H. Donselman. 1986. Influence of photoperiod on winter growth of seven species of tropical landscape trees. J. Environ. Hort. 4:60–62.

Cripps, J.E.L. 1970. A seasonal pattern of apple root growth in Western Australia. J. Hort. Sci. 45:153–161.

Harris, J.R., N.L. Bassuk, R.W. Zobel, and T.H. Whitlow. 1995. Root and shoot growth periodicity of green ash, scarlet oak, Turkish hazelnut, and tree lilac. J. Amer. Soc. Hort. Sci. 120:211–216.

Hartley, C.W.S. 1988. The oil palm. Longman Scientific and Technol., Essex, U.K.

Huck, M.G. and H.M. Taylor. 1982. The rhizotron as a tool for root research. Adv. Agron. 35:1–35.

Jourdan, C. and H. Rey. 1997. Architecture and development of the oil-palm (*Elaeis guineensis* Jacq.) root system. Plant Soil 189:33–48.

Marler, T.E. and L.E. Willis. 1996. Root and stem growth patterns of young 'Mauritius' lychee trees. HortScience 31:815–818.

Langlois, C.G., L. Godbout, and J.A. Fortin. 1983. Seasonal variation of growth and development of the roots of five second year conifer species in the nursery. Plant Soil 71:55–62.

Ploetz, R.C., J.L. Ramos, J.L. Parrado, and E.S. Shepard. 1991. Shoot and root growth cycles of avocado in south Florida. Proc. Fla. State Hort. Soc. 104:21–24.

Reich, P.B., R.O. Teskey, P.S. Johnson, and T.M. Hinckley. 1980. Periodic root and shoot growth in oak. For. Sci. 26:590–598.

Taiz, L. and E. Zeiger. 1991. Plant physiology. Benjamin/Cummings, Redwood City, Calif.

Tomlinson, P.B. 1990. The structural biology of palms. Clarendon Press, Oxford, England.

Willis, L.E. and T.E. Marler. 1993. Root and shoot growth patterns in 'Julie' and 'Keitt' mango trees. Acta Hort. 341:264–270.