

PALM ROOT GROWTH AND IMPLICATIONS FOR TRANSPLANTING

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Abstract. Palms need active root and shoot growth to establish quickly after transplanting. For many palm species, roots grow most abundantly during warmer months and occur within 30 cm (12 in.) of the trunk. Thus, palms can be transplanted year-round in warm regions where air and soil temperatures are nearly always sufficient to ensure adequate root and shoot growth. However, in regions with cool seasons, palms are best transplanted at the beginning of the warm season. For most species, root balls with a 30 cm (12 in.) radius from the trunk and 30 cm (12 in.) deep are adequate because they capture over half the roots. The few species that must grow nearly all their new roots from the trunk after transplanting need a root ball only large enough to protect the root initiation zone, about 15 cm (6 in.) out from the trunk. Species that grow about 30% or more of their roots below 30 cm (12 in.) deep would probably benefit from a deeper root ball, about 60 cm (24 in.) deep.

Key Words. Palms; transplanting; time of year; root ball size; root growth; root initiation zone.

Palm trees are high-value and increasingly common components of landscapes wherever they can be grown. Large, older specimens are in great demand and command a premium price. They are usually dug and removed from existing landscape sites or from a commercial nursery field, transported, and replanted at another site, creating an instant mature landscape.

Specimen palms are relatively easy to transplant compared to broad-leaved and coniferous trees. A relatively small root ball is necessary when transplanting most palms because, as monocots, they have an adventitious root system composed of numerous fibrous primary (first-order) roots that grow independently and periodically from the root initiation zone (RIZ), the area at the base of the stem or trunk near or at ground level from which new roots grow (Tomlinson 1990). In California and the southwestern United States, it is standard industry practice for a root ball to extend from the trunk only about 15 to 30 cm (6 to 12 in.) when transplanting palms up to 20 m (60 ft) tall with trunks 30 to 100 cm (12 to 39 in.) in diameter. Generally, transplanted palms will establish as long as they grow new roots in a timely manner.

Despite the ease of transplanting palms, a significant number do not survive, or they require an inordinate length of time to establish. Thirty percent or more of palms in some

installations fail to establish (Meerow 2000). Rapid growth of new roots from the RIZ and/or regrowth of roots cut during transplanting are critical for successful establishment. While there are many factors affecting palm root regeneration and successful transplanting, the time of year and root ball size are among the most important.

There is limited research-based information on the seasonality of palm root growth and root ball size as they relate to root growth. Nearly all the information was developed for a few species in Florida, U.S., which has a warm, humid climate—unlike palm-growing regions with a Mediterranean climate where winters are cool and with little rain and summers are warm to hot and rainless.

PREVIOUS WORK

Although palms are transplanted year-round in some areas, the traditional recommendation is to transplant them during the warmer times of the year (Donselman 1981; Hodel 1995, 1996, 1997; Broschat and Meerow 2000). Broschat (1998) reported that palm root and shoot growth are greatest when soil and air temperatures are highest. He suggested that palms could be transplanted at any season in tropical areas and southern Florida, because root and shoot growth occurred year-round. However, he suggested that winter planting was not advisable in cooler climates.

In preliminary studies, Hodel et al. (1998) and Pittenger et al. (2000) reported that, in southern California, root growth of most palms tended to be highest during the warmer months from spring through fall. However, the landscape industry in southern California transplants especially hardy palms, such as *Chamaerops humilis* (European or Mediterranean fan palm), *Phoenix canariensis* (Canary Island date palm), *P. dactylifera* (date palm), *Syagrus romanzoffiana* (queen palm), *Trachycarpus fortunei* (Chinese windmill palm), *Washingtonia filifera* (California fan palm), and *W. robusta* (Mexican fan palm) year-round to keep pace with development and demand, although the success rate is variable.

The optimal root ball size when transplanting palms has been the subject of much debate and speculation. Traditional recommendations range from nearly no root ball to one as big as possible. Broschat and Donselman (1984a, 1984b) reported that palm root balls commonly extend 45 cm (18 in.) out from the trunk because most roots cut during transplanting die and must be replaced by roots originating from the trunk. How-

ever, Tomlinson (1961) had noted that severed palm roots usually regrow from just proximal of the cut.

Understanding how palm roots respond to cutting is critical to determining the optimal root ball size for successful transplanting (Broschat and Meerow 2000). In Florida on field-grown palms, Broschat and Donselman (1984a, 1984b, 1990) reported that the response of roots to cutting varies among species. In *Phoenix reclinata* (Senegal date palm), *Roystonea regia* (royal palm), *Syagrus romanzoffiana*, and *Washingtonia robusta*, some severed roots regrow from just proximal of the cut and, generally, the percentage of regrown roots increases the farther the roots are cut from the trunk. Thus, they advised that a relatively large root ball was important for root regrowth and successful establishment of these species. In contrast, they discovered in *Cocos nucifera* that about half of severed roots regrow regardless of the distance they are cut from the trunk, suggesting that root ball size was less important for this species. However, another interpretation of their data shows that a root ball extending 15 cm (6 in.) out from the trunk would be sufficient for nearly all these species because about half or more of all new roots are found within that distance.

In *Sabal palmetto*, Broschat and Donselman (1984a, 1984b) stated that nearly all cut roots die back to the trunk and nearly all new roots grow from the RIZ. Because this species must grow an entirely new root system from the RIZ to establish successfully, they recommended a root ball only large enough to protect the RIZ.

Phoenix reclinata, *Roystonea regia*, and *Washingtonia robusta* grow large numbers of new roots from the RIZ, while *Cocos nucifera* (coconut palm) and *Syagrus romanzoffiana* grow relatively few (Broschat and Donselman 1984a, 1984b). In the latter two species, however, the number of cut roots that regrow is large and surpassed the number of new roots that grow from the RIZ. *Phoenix dactylifera* offshoots responded similarly, with over two-thirds of new root growth originating from roots severed during removal from the mother palm, all of which were cut only 2 to 10 cm (1 to 4 in.) long (Hodel and Pittenger 2003).

Minimum recommended root ball sizes (measured by the distance out from the trunk) are 15 to 30 cm (6 to 12 in.) for *Syagrus romanzoffiana*, 30 to 60 cm (12 to 24 in.) for *Washingtonia robusta*, and at least 60 cm (24 in.) for *Phoenix reclinata* and *Roystonea regia*, because there is little regrowth of roots cut shorter than these lengths (Broschat and Donselman 1984a, 1984b, 1990). Root balls for the last three species are larger in order to encompass a sufficient percentage of regrown roots. Root pruning is recommended 2 to 3 months prior to transplanting for these species in order to stimulate a large number of new roots to grow from the RIZ so that a smaller root ball could be taken (Broschat and Donselman 1984a, 1984b, 1987, 1990). Perhaps the most important interpretation of Broschat and

Donselman (1984a, 1984b) was that most of a palm's roots occur within 30 cm (12 in.) of the trunk.

Root pruning prior to transplanting could benefit species that grow most of their new roots from regrown cut roots because it would shorten or eliminate the length of time for the cut roots to regrow after transplanting (Broschat and Donselman 1987). Later, Meerow (1992) and Broschat and Meerow (2000) placed less emphasis on root pruning but said it might be useful in some cases, although they presented no supporting data.

More recently, the ability of cut palm roots to regrow as a determinate of root ball size has lost favor in transplanting guidelines. Meerow (1992), Meerow and Broschat (1992), and Broschat and Meerow (2000) now simply recommend a root ball extending at least 20 cm (8 in.) out from the trunk for single-stemmed species up to 5 m (15 ft) tall and at least 30 cm (12 in.) out from the trunk for larger or multi-stemmed species. In species where few or no severed roots survive, such as *Sabal palmetto*, they recommend a root ball 10 to 15 cm (4 to 6 in.) out from the trunk, just large enough to protect the RIZ. However, no supporting data are offered for these newer recommendations.

In some cases, plant maturity may affect transplant success. In *Chamaedorea elegans* and *Phoenix roebelinii*, root growth is dependent on the presence of a RIZ that does not form until the palm stem attains its maximum diameter and begins to elongate vertically (Broschat and Donselman 1990). However, in *Phoenix dactylifera* (Hodel and Pittenger 2003) and *Phoenix canariensis* and *Syagrus romanzoffiana* (Hodel et al. 2003), the RIZ develops and becomes active at a much earlier stage, well before the stem attains its maximum diameter and elongates vertically.

These conflicting findings and interpretations raise questions about the importance of root ball size, regrowth of severed roots, and growth of new roots from the trunk (RIZ) to successful transplanting. Perhaps time of year and total number of new roots produced, regardless of their origin, are as or more important than root ball size or the origin of new roots. The objective of this study was to assess the seasonality and distribution of palm root growth in 16 species of ornamental palms in a Mediterranean climate to provide the landscape industry with clear, precise information about the optimal time of year and root ball size for transplanting palms.

METHODS

From June 1997 through December 2000, we conducted a field study with mature, established specimens of 16 palm species (Table 1) at The Los Angeles County Arboretum & Botanic Garden in Arcadia, California, U.S. This site is about 25 km (16.5 mi) east of Los Angeles and has a Mediterranean climate and a sandy clay loam soil. The palms ranged from 30 to 50 years of age according to arboretum accession records and were 2 to 10 m (6 to 30 ft) tall.

Table 1. Palm species used in root growth study, The Los Angeles County Arboretum & Botanic Garden, Arcadia, California, 1997–2000.

Species	Common name	Origin
<i>Archontophoenix cunninghamiana</i>	king palm	southeastern Australia
<i>Brahea edulis</i>	Guadalupe palm	Guadalupe Island, Mexico
<i>Butia capitata</i>	pindo palm, jelly palm	northern Argentina, southern Brazil
<i>Caryota mitis</i>	clustered fishtail palm	southeastern Asia, Malaysia, Indonesia
<i>Chamaerops humilis</i>	European fan palm	southern Europe, northern Africa
<i>Livistona chinensis</i>	Chinese fan palm	southern Japan, southern China
<i>Livistona decipiens</i>	ribbon fan palm	eastern Australia
<i>Phoenix canariensis</i>	Canary Island date palm	Canary Islands
<i>Phoenix reclinata</i>	Senegal date palm	tropical Africa
<i>Rhapidophyllum hystrix</i>	needle palm	southeastern United States
<i>Sabal etonia</i>	palmetto, cabbage palm	southeastern United States
<i>Serenoa repens</i>	saw palmetto	southeastern United States
<i>Syagrus romanzoffiana</i>	queen palm	northern Argentina, southern Brazil
<i>Trachycarpus fortunei</i>	Chinese windmill palm	southern China

Using a gasoline-powered trencher, we dug a trench 15 cm wide × 60 cm deep × 90 cm long (6 × 12 × 36 in.) in June on a tangent from the base of each of the three, single-tree replicates of each species. Using a spade and shovel, we manually dug trenches on three additional, single-tree replicates of two species, *Archontophoenix cunninghamiana* and *Livistona chinensis*, to determine whether roots cut in this method responded differently than those cut by the trencher. We backfilled each trench with perlite and covered it with 2.5 to 7.5 cm (1 to 3 in.) of mulch. We adapted our technique from that of Broschat and Donselman (1984a, 1984b, 1990).

We divided each trench into four zones: 15, 30, 60, and 90 cm (6, 12, 24, and 36 in.) from the trunk base. Each of these zones was divided into two depths of 0 to 30 cm (0 to 12 in.) and 30 to 60 cm (12 to 24 in.), resulting in a total of eight trench zones. Zones A, B, C, and D were the upper depth zones, while E, F, G, and H were the lower depth zones.

Palms were well irrigated throughout the study to ensure the perlite was kept moist. At 3-month intervals over the next 3 years, we re-excavated each trench to harvest and count all roots, regardless of size or origin, growing into each of the eight trench zones and determined total mean root number per zone. We oven dried harvested roots at 105°C (221°F) until constant weight was achieved and determined total mean root dry weight per zone. We divided root dry weight by root number to calculate mean individual root size (weight per root) per zone. At each 3-month harvest, we recorded the soil temperature using a thermometer placed 10 cm (4 in.) deep in the trench. Although we did not determine the origin of each of the new roots, we made general observations about the presence of regrown severed roots.

Because rapid root regrowth is critical to transplant success, we combined data from each upper zone with its corresponding lower zone for analysis. Thus, each palm's data

from zone A were combined with E, B with F, C with G, and D with H to determine the lateral root distribution. We also compared the combined four upper zones with the combined four lower zones to determine the root vertical distribution.

The experimental design was completely randomized with each of the 16 species represented by three, healthy, similar-sized and -aged, single-tree replications. We analyzed seasonality and lateral distribution of roots by one-way ANOVA and separated means using least significant difference (LSD). We analyzed vertical root distribution by paired t-tests.

RESULTS

Mean annual root growth or numbers varied among species over the 3 years of our study (Table 2). There was no significant difference in new root numbers between machine-dug and hand-dug trenches (data not shown). Species with consistently high numbers, over 50 roots annually, include *Livistona decipiens*, *Phoenix canariensis*, *P. reclinata*, *Syagrus romanzoffiana*, *Trachycarpus fortunei*, *T. wagnerianus*, and *Washingtonia robusta*—the latter the highest, with over 150 roots. Species with consistently low numbers, fewer than 20 roots annually, include *Archontophoenix cunninghamiana*, *Brahea edulis*, *Butia capitata*, *Chamaerops humilis*, and *Serenoa repens*, with the *Brahea* the lowest—typically only one to two annually.

Annual root numbers for a species varied annually, but differences were significant in only four species (Table 2). Root numbers decreased after year 1 in *Brahea edulis* and *Livistona chinensis* but increased in year 3 in *Phoenix canariensis*. Root numbers in *Chamaerops humilis* had a unique low-high-low pattern over 3 years.

Mean root weight did not differ annually except in *Brahea edulis* and *Livistona chinensis*, which decreased over time, and in *Phoenix canariensis*, which increased over time (Table 2). Mean root size differed annually only in *Butia*

Table 2. Mean total root numbers (n), mean total root dry weights (g), and mean individual root size (g/n) of 16 species in all trench zones by year, The Los Angeles County Arboretum & Botanic Garden, Arcadia, California, 1997–2000.

Species	Number (n)	Weight (g)	Size (g/n)
<i>Archontophoenix cunninghamiana</i>			
1997–1998	17.4	9.5	0.516
1998–1999	19.4	18.8	0.787
1999–2000	21.9	15.1	0.712
<i>Brahea edulis</i>			
1997–1998	15.6 a	2.7 a	0.244
1998–1999	1.3 b	0.5 b	0.109
1999–2000	1.8 b	1.0 b	0.234
<i>Butia capitata</i>			
1997–1998	11.2	6.4	0.548 a
1998–1999	12.0	4.0	0.191 ab
1999–2000	25.2	9.4	0.343 b
<i>Caryota mitis</i>			
1997–1998	34.3	7.9	0.384
1998–1999	31.1	4.5	0.112
1999–2000	18.5	2.5	0.129
<i>Chamaerops humilis</i>			
1997–1998	13.8 b	2.5	0.121
1998–1999	28.0 a	6.4	0.176
1999–2000	15.0 b	2.3	0.150
<i>Livistona chinensis</i>			
1997–1998	46.8 a	42.4 a	0.798
1998–1999	16.0 b	8.4 b	0.518
1999–2000	22.6 b	17.7 b	0.635
<i>Livistona decipiens</i>			
1997–1998	63.3	30.4	0.413
1998–1999	65.5	28.7	0.292
1999–2000	109.8	47.4	0.255
<i>Phoenix canariensis</i>			
1997–1998	49.9 b	20.2 b	0.356
1998–1999	56.7 b	35.9 ab	0.562
1999–2000	185.7 a	104.4 a	0.453
<i>Phoenix reclinata</i>			
1997–1998	86.6	37.5	0.425
1998–1999	122.0	67.4	0.379
1999–2000	151.6	116.1	0.573
<i>Rhapidophyllum hystrix</i>			
1997–1998	32.3	3.7	0.096
1998–1999	30.7	4.7	0.156
1999–2000	18.0	3.8	0.141
<i>Sabal etonia</i>			
1997–1998	20.4	4.3	0.218
1998–1999	19.3	4.8	0.248
1999–2000	30.5	6.2	0.239
<i>Serenoa repens</i>			
1997–1998	18.0	5.3	0.423
1998–1999	19.3	6.6	0.217
1999–2000	30.5	4.3	0.181

Means in the same column within a species followed by a different letter are significantly different according to LSD, $P < 0.05$.

Table 2 (continued). Mean total root numbers (n), mean total root dry weights (g), and mean individual root size (g/n) of 16 species in all trench zones by year, The Los Angeles County Arboretum & Botanic Garden, Arcadia, California, 1997–2000.

Species	Number (n)	Weight (g)	Size (g/n)
<i>Syagrus romanzoffiana</i>			
1997–1998	136.4	36.5	0.243
1998–1999	96.8	44.2	0.267
1999–2000	67.5	21.3	0.229
<i>Trachycarpus fortunei</i>			
1997–1998	76.8	5.9	0.090
1998–1999	31.8	2.9	0.043
1999–2000	69.3	8.7	0.076
<i>Trachycarpus wagnerianus</i>			
1997–1998	78.8	16.9	0.189 a
1998–1999	111.2	15.0	0.116 b
1999–2000	124.6	24.4	0.113 b
<i>Washingtonia robusta</i>			
1997–1998	154.0	22.2	0.144
1998–1999	174.1	21.5	0.083
1999–2000	161.4	17.3	0.077

Means in the same column within a species followed by a different letter are significantly different according to LSD, $P < 0.05$.

capitata and *Trachycarpus wagnerianus*, which decreased over time (Table 2).

Although not counted and analyzed, we observed that all species had severed roots that regrew, some rather prolifically, with up to several new roots per severed root.

Seasonality of Growth

Soil temperatures varied seasonally, averaging 10°C (50°F) in December, 13°C (55°F) in March, 20°C (68°F) in June, and 21°C (70°F) in September. Mean root numbers were significantly higher in the warmer months (spring, summer, and/or fall) for most species (Table 3). Only *Brahea edulis*, *Chamaerops humilis*, and *Livistona chinensis* lacked distinct seasonality, although they tended to have higher numbers in the summer and fall. Maximum mean warm-season root numbers ranged from about 11 in *Brahea edulis* to 329 in *Washingtonia robusta*. In most species, maximum warm-season numbers were 70 or less, although they were well over 200 in six species (*Livistona decipiens*, *Phoenix canariensis*, *P. reclinata*, *Syagrus romanzoffiana*, *Trachycarpus wagnerianus*, and *W. robusta*).

Seven species (*Archontophoenix cunninghamiana*, *Livistona decipiens*, *Phoenix canariensis*, *Sabal etonia*, *Serenoa repens*, *Syagrus romanzoffiana*, and *Trachycarpus wagnerianus*) had highest root numbers in the summer, most with two to ten times as many roots in the summer as in other seasons.

Six species had highest root numbers in two or more of the warmer seasons: *Butia capitata*, *Caryota mitis*, and *Rhapidophyllum hystrix* in the summer and fall; *Phoenix*

reclinata and *Washingtonia robusta* in the spring and summer; and *Trachycarpus fortunei* in the spring, summer, and fall.

Mean winter numbers were low in all species except *Washingtonia robusta*, which averaged nearly 28 roots. *Caryota mitis* and *Serenoa repens* averaged less than one root in the winter, the lowest among all species.

Mean root weight increased during the warmer seasons except in *Brahea edulis* and *Livistona chinensis*, which had no seasonal differences (Table 3). Mean root size increased during the warmer seasons in half the species: *Archontophoenix cunninghamiana*, *Livistona decipiens*, *Phoenix canariensis*, *Rhapidophyllum hystrix*, *Serenoa repens*, *Syagrus romanzoffiana*, *Trachycarpus wagnerianus*, and *Washingtonia robusta* (Table 3). The remaining species had no seasonal differences in root size.

Root Distribution

Lateral Distribution. With the exception of *Rhapidophyllum hystrix*, mean new root numbers were highest in the zones closest to the trunk and lowest in the zones farthest away (Table 4). All species had at least 50% of growth within 30 cm (12 in.) of the trunk, and three (*Livistona decipiens*, *Trachycarpus fortunei*, and *Washingtonia robusta*) had more than 50% of growth within 15 cm (6 in.) of the trunk.

Vertical Distribution. Mean new root numbers in 13 of the 16 species was significantly higher (>60% of new roots) in the combined upper zones 0 to 30 cm (0 to 12 in.) deep than in the combined lower zones 30 to 60 cm (12 to 24 in.) deep (Table 5). These 13 species grew at least twice as many

Table 3. Mean total root numbers (n), mean total root dry weights (g), and mean individual root size (g/n) of 16 species of palms in all trench zones by season, The Los Angeles County Arboretum & Botanic Garden, Arcadia, California, 1997–2000.

Species and season	Number (n)	Weight (g)	Size (g/n)
<i>Archontophoenix cunninghamiana</i>			
Winter (Jan.–Mar.)	3.0 b	1.0 b	0.285 b
Spring (Apr.–Jun.)	21.3 b	10.0 b	0.528 ab
Summer (Jul.–Sep.)	39.8 a	36.0 a	0.807 a
Fall (Oct.–Dec.)	14.2 b	10.9 ab	0.892 a
<i>Brahea edulis</i>			
Winter (Jan.–Mar.)	2.0	0.6	0.302
Spring (Apr.–Jun.)	4.9	1.1	0.200
Summer (Jul.–Sep.)	7.2	2.1	0.499
Fall (Oct.–Dec.)	10.8	1.8	0.214
<i>Butia capitata</i>			
Winter (Jan.–Mar.)	2.4 b	2.0 b	0.315
Spring (Apr.–Jun.)	10.4 b	4.3 b	0.503
Summer (Jul.–Sep.)	39.4 a	14.2 a	0.298
Fall (Oct.–Dec.)	12.1 ab	5.7 ab	0.327
<i>Caryota mitis</i>			
Winter (Jan.–Mar.)	0.4 b	0.0 b	0.067
Spring (Apr.–Jun.)	4.3 b	0.3 b	0.089
Summer (Jul.–Sep.)	70.3 a	9.8 a	0.127
Fall (Oct.–Dec.)	36.8 ab	9.6 a	0.439
<i>Chamaerops humilis</i>			
Winter (Jan.–Mar.)	13.0	1.6 b	0.116
Spring (Apr.–Jun.)	11.6	1.4 b	0.116
Summer (Jul.–Sep.)	28.7	7.8 a	0.189
Fall (Oct.–Dec.)	22.4	4.1a b	0.175
<i>Livistona chinensis</i>			
Winter (Jan.–Mar.)	9.1	4.2	0.434
Spring (Apr.–Jun.)	29.7	19.5	0.622
Summer (Jul.–Sep.)	42.9	28.6	0.724
Fall (Oct.–Dec.)	32.1	39.0	0.822
<i>Livistona decipiens</i>			
Winter (Jan.–Mar.)	4.4 b	1.1 b	0.217 b
Spring (Apr.–Jun.)	23.5 b	3.7 b	0.222 b
Summer (Jul.–Sep.)	214.4 a	101.1 a	0.445 a
Fall (Oct.–Dec.)	75.8 b	36.1 b	0.364 ab
<i>Phoenix canariensis</i>			
Winter (Jan.–Mar.)	7.0 b	2.2 b	0.344 bc
Spring (Apr.–Jun.)	78.4 b	29.2 b	0.319 c
Summer (Jul.–Sep.)	241.6 a	150.9 a	0.620 a
Fall (Oct.–Dec.)	62.6 b	31.8 b	0.544 ab
<i>Phoenix reclinata</i>			
Winter (Jan.–Mar.)	13.1 c	2.8 b	0.269
Spring (Apr.–Jun.)	151.5 ab	55.3 b	0.360
Summer (Jul.–Sep.)	229.9 a	170.4 a	0.601
Fall (Oct.–Dec.)	76.0b c	48.1 b	0.578
<i>Rhapidophyllum hystrix</i>			
Winter (Jan.–Mar.)	3.7 b	0.1 c	0.057 b
Spring (Apr.–Jun.)	12.1 b	1.6 c	0.132 ab
Summer (Jul.–Sep.)	50.8 a	9.2 a	0.168 a
Fall (Oct.–Dec.)	41.4 a	5.3 b	0.141 a

Means in the same column within a species followed by a different letter are significantly different according to LSD, $P < 0.05$.

Table 3 (continued). Mean total root numbers (n), mean total root dry weights (g), and mean individual root size (g/n) of 16 species of palms in all trench zones by season, The Los Angeles County Arboretum & Botanic Garden, Arcadia, California, 1997–2000.

Species and season	Number (n)	Weight (g)	Size (g/n)
<i>Sabal etonia</i>			
Winter (Jan.–Mar.)	2.2 b	0.5 b	0.303
Spring (Apr.–Jun.)	9.1 b	1.6 b	0.516
Summer (Jul.–Sep.)	67.0 a	14.9 a	0.218
Fall (Oct.–Dec.)	15.3 b	3.5 b	0.286
<i>Serenoa repens</i>			
Winter (Jan.–Mar.)	0.2 b	0.0 b	0.000 b
Spring (Apr.–Jun.)	5.3 b	0.8 b	0.135 b
Summer (Jul.–Sep.)	58.0 a	18.7 a	0.395 ab
Fall (Oct.–Dec.)	3.8 b	2.1 b	0.565 a
<i>Syagrus romanzoffiana</i>			
Winter (Jan.–Mar.)	10.2 b	0.9 b	0.083 c
Spring (Apr.–Jun.)	33.8 b	7.0 b	0.200 bc
Summer (Jul.–Sep.)	295.2 a	107.9 a	0.374 a
Fall (Oct.–Dec.)	61.8 b	20.8 b	0.313 ab
<i>Trachycarpus fortunei</i>			
Winter (Jan.–Mar.)	5.5 b	0.5 b	0.051
Spring (Apr.–Jun.)	77.0 ab	5.1 ab	0.053
Summer (Jul.–Sep.)	110.6 a	12.5 a	0.096
Fall (Oct.–Dec.)	44.2 a b	5.2 ab	0.080
<i>Trachycarpus wagnerianus</i>			
Winter (Jan.–Mar.)	11.7 b	1.1 b	0.092 b
Spring (Apr.–Jun.)	102.9 b	11.1 b	0.128 ab
Summer (Jul.–Sep.)	241.9 a	49.6 a	0.208 a
Fall (Oct.–Dec.)	62.9 b	13.2 b	0.155 ab
<i>Washingtonia robusta</i>			
Winter (Jan.–Mar.)	27.9 b	0.3 c	0.019 b
Spring (Apr.–Jun.)	265.2 a	23.8 b	0.095 ab
Summer (Jul.–Sep.)	328.7 a	53.4 a	0.173 a
Fall (Oct.–Dec.)	30.9 b	3.7 c	0.129 a

Means in the same column within a species followed by a different letter are significantly different according to LSD, $P < 0.05$.

roots in the upper as in the lower zone. *Brahea edulis* and *Trachycarpus fortunei* grew nearly all their roots in the upper zone. New roots of *Butia capitata*, *Livistona chinensis*, and *Syagrus romanzoffiana* were evenly distributed between the upper and lower zones. Thus, in all species, at least 50% of root growth occurred in the upper 30 cm (12 in.) of soil.

DISCUSSION

There are large differences in root growth among palm species. Our results of seasonality of root growth support the work of Broschat (1998) and the popular belief that palm roots grow most actively in the warmest months.

Winters in California (a region with a Mediterranean climate) are sufficiently cool and long to reduce root growth in most species. Thus, the best time to transplant palms in Mediterranean climates is the late spring to early summer

(May to July in the Northern Hemisphere). Transplanting at this time provides a long, warm period that promotes root growth to ensure establishment. Late spring to early summer transplanting might be critical for rare and/or unusually valuable specimens, those species that grow relatively few roots per year, or for species that grow a preponderance of new roots in the summer.

This recommendation does not mean that certain species cannot be successfully transplanted in the fall or winter in Mediterranean climates. However, the opportunity for successful transplanting is lowest in the fall and winter and highest in the late spring to early summer, particularly for species that grow few roots in the cooler seasons. If transplanting in the fall and winter, judicious attention must be given to other factors that affect transplant success, such as digging and handling, planting depth, and irrigation.

Table 4. Mean new root numbers and percentage (in parentheses, rounded to a whole number) of 16 palm species by lateral distance from the trunk and to 60 cm deep, The Los Angeles County Arboretum & Botanic Garden, Arcadia, California, 1997–2000.

Species	Lateral distance from trunk			
	0–15 cm	15–30 cm	30–60 cm	60–90 cm
<i>Archontophoenix cunninghamiana</i>	6.6 a (34)	6.3 a (32)	4.8 a (25)	1.9 b (10)
<i>Brahea edulis</i>	3.0 a (48)	2.2 a (35)	0.8 b (13)	0.3 b (4)
<i>Butia capitata</i>	6.7 a (42)	5.3 b (33)	3.1 c (19)	1.1 d (7)
<i>Caryota mitis</i>	7.2 a (26)	7.4 a (26)	8.6 a (31)	4.7 b (17)
<i>Chamaerops humilis</i>	6.2 a (37)	4.0 b (24)	3.9 b (24)	2.6 b (16)
<i>Livistona chinensis</i>	12.9 a (46)	7.2 b (25)	5.5 b (19)	2.8 c (10)
<i>Livistona decipiens</i>	41.7 a (52)	20.9 b (26)	14.4 c (18)	2.5 d (3)
<i>Phoenix canariensis</i>	32.7 a (34)	22.5 b (23)	27.1 ab (28)	15.2 c (16)
<i>Phoenix reclinata</i>	49.8 a (40)	32.4 b (26)	24.2 b (19)	19.2 c (15)
<i>Rhapidophyllum hystrix</i>	7.2 b (27)	5.9 b (22)	10.8 a (40)	3.1 c (11)
<i>Sabal etonia</i>	9.4 a (40)	6.4 b (27)	5.4 b (23)	2.2 c (9)
<i>Serenoa repens</i>	7.4 a (43)	4.2 b (24)	3.4 b (20)	2.3 b (13)
<i>Syagrus romanzoffiana</i>	36.9 a (37)	24.1 b (24)	25.0 b (25)	14.8 c (14)
<i>Trachycarpus fortunei</i>	24.8 a (41)	19.3 b (33)	13.4 b (23)	1.8 c (3)
<i>Trachycarpus wagnerianus</i>	61.4 a (59)	31.7 b (30)	10.3 c (10)	1.5 d (1)
<i>Washingtonia robusta</i>	84.1 a (52)	47.5 b (29)	27.4 c (17)	4.2 d (3)

Means in the same **row** followed by a different letter are significantly different according to paired t-tests between columns, $P < 0.05$.

Because cool, moist winters and warm, dry, nearly rainless summers characterize Mediterranean climates, irrigation is typically required when transplanting palms in these regions. In warm, humid subtropical or tropical regions with distinct wet and dry seasons, it is best to transplant palms at the beginning of the rainy season if irrigation is lacking and landscapers are relying on rain to maintain soil moisture in the root zone at adequate levels. In many warm, humid subtropical or tropical regions, the rainy season corresponds to the warmer months of the year.

Although we did not distinguish size when we harvested and counted roots, the increase in root size during the warmer months might be reflective of an increase of new primary (first-order) roots growing from the RIZ or even regrown, severed primary roots. New and regrown primary roots are much larger than secondary (second-order) roots (Tomlinson 1990).

Our data are consistent with the later ones of Meerow (1992) and Broschat and Meerow (2000) for root ball size and suggest that root balls extending 30 cm (12 in.) out from the trunk are sufficient for transplanting because they capture about 50% or more of the roots. Even smaller root balls extending only 15 cm (6 in.) out from the trunk would be adequate for species that have 50% or more of their roots within this distance.

Our data also suggest that a root ball 30 cm (12 in.) deep would include most roots in most species. A deeper root ball (60 cm [24 in.] deep or more) would be advantageous for *Butia capitata*, *Livistona chinensis*, and *Syagrus romanzoffiana* to capture most of their roots. Consider root balls 60 cm (24 in.) or more deep for species with large number of roots (>30%)

Table 5. Mean new root numbers and percentage (in parentheses, rounded to a whole number) of 16 palm species by two depth zones and out to 90 cm from the trunk, The Los Angeles County Arboretum & Botanic Garden, Arcadia, California, 1997–2000.

Species	Depth	
	0–30 cm	30–60 cm
<i>Archontophoenix cunninghamiana</i>	14.0 a (72)	5.6 b (29)
<i>Brahea edulis</i>	5.7 a (92)	0.5 b (9)
<i>Butia capitata</i>	8.5 (53)	7.6 (47)
<i>Caryota mitis</i>	21.4 a (77)	6.5 b (23)
<i>Chamaerops humilis</i>	14.4 a (76)	4.6 b (24)
<i>Livistona chinensis</i>	15.0 (53)	13.5 (48)
<i>Livistona decipiens</i>	66.6 a (84)	13.0 b (16)
<i>Phoenix canariensis</i>	78.5 a (80)	18.9 b (20)
<i>Phoenix reclinata</i>	77.7 a (67)	38.7 b (33)
<i>Rhapidophyllum hystrix</i>	17.3 a (64)	9.7 b (36)
<i>Sabal etonia</i>	16.4 a (70)	7.1 b (30)
<i>Serenoa repens</i>	12.3 a (73)	4.5 b (27)
<i>Syagrus romanzoffiana</i>	49.8 (50)	50.5 (50)
<i>Trachycarpus fortunei</i>	45.8 a (77)	13.5 b (23)
<i>Trachycarpus wagnerianus</i>	91.6 a (97)	2.5 b (3)
<i>Washingtonia robusta</i>	116.5 a (71)	46.7 b (29)

Means in the same **row** followed by a different letter are significantly different according to paired t-tests between columns, $P < 0.05$

in the 30 to 60 cm (12 to 24 in.) deep zone. A deeper root ball might also aid in stabilizing and anchoring the palm.

Although Broschat and Donselman (1984a, 1984b, 1990) concluded that maximum palm transplant success depends on the root ball being large enough to ensure that a maximum or high percentage of severed roots regrow, our

findings support the concept that the total number of new roots that grow and their density, regardless of their origin, are the key factors in determining root ball size. Because rapid growth of a large number of new roots from the RIZ and/or from regrowth of severed roots is most critical to transplant success, in most cases root balls extending 30 cm (12 in.) out from the trunk are sufficiently large to ensure that this growth occurs.

Even if the ability of severed roots to regrow is critical to determining root ball size, the total number of roots that regrow might be more important than the percentage of roots that regrow. For example, Broschat and Donselman (1984a, 1984b) reported that *Cocos nucifera* generally had 50% of cut roots regrow regardless of distance from the trunk. However, there were so few roots beyond 30 cm (12 in.) from the trunk in their study (only 14 out of a total of 160 regrown roots in all zones combined) that the high rate of regrowth in that area is irrelevant. In *C. nucifera*, *Roystonea regia*, and *Syagrus romanzoffiana*, the distance from the trunk at which 30% of roots regrew actually did encompass nearly a third or more of the total number of regrown roots in all the zones combined. Unfortunately, Broschat and Donselman (1990) reported only percentages of regrown roots, not actual numbers, for *Phoenix reclinata* and *Washingtonia robusta*.

In many instances, the ability of severed palm roots to regrow might be more apparent than real. While we observed that most severed roots did not regrow at the cut point, neither did they always die. Some severed roots remained alive and appeared to be functional. Also, some severed roots that appeared to die did so only for a short distance and actually regrew into the trench from several centimeters proximal of the cut. When these regrown severed roots entered the trench, they appeared like new roots from the RIZ. Unless each root entering the trench is traced back to its origin, it is impossible to determine whether the root grew from the RIZ or from a severed root. Hodel and Pittenger (2003) showed that most severed roots of *Phoenix dactylifera* offshoots regrew, often within 2 cm (0.8 in.) of the trunk, but appeared as new roots from the RIZ when they emerged from the root ball. Thus, many of the roots reported as growing from the RIZ in earlier studies likely regrew from severed roots.

Root Pruning

Although they provided no supporting data, Broschat and Donselman (1984a, 1984b, 1987, 1990) stated that root pruning 1 to 3 months prior to transplanting would grow a new root system faster because it stimulates new roots to grow from the RIZ prior to moving the palm, thus minimizing transplant shock. However, palm root growth is greatest during the warmer times of the year when soil and air

temperatures are highest and, that in tropical areas and southern Florida, root growth is frequent and regular year-round (Broschat 1998). Thus, it is likely that the root growth from the RIZ in their studies was in response to the warm soil and air temperatures rather than the cutting of roots.

Broschat and Donselman (1987) also concluded that root pruning would benefit even species that produce most of their new roots from regrowth of severed roots because it would shorten or even eliminate the length of time for the cut roots to regrow after transplanting. More recently, Meerow (1992) and Broschat and Meerow (2000) placed less emphasis on root pruning but said it might be useful in some cases. Harris et al. (2004) also supported the practice. Even if root pruning does provide these positive benefits, there is still a serious concern with this practice because any new roots that grow from the RIZ or regrow from roots severed during pruning will be highly susceptible to damage during the digging, transporting, and replanting processes. After root pruning, transplanting too early might lose the purported benefit of this practice, while waiting too long to transplant might damage any new roots that had grown. Thus, we feel that root pruning palms prior to transplanting has little merit.

SUMMARY AND CONCLUSIONS

For many palm species, most roots occur within 30 cm (12 in.) of the trunk and, in Mediterranean climates, are produced most abundantly during the warmer months, especially in the summer. Palms need active root and shoot growth to establish quickly after transplanting. Palms can be transplanted year-round in warm regions where air and soil temperatures are nearly always sufficient to ensure adequate root and shoot growth. In contrast, palms are best transplanted at the beginning of the warm season in regions where air and soil temperatures are insufficient for adequate growth for several months of the year. Thus, the best time to transplant palms in Mediterranean climates is the late spring to early summer because this time provides a long, warm period that promotes root and shoot growth to ensure quick establishment.

Root balls with a 30 cm (12 in.) radius from the trunk and 30 cm (12 in.) deep are adequate for most palms when transplanting because this size captures well over half the roots. The few palms that must grow nearly all their new roots from the RIZ after transplanting need a root ball only big enough to protect the RIZ, about 15 cm (6 in.) out from the trunk. Palms that grow about 30% or more of their roots below 30 cm (12 in.) deep and exceptionally large specimens would probably benefit from a deeper root ball, about 60 cm (24 in.) deep.

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Résumé. Les palmiers ont besoin d'une croissance active des racines et des pousses pour s'établir rapidement après la transplantation. Pour la plupart des espèces de palmiers, la croissance des racines doit être abondante durant les mois chauds et se faire dans les premiers 30 cm de distance du tronc. De ce fait, les palmiers peuvent être transplantés durant toute l'année dans les régions chaudes lorsque la température de l'air et du sol est à peu près suffisante pour assurer une croissance adéquate des racines et des pousses. Cependant, dans les régions avec une saison plus froide, les palmiers sont mieux d'être transplantés au début de la saison chaude. Pour la plupart des espèces, une motte de racines de 30 cm de rayon à partir du tronc et de 30 cm de profondeur est adéquate parce qu'elle contient plus de la moitié des racines. Les quelques espèces qui doivent produire la croissance de toutes leurs nouvelles racines à proximité immédiate du tronc lors de la transplantation n'ont besoin que d'une motte de racines suffisamment large pour protéger la zone d'initiation racinaire, soit environ 15 cm du tronc. Les espèces qui produisent 30% ou plus de leurs racines sous les 30 cm de profondeur bénéficieraient sans doute mieux d'une motte plus profonde, soit d'environ 60 cm de profondeur.

Zusammenfassung. Palmen brauchen aktive Wurzeln und Triebe, um sich nach der Verpflanzung schnell zu regenerieren. Bei den meisten Palmenarten wachsen die Wurzeln am besten während der warmen Monate und tauchen innerhalb von 30 cm vom Stamm auf. Daher können Palmen in warmen Regionen, die entsprechende Luft- und Wassertemperaturen bieten, das ganze Jahr über verpflanzt werden. In kühleren Regionen werden Palmen am besten zu Beginn der warmen Saison verpflanzt. Für die meisten

Arten sind Wurzelballen mit 30 cm Radius vom Stamm und 30 cm Tiefe angemessen, weil sie gut die Hälfte der Wurzelmasse enthalten. Die wenigen Arten, die nahezu all ihre Wurzeln nach der Verpflanzung neu bilden müssen, brauchen einen Wurzelballen, der grade so groß ist, um die Wurzelbildungszone zu bedecken, ca. 15 cm vom Stamm. Arten, die 30 % oder mehr ihrer Wurzeln unterhalb von 30 cm Tiefe bilden, würden wahrscheinlich von einem tieferen (60 cm) Wurzelballen profitieren.

Resumen. Las palmeras necesitan un activo crecimiento de raíces y brotes para establecerse rápidamente después del trasplante. Para muchas especies de palmeras el crecimiento de las raíces es más abundante durante los meses más calientes y ocurre dentro de los 30 cm alrededor del tronco. Por lo tanto, las palmeras pueden ser trasplantadas todo el año en regiones calientes, donde las temperaturas del aire y del sol son suficientes para asegurar un adecuado crecimiento de las raíces y brotes. Sin embargo, en regiones con estaciones frías, las palmeras deben ser trasplantadas al principio de las estaciones calurosas. Para la mayoría de las especies, las bolas de raíces con un radio de 30 cm y 30 cm de altura son adecuadas porque ellas capturan más de la mitad de las raíces. Las pocas especies cuyas nuevas raíces deben crecer cerca del tronco después del trasplante, solo necesitan una bola lo suficientemente grande para proteger la zona de iniciación, cerca de 15 cm afuera del tronco. Las especies que crecen cerca del 30% o más de sus raíces debajo de los 30 cm de profundidad, deberán probablemente beneficiarse de una bola más profunda, con cerca de 60 cm de altura.