Nutrient Distribution, Dynamics, and Sampling in Coconut and Canary Island Date Palms

Timothy K. Broschat

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

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ABSTRACT. All leaves from 10 replicate *Cocos nucifera* L. 'Malayan Dwarf' (COC) and *Phoenix canariensis* Chabaud (CID) trees were sampled for leaf nutrient analysis. In addition, the leaflets of the youngest fully expanded leaves and the third oldest leaves were divided into five groups along the primary leaf axis and these leaflets were then cut into thirds to determine nutrient distribution patterns within leaves and leaflets. Nutrient remobilization rates were calculated for N, P, K, Mg, and Mn. Results showed that N, P, and K were highly mobile within and between leaves of both species of palms. Up to 31% of the N, 66% of the K, and 37% of the total P in the oldest leaves were ultimately remobilized to newer leaves within the palm. Magnesium remobilization rates averaged $\approx 71\%$ for CID but only $\approx 10\%$ for COC. The middle-aged leaves appeared to be the primary sink for Mg in COC, rather than the youngest leaves as in CID. Manganese was also quite mobile in both species, with up to 44% of the total Mn remobilized in CID. Samples consisting of recently matured leaves were determined to be the most appropriate for Ca, Fe, Mg (COC only), and Zn, but oldest leaves are more suitable for N, P, K, and Mn analysis.

Nutrient remobilization from senescing leaves is important for nutrient conservation in deciduous trees (Chapin and Kedrowski, 1983; Oland, 1963; Grigal et al., 1976). In evergreen trees, where leaves function for >1 year, remobilization of mobile elements such as N, P, K, and Mg from older leaves on a shoot to actively growing shoot apices can occur long before leaf senescence (Helmisaari, 1992; Nambiar and Fife, 1987). Under nutrient deficiency conditions, deficiency symptoms of these elements often appear on the oldest leaves of each shoot. The relative importance of nutrient remobilization from older leaves, under conditions of nutrient deficiency, has often been debated (Nambiar and Fife, 1991). Because of remobilization, nutrient concentration gradients exist among leaves on a single shoot and also within individual leaves (Leuning et al., 1991).

Nutrient remobilization rates have been calculated for several species of conifers and broadleaf evergreen trees (Chapin and Kedrowski, 1983; Helmisaari, 1992; Nambiar and Fife, 1987; Wendler et al., 1995). However, comparable data for palms do not exist. A large portion of a palm's biomass is tied up in its leaves, which represent a large potential reserve of usable nutrients. Palms also grow continuously throughout the year, in contrast to the strong seasonality of growth in most temperate trees. Thus, nutrient remobilization patterns are expected to differ from those of broadleaf and coniferous trees.

Leaf nutrient analysis is an important tool for diagnosing nutritional disorders in palms (Chase and Broschat, 1991). For most plants, samples taken from recently matured leaves are analyzed for all nutrient elements. Because of nutrient remobilization and its effects on nutrient distribution patterns, these leaves may not be the best choice for diagnosing nutrient deficiencies of mobile elements in palms. The objectives of this study were to determine the distribution patterns of eight nutrient elements within the canopy, leaves, and leaflets of coconut (COC)

and Canary Island date (CID) palms and to determine which leaves are the best indicators of palm nutritional status for each of these elements. Remobilization rates for mobile elements were also calculated for these two species growing under conditions of nutrient deficiency. Coconut palms are economically important for food and oil production throughout the humid tropics, whereas CID is an important landscape palm, particularly in Mediterranean climates.

Materials and Methods

Ten replicate trees of COC and CID growing in a Margate Fine Sand soil in Broward County, Fla., were used in this study. The COC were ≈ 15 years old, averaged ≈ 8 m tall, and were fruiting at the time of this study. The CID were ≈ 12 years old, ≈ 5 m tall, and were not flowering or fruiting at the time of this study. Both species were growing in unfertilized plots, with individual palms spaced ≈ 6 m apart. The rate of leaf production was determined by marking the newest emerging leaf (spear leaf) and counting the number of new leaves produced during a 1-year period. The total number of living leaves retained by each tree was also recorded at the time of leaf sampling.

Leaf tissue samples for subsequent elemental analyses consisted of the middle three (for COC) or six (for CID) leaflets on every leaf within the canopy. Leaves were numbered, with no. 1 being the youngest fully expanded leaf. Leaves were considered to be fully expanded when all leaflets, including the spine leaflets in CID, had emerged and were oriented perpendicularly to the rachis. Some petiole elongation continued after this stage for CID, but leaflet dry mass, leaflet area, and leaflet dry mass per unit area were not found to differ significantly between recently matured and the oldest leaves within the canopy of both species.

The youngest and third oldest leaf on each palm were also used to determine elemental distribution patterns within an individual leaf. These leaves were divided into five equal-length segments along the rachis axis, and within each of these segments, individual leaflets were further divided into three equal length segments. The two oldest leaves of each palm were not used for this part of the study, since leaf or leaflet tips of these leaves were usually necrotic

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due to K deficiency. Mills and Jones (1996) recommend excluding dead plant tissue from samples to be used for nutrient analysis.

Nutrient remobilization rates were calculated by the following equation: $[E]_Y \cdot LFWT_Y - [E]_O \cdot LFWT_O / \text{Time}$, where $[E]_Y$ and $[E]_O$ are the leaf concentrations of an element in the youngest fully expanded and oldest leaves, respectively, $LFWT_Y$ and $LFWT_O$ are the dry mass of the youngest fully expanded and oldest leaves, respectively, and time is the number of years required for the youngest leaf to become the oldest leaf within a palm canopy. This equation assumes that the nutrient content of the current oldest leaf started out the same as the current newest leaf. Since these palms had been growing in equilibrium with their environment for their entire lives with no supplemental fertilization, this assumption should be valid.

Because COC growing in nutrient poor sand soils usually exhibit K deficiency symptoms of varying severity, each leaf was subjectively rated on a scale of 0 to 10 according to the following criteria: 0 = no symptoms; 3 = light yellow spotting; 5 = moderate spotting, some marginal necrosis; 7 = severe necrosis; 10 = leaf dead except for petiole. CID growing under similar conditions usually exhibit some degree of Mg deficiency symptoms, rather

than K deficiency. Each leaf of these palms was similarly rated for Mg deficiency symptom severity according to this scale: 0 = no symptoms; 3 = 30% of each leaflet yellow; 5 = 50% of each leaflet yellow; 7 = 70% of each leaflet yellow, considerable tip necrosis; 10 = no green on leaf, severe tip necrosis.

Leaf samples were dried at 60 °C, ground in a Wiley Mill, and digested using a modified $H_2SO_4-H_2O_2$ method in a microwave oven (Allen, 1974). Nitrogen was determined using the Nesslerization method, P by the ascorbic acid method, and K, Ca, Mg, Mn, Fe, and Zn by atomic absorption spectrophotometry (Greenberg et al., 1992). Regression analysis was performed on the leaf nutrient analysis data using SAS (SAS Institute, Cary, N.C.). Models were selected based on R^2 values. Mean separations among sample position classes was done using the Waller-Duncan k ratio method.

Results and Discussion

LEAF PRODUCTION RATES. The COC in this study produced an average of 9.5 leaves/year, with each leaf lasting ≈ 1.4 years before senescing. On the other hand, CID produced an average of 49.8 leaves/year, with each leaf living ≈ 1.3 years. The COC retained a median of 13 leaves per palm, whereas CID retained 63 leaves.

NITROGEN. Nitrogen concentrations in COC leaves remained constant or increased slightly from leaf 1 to leaf 5, but decreased with increasing leaf age thereafter (Fig. 1A). A similar slight increase in N concentration in the first five leaves was reported for African oil palm (*Elaeis guineensis* Jacq.) (Prevot and Montbreton, 1958; Scheidecker and Prevot, 1954). This drop in N concentration in CID did not occur until about leaf 15, however (Fig. 2A). Since N is considered to be mobile within plants, this gradual decrease in N concentration with increasing leaf age was expected. The oldest leaves on these palms should therefore be the best indicators of palm N status when sampling for leaf nutrient analysis.

There were no significant differences in concentration of N or any other nutrient element from various positions within a leaf or leaflet for the youngest leaves of either species (data not shown). Therefore, any decreases in sample nutrient concentrations from various positions on a leaf or leaflet on the oldest leaves were attributed to remobilization of those elements to other parts of the palm.

Within an individual third oldest leaf, N concentrations in COC did not vary among leaflets, but N concentrations increased acropetally within a single leaflet (Fig. 3A, Table 1). This trend was also observed on 'Nigerian Tall' coconut palms (Amalu et al., 1988). For CID, N concentrations increased, then decreased acropetally within a single leaflet, but did not vary significantly between leaflets on a leaf (Fig. 4A, Table 1).

Fig. 1. Relationships between leaf position and foliar nutrient content for *Cocos nucifera* 'Malayan Dwarf'. Leaf 1 is the youngest fully expanded leaf on a palm.

Remobilized N, as suggested by decreasing N concentrations with increasing leaf age, must therefore originate in the basal sections of leaflets on older leaves. Although younger leaves represent obvious sinks for remobilized N and other mobile elements, the relative contributions of remobilized elements to stem, root, flower, or fruit nutrient composition cannot be determined from these data. Annual N remobilization rates ranged from 3.17 g/leaf/year for CID to 5.18 g/leaf/year for COC (Table 2). About 31% of the total N in the oldest leaves of CID was remobilized, compared to 23% for COC.

Because CID produce many more leaves than COC, the turnover of N within the palm canopy is actually much higher for CID (158 g/tree/year) than for COC (49 g/tree/year). The minimum N concentrations in the oldest leaves of COC (1.5%) and CID (1.8%) suggest that these palms are much less efficient at resorbing N from older leaves than are most broadleaf and coniferous trees (Killingbeck, 1996).

Although the total percentage of N remobilized from older leaves in these palms is within the range reported for a wide variety of temperate broadleaf and coniferous trees, the timing of this remobilization is quite different for palms (Escudero et al., 1992a; 1992b). The data in Figs. 1A and 2A suggest that N is gradually but steadily remobilized from older palm leaves. Leaves of broadleaf evergreen trees such as *Quercus ilex* L. live for 2 to 3 years, yet N reabsorption occurs just before leaf abscission, as occurs in deciduous trees (Escudero et al., 1992a).

On the other hand, nutrient remobilization from older leaves of evergreen conifers occurs independently of leaf senescence, and N remobilized from older leaves during growth flushes may be replaced during the summer (Escudero, et al., 1992a; Nambiar and Fife, 1987). In evergreen subtropical broadleaf trees such as *Eucalyptus globulus* Labill., leaf N remobilization also occurred during periods of active growth, but replacement of remobilized N was not reported (Wendler et al., 1995). Root and shoot growth in COC occurs year-round at a more or less constant rate in tropical climates (T. Broschat, unpublished data). Flowering and fruiting in COC are also year-round. However, the seasonality of CID flowering and fruiting was not a factor in this study, since the plants used were not of flowering age. Nitrogen remobilization in these palms is thus a constant process related to new growth N requirements, rather than merely the reabsorption of N just before leaf abscission that occurs in temperate broadleaf trees.

PHOSPHORUS. Leaf P concentrations decreased steadily with increasing leaf age through about leaf 10 in the canopies of COC and CID (Figs. 1B and 2B). Little further decrease in P concentrations occurred in older leaves of both species. COC and CID leaf samples for P analysis taken from leaf 10 or older leaves should therefore give a better

indication of palm P status than the youngest fully expanded leaves that are normally sampled. Prevot and Montbreton (1958) showed that P concentrations in African oil palm leaves decreased very little after leaf 9, which contained $\approx 1.8 \text{ mg}\cdot\text{g}^{-1}$. This suggests that only P in excess of $1.2 \text{ mg}\cdot\text{g}^{-1}$ for COC or $1.8 \text{ mg}\cdot\text{g}^{-1}$ for CID and African oil palms is readily retranslocated. On the other hand, a review by Killingbeck (1996) showed that 83 of 89 species of woody broadleaf and coniferous plants were able to reduce P in senescing leaves to concentrations of $<1.2 \text{ mg}\cdot\text{g}^{-1}$.

Within the third oldest leaf, P concentrations for both species showed no systematic trends in distribution, either within a leaf or an individual leaflet (Figs. 3B and 4B, Table 1). Amalu et al. (1988) reported a similar lack of a P concentration gradient within leaves or leaflets of 'Nigerian Tall' coconuts.

Annual P remobilization rates averaged 0.37 g/leaf/year for CID and 0.72 g/leaf/year for COC (Table 2). Although the total amount of P remobilized per palm leaf is only about one-tenth that of N, the percentage of P in older leaves that is remobilized (34% for COC and 37% for CID) is actually higher than for N. Escudero et al. (1992b) also reported higher remobilization rates for P than for N in most of 21 species of temperate trees. They found no

Fig. 2. Relationships between leaf position and foliar nutrient content for *Phoenix canariensis*. Leaf 1 is the youngest fully expanded leaf on a palm.

relationship between N and P remobilization rates and leaf longevity or type of tree (deciduous, coniferous evergreen, or broadleaf evergreen). Tropical evergreen and deciduous broadleaf trees also did not differ significantly as a group from temperate trees with respect to N and P remobilization rates (Chapin and Kedrowksi, 1983). In most broadleaf trees, P remobilization occurred most rapidly just before leaf abscission, but, in palms, P remobilization was most rapid during the first few months after a new leaf emerged and diminished to almost nothing during the last few months of leaf life.

POTASSIUM. Potassium concentrations in leaves of COC and CID decreased with increasing leaf age, but at decreasing rates (Figs. 1C and 2C). A similar relationship between leaf age and K concentrations was reported for 'Nigerian Tall' coconuts (Amalu et al., 1988) and African oil palm (Prevot and Montbreton, 1958). The oldest leaves of these species should thus be the best indicators of palm K status. Within the third oldest leaf, K concentrations decreased acropetally in COC, but position on a single leaflet did not significantly affect K concentrations (Fig. 3C, Table 1).

All of the COC in this study showed symptoms of moderate K deficiency, and symptom severity was highly correlated with leaf position and leaf K concentrations (Fig. 5 A and B). COC leaves with K concentrations $>9 \text{ mg} \cdot \text{g}^{-1}$ did not exhibit any symptoms of K deficiency. Visually, K deficiency symptoms in COC and most other palms examined increase in severity acropetally within a single old leaf (Chase and Broschat, 1991).

Potassium concentrations within the third oldest CID leaves did not vary in any systematic pattern (Fig. 4C, Table 1). Potassium remobilization rates averaged 8.4 g/leaf/year for COC, but 2.3 g/leaf/year for CID (Table 2). The percentage of K remobilized from old COC leaves was 60% versus 66% for CID. This apparent difference in the absolute quantity of K remobilized versus the percentage of K remobilized from different species of palms can be explained by differences in average leaf dry mass (481 g for CID versus 1440 g for COC).

The percentage of K remobilized from older leaves to new growth varies widely among species of nonpalm trees (Chapin and Kedrowksi, 1983; Jonasson, 1989). For most of the species studied, the percentage of K remobilized was higher than for P and about equal to that of N.

Although K was remobilized continuously throughout the life of COC and CID leaves, the remobilization rate was higher during the first 3 to 4 months of palm leaf life. The timing of K retranslocation is not known for most temperate trees, but in *Cistus monspeliensis* L., a Mediterranean evergreen shrub, K pools in leaves of varying ages closely follow those reported here for COC and CID (Jonasson, 1989).

Fig. 3. Effects of sampling position on foliar nutrient concentrations in the third oldest leaves of *Cocos nucifera* 'Malayan Dwarf'. White bars indicate leaflet samples and shaded bars are for leaf samples. Leaflet or leaf position 1 represents the most proximal section of the leaflet or leaf, whereas position 3 or 5 represents the most distal for leaflets and leaves, respectively. Data represent means separated by the Waller-Duncan k ratio method.

CALCIUM. Leaf Ca concentrations increased consistently with increasing leaf age in COC and CID, although the rate of increase declined considerably after about leaf 40 in CID (Figs. 1D and 2D). The youngest fully expanded leaf should thus be the best indicator of palm Ca status in these two species. Prevot and Montbreton (1958) and Scheidecker and Prevot (1954) showed a similar increase in leaf Ca concentrations with increasing leaf age in African oil palm, but Amalu et al. (1988) reported a slight decrease in Ca concentrations with increasing leaf age for 'Nigerian Tall' coconuts. Few papers have been published on the relationship between leaf age and Ca concentrations in nonpalm trees, but Jonasson (1989) showed a steady increase in leaf Ca with increasing leaf age for *Cistus monspeliensis*.

Within the third oldest leaf of COC, Ca concentrations significantly increased acropetally within a leaflet, but decreased acropetally among leaflets on a single leaf (Fig. 4D, Table 1). No significant differences in Ca concentrations occurred in various parts of CID leaves or leaflets (Fig. 4D, Table 1). Amalu et al. (1988) also found no consistent pattern in Ca concentrations in various segments of leaves of 'Nigerian Tall' coconuts. Since these data indicate that Ca was immobile within these two species

of palms, remobilization rates could not be calculated.

MAGNESIUM. Magnesium concentrations in COC leaves increased up to about leaf 4 and then decreased with increasing leaf age thereafter (Fig. 1E). In CID, however, this pattern was reversed. Magnesium concentrations decreased, then increased with increasing leaf age (Fig. 2E). Prevot and Montbreton (1958) reported that Mg concentrations increased initially, then decreased with leaf age in African oil palms. Their plots of Mg concentration versus leaf age are about intermediate between those of COC and CID in this study. Amalu et al. (1988) showed that Mg increased with leaf age for 5-year-old 'Nigerian Tall' coconuts but no variation occurred in Mg concentrations with leaf age for 11- to 13-year-old palms. Clearly, the relationship between leaf Mg concentrations and leaf age vary among palm species and even among varieties of coconut palms. Similar variations in Mg concentrations versus leaf age were reported for broadleaf evergreen shrubs by Jonasson (1989).

Within the third oldest leaf of COC, Mg concentrations decreased acropetally within a single leaflet as well as the entire leaf (Fig. 3E, Table 1). For CID, however, Mg concentrations decreased acropetally within a leaflet but increased acropetally

within the entire leaf (Fig. 4E, Table 1). This suggests that Mg is remobilized from the distal portions of palm leaflets for both species. This is consistent with observed visual symptoms of Mg deficiency, which typically appear as broad yellow bands along the outer margins of the entire leaf (Chase and Broschat, 1991). In CID, remobilized Mg comes primarily from the basal portions of middle-aged leaves, but in COC it comes from distal portions of the oldest leaves. Unlike other elements, remobilized Mg in COC appeared to move into middle-aged leaves, rather than youngest leaves. One obvious difference between the COC and CID used in this study is the presence of flowers and fruit on COC but not on CID. Although the flowers and fruit of COC were not analyzed for their nutrient content in this study, the large biomass of fruit on most COC could represent a substantial sink for retranslocated Mg.

Most of the CID in this study showed moderate Mg deficiency symptoms and symptom severity correlated well with leaf position and leaf Mg concentrations (Figs. 5 C and D). Magnesium deficiency symptoms did not appear on leaves having $\geq 1.2 \text{ mg}\cdot\text{g}^{-1}$ of Mg.

For COC, either the most recently matured leaf or the oldest leaf

should be equally good indicators of palm Mg status, but, for CID, leaves about two-thirds of the way down in the canopy should give a better indication of palm Mg status than younger or older leaves. Although the distal portion of leaflets from both species are more sensitive to Mg status than the basal portions, samples consisting of the entire leaflet should yield good results since entire leaflet samples will always contain some tissue with the lowest Mg content.

Magnesium remobilization rates for COC based on leaf 1 averaged only 0.04 g/leaf/year , but averaged 4.42 g/leaf/year for CID. The total percentage of Mg remobilized from the oldest leaf was only $\approx 10\%$ for COC, but 71% for CID (Table 2). However, if remobilization rates are based on the maximal Mg content of leaf 4, rather than the lower Mg content of leaf 1, then 13% of the Mg in the oldest COC leaves was remobilized. CID are highly susceptible to Mg deficiency (Chase and Broschat, 1991), but studies on other types of plants have failed to show a consistent relationship between nutrient deficiency symptom severity and remobilization rates (Nambiar and Fife, 1991). Percentages of Mg remobilized from five species of temperate broadleaf evergreen shrubs also varied widely from 0% to 25% (Jonasson, 1989).

MANGANESE. Manganese concentrations in COC leaves increased from leaf 1 to leaf 2, but then decreased with increasing leaf age until about leaf 8. Older leaves had relatively constant Mn concentrations (Fig. 1F). For CID, Mn concentrations decreased consistently with in-

Fig. 4. Effects of sampling position on foliar nutrient concentrations in the third oldest leaves of *Phoenix canariensis*. White bars indicate leaflet samples and shaded bars are for leaf samples. Leaflet or leaf position 1 represents the most proximal section of the leaflet or leaf, whereas position 3 or 5 represents the most distal for leaflets and leaves, respectively. Data represent means separated by the Waller-Duncan k ratio method.

creasing leaf age, although the oldest 20 or so leaves showed little change in Mn levels (Fig. 2F). There were no significant differences in Mn concentrations among samples from various parts of a single leaf or leaflet for either species (Figs. 3F and 4F, Table 1). These data suggest that samples for leaf Mn analysis should be taken from the 5 (COC) or 20 (CID) oldest leaves on a palm.

Although decreasing leaf Mn concentrations in association with increasing leaf age suggests that Mn is quite mobile within these palms, visual deficiency symptoms always occur only on newly emerging leaves (Chase and Broschat, 1991). Manganese remobilization rates for CID averaged 5.2 mg/leaf/year, with $\approx 45\%$ of the total Mn content of old leaves being remobilized.

For COC, leaf 1 does not appear to be the primary sink for remobilized Mn, but calculations based on leaf 1 indicate that $\approx 18\%$ of the total Mn was remobilized. If remobilization rates are calculated using maximal concentrations of leaf 2 rather than leaf 1, then $\approx 33\%$ of the Mn content of the oldest leaf was ultimately remobilized. The fact that the youngest leaves of COC are not the primary sinks for remobilized Mn, as is the case with CID, may explain why CID are much less susceptible to Mn deficiency than COC (Chase and Broschat, 1991). Although few studies have been published on the relationship between leaf Mn content and leaf age in nonpalm trees, Helmisaari (1992) reported that Mn content of young *Pinus sylvestris* L. decreased with increasing leaf age and suggested that Mn was slightly mobile in this species.

IRON. Leaf Fe concentrations increased initially, then decreased slightly with increasing leaf age for CID and COC (Figs. 1G and 2G). Leaf samples for Fe analysis should therefore be taken from the most recently matured leaves for both species. The slight decrease in Fe content of the oldest palm leaves suggests that this element is slightly mobile within palms. In COC the sink for Fe appears to be the leaves in the middle of the canopy, whereas in CID maximum Fe content occurs about three-fourths of the way down the canopy. If remobilization rates are calculated based on maximum Fe concentrations of leaf 5 of COC and leaf 46 of CID, then 14% of the Fe in COC oldest leaves and 15% of the Fe in CID oldest leaves was remobilized. Iron concentrations increased acropetally within a single leaf for both species and within a single leaflet for COC (Figs. 3G and 4G).

ZINC. Zinc concentrations in COC and CID were not significantly affected by leaf position (Figs. 1H and 2H). Therefore, leaf samples for Zn analysis could be taken from any aged leaf for these two species. However, Zn concentrations decreased acropetally within a leaflet of COC and increased acropetally within CID leaves (Figs. 3H and 4H, Table 1).

Fig. 5. Relationships between K or Mg deficiency ratings and leaf position and leaf K or Mg concentrations for K-deficient *Cocos nucifera* 'Malayan Dwarf' and Mg-deficient *Phoenix canariensis*. Leaf 1 is the youngest fully expanded leaf on a palm. A nutrient deficiency rating of 0 indicates no deficiency symptoms present, whereas a rating of 10 indicates severe deficiency symptoms.

Conclusions

Nitrogen, P, and K appear to be highly mobile within and between leaves of COC and CID, with a significant percentage of the N, P, and K content of the oldest leaves remobilized into new growth. Remobilization of N, P, and K occurred throughout the life of a palm leaf, rather than primarily just before leaf senescence, as occurs in most broadleaf trees. Magnesium was highly mobile for CID, but much less so for COC. Magnesium accumulated in the middle-aged leaves of COC rather than in the youngest leaves, as in CID. Although Mn deficiency symptoms occurred only on newly emerging leaves in palms, this element was shown to be mobile within COC and CID, the sink in COC being leaves 2 to 4, rather than leaf 1. Iron was slightly mobile in both species, with the sink being middle-aged leaves rather than the youngest leaves. In general, nutrient remobilization rates for CID were higher than for COC. This difference can best be explained by the more rapid turnover of leaves in CID (9.5/year for COC vs. 49.8 for CID).

Because of nutrient remobilization and its resultant nutrient concentration gradients among leaves within a palm canopy, samples consisting of the most recently matured leaves for nutrient analysis are probably not the best indicators of palm nutrient status. Recently matured leaves appear to be the most appropriate for Ca and Fe and can be suitable for Mg in COC and Zn for both species. However, the oldest leaves should yield much better results for N,

Table 1. Simple linear correlations (r) between foliar nutrient concentrations and sampling positions within leaves or leaflets of *Cocos nucifera* 'Malayan Dwarf' and *Phoenix canariensis*.

Sampling position	N	P	K	Ca	Mg	Mn	Fe	Zn
<i>Cocos nucifera</i>								
Leaf	0.132	0.238	-0.303**	-0.340***	-0.331***	0.093	0.266*	0.089
Leaflet	0.591***	0.194	0.171	0.360***	-0.336***	0.084	0.623***	-0.494***
<i>Phoenix canariensis</i>								
Leaf	0.119	0.254*	0.126	0.194	0.372***	0.226	0.496***	0.527***
Leaflet	0.273**	0.096	0.384***	0.068	-0.397***	0.142	0.276**	0.229*

***, ***, Significant at $P < 0.05$, 0.01 , and 0.0001 , respectively.

Table 2. Remobilization rates for mobile elements in *Cocos nucifera* 'Malayan Dwarf' and *Phoenix canariensis*.

Remobilization	N	P	K	Mg	Mn
rate	(g)				(mg)
<i>Cocos nucifera</i>					
Amount mobilized/leaf/year ^z	5.18	0.72	8.44	0.04	65.9
Percent mobilized/leaf	22.9	33.9	59.6	9.9	17.6
<i>Phoenix canariensis</i>					
Amount mobilized/leaf/year ^y	3.17	0.37	2.25	4.42	5.15
Percent mobilized/leaf	31.0	37.2	66.4	71.4	44.5

^zBased on an average leaf dry mass of 1440 g.

^yBased on an average leaf dry mass of 481 g.

P, K, and Mn, and can be suitable for Mg in COC and Zn for both species. Leaves two-thirds of the way down in the canopy of CID should be optimal for Mg monitoring in this species. Unfortunately, recommended tissue concentrations for palms are often based on recently matured leaf samples (Jones et al., 1991; Mills and Jones, 1996), although Reuter and Robinson (1986) recommend sampling leaf 17 for African oil palm for all elements.

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