Fertilization of Landscape Palms to Reduce Nitrogen and Phosphate Impacts on the Environment

Timothy K. Broschat
University of Florida, Fort Lauderdale Research and Education Center, 3205 College Avenue, Davie, FL 33312

Abstract. Palms are an increasingly important element in landscapes in the subtropical and warm temperate regions of the United States. Unfortunately, palms have very high nutritional requirements and rarely can be found without at least one nutrient deficiency, especially on the sandy and calcareous soils of the southeastern United States. These deficiencies are conspicuous and usually, reduce canopy size and vigor, and can become fatal. Current maintenance fertilizer recommendations for landscape palms in Florida growing in these soils entail four applications per year of an 8N–0.9P–10K–4Mg plus micronutrients palm fertilizer. However, because phosphorus (P) and nitrogen (N) are considered pollutants of ground and inland and coastal surface waters, it is important to apply only as much of these elements as necessary for palm health. This study showed that areca palms (Dypsis lutescens) can be grown in a native sandy soil or in a calcareous fill soil without supplemental P and with no N applied during the rainy summer months of June through September when application of these elements may be legally restricted. It also demonstrated that the negative effects caused by high N:potassium (K) ratio turf fertilizers can be mitigated by adding a controlled release palm fertilizer that contains no N or P. Because of strong dilution effects in this study, leaf nutrient concentrations were found to be poor indicators of palm quality and nutritional status.

Palms are an important component of landscapes in subtropical and warm temperate climates of the United States as a result of their bold leaf texture, small footprint in the landscape, and the tropical or Mediterranean look they impart to a landscape. Although palms have some of the highest nutrient requirements of any plants, most palms in the southeastern United States are grown in sandy, nutrient-poor soils (Broschat, 2009). The result is that most landscape palms within the southeastern United States are deficient in one or more elements. These deficiencies result in chlorosis, necrosis, or malformation of leaves; reduction in canopy size (number of leaves supported by the palm); trunk tapering or bending; and even death of the entire palm (Broschat and Elliott, 2005; Elliott et al., 2004). Because palms have only one apical meristem per trunk and no aerial lateral meristems, nutrient deficiencies that might cause only a twig dieback in broadleaf trees can be fatal in palms (Broschat, 2009). Also, because palms have such large leaves, deficiency symptoms are highly conspicuous and usually, plants that are grown primarily for aesthetic purposes. Six nutrient elements are commonly deficient in palms in the southeastern United States [N, K, magnesium (Mg), iron (Fe), manganese (Mn), and boron (B)], and a deficiency of any one of these elements will affect palm aesthetic quality and health (Broschat, 2009). Broschat (1999) determined that fertilizers having a N:K:O:Mg ratio of 2:3:1 are required to grow deficiency-free palms in the sandy and calcareous soils of the southeastern United States. Significant deviations from this analysis cause nutrient imbalances that can induce or exacerbate deficiencies of K and/or Mg. For example, turf fertilizers with N:K:O ratios of 2:1 or 3:1, which contain no Mg or micronutrients except for Fe, have been shown in Florida to exacerbate K deficiencies and induce Mg deficiencies (Broschat, 2009). Similarly, too much K will also induce Mg deficiency. Currently, the recommended fertilizer for palms in these soils has an analysis of 8N–0.9P–10K–4Mg plus micronutrients (hereafter 8–2–12) (Broschat, 2005a).

Because sandy and calcareous fill soils in southeastern United States have very low cation exchange capacities and are highly leached, there are serious concerns about the effects of N and P fertilizers applied to landscapes on the quality of surface and groundwaters. Excess P has been blamed for inland and coastal algal blooms, eutrophication of lakes, and proliferation of invasive cattails in the Florida Everglades (Anderson et al., 2002; Conley et al., 2009; Paerl, 2009). Nitrate-N is considered a human health hazard to children at concentrations greater than 10 ppm in drinking water (U.S. Environmental Protection Agency, 1995) but has also been implicated in the degradation of the near shore marine environments. As a result, a Florida statute (Urban Turf Fertilizer Rule RE-1.003) prohibits application of P in excess of 1.6 g Pm–2/year to home lawns unless justified by a soil test documenting a P deficiency in the soil. The recommended palm fertilizer application rate of 73 g·m–2 of canopy area four times per year results in 23 g of N and 2.5 g of P being applied per square meter per year (Broschat, 2000a).

These palm fertilization recommendations also state that turfgrass growing within 15 m of a palm should be fertilized only with the 8–2–12 palm fertilizer because palm roots can extend 15 m or more from the trunk. Thus, the recommended palm fertilizer rate would result in P applications in excess of those allowable for home lawns in Florida. Furthermore, ordinances in some Florida counties prohibit the application of any N or P fertilizers during the rainy months of June through September as a result of concerns about runoff into coastal waters.

Palm requirements for P are unknown. Phosphorus deficiency in palms is believed to be rare, but it is not unknown. It has been experimentally induced in several species of palms in sand culture (Broschat, 1984; Bull, 1958) and has been observed on extremely P-deficient soils (P < 0.25 ppm) in south Florida (Broschat and Elliott, 2009). Symptoms of P deficiency are uniform yellow–green discoloration of the foliage that could easily be confused with N deficiency or other problems (Broschat, 1984; Elliott et al., 2004). The most characteristic symptom of P deficiency, however, is a complete cessation of growth, something that will only be apparent if the palm is observed over time. This suggests that palm P requirements are much lower than those of most other crops where soil P concentrations in sandy soils lower than 20 ppm are considered deficient in this element (Anon, 2007). Because most soils in southeastern United States where palms are grown probably contain sufficient P for normal palm growth without supplemental P provided by fertilizers, it may be possible to eliminate all P from routine palm fertilization programs, thus eliminating one potential source of environmental pollution.

Similarly, N requirements for palms in landscapes are largely unknown. Nitrogen deficiency is uncommon among palms growing in landscapes in southeastern United States but is occasionally observed in areca palm (Dypsis lutescens), queen palm (Syagrus romanzoffiana (Cham.) Glassman) and Veitchia H. Wendl. spp. (Broschat, 2009). Still, although N deficiency is rare, N is the element that most strongly affects growth rate and thus N fertilization is needed for field production of palms and establishment and early growth phases in the landscape (Broschat and Moore, 2010, 2012). Soils containing organic matter appear to release sufficient N for good palm growth and quality and these

Received for publication 11 Dec. 2014. Accepted for publication 15 Jan. 2015.

This research was supported by the Florida Agricultural Experiment Station and by the USDA National Institute of Food and Agriculture Hatch project FIA-FTL-004945.

I thank William Latham, Susan Thor, and Andy Warren for their assistance in this project.

*To whom reprint requests should be addressed; e-mail tkbr@ufl.edu.
soils may not require supplemental N to the
degree that sand or calcareous soils do. In st.
uginegress (Stenotaphrum secundatum)
lawns, Broschat et al. (2008) showed that
during the rainy summer months in south
Florida, unfertilized turf had quality equal to
turf receiving 23 g N/m²/year, presumably as
a result of release of N from decomposing
thatch and clippings. Thus, it may be possible
to eliminate all N from landscapes fertilized
during those rainy summer months of June
through September in areas where N applica-
tions are prohibited. Because K, Mg, and
micronutrient requirements of palms are
greater during the summer months as a result
of rapid growth, and these elements are not
considered to be environmental pollutants,
applications of an 8N–0P–10K–4Mg plus
micronutrients (hereafter 8–0–12–16) palm fer-
tilizer in February, May, and November but
a no-N equivalent product such as 0N–0P–
13.3K–6Mg (hereafter 0–0–16) in August
should theoretically provide adequate nutri-
tion for palms while reducing N inputs and
eliminating all P inputs into the environment.

Finally, as discussed previously, applica-
tion of a typical turfgrass fertilizer that is
relatively high in N, but low in K, and contains
no Mg or micronutrients, either directly to
palms or indirectly through application to turf
as far away as 9 m from a palm, has been
shown to induce or exacerbate K and Mg
deficiencies in several species of palms, some-
times fatally (Broschat, 2005a; Broschat et al.,
2008; Broschat and Moore, 2010). As a result,
Broschat (2005a) recommends fertilizing any
turf within 15 m of a palm only with an 8–2–12
calculator fertilizer to prevent such problems.
However, in some landscape situations, land-
scape professionals may not be able to control
what is being applied to adjacent turf in the
landscape. If the 8–2–12 palm fertilizer is
applied to the palm at its recommended rate
turf under or near the palm receives a
typical turf fertilizer that is high in N but
low in K and contains no Mg or micronutrients,
the combined N from these applications could
result in excessively high N:K and N:Mg ratios
and exacerbate K and Mg deficiencies in the
palms. Under such circumstances, application
of a palm fertilizer that contains no N such as
0–0–16 to the area under the palm canopy
could potentially mitigate the negative effects
of the nearby turf fertilization.

The objectives of this experiment were to
determine if: 1) areca palms can be grown
without supplemental P in sandy or calcare-
ous landscape soils; 2) areca palms can grow
without supplemental N during the summer
rainy months of June through September in
southern Florida; and 3) a 0–0–16 fertilizer
can be used to mitigate potential damage to
palms caused by application of high N
fertilizers to palms or nearby turfgrass.

Materials and Methods

Areca palms were used because they are
sensitive to all of the common deficiencies
associated with palms, including N. A field
planting of areca palms was established in
Davie, FL, in May 2010 by planting 10-L
container-grown palms on 4.5-m centers in a
plot of Margate fine sand soil (siliceous, hyperthermic Mollic Psammumaquent) and
another nearby plot having 30 to 40 cm of
calcareous fill soil (crushed limestone) added
to the surface, the latter being typical of soils
used for planting palms in street medians,
highway rights-of-way, and many new com-
mercial and residential landscapes in Florida.

Table 1. Physical and chemical properties of the calcareous fill and native sand soils in Davie, FL.a

| Soil type         | Organic matter (%) | Bray-1 P (ppm) | K (ppm) | Mg (ppm) | Ca (ppm) | pH (meq/100 g) |
|-------------------|--------------------|----------------|---------|----------|----------|----------------|
| Fill              | 2.5                | 1.8            | 3.8     | 9.8      | 1433     | 8.4            |
| Native sand       | 3.3                | 2              | 2.8     | 20.5     | 825      | 6.5            |

| Data are means of four replicate samples from each soil type. Analyses were performed by A & L
| Physical and nutrient analysis results of four
| replicate samples of each of these soils was
| determined by A & L Southern Laboratories (2010).
| Chemical and commercial and residential landscapes in Florida.
| and Mn by atomic absorption spectroscopy (Perkin-Elmer, Waltham, MA).

Because the various plant quality mea-
surements used were all to some degree
intercorrelated, principal component analysis

Table 2. Fertilizer treatments applied to areca palms (Dypsis lutescens) planted in calcareous fill or native

| Treatment | Formulation | Application times  | N   | P   | K   | Mg  | Fe  | Mn  | Amount applied (g/m²/year) |
|-----------|-------------|--------------------|-----|-----|-----|-----|-----|-----|---------------------------|
| 1         | No fertilizer |                   | 0   | 0   | 0   | 0   | 0   | 0   |                           |
| 2         | 24–0–11  | February, May, August, November | 23.5 | 0   | 9.0 | 0   | 2.9 | 1.0 |                           |
| 3         | 24–0–11  | February, May, August, November | 23.5 | 0   | 9.0 | 0   | 2.9 | 1.0 |                           |
| 4         | 0–0–16  | February, May, August, November | 0   | 20.0 | 8.8 | 0.9 | 2.9 | 1.0 |                           |
| 5         | 8–0–12  | February, May, August, November | 23.5 | 0   | 30.0| 18.0| 3.5 | 3.8 |                           |
| 6         | 8–0–12  | February, May, August, November | 23.5 | 0   | 30.0| 18.0| 3.5 | 3.8 |                           |
| 7         | 8–2–12  | February, May, August, November | 0.0 | 7.5  | 0   | 0.3 | 1.1 |     |                           |
| 8         | 32–0–10  | February, May, August, November | 23.5 | 0   | 6.1 | 0   | 1.5 | 0   |                           |
| 9         | 32–0–10  | February, May, August, November | 23.5 | 0   | 6.1 | 0   | 1.5 | 0   |                           |

aLesco, Cleveland, OH.

bNurseymen’s Sure Gro, Vero Beach, FL.

cScots Co., Marysville, OH.

N = nitrogen; P = phosphorus; K = potassium; Mg = magnesium; Fe = iron; Mn = manganese.
was used to reduce the five original quality variables to a single index of overall quality, namely the scores on the first principal component (Broschat, 1979). All data were standardized to a mean of 0 and a SD of 1 to eliminate the effects of measurement unit scale differences using PROC STANDARD (SAS Version 9.2; SAS Inst., Cary, NC). Principal component analysis was performed using PROC PRINCOMP with scoring by PROC SCORE. In this analysis the first principal component accounted for $\approx 58\%$ of the variance of the original five variables (Table 3). All five of the original variables showed high positive correlations with the first principal component, making it a useful index of overall quality. Similarly, principal component analysis using only the plant size variables of height and number of leaves produced a useful index for plant size. In this case, the first principal component accounted for nearly 89% of the variability in the original two plant size variables. The plant size and overall plant quality scores as well as the leaf nutrient analysis data were subjected to analysis of variance (PROC GLM) with mean separations done by the Waller–Duncan k-ratio method ($P = 0.05$). Pearson correlation coefficients generated using PROC CORR were used to demonstrate relationships among the various plant quality and nutrient composition variables.

### Results and Discussion

Control plants receiving no fertilizer had the lowest quality scores on both the native sand soil and the calcareous fill soil (Table 4). Analysis of variance on visual rating data showed that unfertilized palms had significantly lower ratings for N, K, and chlorosis than for all fertilized treatments (data not shown).

Fertilization of areca palms with a 24–0–11 or 32–0–11 turf fertilizer (Treatments 2 and 7) significantly reduced overall plant quality on the fill soil but not on the sand soil (Table 4). The use of these fertilizers alone also reduced palm size on the fill soil as did the 32–0–11 fertilizer on the sand soil. However, addition of 0–0–16 to 24–0–11 or 32–0–11-treated palms (Treatments 3 and 8) to maintain proper N:K ratios for palms resulted in plant quality similar to that of palms receiving the standard 8–2–12 fertilizer (Treatment 6) on both soil types. Analysis of variance of the original variables data showed that K ratings, number of leaves (a measure of K deficiency severity), and overall height were significantly lower for palms receiving only the two turf fertilizers on the fill soil (data not shown). Because N ratings were not similarly affected, this reduction in plant quality can be attributed to insufficient K in the turf fertilizers.

For both soils, areca palms fertilized with 8–0–12 year-round (Treatment 4) or 8–0–12 in February, May, and November but 0–0–16 in August (Treatment 5) had equivalent quality as those receiving the standard 8–2–12 fertilizer (Treatment 6) (Table 4). This suggests that P was not a limiting factor in areca palm growth in either soil. Analysis of soil samples from both soil types showed P concentrations of less than 2 ppm (Table 1), levels that are considered very low for most crops (Anon, 2007), but appear to be adequate for areca palms. At no time were symptoms of P deficiency observed on palms in any treatment.

The equivalent quality of areca palms grown with 8–0–12 applied year-round and those receiving 8–0–12 in February, May, and November but 0–0–16 in August also suggests that N is not a limiting factor during the summer months. This may be the result of decomposition of organic matter in the soil releasing N or reserves of N within the plants that are sufficient to carry them over until N is reapplied in November. Nitrate in precipitation may also have been a contributing factor. Broschat et al. (2008) showed that during the rainy summer months in south Florida, unfertilized st. augustinegrass (*Stenotaphrum secundatum*) had quality equal to grass receiving 23 g N/m²/year.

On both soils areca palms receiving only 32–0–10 (Treatment 7) generally had the highest leaf N, P, K, and Fe concentrations (Table 5). Unfertilized control palms growing in the sand soil similarly had high concentrations of N, P, and Mg in their leaves. These were treatments that produced palms with the lowest size scores and overall quality scores (Table 4). Addition of 0–0–16 to palms receiving 32–0–10 resulted in lower leaf N, P, Mg, Mn, and Fe concentrations, but larger size and overall quality, similar to those in palms receiving one of the 8–0–12 treatments.

The high positive correlations (Tables 3 and 6) between N and K deficiency ratings and chlorosis severity with palm size and overall quality suggest that N, K, and a micro-nutrient responsible for the new leaf chlorosis were limiting palm growth and quality. Correlation analysis of the data with both soil types combined showed significant negative correlations between plant size or overall plant quality and leaf concentrations of N, P, K, Mg, and Fe (Table 6). This suggests a strong dilution effect for these elements. However, leaf Mn concentrations were positively correlated with both plant size and overall plant quality, indicating that Mn was likely a deficient and limiting element in this experiment.

Leaf K concentrations were not well correlated with any plant quality or leaf nutrient concentration variable except for leaf N and P (Table 6). Because K is a mobile element within palms, new leaves such as those sampled for nutrient analysis usually show little of the variability in leaf K concentrations that older leaves show and are thus poor indicators of plant K status (Broschat, 1997; Broschat and Elliott, 2004). In general, leaf nutrient concentrations were poorly correlated with the severity of visual deficiency symptoms as a result of these dilution effects.

Chlorosis severity was also negatively correlated with leaf concentrations of all elements except for Mn, suggesting that Mn deficiency had a stronger effect on palm

### Table 3. Correlations of the original areca palm (*Dypsis lutescens*) quality variables with the first principal component for principal component analyses using all plant quality variables (Quality) or only plant size variables (Size).

| Variable          | Quality | Size   |
|-------------------|---------|--------|
| Height            | 0.508   | 0.707  |
| Leaves            | 0.506   | 0.707  |
| Nitrogen rating   | 0.386   |        |
| Potassium rating  | 0.458   |        |
| Chlorosis         | 0.355   |        |
| Eigenvalue        | 2.940   | 1.772  |
| Proportion of variance | 0.588 | 0.868  |

### Table 4. Overall plant quality and size scores for areca palms (*Dypsis lutescens*) grown in native sand soil or a calcareous fill soil in southern Florida.

| Treatment | Fertilizer | Application times | Native sand soil | Calcareous fill soil |
|-----------|------------|-------------------|------------------|---------------------|
|           | Quality score | Size score | Quality score | Size score |
| No fertilizer | 89.5 b | 95.6 b | 58.3 b | 67.7 b |
| 24–0–11   | 101.2 ab | 119.8 ab | 68.1 b | 79.6 b |
| 24–0–11   | 105.0 ab | 124.6 ab | 91.4 a | 107.5 a |
| 0–0–16    | 114.6 a | 136.6 a | 92.6 a | 109.1 a |
| 8–0–12    | 115.9 a | 136.6 a | 91.1 a | 111.2 a |
| 8–0–12    | 116.6 a | 138.1 a | 93.9 a | 108.6 a |
| 8–0–10    | 100.2 ab | 118.6 ab | 89.3 a | 103.1 a |
| 8–0–10    | 100.2 ab | 118.6 ab | 89.3 a | 103.1 a |
| 0–0–16    | 100.2 ab | 118.6 ab | 89.3 a | 103.1 a |
| P value   | 0.033 | <0.0001 | <0.0001 | <0.0001 |

*Data are means for nine replicate palms for each treatment and soil type.

†Mean separation within columns by the Waller–Duncan k-ratio method, $P = 0.05$.**

*HortScience Vol. 50(3) March 2015*
growth than on chlorosis severity. Thus, more chlorotic palms did not have lower Mn concentrations in their leaves because reduced growth rates reduced the chances for Mn dilution within these plants. All of the palms in both soil types had extremely low leaf Mn concentrations with some below the detection limits for this element by our analytical methods (Table 5). In contrast, Mills and Jones (1996) consider 47 ppm to be the lower sufficiency limit for this species. With the exception of Mg, all of the other elements examined in this study were within the sufficiency range given for areca palms.

| Table 5. Nutrient concentrations for areca palms (*Dypsis lutescens*) grown in calcareous fill or native sand soils in southern Florida.* |
|---|---|---|---|---|---|---|---|
| Soil | Treatment | Fertilizer Application times | N (%) | P (%) | K (%) | Mg (ppm) | Mn (ppm) | Fe (ppm) |
| Fill | None | 24–0–11 February, May, August, November | 1.48 b | 0.14 bc | 0.75 b | 1,551 | 5.3 bc | 33.2 cd |
| Fill | None | 24–0–11 February, May, August, November | 1.16 c | 0.10 d | 0.66 b | 1,197 | 12.4 ab | 33.6 cd |
| Fill | None | 8–0–12 February, May, August, November | 1.26 bc | 0.11 d | 0.67 b | 1,390 | 15.5 a | 42.2 bc |
| Fill | None | 8–0–12 February, May, November | 1.12 c | 0.11 d | 0.64 b | 1,263 | 3.3 c | 35.0 cd |
| Fill | None | 8–2–12 August | 1.24 bc | 0.14 b | 0.98 a | 1,639 | 7.0 bc | 27.0 d |
| Fill | None | 32–0–10 February, May, August, November | 1.80 a | 0.17 a | 1.09 a | 1,596 | 0.1 c | 55.0 a |
| Fill | None | 32–0–10 February, May, August, November | 1.29 bc | 0.12 cd | 0.76 b | 1,232 | 5.4 bc | 35.2 cd |
| Fill | None | 32–0–10 August | 1.45 ab | 0.12 bcd | 0.75 b | 1,242 abc | 3.0 c | 41.8 |
| Fill | None | 24–0–11 February, May, August, November | 1.53 ab | 0.12 bcd | 0.69 c | 1,242 abc | 3.0 c | 41.8 |
| Fill | None | 24–0–11 February, May, August, November | 1.43 bc | 0.10 c | 0.65 c | 1,059 c | 18.5 a | 37 |
| Fill | None | 24–0–11 August | 1.31 bc | 0.11 de | 0.64 c | 1,052 c | 7.0 c | 34.4 |
| Fill | None | 8–2–12 August | 1.37 ab | 0.14 ab | 0.93 ab | 1,337 ab | 23.5 a | 33.7 |
| Fill | None | 32–0–10 February, May, August, November | 1.48 ab | 0.14 ab | 0.99 a | 1,335 ab | 0.7 c | 50.2 |
| Fill | None | 32–0–10 August | 1.25 c | 0.13 bc | 1.04 a | 1,252 abc | 3.7 c | 35.8 |

**P value**

| Fill | None | 0.0001 | <0.0001 | 0.0006 | 0.05 | 0.0015 | 0.0001 |
|----|----|----|----|----|----|----|----|

| Sand | None | 1.57 a | 0.15 a | 0.72 bc | 1,384 a | 7.9 bc | 49.7 |
|----|----|----|----|----|----|----|----|
| Sand | None | 1.53 ab | 0.12 bcd | 0.69 c | 1,242 abc | 3.0 c | 41.8 |
| Sand | None | 1.43 bc | 0.10 c | 0.65 c | 1,059 c | 18.5 a | 37 |
| Sand | None | 1.31 bc | 0.11 de | 0.64 c | 1,052 c | 7.0 c | 34.4 |
| Sand | None | 1.37 ab | 0.14 ab | 0.93 ab | 1,337 ab | 23.5 a | 33.7 |
| Sand | None | 1.48 ab | 0.14 ab | 0.99 a | 1,335 ab | 0.7 c | 50.2 |
| Sand | None | 1.25 c | 0.13 bc | 1.04 a | 1,252 abc | 3.7 c | 35.8 |
| Sand | None | 1.45 ab | 0.12 bcd | 0.75 b | 1,242 abc | 3.0 c | 41.8 |
| Sand | None | 1.43 bc | 0.10 c | 0.65 c | 1,059 c | 18.5 a | 37 |
| Sand | None | 1.31 bc | 0.11 de | 0.64 c | 1,052 c | 7.0 c | 34.4 |
| Sand | None | 1.37 ab | 0.14 ab | 0.93 ab | 1,337 ab | 23.5 a | 33.7 |
| Sand | None | 1.48 ab | 0.14 ab | 0.99 a | 1,335 ab | 0.7 c | 50.2 |
| Sand | None | 1.25 c | 0.13 bc | 1.04 a | 1,252 abc | 3.7 c | 35.8 |

**P value**

| Sand | None | 0.043 | <0.0001 | 0.0005 | 0.0018 | <0.0001 | NS |
|----|----|----|----|----|----|----|----|

*Data represent means from nine replicate plants per treatment.

Mean separation by the Waller–Duncan k-ratio method, \( P = 0.05 \).

N = nitrogen; P = phosphorus; K = potassium; Mg = magnesium; Mn = manganese; Fe = iron; NS = nonsignificant.

**Table 6. Pearson correlations among quality, size, nitrogen and potassium deficiency ratings, new leaf chlorosis severity, and leaf nutrient concentration variables in areca palms (*Dypsis lutescens*).**

| Quality | Size | Ht | Leaves | N rating | K rating | Chlorosis | Leaf N | Leaf K | Leaf Mg | Leaf Mn | Leaf Fe |
|---------|------|----|--------|----------|----------|-----------|--------|-------|--------|--------|--------|
| Quality | 1.000 |     | 1.000 |          |          |           |        |       |        |        |        |
| Size    | 0.993 | 1.000 |     |          |          |           |        |       |        |        |        |
| Height  | 0.999 | 0.999 | 1.000 |          |          |           |        |       |        |        |        |
| Leaves  | 0.787 | 0.785 | 0.772 | 1.000    |          |           |        |       |        |        |        |
| N rating | 0.397 | 0.385 | 0.381 | 0.406    | 1.000    |           |        |       |        |        |        |
| K rating | 0.548 | 0.535 | 0.532 | 0.501    | 0.372    | 1.000     |        |       |        |        |        |
| Chlorosis | 0.406 | 0.387 | 0.384 | 0.374    | 0.485    | 0.330     | 1.000  |       |        |        |        |
| Leaf N  | –0.180 | –0.174 | –0.172 | –0.195   | –0.338   | –0.253    | –0.331 | 1.000  |        |        |        |
| Leaf P  | –0.428 | –0.423 | –0.422 | –0.277   | –0.517   | –0.386    | –0.463 | 0.283  | 0.632  | 0.476  | 1.000  |
| Leaf K  | –0.128 | –0.127 | –0.132 | 0.057    | 0.020    | 0.001     | 0.001  | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| Leaf Mg | –0.480 | –0.473 | –0.476 | –0.260   | –0.412   | –0.354    | –0.412 | 0.283  | 0.632  | 0.476  | 1.000  |
| Leaf Mn | 0.329  | 0.329  | 0.330  | 0.213    | 0.200    | 0.092     | –0.005 | –0.304 | –0.186 | –0.291 | 1.000  |
| Leaf Fe | –0.256 | –0.251 | –0.247 | –0.302   | –0.294   | –0.276    | –0.367 | 0.523  | 0.356  | 0.011  | –0.004 | 1.000  |

*Numbers below correlation coefficients are \( P \) values (n = 121).

N = nitrogen; P = phosphorus; K = potassium; Mg = magnesium; Mn = manganese; Fe = iron; NS = nonsignificant.
Anon, 2007. Procedures used by state soil testing laboratories in the southern region of the United States. Southern Cooperative Series Bull. No. 190-D.

Broschat, T.K. 1979. Principal component analysis in horticultural research. HortScience 14:114–117.

Broschat, T.K. 1984. Nutrient deficiency symptoms in five species of palms grown as foliage plants. Princes 28:6–14.

Broschat, T.K. 1990. Potassium deficiency of palms in south Florida. Princes 34:151–155.

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. 1999. Nutrition and fertilization of palms. Palms 43:73–76.

Broschat, T.K. 2005a. Fertilization of field-grown and landscape palms in Florida. Univ. Fla. Env. Hort. Dept. Circ. ENH1009. 19 Feb. 2015. <http://edis.ifas.ufl.edu/ep261>.

Broschat, T.K. 2005b. Nutrient deficiencies of landscape and field-grown palms in Florida. Univ. Fla. Env. Hort. Dept. Circ. ENH1018. 19 Feb. 2015. <http://edis.ifas.ufl.edu/ep273>.

Broschat, T.K. 2009. Palm nutrition and fertilization. HortTechnology 19:690–694.

Broschat, T.K. and M.L. Elliott. 2004. Nutrient distribution and sampling for leaf analysis in st. augustinegrass. Commun. Soil Sci. Plant Anal. 35:2357–2367.

Broschat, T.K. and M.L. Elliott. 2005. A key to common landscape palm disorders and diseases in the continental United States. Palms 49:143–148.

Broschat, T.K. and M.L. Elliott. 2009. Effects of fertilization and microbial inoculants applied at transplanting on the growth of Mexican fan palm and queen palm. HortTechnology 19:324–330.

Broschat, T.K. and E.F. Gilman. 2013. Effects of fertilization and pruning on canopy leaf number and potassium deficiency symptom severity in Sabal palmetto. Palms 57:84–88.

Broschat, T.K. and K.A. Moore. 2010. Effects of fertilization on the growth and quality of container-grown areca palms and Chinese hibiscus during establishment in the landscape. HortTechnology 20:389–394.

Broschat, T.K. and K.A. Moore. 2012. Fertilization rate and placement effects on areca palms transplanted from containers or a field nursery. Arboriculture and Urban Forestry 38:146–150.

Broschat, T.K., D.R. Sandrock, M.L. Elliott, and E.F. Gilman. 2008. Effects of fertilizer type on quality and nutrient content of established landscape plants in Florida. HortTechnology 18:278–285.

Bull, R.A. 1958. Symptoms of calcium and phosphorus deficiency in oil palm. Nature 182:1749–1750.

Conley, D.J., H.W. Paerl, R.W. Howarth, D.F. Boesch, S.P. Seitzinger, K.E. Havens, C. Lancelot, and G.E. Likens. 2009. Controlling eutrophication: Nitrogen and phosphorus. Science 323:1014–1015.

Elliott, M.L., T.K. Broschat, J.Y. Uchida, and G.W. Simone. 2004. Compendium of ornamental palm diseases and disorders. Amer. Phytopath. Soc. Press, St. Paul, MN.

Hach, C.C., B.K. Bowden, A.B. Koplove, and S.V. Brayton. 1987. More powerful peroxide Kjeldahl digestion method. J. Offic. Anal. Chem. 70:783–787.

Kabata-Pendas, A. and H. Pendas. 1984. Trace elements in soils and plants. CRC Press, Boca Raton, FL.

Kao, S. 1996. Phosphorus, p. 869–920. In: Bartels, J.M. (ed.). Methods of soil analysis. Part 3. Chemical methods. Soil Sci. Soc. Amer., Madison, WI.

Lindsay, W.L. 1991. Inorganic equilibria affecting micronutrients in soils, p. 89–112. In: Mortvedt, J.J., F.R. Cox, L.M. Shuman, and R.M. Welch (eds.). Micronutrients in agriculture. 2nd ed. Soil Sci. Soc. Amer., Madison, WI.

Mills, H.A. and J.B. Jones, Jr. 1996. Plant analysis handbook II. Micro-Macro Publishing, Athens, GA.

Paerl, H.W. 2009. Controlling eutrophication along the freshwater-marine continuum: Dual nutrient (N and P) reductions are necessary. Estuaries 32:593–601.

U.S. Environmental Protection Agency. 1995. National water quality: 1994 report to Congress (appendices). U.S. Environmental Protection Agency, Washington, DC.