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Leaf Nutrient Levels for Pecans

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Leaf Nutrient Levels for Pecan in Southern Arizona

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Abstract

Measurement of nutrients in leaf tissue is a practical method of monitoring the nutritional status of perennial crops such as pecan (Carya illinoensis, Wang. C. Koch). Accurate interpretations require known standard concentrations for the crop and region. To determine standard concentrations for pecans, focusing on those grown in the desert southwest, we conducted a survey of 135 'Western Schley' pecan trees in Arizona for two years. Leaf nutrient concentrations and yield were collected for each tree. Leaf nutrient concentrations from the highest yielding trees (50th yield percentile) were used to calculate a mean and coefficient of variation (CV) for each nutrient. Results were compared to data from New Mexico, Georgia, and Sonora Mexico. Relatively large differences were noted in mean K, Ca, B, Cu, Fe, Mn, and Zn levels. Nutrient interpretation ranges were calculated based on Arizona population statistics using the Balance Index method.

Leaf sampling provides a practical means for evaluating plant nutrient status because leaf tissue composition reflects the amount of nutrients taken up and assimilated by the plant. Leaf tissue analysis has been widely used for nutrient evaluation of a large range of crop species, and it is particularly useful for monitoring long-term fertility management in perennial crops, such as pecans (O'Barr and McBride, 1980).

The procedures for collecting, handling, and analyzing pecan leaves for nutrient concentration are well established (Herrera, 2000; O'Barr and McBride, 1980). The middle pairs of leaflets are collected from the middle leaves of the current year's growth after shoot growth has terminated. Leaflets are collected from all sides of each tree. In the southwest U.S. the recommended sampling period is from late July to early August. For analyses of leaf samples to be useful, nutrient concentrations must be compared against standard nutrient values. It is critical that appropriate standards be used for interpretations to be valid.

It is recognized that crop plants grown in various regions of the country may vary in nutrient composition, even though the crops grown in each region may be healthy. For example, Walworth and Sumner (1988) noted that the acceptable ear leaf Mg level for corn (*Zea mays,* L.) grown in the acidic, highly weathered soils of the Southeastern U.S. is lower than that for corn grown in the midwestern part of the country. Thus, it is desirable to generate plant leaf tissue standards in the same geographic and climatic area in which trees are to be sampled. Comparison of nutrient analysis results with incorrect standards can lead to errors in interpretation and subsequent fertilization practices.

Establishment of nutrient standards requires a data base that links crop yield parameters (yield and quality) with leaf nutrient levels. It is further necessary to have a range of both leaf nutrient levels and crop yields. Kenworthy (1961) developed a method for use in perennial orchard species wherein natural and grower-induced variation are utilized rather than that imposed via fertilizer treatments in typical experimental designs. This method precludes development of direct relationships between leaf nutrient concentration and yield, or use of statistical regression. However, Kenworthy found that the mean tissue concentration from the higher yielding members of a data set generated in this fashion provided a good estimate of acceptable nutrient concentration values. Furthermore, he found that the coefficient of variation (CV) associated with this population of data points provides a practical method of determining the normal or acceptable range of each nutrient.

We conducted a two year survey of production pecan orchards in Arizona to generate a data base for development of leaf tissue nutrient standards. We utilized similar surveys conducted in New Mexico, Georgia, and Sonora, Mexico for comparative purposes.

Materials and Methods

Plots were established in 2003 in 27 blocks of 'Western Schley' pecans in 12 orchards across southeastern Arizona, thus providing a wide range of soils and management techniques including pruning, tree spacings, and irrigation regimes. In each block, 5 trees with heavy nut crops (identified visually) were selected to be monitored, giving a total of 135 trees. A composite leaf sample was collected from each tree following standard leaf sampling protocol (O'Barr and McBride, 1980; Herrera, 2000). Samples were immediately refrigerated for transport to the laboratory, where they were washed in a dilute phosphate-free detergent, rinsed three times in deionized water, and finally rinsed in ultra-pure (18.2 MΩ) water. Leaves were then dried for 24 hrs at 60^{o} C and ground with a mortar and pestle. Samples were analyzed for N by combustion using a Leco FP528. Ground leaf tissue was digested using a block digester (Martin Machine, Magnum Series F-4) with HNO_3, HCl, and H_2O_2. All remaining nutrients (Ca, Mg, K, P, S, B, Zn, Fe, Mn, Ni, and Cu) were measured in the digestate by ICP on a Spectro Modula M120 (Kalra and Maynard, 1998).

Yield data were collected by manually gathering nuts from wedge-shaped areas under each tree at the end of the growing season (Worley and Smith, 1984). Each wedge constituted 1% of the area under each tree. Four wedges were sampled per tree. The harvested samples were cleaned to remove shucks and debris, and allowed to air dry. The sample was weighed and yields were converted to "per hectare" yields based on orchard tree spacing. This procedure was repeated using the same trees in 2004 thus giving us data from both an "on" and "off" year. The only change was a reduction in the number of trees to 120, as several blocks were lost due to land development.

A database was constructed such that the data from each tree, in each year, represented one data point. It has been demonstrated using the high-yielding members of a data base reduces skew, although the actual yield cutoff selected has a minimal impact on relevant population statistics (Letzsch and Sumner, 1984). Data were sorted based on yield and, using the 50th yield percentile as a cutoff, trees yielding less than 1121 kg per hectare were discarded from the data set. The means and CVs for each element were determined using the remaining high yield trees.

Recommended concentration ranges were determined using the Balance Index method of Kenworthy (1961). This method normalizes sample nutrient concentrations based on a standard value (the mean concentration) and the CV via the following equations, where X = sample nutrient concentration; CV = coefficient of variation; S = population mean; and B = balance index.

$$B = \left[\left(\frac{X}{S} \right) \times 100 \right] - \left[\left(100 - \left\{ \left(\frac{X}{S} \right) \times 100 \right\} \right) \times \left(\frac{CV}{100} \right) \right]$$

if X < S and

$$B = \left[\left(\frac{X}{S} \right) \times 100 \right] - \left[\left(\left\{ \left(\frac{X}{S} \right) \times 100 \right\} - 100 \right) \times \left(\frac{CV}{100} \right) \right]$$

if X > S.

"Low" nutrient concentration ranges are defined by balance indices falling between 50 and 82, "normal" nutrient concentration ranges by balance indices between 83 and 116, and "high" by indices from 117 to 150 (Kenworthy, 1961).

Arizona data were compared to nutrient concentrations reported for Georgia pecans by Beverly and Worley (1992), concentrations calculated from data collected in the Mesilla Valley in New Mexico (McCaslin and Boyse, 1999), and concentrations from data collected in Sonora, Mexico (Núñez, et al., 2001). The Georgia concentrations were based on the 75th yield percentile (n range = 274 to 641), whereas the New Mexico and Arizona values were based on the 50th yield percentile (AZ n=237; NM n=22). A lower yield cutoff was selected for the New Mexico and Arizona data because those data sets contain fewer members and higher overall yield levels. As noted (Letzsch and Sumner, 1984), the yield cut off had a negligible effect on nutrient concentration means. The Sonora, Mexico data were only collected from high-yielding trees, so the entire database population was used (n=30). Means were compared by ANOVA and separated by least significant difference ($LSD_{0.05}$).

Results and Discussion

Mean leaf nutrient concentrations determined from data collected in Arizona, along with those from Georgia, New Mexico, and Sonora Mexico are presented in Table 1. The mean N concentrations from New Mexico (24.7 $g \cdot kg^{-1}$) and Sonora (24.8 $g \cdot kg^{-1}$) were nearly identical and lower ($P<0.05$) than that from Arizona (25.5 $g \cdot kg^{-1}$), whereas those from Georgia (27.2 $g \cdot kg^{-1}$) were significantly higher than Arizona. The values from the three western locations are at the bottom of, or below the sufficiency ranges reported by Jones et al. (1991) (27.0 - 35.0 $g \cdot kg^{-1}$) or Robinson et al. (1997) (25.0 - 30.0 $g \cdot kg^{-1}$), suggesting that current standards may be too high. The phosphorus mean from Georgia (1.40 $g \cdot kg^{-1}$) was significantly higher than those from Arizona or New Mexico (1.32 and 1.30 $g \cdot kg^{-1}$, respectively). All levels are near the bottom of or below current sufficiency ranges reported by Jones et al. (1991) and Robinson et al. (1997) (1.4 - 3.0, and 1.2 - 3.0 $g \cdot kg^{-1}$, respectively), suggesting that the published ranges are too high for nut-bearing pecans. However, in contrast to the values from this study and the others cited here, Sparks (1989) reported that dry weight of pecan seedlings was maximized by leaf P levels of 1.9 to 2.2 $g \cdot kg^{-1}$, although deficiency symptoms were only noted when leaf P fell to 0.8 $g \cdot kg^{-1}$. Potassium means ranged from 9.1 to 13.3 $g \cdot kg^{-1}$ versus sufficiency ranges of 12.5 - 25.0 and 7.5 - 15.0 $g \cdot kg^{-1}$ (Jones et al., 1991 and Robinson et al, 1997, respectively).

Calcium levels were higher in leaves collected from Arizona trees (20.2 $g \cdot kg^{-1}$) compared to other locations (14.5 to 15.9 $g \cdot kg^{-1}$). The mean value from Arizona was above the sufficiency range of Jones et al. (1991) (10.0 - 17.5 $g \cdot kg^{-1}$). Magnesium levels were also highest in Arizona samples and lowest in those from Georgia. The differences in Ca and Mg levels may be reflective of the relatively high base saturation generally found in arid region soils versus the acidic, highly leached soils of Georgia. As noted previously, ear leaf Mg levels were lower in corn grown in Georgia than in the younger, less weathered soils of the Midwest. All of the Mg levels were considerably higher than leaf Mg levels causing Mg deficiency (2.0 $g \cdot kg^{-1}$) (Sparks,1976a) and are within recommended sufficiency ranges of 3.0 - 6.0 $g \cdot kg^{-1}$ (Jones, et al., 1991) and 3.0 - 7.0 $g \cdot kg^{-1}$ (Robinson et al., 1997).

Boron levels were higher in Arizona and New Mexico than in Georgia. Arizona and New Mexico values (111 and 137 $mg \cdot kg^{-1}$, respectively) are higher than the sufficiency ranges of Jones et al. (1991) (15 - 50 $mg \cdot kg^{-1}$) or Robinson et al. (1997) (20 - 50 $mg \cdot kg^{-1}$). Blackmon and Winsor (1946) reported B toxicity associated with a leaf concentration of 530 $mg \cdot kg^{-1}$, and recommended 312-375 $mg \cdot kg^{-1}$ as a safe level.

Copper concentrations in New Mexico samples were higher than in those from other locations. All were within the sufficiency ranges of Jones et al. (1991) (6 - 30 $mg \cdot kg^{-1}$) and Robinson et al. (1997) (5 - 50 $mg \cdot kg^{-1}$).

Mean Fe levels were much higher in Sonora Mexico leaves (214 $mg \cdot kg^{-1}$) than in leaves from other locations. The leaves from Sonora were washed prior to analysis, so we do not believe that soil contamination is the source of the leaf Fe, but offer no explanation for the observed levels. Leaf Fe concentrations in samples collected in Sonora during the 2005 growing season were found to be similar to those reported here (data not shown). Georgia Fe levels (89 $mg \cdot kg^{-1}$) are higher than those from Arizona (62 $mg \cdot kg^{-1}$) or New Mexico (67 $mg \cdot kg^{-1}$), differences that may be related to the relatively weathered, acidic soils found in Georgia. Sparks (1976b) noted Fe deficiency symptoms when leaf Fe concentrations were 50 mg·kg^{-1}, whereas trees with 64 mg·kg^{-1} had no symptoms. Iron is considered sufficient if it is between 50 - 300 mg·kg^{-1} (Jones et al., 1991; Robinson et al., 1997).

Manganese levels in pecan leaves collected in Arizona (397 mg·kg^{-1}) were higher ($P<0.05$) than those from Georgia (324 mg·kg^{-1}) and Sonora (324 mg·kg^{-1}), and considerably higher than those from New Mexico (85 mg·kg^{-1}). High Mn levels were expected in pecans grown in acidic, Southeastern soils, but not in those grown in alkaline Arizona and Sonora soils. The reason for high levels of Mn in Arizona and Sonora trees is not known; however, Mn toxicity was visually identified, and leaf concentrations exceeding 5000 mg·kg^{-1} were observed during the Arizona survey (data not shown). Manganese levels in New Mexico pecans may be lower because the surveyed area is comprised of relatively sandy river valley soils, whereas Arizona and Sonora pecan production is largely on upland soils. Deficiency symptoms have been related to a leaf Mn level of 7 mg·kg^{-1} (Smith and Cheary, 2001) and toxicity with a level of 577 mg·kg^{-1} (Storey et al., 1985), however trees in the Arizona survey with levels of 800 - 1000 mg·kg^{-1} did not exhibit toxicity symptoms. Sufficiency ranges have been reported to be 200 - 500 mg·kg^{-1} (Jones et al., 1991) and 150 - 500 mg·kg^{-1} (Robinson et al., 1997).

All of the trees in the Arizona survey were foliarly fertilized with Zn. Not surprisingly, the mean Zn level was 174 mg·kg^{-1}, which is well above the sufficiency range of 50 - 100 mg·kg^{-1} (Jones et al., 1991; Robinson et al., 1997). Zinc levels from the other locations were lower ($P<0.05$) than those found in Arizona, but still within the sufficiency range.

"Low", "normal", and "high" nutrient ranges were constructed based on the ranges of the Balance Index method (Kenworthy, 1961) from the Arizona data (Table 2). In general, all the nutrient ranges are in agreement with published ranges. However, the lower limit of the Arizona N range (20.5 $g \cdot kg^{-1}$) is considerably lower than that of Jones et al. (1991) (27.0 $g \cdot kg^{-1}$) or Robinson et al. (1997) (25.0 $g \cdot kg^{-1}$), suggesting that the published ranges may be too high. Similarly, the lower end of the Arizona normal P range is below the published ranges. In contrast, the Arizona Ca range (15.7 - 24.2 $g \cdot kg^{-1}$) is higher than the published ranges (10.0 - 17.5 and 7.0 - 15.0, Jones et al., 1991 and Robinson et al., 1997, respectively), as is the lower limit of our Mg range.

The Arizona B range (74- 146 $mg \cdot kg^{-1}$) is considerably higher than the published ranges of Jones et al. (1991) and Robinson et al.(1997), but close to the New Mexico range of 50 - 200 $mg \cdot kg^{-1}$ of Herrera (1998). The bottom of "normal" Fe range for Arizona (43-81 $mg \cdot kg^{-1}$) is lower than the concentration reported to coincide with Fe deficiency symptoms by Sparks (1976b), but similar to the ranges of Herrera (1998) (50-250 $mg \cdot kg^{-1}$) and of Jones et al. (1991) and Robinson et al.(1997) (50 – 300 $mg \cdot kg^{-1}$). No visual Fe deficiency symptoms were observed in any of the Arizona trees monitored.

The "normal" range of Mn levels in Arizona is 104 - 674 $mg \cdot kg^{-1}$. This range is much broader than those of Jones et al. (1991) and Robinson et al.(1997), but close to the New Mexico range of 100 - 600 $mg \cdot kg^{-1}$ of Herrera (1998). In addition, observations suggest that Mn concentration can exceed the Arizona range without noticeable deleterious effects and that Mn toxicity does not occur until leaf Mn concentrations are above 1200 $mg \cdot kg^{-1}$ (data not shown).

Mouse-ear in pecan trees in Georgia has recently been related to nickel deficiency in trees with leaf Ni concentrations below 4.0 $mg \cdot kg^{-1}$ (Wood et al., 2004). This concentration falls into the middle of the "low" range of concentrations for Arizona trees. Therefore, staying within the normal range should help to prevent this disease.

The leaf Zn concentration range from the Arizona study is probably not reflective of tree Zn requirements because foliar Zn applications were made to all trees in the survey. Although the collected leaves were thoroughly washed to remove spray residues, the "normal" Zn concentration range of 86-257 $mg \cdot kg^{-1}$ was higher than other published ranges or the 48 $mg \cdot kg^{-1}$ critical concentration reported by Sparks (1994). Thus the Arizona data may be skewed by an abundance of trees with excessive Zn concentrations resulting from foliar Zn applications.

Leaf nutrient concentration ranges developed through this study are suggested for regional interpretation of pecan leaf samples. The variations noted in mean nutrient concentrations from Arizona, Georgia, New Mexico, and Sonora Mexico suggest that regional nutrient sufficiency ranges should be considered to ensure accurate nutritional diagnoses.

Literature Cited

Beverly, R.B. and R.E. Worley. 1992. Preliminary DRIS diagnostic norms for pecan. HortScience 27:271.

Blackmon, G. H. and H. W. Winsor. 1946. Boron uptake in pecans. Amer. Soc. Hort. Sci. 47:149-152.

Herrera, E. 2000. Sampling pecan leaves for analysis. College of Agriculture and Home Economics Guide H-619. New Mexico State University, Las Cruces, NM.

Herrera, E. 1998. Interpreting leaf analysis and deficiency symptoms of pecans. College of Agriculture and Home Economics Guide H-617. New Mexico State University, Las Cruces, NM.

Jones, J.B. Jr., B. Wolf, and H.A. Mills. 1991. Plant Analysis Handbook. Micro-Macro Publishing, Inc., Athens, GA.

Kalra, Y.P. and D.G. Maynard. 1998. Microwave digestion of plant tissue in an open vessel. p. 63-67. *In* Yash Kalra (ed.) Handbook of Reference Methods for Plant Analysis. CRC Press, New York

Kenworthy, A.L. 1961. Interpreting the balance of nutrient-elements in leaves of fruit trees. p. 28-43. *In* Walter Reuther (ed.) Plant Analysis and Fertilizer Problems. Amer. Inst. Biol. Sci., Pub. No. 8, Washington D.C.

Letzsch, W.S. and M. E. Sumner. 1984. Effect of population size and yield level in selection of diagnosis and recommendation integrated system (DRIS) norms. Commun. Soil Sci. Plant Anal. 15:997-1006.

McCaslin, R.D. and L.G. Boyse. 1999. Nutrient status of pecans in the mesilla valley. Western Pecan Conference Proceedings, 33: 89-94. Las Cruces, New Mexico, March 7-9, 1999.

Núñez, J.H.M . 2001. Nutricion y fertilizacion. P. 63-91. In: Núñez, J.H.M., B.G.Valdez, G.D. Gerardo, E.C. Valenzuela. El nogal pecanero en Sonora. Libro Tecnico No. 3. Instituto Nacional de Investigaciones Forestales, Agricolas Y Pecuarias. Hermisillo, Sonora, Mexico.

O'Barr, R.D., and J.M. McBride. 1980. Pecan leaf sampling for commercial groves. Pecan South 7(3):42-44.

Robinson, J.B., M. Treeby, and R.A. Stephenson. 1997. Fruits, vines and nuts. P. 347-382. In: D.J. Reuter and J.B. Robinson (eds.) Plant analysis, an interpretation manual. CSIRO Publishing, Collingwood, Victoria, Australia.

Smith, M.W. and B.S. Cheary. 2001. Manganese deficiency in pecan. HortScience 36(6):1075-1076.

Sparks, D. 1976a. Magnesium nutrition & the pecan - A review. Pecan South 13(3):384-387.

Sparks, D. 1976b. Iron deficiency in pecans. Pecan South 13(4):448-449.

Sparks, D. 1989. Current recommendations for leaf P levels too low, study shows. Pecan South 23(1):9-13.

Sparks, D. 1994. Leaf zinc for maximum yield, growth in pecan. Pecan South 27(2):19-24.

Storey, J.B., D. Joy, and L. Sistrunk. 1985. Manganese toxicity shows up as brown specks on pecan leaves. Pecan South 19(6):32-33.

Walworth, J.L., and M.E. Sumner. 1988. Foliar diagnosis: A review. p. 193-241. In B. Tinker and A. Läuchli (eds) Advances in Plant Nutrition, Vol. 3. Praeger, New York.

Wood, B.W., C.C. Reilly, and A.P. Nyczepir. 2004. Mouse-ear of Pecan: A Nickel Deficiency. HortScience 39(6): 1238-1242

Worley, R. E. and M. Smith 1984. A method of estimating pecan yield. J. Amer. Soc. Hort. Sci. 19: 664.

Table 1. Means of leaf nutrient concentrations from high-yielding trees in commercial pecan orchards in Arizona, Georgia, New Mexico, and Sonora Mexico.

		Arizona	New Mexico[w]	Sonora[x]	Georgia[y]
Nitrogen		25.5b[z]	24.7c[z]	24.8c[z]	27.2a[z]
Phosphorus		1.32b	1.30b	--	1.40a
Potassium		12.6b	13.3a	9.1d	10.2c
Calcium	$g\cdot kg^{-1}$	20.2a	14.7c	15.9b	14.5c
Magnesium		4.94a	4.17c	4.6b	3.82d
Sulfur		1.72b	2.23a	--	--
Boron		111b	137a	--	40c
Copper		7.9c	12.0a	7.2d	9.69b
Iron		62c	67c	214a	89b
Manganese	$mg\cdot kg^{-1}$	397a	85c	324b	324b
Nickel		11.4	--	--	--
Zinc		174a	73c	54.6d	126b

[w] McCaslin and Boyse, 1999

[x] Núñez et al., 2001.

[y] Beverly and Worley, 1992

[z] Numbers in each row followed by different letters are statistically different at the 0.05 level based on ANOVA with separation by least significant difference ($LSD_{0.05}$).

Table 2. “Low”, “Normal”, and “High” pecan leaf tissue nutrient concentration ranges based on population means and coefficients of variation of Arizona pecan trees in the 50th yield percentile of sampled trees, and previously published nutrient sufficiency ranges.

Nutrient		Low	Normal	High	Sufficiency Range	
					Jones et al., 1991	Robinson et al., 1997
Nitrogen		11.5-20.4	20.5-29.5	29.6-38.5	27.0-35.0	25.0-30.0
Phosphorus		0.3-0.9	1.0-1.5	1.6-2.3	1.4-3.0	1.2-3.0
Potassium		4.5-9.9	10.0-15.8	15.9-21.5	12.5-25.0	7.5-15.0
Calcium	$g \cdot kg^{-1}$	7.2-15.8	15.7-24.2	24.3-32.6	10.0-17.5	7.0-15.0
Magnesium		1.8-3.8	3.9-5.8	5.9-8.0	3.0-6.0	3.0-7.0
Sulfur		0.7-1.3	1.4-1.9	2.0-2.7	--	1.5-2.5
Boron		4-73	74-146	147-217	15-30	25-30
Copper		3-5	6-9	10-13	6-30	5-50
Iron		6-42	43-80	81-118	50-300	50-300
Manganese	$mg \cdot kg^{-1}$	0-103	104-673	674-1227	200-500	150-300
Nickel		2.8-8.4	8.5-14.2	14.3-20.0	--	--
Zinc		0-85	86-256	257-423	50-100	50-100