Effects of Foliar-applied Boron on Fruit Retention, Fruit Quality, and Tissue Boron Concentration of Pecan

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Abstract. Previous studies with a variety of tree species have demonstrated enhanced flowering, fruit set, and yield with foliar boron (B) applications. The effects of foliar-applied B on pecan [*Carya illinoensis* (Wangenh.) K. Koch] in the southeastern United States are poorly understood. This study was undertaken to investigate the effect of foliar B application on leaf tissue B concentration, fruit retention, and kernel quality of pecan. Controlled pollination studies showed no effect of B on fruit retention of ‘Stuart’ pecan. Tissue B concentration, fruit retention, and percent kernel of ‘Desirable’ pecan were occasionally enhanced by both two and five B applications made before and through the pollination window in multiple studies over 3 years. As long as leaf B is within the recommended sufficiency range, timing of foliar B application during the critical prepollination period appears to be more valuable for pecan production than are increasing leaf B levels. Given the production enhancements observed here, and the low cost of B fertilizers, the practice of foliar B application merits consideration as a component of pecan orchard management when tank-mixed with normal prepollination pesticide or nutrient sprays.

Foliar boron (B) applications have been observed to promote flowering, fruit set, and yield in a variety of perennial tree crops (Batjer and Thompson, 1949; Hanson et al., 1985; Nyomora et al., 1999; Stephenson and Gallagher, 1987). Because B is passively absorbed and transported through the transpirational stream, deficiencies of B may be transitory (Brown et al., 1996; Hu and Brown, 1997; Raven, 1980). Such deficiencies commonly occur during periods of rapid plant growth, especially during flowering and seed set. Premature flower and fruit drop of tree crops has been attributed to B deficiency, suggesting that B movement to reproductive structures is restricted or that growth and development of floral structures have a higher demand for B than do vegetative structures (Dell and Huang, 1997).

Reductions in crop yield and quality in low B soils potentially result from impaired reproductive development during the flowering/fruiting cycle (Dell and Huang, 1997). Pecan [*Carya illinoensis* (Wangenh.) K. Koch] is a wind-pollinated, monoecious crop

exhibiting heterodichogamy. Main pecan cultivars in a block require a pollinizer with suitable pollen-release phenology, located within ≈49 m from the main cultivar, to maximize crop potential (Wood, 1997). Although genetic factors account for most of the potential of the pollinizer, other variables, including mineral nutrition of the plant, may influence pollen quality and its subsequent performance (Nyomora et al., 2000).

A natural abortion of pecan fruit occurs during four periods within the growth cycle of the pecan fruit (Sparks and Heath, 1972). The severity of these fruit abortions or “drops” may vary by cultivar (Sparks and Madden, 1985). Under normal conditions, the most widely planted pecan cultivar in the Southeast, ‘Desirable’, experiences an average fruit abortion of ≈40% to 60% during the second drop (Sparks and Madden, 1985). Studies by Yates and Sparks (1995) suggest that embryo sacs of abortive fruit from the second drop were shriveled and contained an egg apparatus similar to that observed in unfertilized eggs. The second drop of pecan fruit, occurring between 14 and 45 d after pollination, coincides with abscission of nonpollinated flowers and is attributed to unsuccessful fertilization of the egg (Sparks and Madden, 1985).

Yield enhancement by foliar B applications in perennial tree crops has long been recognized. Nyomora et al. (1999) demonstrated that foliar B applications resulted in increased fruit set of almond [*Prunus dulcis* (Mill D.A. Webb)]. Fruit set has also been enhanced with foliar B in ‘Italian’ prune (*Prunus domestica* L.) and ‘Anjou’ pear (*Pyrus communis* L.) (Batjer and Thompson, 1949; Hanson et al., 1985). Fruit set of sour cherry (*Prunus cerasus* L.) was increased by as much as 100% with foliar B applications (Hanson, 1991a, 1991b). Stephenson and Gallagher (1987) found that foliar B sprays enhanced kernel quality in macadamia [*Macadamia integrifolia* (Maiden and Betche)]. Foliar B sprays also led to a greater total mass and decreased hull percentage of almond (Nyomora et al., 1997).

Soil B availability is influenced by soil texture, pH, liming, organic matter, interrelationships with other nutrients, and, most notably, soil moisture (Wood, 1999). Many of the soils on which pecans are grown in the southeastern United States are coarse-textured, well-drained sands, or sandy loams from which B may leach readily. In addition, excessive soil applications of B can potentially induce leaf scorching and reduced fruit set (Blackmon and Winsor, 1946). These factors combined with the relatively immobile nature of B within the plant indicate that foliar B applications would be an efficacious method of providing B to pecan reproductive tissues. However, the effects of foliar-applied B on pecan in the southeastern United States are poorly understood. The objective of this study was to investigate the effect of foliar B application on leaf tissue B concentration, fruit retention, and kernel quality in pecan.

Materials and Methods

Controlled pollination. Boron was applied to individual terminal branches of five ‘Desirable’ pecan trees at rates of 0, 84, and 168 mg·L⁻¹ B in water through a hand sprayer. Top-Side Liquid Boron (Triangle Chemical, Macon, GA), a commercial product containing 6% B with tetraboric acid (H₂B₄O₇) as the B source, was used in all studies. Each rate was replicated on five separate terminal branches per tree. Trees were located in a research orchard at the University of Georgia Ponder Research Farm, Tift County, GA. Treatments were applied at stage II (Yates and Sparks, 1992) of anther development (≈50% of maximum length). Individual sun-exposed terminal branches at midcanopy height were sprayed to runoff (≈0.76 L of spray solution per terminal). Terminal branches were sprayed weekly during the bloom period with chlorpyrifos to minimize thrips damage to staminate flowers. Catkins were collected from the field on 13 Apr. 2007 when approximately half of the catkins had begun to dehisce. Catkins were pooled by treatment and placed on wrapping paper in a cool laboratory and allowed to dehisce. Pollen was collected and was passed through a 140-mesh brass

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sieve and stored in polypropylene tubes at 4 °C until use.

Five sun-exposed terminal branches at midcanopy height were treated with B at rates of 0, 84, and 168 mg·L⁻¹ B on each of five replicate 'Stuart' pecan trees on 19 Apr. 2007, about 1 week before anthesis. For controlled pollination of female flowers on treatment shoots, flowers were bagged with 3-cm diameter cellulose sausage casings cut into 15-cm lengths (Traub and Romberg, 1933). The bags were applied on 19 Apr. 2007, about one week before anthesis. Stigma receptivity was determined by observing nearby pistillate flowers for the presence of rounded projecting papillae on the stigmas (Wetzstein and Sparks, 1989). Bagged pistillate flowers of each treatment were pollinated on 26 Apr. 2007, which was judged to be peak receptivity. Pollen from treated and untreated 'Desirable' shoots was collected and stored as outlined previously. Pollen treated with B at rates of 0, 84, or 168 mg·L⁻¹ was applied to control and treated 'Stuart' pistillate flowers by inserting a hypodermic needle into the bag and puffing a small amount of pollen in the vicinity of the stigmas. Bags were removed from shoots on 8 May 2007 when flowers were no longer receptive. Insects and disease were controlled by spraying appropriate pesticides throughout the growing season to prevent the confounding effect of insect-induced abortion of fruit.

Fruit retention after the second drop of pecan fruit was estimated by counting the number of fruit scars and the number of remaining fruit on all bagged terminals for each of the five data trees on 30 July 2007. Percent fruit retention was determined by dividing the number of fruit by the number of fruit + fruit scars for each terminal. Fruit scars or fruit on the spike apex were not counted, because fruit from this location on the peduncle tend to be small, underdeveloped, and are frequently aborted (Sparks and Madden, 1985). Data were arcsine-transformed and analyzed by split-plot analysis of variance. Pistillate flower B rate was used as the whole plot effect, whereas pollen B rate was used as the split plot effect. Means were separated using Fisher's protected least significant difference ($P < 0.05$).

Large-plot orchard studies. Studies were conducted in five separate commercial 'Desirable' pecan orchards over the course of 3 years. Test sites were located in Crisp, Dougherty, Peach, Sumter, and Lowndes Counties, GA. No signs of B deficiency were apparent at any location and all leaf B concentrations were within or above the adequate B sufficiency range for vegetative growth (15 to 50 mg·kg⁻¹) (Plank, 1988). Treatments consisted of Top Side Liquid Boron. Boron was applied at rates of 0 and 84 mg·L⁻¹ B in water. Applications were made with a commercial air blast sprayer delivering 935 L water volume per hectare. Insects and disease were controlled by spraying appropriate pesticides in all plots throughout the growing season to prevent

the confounding effect of insect-induced fruit abortion (Hudson et al., 2007).

Five boron applications. In Dougherty County, the experiment was conducted on 'Desirable' trees in 2005 and 2006. Trees were planted in 1984. Treatments were arranged in a randomized block design. Plots consisted of one tree row and were replicated three times in 2005 and four times in 2006. Plots were separated by an unsprayed border row. Five trees of uniform size and appearance were selected as data trees within each row. All data are presented as the mean response of the five sampled trees per plot. Treatments were applied before pistil receptivity (≈ 3 weeks before anthesis) and continued every 14 d for a total of five applications. In 2005, fruit retention after the second drop of pecan fruit was estimated by counting the number of fruit scars and the number of remaining fruit on 10 random sun-exposed terminals at midcanopy height per plot in mid-July. In 2006, fruit retention after the second drop of pecan fruit was estimated by counting the number of fruit scars and the number of remaining fruit on eight sun-exposed terminals at midcanopy height for each of the five data trees within each plot in mid-July. Percent fruit retention was calculated as described for the hand-pollination study described previously.

Two boron applications. During 2006, four additional locations (Crisp, Lowndes, Peach, and Sumter Counties) were added to the study. Treatments and experimental design were the same as that described for Dougherty County, except that treated trees only received two foliar B applications. All treatments were replicated four times. Planting year was 1981, 1986, 1992, and 1993 for the Crisp, Lowndes, Peach, and Sumter County orchards, respectively. Treatments were applied before pistil receptivity (≈ 3 weeks before anthesis) and again 14 d later. Fruit retention after the second drop of pecan fruit was estimated by counting the number of fruit scars and the number of remaining fruit on eight sun-exposed terminals at midcanopy height for each of the five data trees within each plot in mid-July. Percent fruit retention was calculated as for the hand-pollination study described previously.

Comparison of number of applications. During 2007, experiments were conducted at the Crisp and Peach County locations described. Experimental design was the same as that previously described for the 2006 studies. Treatments were 0, 2, and 5 B applications replicated four times and applied at the rate of 84 mg·L⁻¹, beginning before pistil receptivity (≈ 3 weeks before anthesis) and at 14-d intervals thereafter until the assigned number of applications was met. Fruit retention after the second drop of pecan fruit was estimated by counting the number of fruit scars and the number of remaining fruit on 10 sun-exposed terminals at midcanopy height for each of the five data trees within each plot in mid-July. Percent fruit retention was calculated as described for the hand-pollination study.

Leaf and nut quality sampling. Leaf samples were collected in late July by collecting eight leaflet pairs from each of the five data trees. All leaflet samples were taken from the middle leaf of sun-exposed terminals. Leaflets from all five data trees within a plot were pooled for the sample. Leaflet samples were washed in a dilute phosphate-free detergent solution (0.1% detergent) followed by rinsing with deionized water. Leaves were then dried to a constant weight at 80 °C and ground in a Wiley Mill (Wiley, Philadelphia, PA) to pass a 1-mm screen. Boron was measured by an inductive coupled plasma spectrophotometer coupled to a Digiblock 3000 (SCP Science, Baie D'Urfé, Quebec, Canada).

At maturity, a sample of 10 nuts from each of the five data trees in each plot were harvested by hand at midcanopy height directly from the tree after shuck dehiscence but before falling from the shuck. Nuts were pooled by plot, allowed to dry for 21 d, weighed, cracked, and shelled by hand to determine weight per nut and percent kernel. During 2005 and 2006, data were analyzed by *t* test to compare B-treated and untreated trees. In 2007, all data were analyzed by analysis of variance and means were separated using Fisher's protected least significant difference ($P < 0.05$). All percent kernel and percent fruit retention data were arcsine-transformed to meet the assumptions of a normal distribution (Zar, 1996).

Results

Controlled pollination

Fruit retention of hand-pollinated 'Stuart' pecans was not significantly affected by foliar applied B treatments (data not presented).

Large-plot orchard studies

Five boron applications. Five foliar B applications increased leaf B concentrations during 2005 and 2006 (Table 1). Boron application also increased fruit retention ($P \leq 0.05$) of 'Desirable' pecan in 2005, but not in 2006 (Table 1). Weight per nut was unaffected (data not presented). An increase ($P \leq 0.05$) in percent kernel was observed in 2006, but not in 2005 (Table 1).

Table 1. Effects of five foliar boron (B) applications on pecan leaf B concentration, fruit retention, and percent kernel of 'Desirable' pecan in 2005 and 2006.^z

	Leaf B (mg·kg ⁻¹)	Fruit retention (%)	Percent kernel
2005			
Untreated	95.1 b	54.7 b	51.7 a
Boron	112.3 a	66.6 a	55.2 a
2006			
Untreated	89.3 b	52.7 a	54.2 b
Boron	108.0 a	54.0 a	55.9 a

^zAll data are presented as the mean response of five trees per plot. Means followed by the same letter are not significantly different according to Fisher's least significant difference ($P \leq 0.05$).

Two boron applications (2006). Leaf B concentration was increased ($P \leq 0.05$) by two B sprays at the Peach County location in 2006 (Table 2). Boron increased fruit retention ($P \leq 0.05$) at the Sumter County location (Table 2). Neither weight per nut (data not presented) nor percent kernel (Table 2) was improved by two applications of B at any location in 2006.

Comparison of number of applications (2007). Boron applications did not affect leaf B concentration during 2007 at either location (Table 3). A treatment $\times$ location interaction was observed for leaf B ($P \leq 0.05$) and for weight per nut ($P \leq 0.05$). No treatment $\times$ location interactions were observed for fruit retention or percent kernel. Both two and five applications of B led to increased ($P \leq 0.05$) fruit retention at both locations and for data pooled across locations (Table 3). Weight per nut was unaffected by B application (data not presented). Percent kernel was increased ($P \leq 0.05$) by five applications of B at the Crisp County location in 2007. When data from both locations were pooled, an increase ($P < 0.05$) in percent kernel was observed with both two and five B applications (Table 3).

Table 2. Effects of two foliar boron (B) applications on pecan leaf B concentration, nut retention, and percent kernel of Desirable pecan at four locations in 2006.^z

	Leaf B (mg·kg ⁻¹)	Fruit retention (%)	Percent kernel
Crisp Co.			
Untreated	44.0 a	50.0 a	50.6 a
Boron	41.5 a	55.0 a	52.3 a
Lowndes Co.			
Untreated	97.0 a	42.2 a	49.9 a
Boron	101.3 a	47.8 a	51.2 a
Peach Co.			
Untreated	47.3 b	43.0 a	50.2 a
Boron	58.0 a	46.0 a	54.5 a
Sumter Co.			
Untreated	78.0 a	44.6 b	47.9 a
Boron	78.3 a	54.5 a	49.1 a

^zAll data are presented as the mean response of five trees per plot. Means followed by the same letter are not significantly different according to Fisher's least significant difference ($P \leq 0.05$).

Table 3. Effects of two and five foliar boron (B) applications on pecan leaf B concentration, nut retention, and percent kernel of Desirable pecan in 2007.^z

	Leaf B (mg·kg ⁻¹)	Fruit retention (%)	Percent kernel
Crisp Co.			
Untreated	37.0 a	46.7 b	47.2 b
Boron (two sprays)	44.3 a	57.0 a	49.8 ab
Boron (five sprays)	41.8 a	53.6 a	51.7 a
Peach Co.			
Untreated	54.3 a	44.2 b	48.7 a
Boron (two sprays)	56.0 a	55.2 a	49.4 a
Boron (five sprays)	59.0 a	55.6 a	50.3 a
Mean ^y			
Untreated	45.6 a	45.4 b	47.9 b
Boron (two sprays)	50.1 a	56.1 a	49.6 a
Boron (five sprays)	50.4 a	54.6 a	51.0 a

^zAll data are presented as the mean response of five trees per plot. Means followed by the same letter are not significantly different according to Fisher's least significant difference ($P \leq 0.05$).

^yData pooled from both locations. Significant ($P \leq 0.05$) treatment $\times$ location interaction for leaf B.

Discussion

Foliar B application potentially confers several advantages for pecan production. Boron application did not lead to increased fruit retention in hand-pollination studies with pistillate 'Stuart' pecan flowers. High variation among trees likely contributed to the insignificant treatment effects. Leaf tissue B concentration, pecan fruit retention, and kernel quality were occasionally enhanced by foliar B application in the large-plot orchard studies. Nut size as expressed by weight per nut was unaffected. Leaf tissue B concentration was increased at the Dougherty County location in 2005 and 2006 by five foliar B applications. Two applications of B increased leaf B only at one location during 2006. Previous studies examining the effect to foliar-applied B on tissue concentration of other fruit and nut crops have shown variable results (Callan et al., 1978; Hanson, 1991b; Nyomora et al., 1997). The inconsistent response of foliar-applied B to significantly increase B tissue levels likely could have resulted from the high variability in initial B concentration, crop load, orchard age, or other environmental conditions among study sites.

Foliar application of B occasionally increased fruit retention of 'Desirable' pecan in 2005 and 2006. Fruit retention was increased by B treatment at both locations in 2007. There was no difference in fruit retention between two and five B applications, indicating that with regard to fruit retention, proper timing of application is more important than frequency of application. The pre-pollination window appears to be a critical time period during which to apply foliar B. Similar effects have been reported in pear (Batjer and Thompson, 1949), hazel nut (*Corylus avellana* L.) (Baron, 1973), Italian prune (Hanson, et al., 1985), sour cherry, and almond (Nyomora et al., 1997). Perica et al. (2001) suggests that B sprays made before receptivity of olive (*Olea europaea* L.) flowers are more beneficial for fruit retention than those made when flowers are receptive. Our results contrast with that of Kilby et al. (1998), who report no increase in fruit

retention of foliar B-treated 'Western Schley' pecan in Arizona.

Boron may play a role in both initial fruit set (through enhancement of pollination and fertilization) and retention of fruit (Nyomora et al., 1997). 'Desirable' pecan, the leading cultivar in Georgia, annually has a substantial June fruit drop of $\approx 40\%$ to 60% resulting from inadequate embryo fertilization (Sparks and Madden, 1985). Aside from failed fertilization, fruit drop may also result from a hormone imbalance that favors abscission (Luckwill, 1953) and resource limitations of carbon and nitrogen (Deng et al., 1991). Each of these factors could potentially be related to B because B is known to affect both carbohydrate and hormone metabolism and translocation (Shelp, 1993).

Percent kernel of 'Desirable' pecan was occasionally increased in two of three years with foliar B application. When the 2007 data were pooled, percent kernel was increased by both two and five applications. Nyomora et al. (1997) reported increased total mass and reduced hull percentage of 'Butte' almond in B-treated trees. Stephenson and Gallagher (1987) found a higher percentage kernel recovery, first-grade kernels, and mean kernel mass from B-treated macadamia trees than from untreated B-deficient trees.

Many aspects of the physiological role of B in plants are poorly understood. Boron deficiency is known to alter cell wall structure, membrane integrity, enzyme activity, and a wide range of plant metabolites (Goldbach, 1997). Nitrate reductase activity and nitrate assimilation have been shown to increase with increasing B supply (Ruiz et al., 1998). Boron can also indirectly affect photosynthesis through its influence on membrane stability (El-Shintinawy, 1999). As a result of its influence on a wide range of physiological processes, B application may influence the movement of photosynthates from leaves to developing fruit, leading to improved kernel filling in otherwise healthy trees (Shelp, 1993).

Reproductive B deficiencies often occur in the absence of vegetative deficiencies. Brown et al. (2002) postulates that the difference in sensitivity suggests that transport of B to floral plant parts is a critical limiting factor and that the relative sensitivity of reproductive parts is a consequence of low B transport rather than an indication of a specific and higher requirement for reproduction. Although B is phloem-mobile in those species containing dulcitol, sorbitol, and mannitol (Brown and Shelp, 1997), its mobility is restricted primarily to the xylem of pecan and is thus transported through the transpirational stream. Additionally, young fruit have poor xylem connections (Wood, 1999). Therefore, it is likely that foliar B applications would be especially valuable in years of dry soils at budbreak and through the developmental period of the staminate and pistillate flowers. If flower development is dependent on a continuous supply of xylem-fed B from the soil, any interruptions in transpiration may potentially reduce fertility

and seed yield. Fruits that are dependent on xylem-transported B are more at risk of B deficiency when xylem water flux is limited relative to growth rate as a result of transpirational constraints (Dell and Huang, 1997).

Although the trees used in our study showed no obvious B deficiency symptoms and were not B-deficient from the standpoint of leaf sufficiency range, they did, on occasion, respond to B application. Previous studies with a variety of tree crops have shown increases in fruit set and yield with foliar B in the absence of vegetative B deficiency symptoms (Baron, 1973; Nyomora et al., 1997; Perica et al., 2001). Our data indicate that foliar B applications beginning at the prepollination stage are sufficient to increase leaf B, fruit retention, and percent kernel of 'Desirable' pecan under certain conditions. The variable results may have been influenced by differences in age of sampled trees and environmental conditions between locations and years. An increase in leaf B did not necessarily correspond to an increase in fruit retention or percent kernel. This further indicates that as long as leaf B concentration is within the recommended sufficiency range, application of B directly to reproductive structures is probably more valuable in terms of enhancing these aspects of production than are increasing leaf B concentrations. Our studies suggest that as long as the critical prepollination period is covered, two foliar B applications are as effective as five applications.

The annual fruit drop of 'Desirable' is an important factor in the ability of this cultivar to produce acceptable yields on an annual basis without promoting severe alternate bearing tendencies. Although return fruit set was not directly examined in the current study, the modest increases in nut retention observed here did not appear to have an unfavorable influence on the return crop of 'Desirable'. Although it is possible that increases in fruit retention and percent kernel would provide the potential for increased yields, we do not currently have data to indicate that foliar-applied B increases pecan yield. A variety of factors aside from B nutrition also contribute to reduced kernel filling and loss of fruit after the June drop of pecan. Among these are soil moisture, environmental conditions, insect damage, and disease.

Although foliar-applied B appears to be a practical and efficient method of providing supplemental B to pecan trees, excessive application of B, particularly at high rates, can potentially result in plant toxicity and reduced production. When applied properly, boron can enhance pecan production, probably through its physiological role in stimulating pollination and fertilization, and transportation of carbohydrates. Given the

increases observed in fruit retention and percent kernel, and the low cost of B fertilizers, foliar application of B merits consideration as a component of pecan orchard management when tank-mixed with normal prepollination pesticides or nutrient sprays.

Literature Cited

- Baron, L.C. 1973. The value of boron sprays on filberts. *Proc. Nut Growers Assoc. of Oregon and Washington* 58:43-44.
- Batjer, L.P. and A.H. Thompson. 1949. Effects of boric acid sprays during bloom upon the set of pear fruits. *Proc. Amer. Soc. Hort. Sci.* 53:141-142.
- Blackmon, G.H. and H.W. Winsor. 1946. Boron uptake in pecans. *Proc. Amer. Soc. Hort. Sci.* 47:149-152.
- Brown, P.H., N. Bellaloui, M.A. Wimmer, E.S. Bassil, J. Ruiz, H. Hu, H. Pfeffer, F. Dannel, and V. Romheld. 2002. Boron in plant biology. *Plant Biol.* 4:205-223.
- Brown, P.H., H. Hu, A. Nyomora, and M. Freeman. 1996. Foliar application enhances almond yields. *Better Crops with Plant Food*, No. 1. Potash and Phosphate Inst. Ref. No. 323054/952233.
- Brown, P.H. and B.J. Shelp. 1997. Boron mobility in plants. *Plant Soil* 193:85-101.
- Callan, N.W., M.M. Thompson, and M.N. Westwood. 1978. Effects on fruit set of Italian prune following fall foliar and spring boron sprays. *J. Amer. Soc. Hort. Sci.* 103:253-257.
- Dell, B. and L. Huang. 1997. Physiological response of plants to low boron. *Plant Soil* 193:103-120.
- Deng, X., S.A. Weinbaum, T.M. DeJong, and T.T. Muraoka. 1991. Pistillate flower abortion in 'Serr' walnut associated with reduced carbohydrate and nitrogen concentrations in wood and xylem sap. *J. Amer. Soc. Hort. Sci.* 116:291-296.
- El-Shintinawy, F. 1999. Structural and functional damage caused by boron deficiency in sunflower leaves. *Photosynthetica* 36:565-573.
- Goldbach, H.E. 1997. A critical review on current hypotheses concerning the role of boron in higher plants: Suggestions for further research and methodological requirements. *J. Trace and Microprobe Tech.* 15:51-91.
- Hanson, E.J. 1991a. Movement of boron out of tree leaves. *HortScience* 26:271-273.
- Hanson, E.J. 1991b. Boron requirements and mobility in tree fruit species. *Current Topics Plant Biochem. Physiol.* 10:240-246.
- Hanson, E.J., M.H. Chaplin, and P.J. Breen. 1985. Movement of foliar applied boron out of leaves and accumulation in flower buds and flower parts of 'Italian' prune. *HortScience* 20:747-748.
- Hu, H. and P.H. Brown. 1997. Absorption of boron by plant roots. *Plant Soil* 193:49-58.
- Hudson, W., J. Brock, S. Culpepper, and L. Wells. 2007. Georgia pecan pest management guide. University of Georgia Cooperative Extension Bulletin 841.
- Kilby, M.W., R. Neja, and R. Call. 1998. Foliar application of boron to pecan trees does not affect fruit set. Citrus and deciduous fruit and nut res. report. Univ. Arizona Publication AZ1051. 9 Oct. 2007. <<http://ag.arizona.edu/pubs/crops/az1051>>.
- Luckwill, L.C. 1953. Studies of fruit development in relation to plant hormones. I. Hormone production by the developing apple seed in relation to fruit drop. *J. Hort. Sci.* 28:14-24.
- Nyomora, A.M.S., P.H. Brown, and M. Freeman. 1997. Fall foliar-applied boron increases tissue boron concentration and nut set of almond. *J. Amer. Soc. Hort. Sci.* 122:405-410.
- Nyomora, A.M.S., P.H. Brown, and B. Krueger. 1999. Rate and time of boron application increase almond productivity and tissue boron concentration. *HortScience* 34:242-245.
- Nyomora, A.M.S., P.H. Brown, K. Pinney, and V.S. Polito. 2000. Foliar application of boron to almond trees affects pollen quality. *J. Amer. Soc. Hort. Sci.* 125:265-270.
- Perica, S., P.H. Brown, J.H. Connell, A.M.S. Nyomora, C. Dordas, and H. Hu. 2001. Foliar boron application improves flower fertility and fruit set of olive. *HortScience* 36:714-716.
- Plank, C.O. 1988. Plant analysis handbook for Georgia. Georgia Coop. Ext. Serv., Athens.
- Raven, J.A. 1980. Short and long distance transport of boric acid in plants. *New Phytol.* 84:231-249.
- Ruiz, J.M., M. Baghour, G. Bretones, A. Belakbir, and L. Romero. 1998. Nitrogen metabolism in tobacco plants: Role of boron as a possible regulatory factor. *Int. J. Plant Sci.* 159:121-126.
- Shelp, B.J. 1993. Physiology and biochemistry of boron in plants, p. 53-85. In: Gupta, U.C. (ed.). Boron and its role in crop production. CRC Press, Boca Raton, FL.
- Sparks, D. and J.L. Heath. 1972. Pistillate flower and fruit drop of pecan as a function of time and shoot length. *HortScience* 4:402-404.
- Sparks, D. and G.D. Madden. 1985. Pistillate flower and fruit abortion as a function of cultivar, time, and pollination. *J. Amer. Soc. Hort. Sci.* 110:219-223.
- Stephenson, R.A. and E.C. Gallagher. 1987. Effects of foliar boron sprays on yield and quality of macadamia. *Scientia Hort.* 32:97-103.
- Traub, H. and L. Romberg. 1933. Methods of controlling pollination in the pecan. *J. Agr. Res.* 47:287-296.
- Wetzstein, H.Y. and D. Sparks. 1989. Stigma-pollen interactions in pecan. *J. Amer. Soc. Hort. Sci.* 114:355-359.
- Wood, B.W. 1997. Source of pollen, distance from pollinizer, and time of pollination affect yields in block-type pecan orchards. *HortScience* 32:1182-1185.
- Wood, B.W. 1999. Boron nutrition of pecan. *Proc. Southeastern Pecan Growers Assn.* 92:47-50.
- Yates, I.E. and D. Sparks. 1992. External morphological characteristics for histogenesis in pecan anthers. *J. Amer. Soc. Hort. Sci.* 117:181-189.
- Yates, I.E. and D. Sparks. 1995. Morphology of postpollination fruit abortion in pecan. *J. Amer. Soc. Hort. Sci.* 120:446-453.
- Zar, J.H. 1996. Biostatistical analysis. 3rd Ed. Prentice Hall Inc., Upper Saddle River, NJ.