

Effects of Foliar Sulfur Sprays on Pecan Independent of Pecan Scab Control

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Abstract. Many commercial pecan [*Carya illinoensis* (Wangenh.) K. Koch] producers routinely spray foliar urea and sulfur (S) in combination with their fungicide sprays, despite very little information available in the scientific literature regarding the effects of these practices on pecan production. The objectives of this study were to investigate the effects of foliar application of elemental S and urea, alone and in combination, on pecan leaf tissue nitrogen (N) and S concentration, pecan nut quality, leaf chlorophyll index (LCI), and pecan scab control. Foliar S sprays increased pecan nut weight over the control in 2 of 3 years of study. Pecan nut weight was unaffected by foliar urea sprays compared with the control, but nut weight was lower for foliar urea sprays compared with foliar S sprays in the first 2 years of study. Neither foliar S nor urea sprays affected pecan scab incidence or severity. Foliar S sprays failed to increase leaf S concentration throughout the study. Pecan leaf N and leaf S concentrations were lower in the foliar urea treatment than in the control and foliar S treatments during the initial year of study; however, no treatment differences were observed for urea after Year 1. Foliar S application enhanced LCI in 2011 and 2012. Leaf chlorophyll index was also increased by the combination of foliar urea and S in 2012. These results suggest that foliar S sprays may provide pecan producers with a tool with which to maximize nut size and increase the profitability of their crop.

Georgia is the largest pecan producer in the United States (U.S. Department of Agriculture, 2009). The coastal plain soils on which most Georgia pecan orchards are established are inherently low in S. In addition, available S leaches readily through the soil profile of the region's loamy sand soils. As a result, S availability does not appear adequate for many southeastern U.S. pecan orchards (Wells, 2009).

Soil S may be immobilized by a variety of factors, including soil organic matter, temperature, moisture, and soil pH. Since the early 1980s, atmospheric S depositions have declined drastically after the enforcement of Clean Air Acts. This led to S deficiency becoming a major nutritional disorder in western Europe (Haneklaus et al., 2003). Leaf elemental S was deficient in almost 90% of Georgia pecan orchards in a recent survey using 0.25% as the minimum leaf sufficiency concentration (Wells, 2009). Average leaf S was below the recommended leaf sufficiency range for S

in both years of the study. However, Smith et al. (2012) have suggested a minimum sufficiency concentration of 0.20% for pecan, which may be a more realistic goal for Southeastern pecan orchard conditions. An insufficient plant supply of S has been shown to reduce crop productivity, diminish crop quality, affect plant health, and impair N use efficiency (Barker and Pilbeam, 2007).

The role of S in helping to manage plant disease has been investigated for centuries. Recently, the concept of sulfur-induced resistance was developed to explain an increased resistance of various crops to fungal pathogens with S fertilization (Bloem et al., 2005). Elemental S has been used as a fungicide in viticulture, arboriculture, and in cereal crops (Legris-Delaporte et al., 1987). Elemental S-based fungicides have been used for many decades to control peach scab, *Fusicladosporium carpophilum* (Partridge and Morgan-Jones) in southeastern U.S. commercial peach orchards (Schnabel et al., 2007). The effects of elemental S on pecan scab have been studied since the 1920s; however, most studies have demonstrated little effect of S on pecan scab *Fusicladium effusum* G. Winter (Bertrand et al., 1981; Waite, 1924).

Foliar urea sprays are known to enhance fruit production in a variety of tree fruit crops (Johnson et al., 2001; Lovatt, 1999; Rosecrance et al., 1998). Many commercial pecan producers in Georgia routinely spray foliar urea in combination with their fungicide sprays. Urea can be absorbed rapidly and efficiently by the leaves of most crop plants (Johnson et al., 2001); however, aside from its effect on the enhancement of zinc uptake by pecan leaves (Smith and Storey, 1979), very little information is available in the scientific literature regarding the effect of foliar urea sprays on pecan production.

The objectives of this study were to investigate the effects of foliar application of elemental S and urea on pecan leaf tissue N and S concentration, pecan nut quality, LCI, and pecan scab control.

Materials and Methods

Study site, experimental design, and sampling. The study was conducted from 2011–13 in a drip-irrigated commercial 'Desirable' pecan orchard planted in 1981 on a 15.2 m × 15.2-m spacing located in Crisp County, GA. The orchard was located at 31°59' N latitude and -83°55' W longitude. All drip emitters were ported to the soil surface. Soil type was Orangeburg loamy sand (loamy, siliceous, thermic Arenic Plinthic Paleudult). The orchard was managed under commercial conditions according to University of Georgia Cooperative Extension recommendations (Hudson et al., 2012). A 3.7-m-wide vegetation-free strip was maintained with the herbicide glyphosate along the tree row in all plots. Row middles consisted of bermudagrass (*Cynodon dactylon* L.) sod. The following treatments were evaluated: 1) foliar S application; 2) foliar urea application; 3) foliar S + urea application; and 4) non-treated control. Treatments consisted of a flowable micronized elemental S material (52%) (KollaSulfur) (Cromartie Agricultural Chemicals, Leesburg, GA). Sulfur was applied at rates of 1.7 g·L⁻¹ S in water. Low biuret urea (46% N) was applied at a rate of 4.8 g·L⁻¹ urea in water. Applications were made with a commercial air blast sprayer delivering 935 L water per hectare. Treatments were applied beginning in mid-April and continued every 14 d for a total of eight sprays.

Treatments were arranged in a randomized complete block design. Plots consisted of one tree row with three replications per treatment. 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.

Foliage was sampled in late July each year by collecting one leaflet pair from 30 compound leaves per tree. All leaflet samples were taken from the middle leaf of sun-exposed terminals. 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

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Mill (Wiley, Philadelphia, PA) to pass a 1-mm screen. Leaves for N analysis were ground with a mortar and pestle. Samples were analyzed for N by combustion using a Leco FP528 protein/N determinator (Leco Corp., St. Joseph, MI). Sulfur was measured by an inductive coupled plasma spectrophotometer coupled to a Digiblock 3000 (SCP Science, Baie D'Urfé, Quebec, Canada).

Leaf chlorophyll index was measured on 11 July 2011, 23 July 2012, and 28 Aug. 2013 using a chlorophyll meter (SPAD-502; Minolta, Ramsey, NJ). Measurement leaves were fully expanded and selected from one pair of middle leaflets of 10 compound leaves per tree. Measurements were taken from three trees per plot.

Nut scab was not measured in 2011 or 2012 as a result of lack of disease symptoms from drought resulting in low disease pressure. Disease ratings were made on 10 Sept. 2013 after pecan shell hardening and completion of all foliar sprays. Twenty random terminals per plot were rated for incidence and severity of pecan scab. Incidence is defined as the percentage of nuts with at least one pecan scab lesion. Severity is defined as the percentage of the pecan shuck surface covered by pecan scab. Rainfall data were obtained from a University of Georgia weather station located 3.9 km from the study site.

At harvest, a composite 50-nut sample was collected from five trees per plot for analysis of individual nut weight and percent kernel. Nuts were shelled and percentage of edible kernel was calculated by dividing the kernel weight for the 50-nut sample by total nut weight.

Statistical analyses of data were performed with SAS (SAS Institute, Cary, NC). Analysis of variance was used to compare treatment effects. Means were separated using Tukey's honestly significant difference test ($P \leq 0.05$).

Results and Discussion

Foliar S sprays increased pecan nut weight over the control in 2 of 3 years of

study (Table 1). Pecan nut weight was unaffected by foliar urea sprays compared with the control, but nut weight was lower for foliar urea sprays compared with foliar S sprays in the first 2 years of study (Table 1). These results contradict that of Bertrand et al. (1981), who found no effect from foliar S on pecan nut weight. However, the Bertrand et al. (1981) study ceased spraying foliar S in mid-July while nuts were still developing and increasing in size. The continuation of foliar S throughout the nut sizing period may help to explain the results obtained in the current study. Bertrand et al. (1981) also suggested that both yield and nut size were likely affected by a severe drought occurring during their study on non-irrigated trees. This may have masked any subtle effect of foliar S on nut weight because soil moisture during the nut sizing period is known to be the primary limiting factor for pecan nut weight and size (Alben, 1957; Magness, 1955; Stein et al., 1989). The current study was conducted in both dry and wet years; however, trees were well irrigated, which may have allowed for the elimination of the potentially confounding factor of drought observed by Bertrand et al. (1981). Although foliar nutrient sprays such as boron have been shown to increase kernel percentage (Wells et al., 2008), percent kernel was unaffected by foliar S or urea sprays (Table 1). This is consistent with previous studies with foliar S on pecan (Bertrand et al., 1981).

The study site received only 31 cm and 41 cm of rainfall from 1 Apr. to 30 Sept. in

2011 and 2012, respectively, which generated very little disease pressure and prevented any meaningful evaluation of treatment effects on pecan scab during the first 2 years of study. However, the study site received 64 cm of rainfall during the same period in 2013, generating intensive disease pressure. Neither foliar S nor urea sprays affected pecan scab incidence or severity in 2013 (Table 2). Sulfur has been used as a fungicide for many years on a variety of crops (Legris-Delaporte et al., 1987), including peach in the southeastern United States at higher rates than that used for pecan in the current study (Schnabel et al., 2007). Pecan producers in the same region also apply S regularly along with fungicide applications; however, the results of our study are consistent with previous studies demonstrating that foliar S application does not improve control of pecan scab (Bertrand et al., 1981; Waite, 1924). Therefore, the observed effect of increased nut weight with foliar S application in the current study is independent of any effect of S on pecan scab control. Foliar-applied S has previously been demonstrated to increase grain yield of cereal crops independent of a fungicidal effect (Scott et al., 1984).

Foliar S sprays failed to increase leaf S concentration throughout the study. Pecan leaf N and leaf S concentrations were lower in the foliar urea treatment than in the control and foliar S treatments during the initial year of study; however, no treatment differences were observed after Year 1 (Table 3). With the exception of the lower leaf N and leaf S

Table 1. Mean pecan nut weight (g) and percent kernel for sulfur, urea, sulfur + urea, and control treatments from 2011–13.

Yr	Treatment	Nut wt (g)	Percent kernel
2011	Sulfur	9.7 a ²	50.7 a
	Urea	9.2 b	50.2 a
	Sulfur + urea	9.5 ab	50.2 a
	Control	9.2 b	50.6 a
2012	Sulfur	11.2 a	52.7 a
	Urea	9.9 b	52.4 a
	Sulfur + urea	10.2 ab	53.1 a
	Control	10.4 ab	52.9 a
2013	Sulfur	9.1 a	51.4 a
	Urea	8.6 ab	53.3 a
	Sulfur + urea	8.6 ab	56.4 a
	Control	8.4 b	53.9 a

²Means followed by the same letter within each year are not different at $P \leq 0.05$ by Tukey's honestly significant difference test.

Table 2. Mean pecan scab incidence (percentage of nuts with at least one pecan scab lesion) and pecan scab severity (percentage of pecan shuck covered by pecan scab) on pecan nuts for sulfur, urea, sulfur + urea, and control treatments in 2013.

Treatment	Pecan scab incidence (%)	Pecan scab severity (%)
Sulfur	99 a ²	17.8 a
Urea	99 a	9.3 a
Sulfur + urea	100 a	15.8 a
Control	100 a	19.5 a

²Means followed by the same letter within each year are not different at $P \leq 0.05$ by Tukey's honestly significant difference test.

Table 3. Mean leaf nitrogen (N) concentration, leaf sulfur (S) concentration, and Soil Plant Analytical Development leaf chlorophyll indexes for sulfur, urea, sulfur + urea, and control treatments in 2011, 2012, and 2013.

Yr	Treatment	Leaf nutrient concn		Leaf chlorophyll index
		N (%)	S (%)	
2011	Sulfur	2.72 a ²	0.20 a	43.6 a
	Urea	2.58 b	0.18 b	42.0 b
	Sulfur + urea	2.70 ab	0.19 ab	42.3 ab
	Control	2.73 a	0.20 a	41.4 b
2012	Sulfur	2.62 a	0.23 a	44.3 ab
	Urea	2.68 a	0.23 a	43.6 bc
	Sulfur + urea	2.75 a	0.24 a	44.9 a
	Control	2.68 a	0.23 a	42.6 c
2013	Sulfur	2.65 a	0.21 a	44.8 a
	Urea	2.59 a	0.21 a	45.7 a
	Sulfur + urea	2.71 a	0.21 a	45.5 a
	Control	2.66 a	0.21 a	44.6 a

²Means followed by the same letter within each year are not different at $P \leq 0.05$ by Tukey's honestly significant difference test.

concentrations in the foliar urea treatment in 2011, it is not surprising that foliar sprays failed to affect leaf N or leaf S. Elemental S must be oxidized before significant quantities can be absorbed by leaves. Because oxidation is a slow process, intracellular sulfate does not become highly concentrated immediately after S application (Barker and Pilbeam, 2007).

Foliar-applied urea is known to be rapidly absorbed in most fruit and nut trees (Klein and Weinbaum, 1985; Rosecrance et al., 1998; Yousseffi et al., 2000). The translocation of urea-N out of leaves and into storage tissues is also rapid, generally occurring within 4 to 7 d of application (Dilley and Walker, 1961; Rosecrance et al., 1998); therefore, unless leaves are sampled soon after foliar urea application, there may be no noticeable increase in leaf N (Rosecrance et al., 1998). The effect of N application on plant performance is largely dependent on the S status of the plant and similarly, maximum plant response to S application will occur only when N is sufficient. The response to this interaction is based largely on the interdependence of uptake and reduction of both N and S and the accumulation of both elements in amounts proportional to their incorporation into protein (Clarkson et al., 1989; Friedrich and Schrader, 1978; Reuveny et al., 1980). Hu and Sparks (1992) suggested that photosynthesis and growth of pecan increased with N supply in relation to the N:S ratio in pecan leaves and that a leaf N:S ratio of 9:1 should be maintained for optimal growth of pecan seedlings. During our study, the N:S ratio ranged from 11:1 to 14:1 and was unaffected by treatment (data not shown). As mentioned previously, leaf N concentration was within the recommended sufficiency range in all treatments. Leaf S was within the recommended sufficiency range suggested by Smith et al. (2012) throughout the study, except in the urea and S + urea treatments during 2011.

The LCI as measured by the SPAD meter serves as a measure of relative chlorophyll content, and more indirectly, leaf N status, and photosynthetic activity (Evans, 1983; Loh et al., 2002; Seeman et al., 1987). Foliar S application enhanced LCI in 2011 and 2012. Leaf chlorophyll index was also increased by the combination of foliar urea and S in 2012 (Table 3), indicating that chlorophyll content and photosynthetic activity may be enhanced by foliar S application or a combination of foliar urea and S. The lack of a treatment response for the LCI during the last year of study may be explained by the later sampling date in 2013. Although LCI is usually closely correlated to leaf N status, this was not the case in the current study. This may be explained by the rapid translocation of urea N to storage tissues and the fact that leaf N concentration was well within the recommended sufficiency range of 2.5% to 3.0% in all treatments as a result of ground application of N fertilizer.

The mechanism by which foliar S sprays enhanced pecan nut weight is unclear, although

it may be associated with enhanced chlorophyll content and photosynthetic activity with foliar S sprays. Although the potential effect of foliar S sprays on pecan leaf scorch mite populations was not measured in the current study, previous studies have demonstrated that pecan leaf scorch mite is suppressed by foliar S sprays (Dutcher et al., 2010), which could potentially play a role in enhanced tree health and photosynthetic activity. However, this requires further investigation. Although our study is consistent with previous studies demonstrating a lack of efficacy of elemental S on pecan scab control, it is possible that foliar S sprays helped to suppress minor secondary pathogens not evaluated in the experiment. Elemental S is known to be a natural component of induced antifungal defense in many plants and is highly toxic to many fungal pathogens representing ascomycetes, basidiomycetes, and deuteromycetes, but not to certain oomycetes such as *Phytophthora* or to bacteria (Cooper and Williams, 2004).

In summary, foliar S sprays enhanced pecan nut weight and LCI independent of pecan scab control, whereas foliar urea sprays failed to provide any measurable benefit for pecan production. Previous studies demonstrating the positive effects of foliar urea sprays on other tree fruit and nut crops, particularly as a means of N supplementation to minimize leaching of fertilizer-derived N and groundwater pollution (Johnson et al., 2001; Yousseffi et al., 2000), suggest that the potential effects of foliar urea sprays on pecan should be investigated further. This information is valuable for commercial pecan producers, particularly in light of the high demand for large-sized in-shell pecans on the Asian market, which has driven recent increases in pecan prices. These results suggest that foliar S sprays may provide pecan producers with a tool with which to maximize nut size and increase the profitability of their crop.

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