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FREP

Towards Development of Foliar Fertilization Strategies for Pistachio to Increase Total Yield and Nut Size and Protect the Environment: A Proof-of-Concept Project

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INTRODUCTION

Foliar fertilization in crop production is encouraged. Replacing soil-applied fertilizer, at least in part, with foliar-applied fertilizer contributes to fertilizer best management practices (BMPs) by reducing the potential for accumulation of nutrients in soil, run-off water, surface water (streams, lakes and the ocean), and groundwater (drinking water supply), where they can contribute to salinity, eutrophication and nitrate contamination in the case of N, all of which have serious consequences on human health and the environment.

When successful, foliar fertilization provides the nutrients required for photosynthesis and other important metabolic functions directly to the leaves to prevent restrictions in carbon fixation, metabolism and plant productivity. Even a transient or incipient deficiency, needs to be corrected quickly. The longer the tree's nutrient status remains at the low end or below the optimal range at key stages of tree phenology, the greater the negative effects on the current year's yield and next year's bloom. Thus, foliar fertilization, which has the potential for being a rapid and efficient method for improving crop nutrient status during periods of high nutrient demand or when soil conditions render soil nutrients less available to the plant, could have a positive impact on yield.

For pistachio, potential yield benefits to be derived from foliar fertilization have yet to be fully realized. Like other deciduous fruit crops, pistachio reproductive growth commences prior to vegetative shoot extension and leaf expansion. Thus, foliar fertilization strategies at early stages of tree phenology by default target reproductive structures, which are typically small. Despite this, bloom sprays of boron, zinc and urea applied to apple or pear increased fruit set and yield (Bajter and Thompson 1949, Righetti n.d., Stover et al. 1999). In the case of pistachio, boron applied in the late dormant stage (just prior to bud swell to 20% bud break) increased 3-year cumulative yield by 20% and reduced blanking as well as non-splits to further increase yield (Brown et al. 1995). The effect on yield of applying urea-N and zinc sprays (individually or in combination, including boron) to pistachio trees at this time remains to be determined. A further difficulty is that pistachio leaves, like those of many other crop plants, have a thick waxy cuticle known to compromise uptake of some foliar-applied nutrients once the leaves mature (Kallsen 2007). The following critical questions related to nutrient uptake by pistachio leaves remain unanswered. Can a sufficient amount of fertilizer be taken up when leaves are 2/3 expanded (and still have a thin cuticle) to provide a yield benefit? Will including urea as a "carrier" in the fertilizer spray sufficiently increase nutrient uptake by mature pistachio leaves to enhance yield?

OBJECTIVES

The objective of our research is to obtain a positive effect on fruit set and yield, nut quality (increased percent split nuts, reduced percent aborted and blank nuts), and retention of floral buds for next year's crop with properly timed foliar fertilization. To meet this objective we are testing the capacity of the three foliar fertilization strategies discussed below to successfully supply key nutrients at phenological stages of high nutrient demand as well as application times reported to be efficacious through previous research.

1. To test Strategy 1-The foliar application of boron (B), zinc (Zn) and urea (N) at bud swell to enhance flower nutrient levels (ovary and/or pollen) to increase fruit set. Despite uptake of only small amounts of nutrients, prebloom foliar applications of these elements have been shown to increase yield in other deciduous tree crops (Cowgill and Compton 1999, Jaganth and Lovatt 1998, Righetti n.d.). To date research into the response of pistachio trees to prebloom foliar-applied zinc have produced mixed results (Uriu 1986, Brown et al. 1994).
2. To test Strategy 2-The application of foliar fertilizers at 1/2- to 2/3-leaf expansion when leaves have a cuticle thin enough for nutrient uptake and sufficient surface area that the amount of nutrient taken up is large enough to enhance tree performance.
3. To test Strategy 3-The use of urea as a carrier to increase uptake of B, Zn, K and thiosulfate (S) into buds and/or leaves, especially during kernel filling when all but the most current pistachio leaves have a fully developed wax cuticle. Urea improved the uptake and efficacy of benzyladenine when hardened pistachio leaves were treated in June and July (Lovatt et. al. 2006). Researchers and growers report its use in foliar treatments (Righetti n.d.).
4. To calculate and disseminate a cost:benefit analysis to growers.

DESCRIPTION

The design is a randomized complete block with 11 treatments (described under strategies 1 through 3 below), including an untreated control, and 15 individual tree replications of each treatment in a commercial orchard owned by Paramount Farming in Kings County. The 14-year-old 'Kerman' pistachio trees on Pioneer Gold 1 rootstock are planted in a row/tree spacing of 19 x 17 feet at 135 trees per acre. The experiment will be conducted for 2 years to determine treatment effects on yield and its components (nut size, split nuts, kernel weight, stained nuts, insect-damaged nuts, blank nuts) and on retention of floral buds for next year's crop. There are buffer trees between treated trees within a row and buffer rows between treated rows. At the specified stages of tree phenology, foliar fertilizers were applied in 100 gallons of water per acre (industry standard). Applications were made using a three-point fan sprayer producing strong canopy movement and fine droplet size. Sets of leaves in the four quadrants of the trees receiving fertilizer sprays were bagged just prior to fertilizer application and uncovered 4 hours later. Buds were sampled prior to foliar applications. Buds and leaves, respectively, were collected 7 to 10 days after the fertilizer application for nutrient analysis. Leaves were also collected at the end of July (the standard time for leaf analysis) and in October to determine if increased leaf nutrient concentrations in response to foliar-applied fertilizers persisted at a level sufficient to "preload" the tree for the following spring bloom. Samples were immediately stored on ice, taken to UCR, washed, oven-dried at 60 ºC, ground to 40-mesh, and sent to the UC-DANR Laboratory at UC-Davis for analysis. Tissues were analyzed for the following: N, S, P, K, Mg, Ca, Fe, Mn, B, Zn, and Cu by atomic absorption spectrometry and inductively coupled plasma atomic emission spectrometry. Additionally, one branch (bearing fruit) in each of the four quadrants of each treated tree was tagged and the initial number of floral buds per branch counted just prior to harvest. At harvest, individual tree yields were taken, and a 20-pound sample was submitted to Paramount Farming for quality assessment. Each year, treatment effects will be determined by ANOVA ($P = 0.05$). After harvest in year 2, treatment effects on cumulative yield parameters will be determined ($P = 0.05$). After harvest in year 2, a factorial analysis by year will be used to test for treatment effects on yield, and quality, floral bud retention and leaf nutrient concentrations. The alternate bearing index [ABI = (year 1 yield - year 2 yield) (year 1 yield + year 2 yield)] will also be calculated for each treatment. All data will be statistically analyzed using the General Linear Model procedure of SAS. A cost:benefit analysis will also be performed to determine the utility of the different foliar fertilizer strategies for pistachio production.

Fertilizer treatments to be tested in each strategy are the following:

1. Strategy 1 - the following treatments were applied at the bud swell to green tip stage of phenology: (1) N [6 lbs/acre, urea (46% N, 0.25% biuret)]; (2) N [6 lbs/acre, urea (46% N, 0.25% biuret)] combined with Zn [5 lb/acre, $ZnSO_4$ (36% Zn)] to test the capacity of urea to increase Zn uptake; (3) N [6 lbs/acre, urea (46% N, 0.25% biuret)], Zn [5 lb/acre, $ZnSO_4$ (36% Zn)] combined with B [5 lb/acre, Solubor (20.5% B)]; and (4) B [5 lb/acre, Solubor (20.5% B)]. We hope to determine whether using urea as a carrier provides any benefit in enhancing zinc and boron uptake.
2. Strategy 2 - the following treatments were applied at 1/2- to 2/3-leaf expansion: (1) Zn [2 lb/acre, $ZnSO_4$ (36% Zn)]; (2) N [6 lbs/acre, urea (46% N, 0.25% biuret)]; and (3) Zn [2 lb/acre, $ZnSO_4$ (36% Zn)] combined with N [6 lbs/acre, urea (46% N, 0.25% biuret)]. Comparison of treatment effects

will resolve whether urea increases Zn uptake and whether Zn and/or N increase fruit retention and yield.

3. Strategy 3 - the following treatments were applied in early June, early July and mid-August (application costs could potentially be reduced in the future by combining fertilizer with fungicide or navel orangeworm sprays): (1) K [10 lb/acre, KTS (0-0-25-17S)]; (2) K [10 lb/acre, KNO_3 (13-0-38)]; (3) N [6 lbs/acre, urea (46% N, 0.25% biuret)]; and (4) K [10 lb/acre, KTS (0-0-25-17S)] combined with N [6 lbs/acre, urea (46% N, 0.25% biuret)]. Comparison of treatment effects on yield will determine whether urea increases K uptake and whether trees need only K or benefit from added N and/or S at this time.

RESULTS AND DISCUSSION

Changes in Pistachio Tree Nutrient Status Over Time

To determine the effect of available soil nutrients on tree nutrient status over time, independent of the foliar fertilizer treatments, we plotted bud and leaf nutrient concentrations for each sampling date for the untreated control trees in this orchard (**Figures 1 and 2**). The orchard received 218.6 lbs N/acre - 17% in April, 33% in May, 25% in June and 25% in July. Leaf N peaked at the end of April, decreased ~1.5% by mid-June, and remained stable thereafter at approximately 2.5%. Applications of K (55.8 lbs/acre) and P (27.9 lbs/acre) were split - 14% in May, 43% in June and 43% in July. Leaf K increased from mid-June through the end of July at ~2.4%. Leaf P peaked at 0.43% in April and decreased to 0.14% or less from June through October. Calcium steadily increased from April through September. Magnesium increased gradually over the entire growing season from 0.18% to 0.53%. Changes in the concentrations of N, P, K, Ca, Mg over time were equivalent to those reported by Brown and Siddiqui (2011). In addition, we report similar changes for S, B, Zn, Fe and Cu. From April 26 through October, leaf B steadily increased. Manganese steadily increased from March through mid-August. Iron decreased precipitously from March to late April, but thereafter increased somewhat erratically. Copper was highest in March (14.59 ppm), decreased to 8 ppm in June and remained just under 8 ppm through October. No B, Mn, Fe or Cu fertilizers were applied to the soil in this experiment. The nutrient content of leaves collected before and after foliar fertilizer treatment reflect these changes in pistachio tree nutrient status and must be considered when interpreting the data. Only the effects due to foliar fertilizer treatment are discussed herein.

Effect of Foliar-Applied Fertilizers on Tissue Nutrient Concentrations.

Effect of fertilizer applications at bud swell to green tip. At the start of the experiment, concentrations of N, P, K Ca, Mg, S, B, Zn, Mn, Fe, and Cu in flower buds collected at bud swell to green tip prior to the first fertilizer applications were not significantly different among trees in all treatments. This confirms that tree nutrient status was uniform for the data trees used in this research. Foliar application of B (alone) at the bud swell to green tip stage increased the bud concentration of B significantly. It must be noted that these buds were collected 19 days after treatment, whereas buds for the other treatments applied at this stage of development were collected only 8 days after treatment. This was because after the boron spray was applied, high winds prevented the application of urea-N, urea-N plus boron,

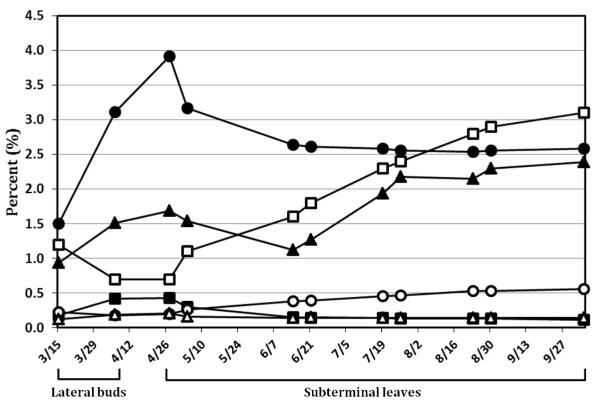

Figure 1. Changes with time in bud and leaf nutrient concentrations of untreated (control) 'Kerman' pistachio trees, Lost Hills, CA: (-●-) Nitrogen, (-■-) Phosphorus, (-▲-) Potassium, (-□-) Calcium, (-○-) Magnesium, and (-∆-) Sulfur.

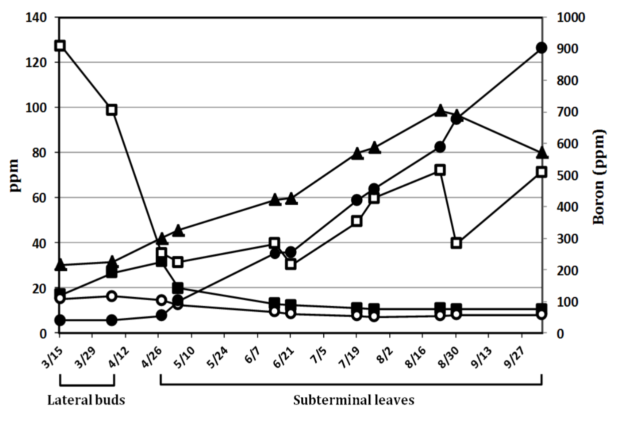

Figure 2. Changes with time in bud and leaf nutrient concentrations of untreated (control) 'Kerman' pistachio trees, Lost Hills, CA: (-●-) Boron, (-■-) Zinc, (-▲-) Manganese, (-□-) Iron, and (-○-) Copper.

and urea-N plus boron and zinc for 11 days and the buds in all treatments were collected 8 days later. Trees sprayed with B plus urea or B plus urea and Zn had significantly greater bud Zn concentrations than either the control trees or trees treated with urea alone. It is interesting to note that trees treated with B plus urea had the highest bud Zn concentration ($P < 0.0001$) even though the trees did not receive Zn fertilizer.

Effect of fertilizer applications at 1/2- to 2/3-leaf expansion. Prior to foliar fertilizer application at 1/2- to 2/3-leaf expansion (LE), there were no significant differences in leaf concentrations of N, P, K, Ca, Mg, S, B, Zn, Mn, Fe, or Cu among fertilizer treatments. Leaf N concentration was significantly greater for trees receiving foliar-applied urea than for control trees. Trees sprayed with Zn or Zn plus urea had intermediate leaf N concentrations relative to the control. Applying Zn at LE did not increase leaf Zn concentration 10 days later.

Effect of fertilizer applications in June, July and August. Mid-June. Prior to the mid-June fertilizer applications, there were no significant differences in leaf nutrient concentrations among treatments. No significant changes in leaf nutrient status due to foliar fertilization were detected 7 days after application. Mid-July. Leaf samples collected prior to treatment in mid-July showed that trees treated with KTS (+/- urea) in mid-June had significantly greater S concentrations than all other treatments (P < 0.0001). Leaves collected after treatment showed that trees receiving KTS and KTS plus urea still had greater S concentrations than trees in all other treatments (P = 0.0004). However, the treatment failed to increase leaf K. Mid-August. Leaves sampled pre-treatment in mid-August showed that trees treated in mid-July with KTS had significantly greater S concentrations than trees in all other treatments (P < 0.0001). These trees continued to have significantly greater concentrations of S after the mid-August fertilizer applications (P < 0.0029). There were no other differences in leaf nutrient concentrations. Three foliar applications of KTS or KNO_3 failed to increase leaf K or N in the case of KNO_3.

Effect of foliar fertilizer applications on tree nutrient status in October. Several foliar fertilizer treatments had a significant effect on tree nutrient status by the end of the season. Soil fertilizers also affected leaf nutrient concentrations by October. Nitrogen. Trees treated with urea in June, July and August had leaf N concentrations that were significantly greater than trees in all other treatments except trees receiving urea, urea + Zn, or Zn at leaf expansion and the control ($P = 0.0113$) (**Table 1**). Control trees had leaf N concentrations that were

Table 1. Effects of canopy-applied fertilizers on leaf macronutrient concentrations of 'Kerman' pistachio trees in October.

Treatment	Application time	N	P	K	Ca	Mg	S
		%					
Urea-N	Bud swell to green tip	2.52 c[z]	0.115 a	2.43 a	3.1 ab	0.56 a	0.138 cd
Urea-N + B	Bud swell to green tip	2.51 c	0.116 a	2.46 a	3.0 abc	0.56 a	0.139 cd
Urea-N + B + Zn	Bud swell to green tip	2.54 bc	0.116 a	2.45 a	3.1 ab	0.58 a	0.138 cd
B	Bud swell to green tip	2.51 c	0.114 a	2.42 a	3.0 abc	0.55 a	0.137 cd
Zn	1/3 to 1/2 leaf expansion	2.57 abc	0.116 a	2.38 a	3.0 abc	0.55 a	0.140 cd
Urea-N	1/3 to 1/2 leaf expansion	2.62 ab	0.117 a	2.47 a	3.1 ab	0.56 a	0.141 cd
Zn + Urea-N	1/3 to 1/2 leaf expansion	2.56 abc	0.117 a	2.45 a	2.9 c	0.55 a	0.143 c
KTS	Jun, Jul, and Aug	2.50 c	0.115 a	2.41 a	3.0 abc	0.57 a	0.197 a
KNO_3	Jun, Jul, and Aug	2.52 c	0.115 a	2.50 a	3.1 ab	0.56 a	0.135 d
Urea-N	Jun, Jul, and Aug	2.65 a	0.117 a	2.43 a	3.1 a	0.57 a	0.142 cd
KTS + Urea-N	Jun and Jul	2.51 c	0.115 a	2.50 a	3.0 bc	0.55 a	0.178 b
Control		2.58 abc	0.117 a	2.39 a	3.1 ab	0.56 a	0.143 c
P-value		0.0113	0.8913	0.7306	0.0928	0.7410	<0.0001

[z] Values in a vertical column followed by different letters are significantly different at the specified *P*-value by Fisher's Protected LSD Test.

intermediate to and not significantly different from any treatment. Sulfur. Foliar-applied potassium thiosulfate (KTS) in June, July and August or KTS plus urea in June and July significantly increased leaf S concentrations relative to all other treatments ($P < 0.0001$) (**Table 1**). Phosporus, Potassium, Calcium and Magnesium. There were no significant differences in leaf P, K, Ca or Mg content among treatments by October (**Table 1**). Zinc. Trees treated with Zn alone or in combination with urea at leaf expansion had significantly greater leaf Zn concentrations than all other treatments ($P < 0.0001$) (**Table 2**). Adding urea increased average leaf Zn over trees sprayed with Zn alone, suggesting that urea enhances Zn uptake at this stage of leaf development. A similar effect was not observed for urea plus Zn and B applied at bud swell to green tip. Boron, Managnese, Iron and Copper. There were no significant differences in leaf B, Mn, Fe or Cu content among treatments by October (**Table 2**).

Effect of Canopy Applications of Fertilizer on Bud Retention

Bud retention was low. By harvest only the apical bud remained on most shoots, with bud retention ranging from 1.1 to 1.3 per shoot. The fertilizer treatments had no effect on bud retention.

Effect of Canopy Applications of Fertilizer on Yield

No foliar fertilizer treatment significantly increased total dry weight of split nuts per tree. The foliar fertilizer treatments also had no effect on nut quality or kernel size (**Table 3**).

The experiment was well designed. No significant differences in the tissue concentrations of any nutrient existed among the trees prior to treatment until July. In July, trees treated with potassium thiosulfate (KTS) (+/- urea) in June had significantly greater leaf S concentrations prior to the second KTS application. Boron decreased in floral buds from 15 March to 6 April in the control trees. Canopy-applied B maintained the B concentration of buds at levels equal to or greater than the B concentration on 15 March and equal to or greater than the leaf B concentration of the untreated control trees on 6 April ($P = 0.0191$). By October, leaves from all trees had equally high concentrations of B (821-1019 ppm), significantly above the suggested optimal range of 150 to 250 ppm (Beede 2004).

The standard time for collecting pistachio leaves for nutrient analysis is late July through mid-August. Analysis of leaves collected on 26 July indicated that Ca, S, Zn, Mn, Fe were all within the optimal range (Beede 2004). Leaf Mg ranged from 0.49% to 0.46% for the treatments. The critical value for Mg is presently 0.6% (Beede 2004), but recent research by Brown and Siddiqui (2011) suggests that 0.45% is a more appropriate critical value. Phosphorus was at the low end of the optimal range to deficient. Leaf P ranged 0.146% to 0.137% (average leaf P was 0.137% for trees in two treatments); the critical value for P is 0.14%. Several nutrient concentrations exceeded their optimal range (the upper value of the optimal range is given in parentheses) (Beede, 2004): B (250) ranged from 452 ppm to 538 ppm; K (2.0%) ranged from 2.1% to 2.29% and N (2.5%) ranged from 2.53% to 2.62%.

By October, Zn alone applied at leaf expansion increased leaf Zn to a value significantly greater than trees in all other treatments except Zn + urea ($P < 0.0001$). When Zn was applied with urea at leaf expansion, it further increased leaf Zn concentration to a value significantly greater than leaf Zn concentrations for trees in all treatments including trees treated with Zn alone ($P < 0.0001$). This result provides clear evidence that urea facilitated the uptake of Zn at this application time. Trees receiving three foliar applications of potassium thiosulfate (KTS) in June, July and August or KTS combined with urea in June and July had significantly greater leaf S concentrations than other treatments 27 days after application that remained greater through October ($P < 0.0001$). Both the KTS and KNO_3 treatments failed to increase leaf K concentrations by October.

Single or multiple foliar applications of urea did not significantly increase leaf N concentrations 7 to 10 days after application but resulted in greater concentrations of N in leaves collected in October ($P = 0.0113$). Three foliar urea applications were better than two. Interestingly, trees receiving three applications of KNO_3 had very low leaf N concentrations by October, suggesting that mature pistachio leaves may absorb urea more efficiently. It was surprising that we significantly increased leaf N concentrations with foliar-urea given the amount of N applied to the soil for the season (218 lbs N/acre). All trees had tissue N concentrations between 2.47% and 2.65% through October. This level is on the high side of the current optimal range of 2.2-2.5% (Beede 2004).

ACCOMPLISHMENTS

Results from Year 1 of this research suggest that pistachio buds at the bud swell to green tip stage take up B as Solubor$^{\Diamond}$ and B and Zn (as $ZnSO_4$) when combined with urea. The results are not confirmatory since the buds were not covered during fertilizer application. Consistent with this interpretation, leaf B concentrations in October were 100 ppm greater (not significant) for trees treated with B and urea than trees treated with B only at bud swell to green tip. In most cases, increases in

Table 2. Effects of canopy-applied fertilizers on leaf micronutrient concentrations of 'Kerman' pistachio trees in October.

Treatment	Application time	B	Zn	Mn	Fe	Cu
		ppm				
Urea-N	Bud swell to green tip	953.3 a[z]	11.17 c	83.5 a	65.2 a	7.42 a
Urea-N + B	Bud swell to green tip	1019.1 a	11.13 c	80.9 a	61.3 a	6.91 a
Urea-N + B + Zn	Bud swell to green tip	996.3 a	10.39 c	78.0 a	61.9 a	6.87 a
B	Bud swell to green tip	912.2 a	9.92 c	84.8 a	58.0 a	7.32 a
Zn	1/3 to 1/2 leaf expansion	835.9 a	56.11 b	86.1 a	65.4 a	7.45 a
Urea-N	1/3 to 1/2 leaf expansion	888.5 a	10.17 c	80.2 a	57.3 a	7.31 a
Zn + Urea-N	1/3 to 1/2 leaf expansion	936.8 a	63.77 a	80.3 a	60.3 a	8.10 a
KTS	Jun, Jul, and Aug	876.1 a	10.64 c	79.6 a	55.6 a	7.67 a
KNO_3	Jun, Jul, and Aug	821.0 a	10.30 c	80.4 a	63.2 a	7.31 a
Urea-N	Jun, Jul, and Aug	981.8 a	10.81 c	82.6 a	65.8 a	7.51 a
KTS + N	Jun and Jul	940.0 a	10.71 c	80.0 a	61.0 a	7.28 a
Control		901.0 a	10.59 c	80.1 a	71.3 a	8.09 a
P-value		0.8002	<0.0001	0.9283	0.7808	0.9471

[z] Values in a vertical column followed by different letters are significantly different at the specified *P*-value by Fisher's Protected LSD Test.

Table 3. Effects of canopy-applied fertilizers on yield and nut quality of 'Kerman' pistachio, Lost Hills, CA. Harvest was 22 August 2011.

Treatment	Application time	Split nut dry wt.	Blank nuts	Dark stained nuts	Insect damage	Embryo dry wt.
		kg/tree	%			-- mg/nut --
Urea-N	Bud swell to Green tip	17.9 a	3.5 a	1.0 a	0.2 a	734 a
Urea-N +B	Bud swell to Green tip	19.5 a	3.1 a	1.0 a	0.2 a	731 a
Urea-N +B + Zn	Bud swell to Green tip	19.4 a	2.8 a	1.2 a	0.2 a	715 a
B	Bud swell to Green tip	20.2 a	3.1 a	0.8 a	0.1 a	729 a
Zn	1/2 to 1/3 leaf expansion	20.7 a	3.4 a	1.0 a	0.1 a	719 a
Urea-N	1/2 to 1/3 leaf expansion	19.8 a	2.9 a	1.3 a	0.1 a	714 a
Zn+ Urea-N	1/2 to 1/3 leaf expansion	18.9 a	3.5 a	1.0 a	0.2 a	722 a
KTS	June, July & August	20.5 a	3.4 a	1.1 a	0.2 a	721 a
KNO_3	June, July & August	19.4 a	3.2 a	0.9 a	0.1 a	733 a
Urea-N	June, July & August	19.0 a	3.5 a	1.3 a	0.1 a	722 a
KTS+ Urea-N	June & July	19.2 a	2.8 a	1.5 a	0.1 a	734 a
Control		19.6 a	3.1 a	0.8 a	0.1 a	726 a
P-value		0.3026	0.4731	0.7214	0.6992	0.5804

[z] Values in a vertical column followed by different letters are significantly different at the specified *P*-value by Fisher's Protected LSD Test.

leaf nutrient concentrations were not detected in leaves that had been covered prior to application and collected for analysis 7 to 10 days later. However, nutrient analysis of leaves collected in October provided clear evidence that several foliar-applied fertilizers had increased tree nutrient status. October leaf analyses demonstrated that Zn (as $ZnSO_4$) applied at LE was absorbed and that urea increased the Zn uptake at this time. October leaf S concentrations were significantly increased by three applications of KTS or two applications of KTS combined with urea compared to all other treatments; however, the desired effect of increasing tree K status was not achieved. Trees that received three applications of urea (June, July and August) had the highest October leaf N concentrations, but not significantly greater than the control trees or trees receiving a single application of urea at leaf expansion. Although our research results demonstrated the successful uptake of foliar-applied fertilizers, no yield benefit was obtained.

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