

Optimum Timing of Potassium Nitrate Spray Applications to ‘French’ Prune Trees

S.M. Southwick

Department of Pomology, University of California, Davis, CA 95616

W. Olson

University of California Cooperative Extension, Butte County, Oroville, CA 95965

J. Yeager and K.G. Weis

Department of Pomology, University of California, Davis, CA 95616

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Abstract. During the fruit growing season, April through August 1990, 1991, and 1992, four sprays of 20–22 liters/tree of KNO₃ were applied to ‘French’ prune trees (*Prunus domestica* L. syn. ‘Petite d’Agen). Spray applications of KNO₃ were compared to single annual soil applications of KCl (1.4–2.3 kg/tree) and sprays of urea + KNO₃ with respect to leaf K and N, fruit size, drying ratio, and dry yield. Potassium nitrate sprays were as effective, or better, than soil-applied K in maintaining adequate levels of leaf K throughout the season. Treatment effects were not carried over into the next year. Lowest leaf K was found in trees where no K had been applied. Those values were below the adequate level of 1.3% K and the untreated group developed K deficiency symptoms. Consistent effects on leaf K were not obtained when urea was applied and no negative effect on leaf K was demonstrated. Equivalent dry yields per tree were obtained by foliar and soil K applications. There was no best time for KNO₃ sprays. Yield per tree was not enhanced when foliar K–N sprays were applied to trees that had levels of 1.3% K or more as of 15 Apr. 1992. Trees that were below optimum K in April tended toward improved dry yields after four K–N sprays. Trees that had no applied K were lowest yielding. Drying ratios and fruit size (number of fruit per kilogram) were not different among K treatments. Dry yields per tree were increased without a decrease in fruit size or an increase in drying ratio with either soil or foliar K application. These results suggest that foliar KNO₃ sprays applied four times throughout the growing season can be used to correct incipient K deficiency in ‘French’ prune and to obtain dry yields equivalent to those obtained with soil applications of KCl.

Potassium deficiency is one of the most significant nutrition management problems in prune culture, accounting for leaf chlorosis, scorching, early leaf and fruit abscission, limb dieback, particularly in the upper canopy (Lilleland, 1932; Lilleland and Brown, 1938), and inferior fruit size and yield (Robbins et al., 1982). Under California conditions, K deficiency has been aggravated by excessive fruit production.

Standard practice to correct K deficiency is to apply K to the soil. Many growers use annual maintenance doses of K₂SO₄ or KCl (e.g., 1.4–2.3 kg/tree) to spread out or reduce costs. Soil application of K even in large amounts has not consistently corrected deficiency at all orchard sites, particularly those with heavy crops grown on fine-textured soils. Soil application of K₂SO₄ at about 9 kg/tree every 3 or 4 years is recommended for deficient trees growing on fine-textured clay soils, but it is costly (Carlson and Uriu, 1981; Olson et al., 1987).

Availability of K to the tree from the soil is not limited to total soil K concentration, but is dependent on soil structure and irrigation, form of K, method of application (McKinnon and Lilleland, 1931; Robbins et al., 1982), equilibrium effects (Carlson and Uriu, 1981; Lilleland, 1946; Lilleland and Brown, 1939), and rootstock and cation balance (Rosen and Carlson, 1984a). Fine-textured soils impede uptake of K (Lilleland, 1946), and, as these soils are poorly draining, K may not penetrate deeply into soils without the addition of gypsum (Carlson et al., 1974) or deep auguring (Robbins et al., 1982). The positional availability of K

(Lilleland and Brown, 1938) is further aggravated by alternate drying and wetting of soil, immobilizing K in a fixed form (Lilleland, 1946). Many Sacramento Valley prune orchards are flood irrigated, which exacerbates the problem by limiting K availability. Drip application of K in irrigation water has been recommended (Carlson and Uriu, 1981; Uriu et al., 1980); however, most prune orchards in California are not appropriately equipped.

Potassium levels in the soil can vary widely within the same orchard and are not indicative of whole tree levels; levels in the soil can be high, yet low in the tree (Robbins et al., 1982). Leaf K has been considered a more representative measure of tree status than soil K (Davis, 1934; Lilleland and Brown, 1938). The amount of leaf K is affected by the availability of soil K, degree of cropping, and fruit growth phase through the season. Application of KNO₃ as a foliar spray has been used to adjust tree K levels in prune (Robbins et al., 1982) and N levels in peach (Leece and Kenworthy, 1971) or by growers as an option in heavy cropping seasons when K supplies from the soil might be limited. Urea as an adjuvant has been reported to increase uptake of some nutrients, such as urea-enhanced phosphoric acid absorption (Okuda and Yamada, 1962). Diver et al. (1985) reported that in pecan seedlings KNO₃ combined with urea showed a linear increase in leaf K concentration with increase in urea concentration over that of foliar-applied KNO₃ alone. However, fall soil application of other forms of N has antagonized the leaf K content in the subsequent season (Kenworthy, 1965). Interactions between N and K levels in some fruit-bearing plants suggest an antagonistic relationship in which leaves of K-deficient plants accumulate N, increasing the incidence and severity of K deficiency symptoms (Forshey and McKee, 1970; Leece, 1975), possibly by increasing K efflux from roots (Rosen and Carlson, 1984b). Potassium-deficient leaves accumulate putrescine

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Table 1. Potassium and nitrogen treatments applied to 'French' prune trees from 1990 through 1992.

Treatment	Treatment timing	Application method	Application rate		
			1990	1991	1992
1 Control	None	None	None	None	None
2 KCl	Fall	Banded at dripline	2.3 kg/tree	2.3 kg/tree	2.3 kg/tree
3 KNO ₃ or KCl + KNO ₃	2× Spring	Sprayed	1 kg/100 liters	---	---
	Fall	Banded at dripline	Not applied	2.3 kg/tree	2.3 kg/tree
4 KNO ₃	2× Spring, 2× summer	Sprayed	1 kg/100 liters	0.7 kg/100 liters	0.7 kg/100 liters
5 KNO ₃	4× Spring	Sprayed	1 kg/100 liters	0.7 kg/100 liters	0.7 kg/100 liters
6 KNO ₃	4× Summer	Sprayed	1 kg/100 liters	0.7 kg/100 liters	0.7 kg/100 liters, 5× spring, summer
7 KNO ₃	2× Spring, 2× summer	Sprayed	1 kg/100 liters tops	0.4 kg/100 liters	0.4 kg/100 liters
8 KNO ₃ + urea	2× Spring	Sprayed	1 kg/100 liters	0.7 kg/100 liters	Treatments 8 & 9 combined, sampled for leaf K and split into treatments 10–13
9 Urea	2× Spring	Sprayed	5 kg/100 liters	5 kg/100 liters	5 kg/100 liters
					10 < 1.3% K, 2.7 kg/tree KN, 4× spring/summer
					11 < 1.3% K, unsprayed
					12 > 1.3% K, 2.7 kg/tree KN, 4× spring/summer
					13 > 1.3% K, unsprayed

above all other nitrogenous compounds, a substance that has been used experimentally to induce K deficiency symptoms (Forshey and McKee, 1970). Its toxicity might in part explain the development of the physical symptoms of chlorosis and browning observed when K deficiency and putrescine accumulation have been positively correlated (Evans et al., 1977).

Potassium nitrate sprays are an option for growers unable to achieve optimum K levels in 'French' prune orchards, especially on fine-textured soils and in heavy cropping years. Our objectives were to determine 1) whether foliar sprays are as effective in maintaining sufficient tree K as maintenance soil doses and 2) an optimum KNO₃ spray timing to minimize K deficiency symptoms.

Materials and Methods

Plant material and site selection. The orchard used in these experiments had a history of chronic K deficiency and was located in the northern Sacramento Valley, in Gridley, Calif. The soil type was a fine-textured Wyman loam. Soil sampling at several locations throughout the orchard indicated that the average exchange-

able K in the soil ranged from 112 to 68 mg·liter⁻¹, as samples were taken from the upper 0.30–1 m below the soil surface, respectively. Experiments were initiated in 1990 and extended over a 3-year period. 'French' prune trees (*Prunus domestica* syn. 'Petite d' Agen') on Myrobalan 29C (*Prunus cerasifera* Ehrh.) rootstock were planted in 1980 with 6 m between rows and 5.5 m between trees (about 303 trees/ha). Irrigation was by orchard flooding consistent with conventional practice. Regular fertilization included a split soil application (March and June) of N at 57–84 kg·ha⁻¹ at each application, but no added K other than that used in the experimental treatments, throughout the experimental period. Full bloom occurred in late March.

Experimental design. The experimental design was a randomized complete block, with 21 blocks of single tree plots × nine treatments. The 3-year study allowed for modifications in quantity, content, and timing of treatment sprays in response to annual results. Treatment blocks were conserved from year to year, with treatment changes indicated in Table 1. Spray applications (20–22 liters/tree, 43–48 kg·ha⁻¹) of KNO₃ and soil applications of KCl (1.4–2.3 kg/tree, 280–460 kg·ha⁻¹) were begun at first full leaf,

Table 2. Effects of potassium and urea application on percentage leaf potassium in 'French' prune.

Treatment	Mean leaf K (% dry wt)					
	1990		1991		1992	
	24 Apr.	9 Aug.	15 Apr.	22 Aug.	15 Apr.	12-Aug
1 Control	1.6 c ^z	2.0 f	1.3	1.1 c	1.3	1.2 b
2 KCl	1.7 bc	2.0 f	1.4	1.5 b	1.4	1.3 ab
3 KNO ₃ 2× spring or KCl + KNO ₃ , 4× spring/summer	1.6 c	2.4 cd	---	---	---	---
4 KNO ₃ 4× spring/summer	1.8 ab	3.1 a	1.3	2.0 a	1.3	1.5 ab
5 KNO ₃ 4× spring	1.9 a	2.8 b	1.2	1.9 a	1.4	1.7 ab
6 KNO ₃ 4× summer	1.9 a	2.8 b	1.3	1.7 ab	1.3	1.5 ab
7 KNO ₃ (tops 1990, 1/2 rate 1991, 1992), 4× spring/summer	1.6 c	3.0 ab	1.3	2.0 a	1.3	1.6 ab
8 KNO ₃ + urea 2× spring	1.6 c	2.5 c	1.3	1.6 ab	1.3 ^{NS}	2.0 ab
9 Urea 2× spring	1.7 bc	2.2 de	1.3	2.0 a	10 < 1.3% K, sprayed	2.3 a
	1.7 bc	2.1 ef	1.3 ^{NS}	1.1 c	11 < 1.3% K, unsprayed	1.0 b
					12 > 1.3% K, sprayed	2.0 ab
					13 > 1.3% K, unsprayed	1.4 ab

^zMean separation by Duncan's multiple range test, $P = 0.05$.

^{NS}Nonsignificant.

Table 3. Effects of method and timing of K application on seasonal change in leaf K (expressed as a percentage of the leaf dry weight) in 'French' prune trees.

Treatment	Change in leaf K (%) from first full leaf (April) until harvest (August)		
	1990	1991	1992
1 Contro	0.4 c ^z	-0.2 c	-0.1 c
2 KCl	0.3 c	0.1 b	-0.1 c
3 KNO ₃ , 2× spring or KCl + KNO ₃ , 4× spring/summer	0.8 b	0.8 a	0.2 ab
4 KNO ₃ 4× spring/summer	1.3 a	0.6 a	0.3 a
5 KNO ₃ 4× spring	0.9 b	0.4 ab	0.2 ab
6 KNO ₃ 4× summer	1.3 a	0.7 a	0.3 a
Mean squares for leaf K (%)			
Source	1990	1991	1992
Treatment (T)	3.7***	2.8***	0.9***
Block (B)	1.1***	0.8***	0.6***
Model	2.0***	1.5***	0.7***
Error	0.1	0.2	0.2

^zMean separation by Duncan's multiple range test, $P = 0.05$.

***Significant at $P \leq 0.05$ or 0.001, respectively.

mid-April. Nitrogen was foliar-applied in the form of urea (Unocal plus, low biuret urea solution; Unocal Chemicals, Division of Union Oil Co., Los Angeles) at 5.3 kg/100 liters in 1990 and 1991. When, after 2 years, analyses indicated no enhancement or antagonism of K uptake by urea, the urea treatments were combined and split into four new treatment groups to allow for K spray application above and below an estimated optimum leaf K level of 1.3% (1.0% to 1.2% considered critical; Carlson and Uriu, 1981; Lilleland, 1946; Lilleland and Brown, 1939).

Leaf analyses. Leaf samples were collected from all trees throughout the season in 1990, and then from a subsample of 10 trees per treatment for the subsequent 2 years. Collections on treated trees were made before a spray application and repeated the following day. About 40 fully expanded spur leaves were randomly collected at about 0.5 m from the periphery from four exposures. In 1990, canopy position effects were tested using the untreated control (treatment 1; Table 1) and treatment 4 (KNO₃, 2× spring/2× summer), with equal numbers of leaves collected from upper (full sun) positions and lower (shaded) canopy positions. Leaf percentage K and N values are reported as combined upper and lower canopy values (except when treated separately in Fig. 1 and Table 5). Nitrogen and potassium analyses were performed by DANR Analytical Laboratory (Univ. of California, Davis, Calif.) in 1990, 1991, and 1992. Leaves were washed in dilute detergent solution, dried, and ground before analyses (Leece, 1972). In 1990, the total Kjeldahl N method was used (Carlson, 1978; Carlson et al., 1990; Issac and Johnson, 1976; Jones, 1989) and the modified Dumas total N combustion method was used in 1991 and 1992 (McGeehan and Naylor, 1988; Sheldrick, 1986; Sweeney, 1989). Extractable K was quantified by atomic emission spectrometry or by atomic absorption spectrometry (Franson, 1985; Johnson and Ulrich, 1959). Leaf N and K were expressed as percentage leaf dry weight.

Harvest data. Fruit were harvested by machine, and fresh and dry yields, fruit size, and drying ratios were determined by standard techniques (Southwick et al., 1994). The crop in 1990 was light; however, yield per tree (dry yield) and fruit quality characteristics (fruit size and drying ratio) were evaluated as a function of treatment. The 1991 and 1992 seasons were moderate to heavy cropping years. Fruit size (number of dry fruit per kilogram) was

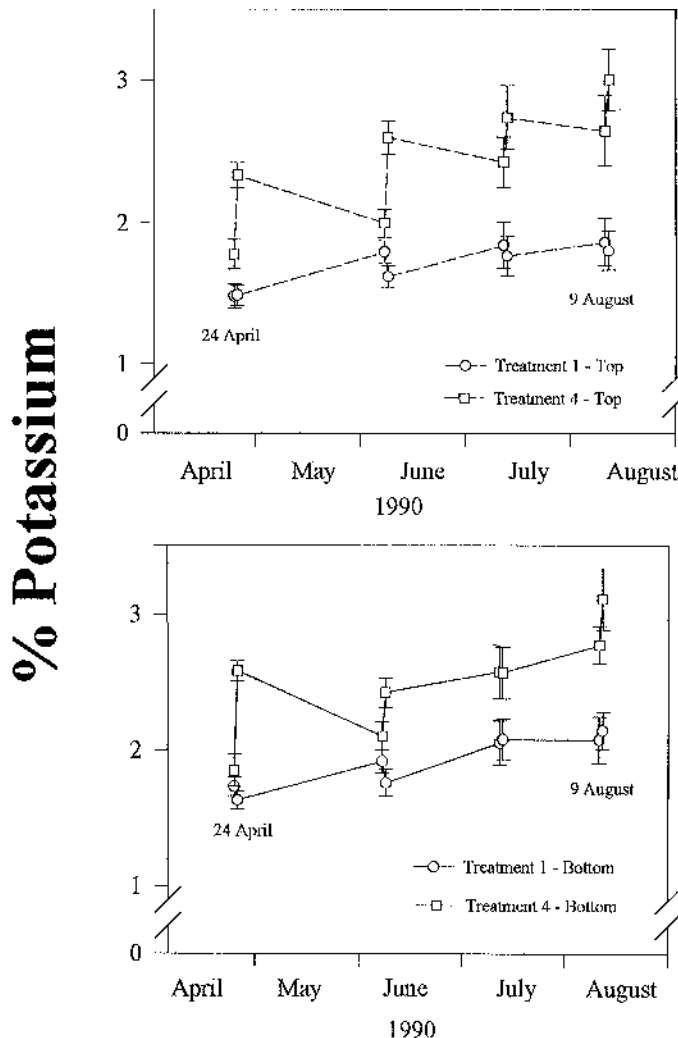


Fig. 1. Seasonal change (1990) in percent leaf K in upper and lower canopies of 'French' prune trees in response to four spring and summer foliar applications of KNO₃ (treatment 4) or no applied K (treatment 1). Bars represent the standard error of the treatment mean.

Table 4. Effects on seasonal change in leaf K of K and urea applications to 'French' prune.

Treatment	1990
1 Control	0.4 c ²
3 KNO ₃ , 2× spring	1.3 a
8 KNO ₃ , 2× spring + urea	0.6 b
9 Urea	0.4 c

²Mean separation by Duncan's multiple range test, $P = 0.05$.

determined after excluding the undersized fruit (smaller than screen size 23 = 1.8 cm). The percentage of undersized fruit was determined after total yield had been ascertained.

Statistical analyses. Analyses of variance (ANOVA) and Duncan's multiple range tests (DMRT) were performed by SAS's GLM procedure (SAS Institute, Cary, N.C.) to test leaf K and N levels, yield, and fruit quality indices, as a function of canopy position, K and N applications, application method, rate, and timing. The statistical model for analyses of variance in which more than one experimental year was considered used years as a split plot with treatment × block as the error term. In cases where nonsignificant differences among treatment means were found in the Duncan's tests, *t* tests were performed, assuming $H_0: \sigma^1 \neq \sigma^2$ (Little and Hills, 1978; Satterthwaite, 1946; Steel and Torrie, 1980).

Results

Effect of application method, rate, and timing of K applications on leaf K levels, treatments 1, 2, 4–7. Although soil analyses indicated a low exchangeable K level, in 1990 leaf K levels in all treatments were well above the adequate range of 1.3% at the beginning and end of the season (Table 2). The highest end-of-season levels in leaf K were seen in treatments that included foliar applications of KNO₃ for all 3 years (Tables 2 and 3). When KNO₃ was applied only to tops of trees (treatment 7; 9 Aug.) in 1990, mean leaf K for upper and lower canopy samples combined were higher than untreated controls, but lower than other KNO₃ treatments, except treatment 8 (KNO₃ + urea). Combination of soil-applied KCl and foliar-applied KNO₃ consistently led to higher leaf K levels compared to untreated controls or KCl alone (treatment 2). Lowest end-of-season levels of leaf K were found in the unfertilized control and the soil-fertilized treatment in 1990 (Table 2, treatments 1 and 2, respectively), and data from 1991, 1992, and a 3-year average (Table 3) indicated end-of-season levels of leaf K in treatments 1 and 2 to be similarly low. Leaf K values measured on 15 Apr. 1991 and 1992 indicated that newly expanded leaves had lower K values than those measured in the previous season (Table 2), except in the 1992 control and urea treatments (treatments 1 and 9, respectively) and there were no significant treatment effects noted for this date when treatment means were compared by Duncan's multiple range test ($H_0: \sigma^1 = \sigma^2$), or by *t* tests (single degree of freedom contrasts, assuming $H_0: \sigma^1 \neq \sigma^2$; data not shown), although different leaf K values were measured as a function of treatment at harvest in 1990 and 1991. By August, leaf K was higher where foliar KNO₃ had been applied. Differences in leaf K levels for 12 Aug. 1992 were less well-differentiated than in August 1991, but the seasonal change in leaf K was different among treatments, with a net reduction in leaf K for nontreated controls and soil-applied KCl (Table 3). Treatment effects for change in K were highly significant throughout the experimental years and an average of all 3 years' data indicated a trend of greater gain in leaf K through the growing season with

foliar applications (Table 3). After averaging 1990 through 1992 data, the greatest seasonal gains in leaf K were found in treatments 3–6, in which foliar sprays of KNO₃ were made. Foliar sprays of K made from April through June led to an increase of roughly 45% K in leaves the day after application (Fig. 1), decreasing over time to a level higher than that found before spraying. It appeared that early sprays contributed to higher spring/summer levels of leaf K, which did not decrease to the level of the control once elevated.

When trees were separated by critical leaf K level (1.3%, treatments 10–13, 1992), trees sprayed with KNO₃ gained in leaf K while untreated trees exhibited a net reduction in leaf K over the course of the season (Table 4). End-of-season leaf K values were highest to lowest as follows: low initial leaf K, sprayed; high initial leaf K, sprayed; high initial leaf K, unsprayed; low initial leaf K, unsprayed (equal values when rounded to one significant figure; Table 2).

Effect of urea applications on leaf K, treatments 8 and 9. Effects of urea on K uptake in trees sprayed in spring with KNO₃ and urea (treatment 8), relative to KNO₃-sprayed trees treated twice in spring (treatment 3), indicated no improvement in percentage of leaf K (Table 2) and minimal improvement in change in leaf K (Table 4) over that of the untreated control or urea-sprayed trees (treatment 9).

Effect of canopy position on leaf K and N. Leaf K was consistently higher in treatment 4 than in the unfertilized control, whether measured in the upper canopy or in the lower (Fig. 1). Leaves in the most exposed regions of tree canopies tended to have lower levels of leaf K than found in leaves from lower, more shaded canopy positions in both sprayed and unfertilized treatments. Spraying only the tops of tree canopies (treatment 7) resulted in leaf K values similar to those with soil-applied KCl (Table 2). Leaf K levels in the light crop year 1990 in upper and lower canopies were above 1.3% in control (untreated) and KNO₃ spray treatment groups (Fig. 1). In 1991, a normal crop year, the upper and lower canopies of untreated control trees exhibited K-deficient levels and the exposed upper canopy was significantly lower in leaf K than the shaded lower canopy (Table 5). Upper canopy leaves had less N compared to levels measured in leaves from lower canopy positions exposed to lower light levels (Table 5).

Effect of KNO₃, KCl, and urea applications on leaf N, treatments 1–9. Trees did not show N deficiency symptoms or fall below optimum levels of leaf N (2.2% is minimally adequate) at any time during the study except for treatments 2 (soil-applied KCl) and 13 (untreated > 1.3% K) on 12 Aug. 1992 (Table 6). Change in leaf N was not significantly different among treatments in 1990 (data not shown); however, net reduction of leaf N in 1991 was least in the KNO₃ + urea (treatment 8) treated trees. On 22 Aug. 1991, trees treated with urea and sprayed with K–N four times through the spring and summer had the highest leaf N. Separation of treatment means by Duncan's test for percentage change in leaf N in 1991 showed a trend toward least net reduction of leaf N in trees treated with urea + KNO₃, followed by trees treated with urea alone, KNO₃, and KNO₃ + KCl treatments, with nontreated trees showing the greatest net reduction in leaf N. Although urea

Table 5. Leaf K and N as affected by canopy position in unfertilized 'French' prune. Data collected 22 Aug. 1991.

Canopy	K (%)	N (%)
Top	0.8 b ²	2.2 b
Bottom	1.1 a	2.8 a

²Mean separation by Duncan's multiple range test, $P = 0.05$.

treatments did not lead to higher leaf K levels, the overall appearance of trees, with respect to K deficiency symptoms, was improved by urea sprays. Percentage N was not different among treatments on 15 Apr. 1991 or 1992, whether tested by Duncan's (Table 6) or *t* tests (data not shown), except for the *t* for treatment 4 vs. the control on 15 Apr. 1992 (*t* value 2.28, significant at *P* = 0.05). Multiple sprays of urea at the rate of 20 liters/acre resulted in leaf phytotoxicity and was observed as a leaf shot-holing (necrotic spots that gave rise to holes).

Effect of K and urea applications on fruit size, drying ratio, and yield. Statistically equivalent dry yields per tree were obtained for all treatments in 1990, and although the number of fruit/kg was highest (a high number of fruit/kg represents a high number of small or undersized fruit) in spring K-N spray treatments, no trend was seen among treatments for fruit quality characteristics (drying ratio) for that year (Table 7). In 1990, trees treated with spring KNO₃ sprays yielded fruit of the same size as KCl-fertilized trees. There were no significant fruit size differences among treatments in 1991, 1992, or in the 3-year average as measured by Duncan's tests (Table 7). Dry yields obtained with spray applications of K were not statistically different than those obtained with soil K applications in 1991 and 1992 as determined by Duncan's tests (Table 7), but they tended to be higher than those obtained from unfertilized controls in 1991 and were significantly higher in 1992 and when the 3 years' data were averaged (Table 7). The *t* values indicated significant improvement in dry yield for treatments 2, 3, 5, and 6 in 1992 compared to the control (Table 9). Urea treatments did not clearly affect yields or fruit size when compared to treatments without urea (data not shown).

Trees that had no applied K developed deficiency symptoms before harvest. Treated trees initially above 1.3% K tended to have the highest dry yields, followed by untreated trees above 1.3% K and treated trees initially below 1.3% K (Table 8). Low-K, untreated trees had the lowest dry yields. The *t* values indicated a significant improvement in dry yield of treatments 11 and 13 (untreated in 1992) compared to the control that had been untreated for 3 years (Table 9). Even though fruit yield was lowest in nontreated trees in 1991, 1992, and the 3-year averages, the percentage of undersized fruit was not increased when compared to soil KCl and spring/summer K-N foliar sprays (data not shown);

refer to Materials and Methods). High fresh yields (data not shown) in KN- and KCl-treated trees coupled with low drying ratios led to high dry fruit yields. Trees with leaf K values above 1.3% in April had higher dry fruit yields and fruit size that was similar or larger, whether treated or not, than trees with leaf K values below 1.3% in April.

Discussion

In all years of experimentation, leaf K gain from foliar K-N sprays was equal to or better than that seen in conventional soil KCl applications, a result not previously reported in the literature. The lack of decrease in leaf K seen in the control in 1990 (an increase was seen, instead) was probably due to the extremely light cropload that year, hence a light to negligible drain on available K. Foliar uptake of K may be more predictable and efficient than from the soil where soil-cation interactions may hinder uptake. Moreover, if the rate of demand for K by the tree is greater than the rate by which K is made available in the soil, deficiency will develop in the plant, regardless of soil amendment. This possibility is even greater during periods of rapid growth, such as the fruit flesh growth phase. Foliar application provides a rapid means to correct incipient deficiency detectable by leaf analyses before development of symptoms. In pecan, where K deficiency affects yield in much the same way as in 'French' prune, annual soil applications of K-N fertilizers do not guarantee sufficient K uptake nor high nut yields (Alben and Hammar, 1964). Foliar application of KNO₃ in pecan has proved to be an efficient method of increasing leaf K (Gossard and Nevins, 1965; Wood et al., 1995) and nut yield (Hunter, 1967).

A normal (nondeficient) K level in late July and August for 'French' prune in California is 1.0% to 1.3% (Carlson and Uriu, 1981), and chlorotic prune leaves symptomatic of K deficiency may have an average leaf K of 0.28% to 0.35% (Evans et al., 1977). The relationship between dry yield and fruit size with leaf K indicates that a higher leaf K is needed to ensure adequate fruit size. High fresh yields per tree coupled with low drying ratios lead to high dry fruit yields. Using the highest combinations of dry fruit yields with adequate fruit size as an index for critical leaf K, we suggest that 1.3% should be considered adequate for improved

Table 6. Effects of soil and foliar potassium and urea treatment on leaf N (%) in 'French' prune.

Treatment	Leaf N (%)							
	1990		1991		1992			
	24 Apr.	9 Aug.	15 Apr.	22 Aug.	Treatment	15 Apr.	Treatment	12 Aug.
1 Control	3.5 ab ^Z	2.4 ab	4.9	2.6 d	1	3.6	1	2.2 bc
2 KCl	3.2 de	2.2 c	4.7	2.8 bcd	2	3.5	2	2.1 c
3 KNO ₃ (2× spring) or KCl+, fall								
KNO ₃ , 2× spring, 2× summer	3.4 bcd	2.4 ab	4.8	2.8 bcd	3	3.7	3	2.3 a
4 KNO ₃ , 4× spring/summer	3.4 bcd	2.7 a	4.8	2.7 cd	4	3.5	4	2.3 a
5 KNO ₃ , 4× spring	3.8 a	2.5 ab	4.9	2.8 bcd	5	3.6	5	2.2 bc
6 KNO ₃ , 4× summer	3.3 cde	2.4 ab	4.7	2.8 bcd	6	3.6	6	2.3 a
7 KNO ₃ , 4× spring/summer	3.3 cde	2.3 bc	4.8	2.8 bcd	7	3.6	7	2.2 bc
8 KNO ₃ , + urea 2× spring	3.5 ab	2.4 ab	4.8	3.2 a	8	3.7	10 < 1.3% K, sprayed	2.2 bc
9 Urea, 2× spring	3.2 de	2.3 bc	4.8 ^{NS}	3.0 b	9	3.6 ^{NS}	11 < 1.3% K, unsprayed	2.2 bc
							12 > 1.3% K, sprayed	2.3 a
							13 > 1.3% K, unsprayed	2.0 c

^ZMean separation by Duncan's multiple range test, *P* = 0.05.

^{NS}Nonsignificant.

cropping with minimal leaf scorch and limb dieback. In our study, trees with leaf K higher than 1.3% had fruit sizes, drying ratios, and dry yields that were not significantly different whether untreated or treated with four foliar K–N sprays. Significant fruit size differences observed among first-year treatments of 1990 may have reflected the previous season's cropping history (unknown) influencing flowering or initial fruit set leading to an expression of fruit size differences regardless of treatment, especially noticeable in light cropping years. Leaf K at this level maintains high yields and large fruit size, possibly by maximizing photosynthetic capabilities (reducing scorch) for better C assimilation by fruit. However, an early season (mid April or first fully mature leaf) leaf K analysis of <1.3%, coupled with a large crop in K deficient-prone soil, may be indicative of late season K deficiency problems in prune trees. Under these conditions, prune trees are more likely to benefit from four K–N sprays, where drip irrigation is not an option.

In our study, there was no single timing combination that was superior, although it might be expected that summer sprays would give a better response in fruit production, leaf K, and reduction of deficiency symptoms, due to the high demand for K in summer by

the developing fruit. Lilleland (1932) and Lilleland and Brown (1938) found that timing of symptom development coincided with the greatest rate of K accumulation by the developing fruit, which also coincided with the time of greatest sugar accumulation. Potassium is essential for the translocation of sugars, and crops with high carbohydrate production, such as prunes, typically have the highest demand for K (Carlson and Uriu, 1981). Davis (1934) reported that K is accumulated by Sugar prune fruit up to 4375-fold from bloom until maturity, and analysis of K use by the various tree parts shows that the main annual removal of K from the orchard is by the fruit (Carlson and Uriu, 1981).

Uneven distribution of leaf K in the exposed and shaded portions of trees reported here supports observed differences in predisposition to deficiency symptoms by the tops and southwest sides of trees, exacerbated by high temperatures (Evans et al., 1977). Low K seems to increase mesophyll resistance to CO₂ movement through the leaf, diminish amounts of chlorophyll (chlorosis), and decrease the rate of ATP and NADPH production, thereby reducing photosynthetic rate (Terry and Ulrich, 1973). Leaves compromised by K deficiency symptoms do not accumulate photosynthates sufficient for rapid carbohydrate accretion and

Table 7. Effects of soil and foliar K treatments on fruit size (no. fruit/kg), drying ratio, and dry yield (kg/tree) in 'French' prune.

Treatment	1990			1991		
	No. fruit/kg	Drying ratio	Dry yield	No. fruit/kg	Drying ratio	Dry yield
1 Control	86.2 c ^z	2.8	8.4	185.7	3.4 a	29.1 b
2 KCl	90.1 bc	2.8	7.3	185.0	3.4 a	33.9 ab
3 KNO ₃ (2× spring) or KCl +, fall						
KNO ₃ , 2× spring, 2×summer	82.9 c	2.7	8.0	171.6	3.3 bc	35.4 a
4 KNO ₃ 4× spring/summer	100.2 a	2.8	9.6	169.2	3.1 c	32.6 ab
5 KNO ₃ 4× spring	96.2 ab	2.8	8.6	172.8	3.2 bc	32.4 ab
6 KNO ₃ 4× summer	89.6 bc	2.7 ^{NS}	7.9 ^{NS}	183.6 ^{NS}	3.2 bc	31.5 ab
	Mean squares (1990)			Mean squares (1991)		
Source	No. fruit/kg	Drying ratio	Dry yield	No. fruit/kg	Drying ratio	Dry yield
Treatment (T)	802.0 ^{***}	0.1	14.0	1194.8	0.2 [*]	54.9
Block (B)	269.2	0.1 ^{***}	29.5 ^{***}	2717.0 [*]	0.2 [*]	140.8 ^{***}
Model	383.4 [*]	0.1 ^{***}	26.0 ^{***}	2412.6	0.2 [*]	123.6 ^{***}
Error	220.6	0.04	11.8	1603.9	0.1	43.9
	1992					
Treatment	No. fruit/kg	Drying ratio	Dry yield			
1 Control	144.1	2.7	24.4 b			
2 KCl	147.5	2.8	34.5 a			
3 KCl + KNO ₃ 4× spring/summer	149.6	2.7	36.7 a			
4 KNO ₃ 4× spring/summer	154.9	2.7	31.1 a			
5 KNO ₃ 4× spring	158.2	2.7	33.5 a			
6 KNO ₃ 4× summer	157.7 ^{NS}	2.8 ^{NS}	32.8 a			
	Mean squares (1992)					
Source	No. fruit/kg	Drying ratio	Dry yield			
Treatment (T)	690.1	0.03	319.6 ^{***}			
Block (B)	2692.8 ^{***}	0.1 ^{***}	377.8 ^{***}			
Model	2295.0 ^{***}	0.1 [*]	364.6 ^{***}			
Error	1069.2	0.1	63.2			

^zMean separation by Duncan's multiple range test, *P* = 0.05.

^{NS,*,**,*} Nonsignificant or significant at *P* ≤ 0.05, 0.01, or 0.001, respectively.

Table 8. The *t* values for effects of soil and foliar K and N treatments on dry yield (kg/tree) and fruit size (no. fruit/kg) in 'French' prune (nonsignificant values not shown).

Year	Treatment					
	2	3	5	6	11	13
<i>Dry yield of control vs. treatments</i>						
1992	2.75**	2.73**	2.33*	2.24*	3.53***	2.30*
<i>No. fruit/kg of control vs. treatments</i>						
1990	4	10				
1992	2.72**	2.15*				

*, **, *** Significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

have a low transpiration rate due to reduced stomatal function, and a high metabolic rate (Evans et al., 1977). In the light crop year of 1990, leaf K levels were above the optimum level in the lower canopy, even in unfertilized trees, a result in keeping with Lilleland's (1932) observation that removal of the crop early in the season decreased scorching. Although the leaf K level in the lower canopy in a normal crop year (1991) was significantly higher than that in the upper canopy of unfertilized trees, it was still below the optimum level (1.3%), demonstrating the potential for K deficiency even in shaded portions. Clearly, solar exposure, high temperatures, and heavy cropping affect leaf K.

High end-of-season leaf K levels were not maintained into the following season by any treatment group as all treatment groups exhibited similarly low leaf K levels in April. This result suggests that there may not be winter carryover of leaf K gain with either soil KCl or foliar KNO_3 applications. Lack of carryover from one growing season to the next most probably was due to the sequestering of K by fruit (Carlson and Uriu, 1981; Davis, 1934) as is also seen in pecan (Sparks, 1977). Kenworthy (1965) reported that postharvest spray applications of KNO_3 have no effect on leaf K the following season. Potassium stored in leaves would be lost to the tree as these abscise. From 2 weeks after full bloom, K levels in bark, wood, and spurs of bearing trees can fall below optimum levels and remain low throughout the season (Davis, 1934) as fruit develop. Accumulation of K from fertilizers, whether soil- or foliar-applied would not necessarily remain in tree tissues after leaves abscise.

Our experiments did not result in any consistently positive or negative effect on leaf K when urea was applied with and without KNO_3 . Urea sprays did not lead to higher leaf K levels, as one might expect if urea were acting to improve the uptake of ionic K, as has been reported for facilitated foliar absorption of ions in combination with urea in other species (Diver et al., 1985; Labanauskas and Puffer, 1964; Okuda and Yamada, 1962; Yamada et al., 1965). However, amelioration of K deficiency symptoms in trees treated with KNO_3 + urea was considered beneficial. Although urea

treatments led to higher leaf N compared to treatments without foliarly applied N, N did not appear to be limiting as deficiency symptoms did not develop, even in treatments 2 and 13 in 1992 in which leaf N was below the minimum considered adequate (Uriu, 1981).

Potassium nitrate sprays have been used to correct K deficiency symptoms in peach (Kenworthy, 1965) and 'Italian' prune (Robbins et al., 1982), and had a positive correlative effect on fruit weight and volume. Based on our data collected at a single problem site, it appears that foliar KNO_3 sprays applied four times in a single season improved dry fruit yields equally as applying 2.3 kg KCl/tree per year compared to nontreated trees. The benefits of foliar K applications for 'French' prune are clear when low leaf K levels develop early in the season and are coupled with moderate to heavy cropping. Foliar sprays preclude soil competition factors, irrigation dependence, slow response of soil uptake and distribution, and soil and groundwater accumulation of inorganic salts.

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Table 9. Effect of foliar K treatments on fruit size (no. fruit/kg), drying ratio, and dry yield (kg/tree) in 'French' prune at a critical potassium level (1.3%) in 1992.

Treatment	No. fruit/kg	Drying ratio	Dry yield	Source	No. fruit/kg	Drying ratio	Dry yield
1 Control	144.1	2.7 b ^z	24.4 b	Treatment	981.5	0.04	262.8*
4 KNO_3 4× spring/summer	154.9	2.7 b	31.2 ab	Block	1654.5***	0.1***	153.4
10 K < 1.3%, KNO_3 4× spring/summer	166.0	2.8 b	29.7 ab	Model	1520.1*	0.1***	191.3*
11 K < 1.3%, unsprayed	147.2	3.0 a	26.0 b	Error	724.8	0.04	99.8
12 K > 1.3%, KNO_3 4× spring/summer	152.8	2.7 b	38.0 a				
13 K > 1.3%, unsprayed	145.1 ^{NS}	2.7 b	33.8 ab				

^zMean separation by Duncan's multiple range test, $P = 0.05$.

^{NS,*,***}Nonsignificant or significant at $P = 0.05$ or 0.001, respectively.

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