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Autumn Foliage Applications of $ZnSO_4$ Reduced Leaf Nitrogen Remobilization in Peach and Nectarine

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Abstract. **Premature defoliation of peach and nectarine *(Prunus persica* L. Batsch) trees resulting from foliar applications of $ZnSO_4$ reduced N remobilization that typically occurs during leaf senescence. Leaf N remobilization in unsprayed control trees ranged from 45% to 50%, irrespective of tree N status. Leaf N remobilization in trees receiving foliar applications of $ZnSO_4$ ranged from a positive influx of N into the leaf to ≈30% of the N remobilized, depending on $ZnSO_4$ application timing and method of expressing leaf N levels. Early $ZnSO_4$ applications resulted in less N remobilization. Measuring leaf N on an area basis was a more precise indicator of N remobilization than N per unit dry weight, because leaf weight per unit area changes during leaf senescence.**

Deciduous fruit and nut trees exhibit annual patterns of nutrient cycling within their perennial tissues, as well as mechanisms for recycling nutrients from their annual organs (Taylor, 1976a). Studies with apple (Murneek, 1930; Oland, 1963a; Spencer and Titus, 1972), peach (Batjer and Westwood, 1958; Cullinan, 1931; Taylor, 1967b; Taylor and van den Ende, 1969), and pistachio (Uriu and Crane, 1977) indicate that mineral nutrients in leaves are remobilized by deciduous tree fruit species during autumnal leaf senescence. Nitrogen and other nutrients, including P and K, are transported, via the phloem, from senescing leaves to perennial organs of trees before abscission.

The importance of reserve N to spring growth resumption and development of deciduous fruit trees has long been recognized (Roberts, 1921; Thomas, 1927; Murneek, 1930; Oland, 1959, 1963b; Mason and Whitfield, 1960; Williams, 1967; Shim et al., 1973; Tromp and Ovaa, 1973; Weinbaum et al., 1980; Kang et al. 1982). Thomas (1927) demonstrated that the resumption of vegetative growth coincided with mobilization of reserves from branches, with more than half of the reserve N being redistributed to the new shoots.

The influence of chemical defoliation on leaf nutrient remobilization in deciduous fruit trees has received little attention. Rakitin and Imamaliev (1959) reported that the defoliants magnesium chlorate and endothal (7-oxabicyclo heptane-2,3-dicarboxylic acid disodium salt) reduced leaf N. They did not, however, determine the effect of chemical defoliation on N remobilization.

Premature abscission of foliage could reduce both leaf N remobilization and late-season uptake of N from soil (Weinbaum et al., 1978). Both processes contribute to the pool of storage N, and new shoot growth in spring is supported primarily by the redistribution of N from reserves (Weinbaum et al., 1978).

The relationship between plant N status and N remobilization during autumnal senescence has not been well-researched. Several studies (Oland, 1960, 1963b; Delap, 1967; Shim et al., 1973; O'Kennedy et al., 1975) have shown that apple trees with leaf N levels elevated by foliar urea applications responded with an increase in the absolute amount of N remobilized during leaf senescence. Taylor and van den Ende (1969) reported that peach trees remobilized 50% of their midsummer leaf N content independently of soil N treatment. In contrast, Cullinan (1931) found that low-N-status peach trees exhibited greater relative N remobilization than that of higher-N-status trees.

Fall foliar application of $ZnSO_4$ to stone fruit trees is widely practiced for prevention of Zn deficiencies in the San Joaquin Valley of California. Late season $ZnSO_4$ applications are not considered to be deleterious to tree performance, even though premature defoliation occurs (Beutel et al., 1983). The objectives of this experiment were to: 1) determine if defoliation following fall foliar applications of $ZnSO_4$ affects the amount of N remobilized from peach and nectarine leaves; and 2) determine the relationship between initial tree N status and N remobilization during autumnal leaf senescence.

Materials and Methods

Plant material. The experiment was carried out on 54 mature trees during the summer and autumn of 1986 at the Kearney Agricultural Center in Parlier, Calif. Mature peach and nectarine ('Flamecrest' and 'Flavortop', respectively) trees, growing in adjacent blocks, were used. The trees were trained to an open-vase system, and received standard commercial management.

Defoliation. Treatments were: Spray 1, applied on 3 Oct.; spray 2, applied on 16 Oct.; and control, trees allowed to defoliate naturally. Spray 1 preceded a "standard" commercial application date by ≈ 2 weeks, and spray 2 was made at the "standard" commercial application time. Both sprays 1 and 2 were zinc sulfate monohydrate (35% Zn) at 4.5 kg/500 liters, applied to runoff with a handgun sprayer. Trees of a given treatment were protected from spray drift by guard trees on each side.

Nitrogen treatments. To determine the relationship between N status and N remobilization, trees from three N treatments were used, each having received the following amounts ($kg \cdot ha^{-1}$) of supplemental N for the previous 3 years: none; 112, applied late summer; and 280, application split between late summer and early spring. Based on midsummer leaf N concentration, N status of the three N treatments was determined to be deficient, moderately deficient, and sufficient, respectively. The N fertilization experiment was set up as a randomized block design. Treatments were imposed across cultivar and N fertilization blocks. Each treatment consisted of 18 trees, with six trees from each of the three N treatments.

Sample collection and analysis. Leaf samples were composited following whole-shoot sampling. The shoots were current

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season's growth, oriented from 0° to 45° above horizontal, ≈ 45 to 60 cm long, located on the south side of the trees, at ≈ 3m above the ground. These shoots were typical of those to be retained for next season's fruit wood. One shoot per tree was selected on each sampling date.

Leaf samples were collected from the nonsprayed, control treatment trees to monitor leaf N concentrations throughout the experiment. Samples were collected monthly from July to October, starting on 22 July. After 2 Oct., samples were collected weekly. Abscised leaves were collected from the spray 1 and spray 2 treatment trees by enclosing a shoot from each tree within a mesh bag following application of the spray. Abscised leaves were collected from the control trees in mesh bags placed before natural abscission. The bags were all collected on the same day, after abscission had occurred.

Dormant shoot samples were collected from each treatment in December. The terminal 20 cm of four shoots per tree were harvested, using selection criteria as above, but including one shoot from the north, south, east, and west sides of the tree and then rinsed in deionized water, oven-dried, and ground for N determination.

Nitrogen and Zn determination. Leaf areas of samples were measured using a LI-COR LI-3000 electronic leaf area meter (LI-COR, Lincoln, Neb.) to allow expression of N on a per-unit leaf-area basis (NLA). Samples were rinsed with tap water and dried at 65C for 48 hr. Dried leaf and shoot samples were weighed and ground to pass a 40-mesh screen. Total N in a 150-mg aliquot of each sample was determined using a modified Kjeldahl procedure (Carlson, 1978).

Zinc concentration of leaf tissue the following summer was determined by atomic absorption spectrophotometry.

Leaf nitrogen remobilization. The difference between leaf N at midsummer and leaf N at time of abscission represents the amount of N remobilized during autumnal senescence. Leaf N remobilization, therefore, was expressed as the change in N per unit leaf area(ΔNLA) and the change in N as a percentage of dry weight(Δ%N) between 22 July and leafdrop. These were calculated by subtracting the leaf fall sample treatment means from the 22 July mean of the control treatment. The relative changes in leaf N (Rel ΔNLA) and (Rel Δ%N) were calculated as a percentage of that present on 22 July on a per-unit-leaf-area and a concentration (percent of dry weight) basis, respectively.

Results and Discussion

Although there were small cultivar differences at specific sampling dates, general trends in NLA and other characteristics measured were similar. Therefore, data were pooled for the peach and nectarine cultivars. Treatment combinations were factorial. Analysis of variance detected no interactions among defoliation and N treatments.

Seasonal trends in leaf nitrogen. Seasonal trends in NLA were similar among the 0, 112, and 280 kg N/ha treatments (Fig. 1). Leaf senescence may have been delayed by the 280-kg treatment as compared with the other treatments. Also, both foliage applications of $ZnSO_4$ increased NLA in the 0 kg trees before leaf abscission. At the time of leaf abscission, NLA of naturally defoliated trees was lower than that of sprayed trees at all N fertilizer levels.

As with leaf N expressed as NLA, trends in percent N were very similar for each N level (Fig. 2). Mean midsummer leaf N contents of trees receiving the 0, 112, and 280 kg N/ha fertilizer treatment were 2.04%, 2.28%, and 2.87% of dry weight,

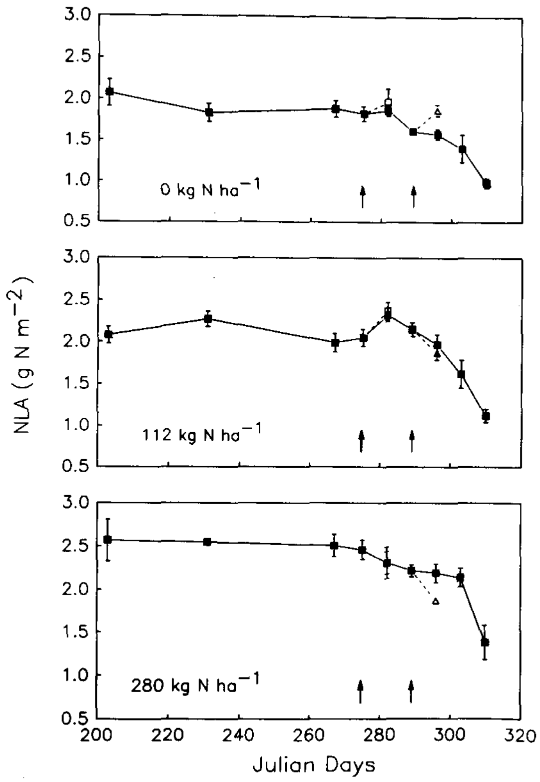

Fig. 1. Seasonal pattern of leaf N per unit leaf area (NLA) for three N and defoliation treatments. Defoliation treatments are indicated as follows: Spray 1, dashed line, open square; spray 2, dashed line, open triangle; control, solid line, solid square. The arrows indicate time of spray application on 3 and 16 Oct., respectively. The vertical bars indicate ± SE; n = 6.

respectively. Percent N of leaves of naturally defoliated trees was lower than that of each spray treatment at time of leaf abscission at all N fertilizer levels. Midsummer to autumn leaf N reductions in naturally defoliated trees have been reported previously, and are evident irrespective of whether leaf N was expressed as a percentage of dry weight (Taylor and van den Ende, 1969; Uriu and Crane, 1977), as milligrams of N per leaf (Uriu and Crane, 1977), or as milligrams N per unit of leaf area (NLA) (Rogers et al., 1953).

When compared to NLA, percent N of control treatments decreased more gradually from mid-season until just before abscission, when there was a marked decreased in both NLA and percent N. Gradual reduction in NLA appears to be initiated at a later time. This difference can be explained when changes in SLW (see below) are considered. NLA remained relatively constant, while SLW increased and percent N decreased. These results are in agreement with reports (Murneek, 1942; Taylor, 1967a) that changes in leaf N concentration may reflect changes in leaf dry matter to a greater extent than changes in the absolute N content of leaves. These results also support the suggestion by Rogers et al. (1953) that leaf N expressed on a leaf area basis more closely reflects the actual seasonal fluctuations in leaf N than does leaf N expressed as a percentage of dry weight.

Seasonal trends in specific leaf weight (SLW) for the three N levels (Fig. 3). were not as similar as those of NLA (Fig. 1) or percent N (Fig. 2). For each N level, however, there was a general trend toward higher SLW from mid-season until late in the season, when SLW decreased. Also, SLW of the 0 and 112

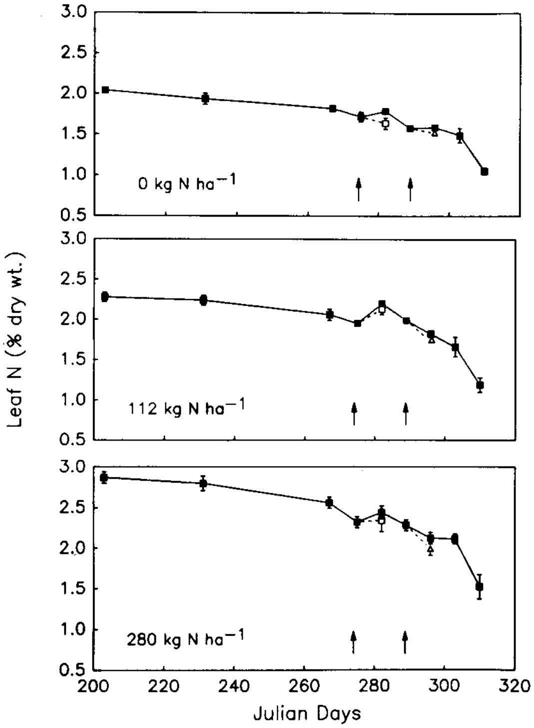

Fig. 2. Seasonal pattern of leaf N concentration (percent dry weight) for three N and defoliation treatments. Defoliation treatments are indicated as follows: Spray 1, dashed line, open square; spray 2, dashed line, open triangle; control, solid line, solid square. The arrows indicate time of spray application on 3 and 16 Oct., respectively. The vertical bars indicate ± SE; n = 6.

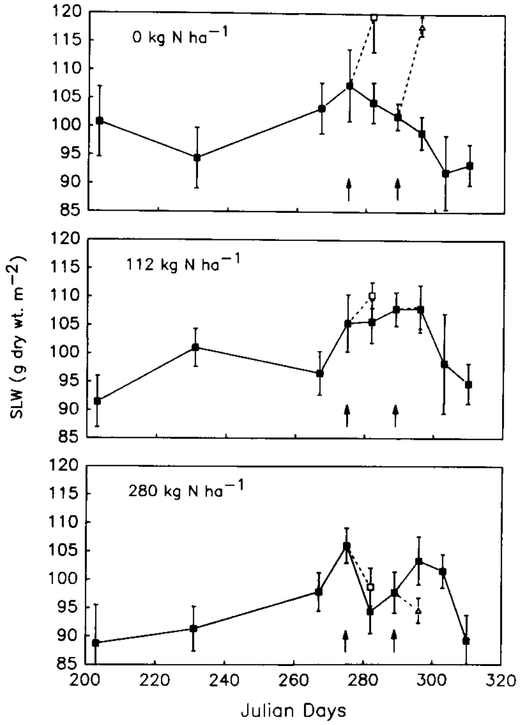

Fig. 3. Seasonal pattern of specific leaf weight (SLW) for three N and defoliation treatments. Defoliation treatments are indicated as follows: Spray 1, dashed line, open square; spray 2, dashed line, open triangle; control, solid line, solid square. The arrows indicate time of spray application on 3 and 16 Oct., respectively. The vertical bars indicate ± SE; n = 6.

kg N/ha treatments increased following spray applications, but decreased in the 280-kg treatment. These increases in SLW of the 0- and 112-kg treatments were consistent between peach and nectarine cultivars. A similar response was noted in $ZnSO_4$ defoliation of plum nursery stock (S.P.C., unpublished data). Further research is necessary to elucidate the cause of these responses.

Effect of $ZnSO_4$ application on nitrogen remobilization. Foliage applications of $ZnSO_4$ to mature peach and nectarine trees reduced leaf N remobilization compared to that of trees allowed to defoliate naturally (Table 1). This effect was consistent across N fertilizer treatments, except at the 280-kg N/ha level. At that N level, N remobilization for spray 2 was not significantly less than that of the control. Also, at the 112-kg level, remobilization depended on timing; the 16 Oct. spray (spray 2) affected leaf N remobilization to a lesser extent than did the 3 Oct. spray (spray 1).

Similar results as those just noted were obtained when leaf N was expressed as a percentage of dry weight (Table 2). The magnitude of treatment effects, however, was apparently lower with leaf N expressed as a percentage of dry weight.

A reduction in N remobilization, due to premature defoliation with $ZnSO_4$ represents a direct loss to the pool of storage N available for subsequent tree growth and development. Assuming that roughly 50% of total above-ground N of mature peach or nectarine trees is contained in the leaf fraction (DeJong and Doyle, 1984), ≈ 25% of above-ground N was mobilized before natural defoliation.

Direct losses resulting from premature defoliation represent a substantial reduction of tree N. Assuming total leaf areas of 160, 250, and 290 m^2 for the 0, 112, and 280 kg N/ha levels

Table 1. Leaf N remobilization expressed as the absolute decrease in N per unit leaf area (ΔNLA) and relative decrease in N per unit leaf area (Rel ΔNLA) for N fertilizer level and $ZnSO_4$ spray treatment between 22 July and defoliation.[z,y]

N applied ($kg \cdot ha^{-1}$)	Spray treatment[x]	ΔNLA ($g\ N/m^{-2}$)[w]	Rel ΔNLA (%)[w]
	Spray 1	0.03 b	1.5 b
0	2	0.28 b	13.2 b
	Control	1.09 a	50.1 a
	Spray 1	−0.17 c	9.1 c
112	2	0.22 b	9.9 b
	Control	0.96 a	45.8 a
	Spray 1	0.52 b	18.3 b
280	2	0.81 ab	29.2 b
	Control	1.19 a	44.9 a

[z]Values shown are means of six observations.
[y]Mean separation within columns at each N fertilizer level by Duncan's multiple range test, $P = 0.05$.
[x]Spray 1, 30 Oct.; spray 2, 16 Oct.
[w]Negative values indicate a net increase in leaf N between 22 July and leaf drop.

(R.S.J., unpublished data), reductions in remobilization are equivalent to 170, 280, and 190 g N/tree, respectively, for the spray 1 (3 Oct.) treatments and 130, 180, and 110 g N/tree, respectively, for the spray 2 (16 Oct.) treatments. This reduction was reflected in a reduced dormant shoot N status the following winter (Table 3). Also, defoliation eliminates the essential photosynthetic organ, shutting down carbon assimilation for the season. Photosynthesis during this late-season period, after ter-

Table 2. Leaf N remobilization expressed as the absolute decrease in percent N (Δ%N) and relative decrease in percent N (Rel Δ%N) for each N fertilizer level and $ZnSO_2$ spray treatment between 22 July and defoliation.[z,y]

N applied ($kg\cdot ha^{-1}$)	Spray treatment[x]	Δ %N (% dry wt)	Rel Δ%N (%)
	Spray 1	0.44 b	21 b
0	2	0.49 b	24 b
	Control	0.99 a	48 a
	Spray 1	0.26 c	11 c
112	2	0.53 b	24 b
	Control	1.09 a	48 a
	Spray 1	0.62 b	21 b
280	2	0.95 b	32 b
	Control	1.35 a	47 a

[z]Values shown are means of six observations.
[y]Mean separation within columns at each N fertilizer level by Duncan's multiple range test, $P = 0.05$.
[x]Spray 1, 3 Oct; spray 2, 16 Oct.

Table 3. Mean N concentrations of dormant shoots for each N fertilizer level and $ZnSO_4$ spray treatments, harvested Dec. 1986.[z,y]

N applied ($kg\cdot ha^{-1}$)	Spray treatment[x]	N (% of dry wt)
	Spray 1	0.67 b
0	2	0.71 b
	Control	0.81 a
	Spray 1	0.89 b
112	2	0.94 b
	Control	1.08 a
	Spray 1	1.03 ab
280	2	1.00 b
	Control	1.14 a

[z]Values shown are means of six observations.
[y]Mean separation within columns at each N fertilizer level by Duncan's multiple range test, $P = 0.05$.
[x]Spray 1, 3 Oct.; spray 2, 16 Oct.

minal bud formation, could contribute significantly to carbohydrate storage (Priestley, 1963). Because leaf function is critical to uptake of NO_3 by roots (Weinbaum et al., 1978), premature defoliation could also reduce the storage pool of N and other nutrients as a result of its effect on reduced nutrient uptake. Clearly, there is a potential for reductions in vegetative and reproductive performance of trees (during years subsequent to defoliation) if trees become N-deficient. Premature defoliation may also reduce reclamation of other phloem-mobile nutrients (Hill, 1980).

Nitrogen status and N remobilization. There was a trend toward decreasing relative remobilization (Rel ΔNLA) from low- to high-N fertilizer levels (Table 1). There were, however, no significant differences in Rel ΔNLA of naturally defoliated trees from each N fertilizer level. Naturally defoliated trees remobilized roughly one-half of the total leaf N present in midsummer samples. The results are very similar when leaf N is expressed as percent N (Table 2). These results are in agreement with work done by Taylor and van den Ende (1969), who found N remobilization to be ≈ 50%, regardless of tree N status.

The independence of efficiency of N remobilization from N status suggests that a relatively constant percentage of total leaf N is partitioned to certain proteins that are hydrolyzed and remobilized during natural senescence for recovery by perennial tissues. Breakdown of ribulose-1,5-bisphosphate (RuBP) carboxylase makes a major contribution to N remobilized during autumnal senescence by apple (Titus and Kang, 1982). RuBP carboxylase activity in wheat is correlated with plant N status (Evans, 1983; Thomas and Thorne, 1975). Efficiency of N remobilization during autumnal senescence may be a reflection of partitioning of N into RuBP carboxylase in peach.

Early foliage application of $ZnSO_4$ decreased leaf N remobilization and N-use efficiency. Delaying $ZnSO_4$ application to the latest possible date would allow the highest efficiency. However, N use efficiency must be weighed against considerations regarding the effectiveness of $ZnSO_4$ applications in preventing Zn deficiencies. More research is needed to identify alternative methods for maintaining good Zn nutrition that would eliminate potential deleterious effects of premature defoliation associated with fall foliar application of $ZnSO_4$.

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