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Nitrogen remobilization and nursery tree growth following autumn defoliation in plum (*Prunus salicina*) trees

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Abstract: Experiments were conducted on "June-budded" nursery plum (*Prunus salicina*) trees to study the effects of early fall defoliation on leaf nitrogen remobilization and spring regrowth. Apparent remobilization of leaf N varied depending on the means of expression. That is, N remobilization was reduced by >10% when expressed on the basis of leaf area as compared with percentage leaf weight. Leaf N remobilization was substantially decreased by defoliation treatments when data were expressed on a leaf area basis. Trees manually defoliated approximately one month prior to natural leaf-fall were only 46% as large as control trees after 3+ months of regrowth the following spring. However, the size of trees receiving defoliating $ZnSO_4$ sprays at the same time as the manual defoliation treatments did not differ significantly from control trees. Budbreak of manually defoliated trees occurred earlier than in control trees, but defoliation with $ZnSO_4$ did not significantly affect budbreak. Fall defoliation treatments did not influence leaf N levels determined after the spring flush of regrowth. Therefore, although $ZnSO_4$ sprays accelerated defoliation in the fall and reduced leaf N remobilization, these treatments did not reduce spring regrowth of nursery trees. In contrast, early fall manual defoliation had substantial effects on both budbreak and regrowth.

1. Introduction

Fall foliar application of $ZnSO_4$ is widely practiced for prevention of Zn deficiencies in deciduous fruit and nut tree nursery stock production in the San Joaquin Valley of California. Premature defoliation of trees following late season $ZnSO_4$ applications has not been perceived as being deleterious to tree performance. Premature abscission of foliage, however, could reduce the remobilization of leaf N and other phloem mobile nutrients by perennial tissues.

Previous studies have been primarily concerned with the evaluation of the efficacy and phytotoxicity of various chemical defoliants of deciduous fruit and nut tree nursery stock (Larsen, 1967; Larsen and Fritts, 1986). Few studies hava considered the effects of defoliation on vegetative regrowth of nursery stock in the spring following treatment. Larsen (op. cit.) reported that following certain defoliation treatments, plants failed to grow normally despite the absence of apparent injury. He noted that a manual defoliation treatment was not included in the experiment, making it impossible to determine if this response was caused by the chemicals or by the adverse effects of defoliation per se.

Jones *et al.* (1973) reported that defoliation with succinic acid – 2, 2-dimethylhydrazide (SADH) increased spring regrowth over that of the control. They thought this increase was a reflection of earlier budbreak also observed in the SADH treatments. In the same experiment, ethephon reduced regrowth despite advanced budbreak. Supraoptimal concentrations of ethephon were associated with increased defoliation and decreased spring regrowth. The decreased regrowth following use of high ethephon concentration in fall was attributed to a detrimental carry-over effect.

Basak *et al.* (1973) reported on regrowth following defoliation with several inorganic compounds under the climatic conditions of central Poland. Shoot growth and trunk diameters of chemically defoliated trees were not significantly different from those of hand defoliated trees or untreated controls. They reported, however, that in a few cases, regrowth decreased in order from untreated controls, to chemically-defoliated trees, to hand-defoliated trees.

Foliar sprays with $ZnSO_4$ in autumn substantially reduced leaf N remobilization in mature peach trees (Castagnoli *et al.*, 1989). The magnitude of the effect was apparently dependent upon timing of $ZnSO_4$ sprays and the N status of the trees. Since spring regrowth of deciduous fruit tree species is highly dependent on stored compounds including N (Taylor, 1967; Taylor and van den Ende, 1969) we were interested in determining the extent to which prophylactic $ZnSO_4$ sprays reduce N remobilization in leaves of nursery trees and if a reduction of remobilization was correlated with a reduction in vegetative regrowth the following spring.

2. Materials and Methods

Plant material. Japanese plum (*Prunus salicina* Lindl., cultivar Simka) were June-budded on seedling peach (*Prunus persica* L., Batsch, cultivar Nemaguard) rootstock, grown at The Burchell Nursery in Oakdale, CA. Other than the experimental treatments described below, the trees were grown under "standard" California commercial fruit tree nursery conditions. Defoliation treatments were applied in the nursery row in the autumn of 1986. Each experimental treatment was applied to two 15-tree blocks randomized in the nursery

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row. Treatments were: manual defoliation, all leaves removed by hand on 14 October; $ZnSO_4$ applied on 14 October; $ZnSO_4$ applied on 28 October; and a control, trees allowed to defoliate naturally. The 14 October spray treatment was timed to precede a "standard" application date by two weeks; the 28 October spray treatment was made on the "standard" application date. Both spray treatments were zinc sulfate monohydrate (35 % Zn) at 3.0 kg/500 liters. Manual defoliation and control blocks received an application of chelated Zn (Hampshire Chelates Zn-EDTA) at 1.2 kg/500 liters, on 2 October. All sprays were applied to runoff with a backpack sprayer. Adjacent blocks were covered with polyethylene tarps to prevent contamination by spray drift. Trees of all treatments were topped at a height of 1.2 m above ground on 14 October.

Leaf samples were collected from the control treatment blocks to monitor leaf N levels throughout the late summer and early autumn. Samples were collected monthly from 1 August to 14 October and weekly thereafter. Abscised leaves were collected from the 14 October and 28 October spray treatment blocks by enclosing five trees in each block within mesh bags following spray application. Abscised leaves were collected from the control blocks in bags placed prior to natural leaf fall. Leaf areas of samples were measured using a Licor LI-3000 electronic leaf area meter to allow expression of N on a per unit leaf area basis (NLA). Samples were rinsed with tap water, dried at 65° C for 48 hours, 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).

It was assumed that the difference between leaf N at midsummer and leaf N at time of abscission represented the amount of N remobilized during autumnal senescence. Leaf N remobilization, therefore, was expressed as the change in N per unit leaf area (△ NLA) and the change in N as a percentage of dry weight (△ % N) between 1 August and leafdrop. These were calculated by subtracting the leaf fall sample treatment means from the 1 August mean of the control treatment. The relative change in leaf N, (R△NLA) and (R△ % N), were calculated as a percentage of that present on 1 August on a per-unit-leaf-area and a concentration (percent of weight) basis, respectively.

The relative distribution of N and dry weight within the nursery trees were determined on 14 October. Five trees were dug and rinsed with tap water, divided into root, stem, and leaf fractions and then dried for 120, 120, and 48 hours, respectively. Nitrogen determinations were made on subsamples as described previously.

The remainder of the experimental trees were undercut mechanically and lifted on 8 December. Fresh weight and trunk caliper 15 cm above the bud union were measured after trees were lifted to determine the effects of treatments on the performance of trees in the nursery row prior to being placed in cold storage at 2.2°C.

Treatment effects on vegetative regrowth. On 20 January 1987, sixty trees, (15 trees from each defoliation treatment, including seven or eight trees from each nursery row block) were planted in a randomized complete block design at Davis, CA. Before planting, the central shoot of each of these trees was headed to a height of about 60 cm, all lateral branches were cut back to the central shoot, and tree fresh weight was recorded.

These trees were grown under conditions typical of a commercial planting until they were harvested, between 24 and 26 June, 1987. Upon harvest, the following parameters were measured on each tree: total new shoot length, total new shoot dry weight, total leaf dry weight, and trunk caliper 15 cm above the bud union. Leaf area and dry weight of a five-leaf subsample were measured to allow estimation of NLA. Determination of leaf N was made as described above.

Upon casual observation, there appeared to be differences among defoliation treatments in time of budbreak. Degree of budbreak was quantified on 25 February by rating trees on a one-to-four scale as follows: 0-50 % of the buds swollen, but the shoots not yet emerging = 1; 50-100 % of the buds swollen, but the shoots not yet emerging = 2; 0-50 % of the buds with shoots emerging = 3; 50-100 % of the buds with shoots emerging = 4.

3. Results

Seasonal trends in leaf nitrogen. Leaf N expressed as NLA (Figure 1) increased slightly from midsummer until mid October and decreased subsequently until leaf abscission. In contrast, percent N decreased continuously from midsummer (3.93 % dry weight) until leaf abscission. Absolute leaf N (NLA) increased during a period when percent N indicated a reduction in leaf N. The observed reduction in percent N can be explained by an increase in specific leaf weight (SLW) rather than an actual reduction in leaf N content. Both NLA and SLW increased following spray applications. Manual defoliation and both spray treatments reduced N remobilization when compared to that of the control treatment (Table 1). Nitrogen remobilization following the 14 October treatments was significantly reduced compared to that of the 28 October spray treatment. Greater recovery of midsummer N occurred in the manual defoliation treatment than in the 14 October spray treatment. This is the result of the an increase in NLA following spray application (see Figure 1). Efficiency of N remobilization by nursery trees was relatively low following natural defoliation (Table 1). The other treatments caused corresponding reductions in the efficiency of N remobilization.

Table 1 – Nursery tree N remobilization expressed as the absolute decrease in NLA (△NLA) and percent N (△ % N) and relative decrease in NLA (R△NLA) and percent N (R△ % N) between 1 August and defoliation.

Spray treatment	△NLA ($g N m^{-2}$)	R△NLA %	△ % N (% dry wt)	R△ % N (%)
Manual defoliation	–0.24[a] ± 0.08	–6.6 ± 2.2	0.77 ± 0.04	19.6 ± 1.1
14 Oct. $ZnSO_4$	0.61 ± 0.07	–17.3 ± 2.1	1.18 ± 0.05	30.1 ± 1.2
28 Oct. $ZnSO_4$	0.13 ± 0.15	3.6 ± 4.3	1.23 ± 0.06	31.5 ± 1.5
Control	1.01 ± 0.08	28.3 ± 2.3	1.42 ± 0.09	36.2 ± 2.3

[a] Negative values indicate a net increase in leaf N between 1 August and leaf fall.

When N remobilization is based on leaf N as a percent of dry weight (Table 1), treatment effects are not as apparent and the apparent efficiency of N remobilization of naturally-defoliated trees is greater because of simultaneous changes in SLW (Fig. 1).

Effect of defoliation on tree growth in the nursery row. Manual defoliation significantly reduced trunk caliper and fresh weight of trees in the nursery row (Table 2). Trees sprayed on 28 October exhibited greater caliper and fresh weight at time of digging than did the other treatments. On 14 October, roots made up the greatest and leaves the smallest fraction of whole-tree dry weight (Table 3). Leaf N, however, comprised the greatest and root N the smallest fraction of whole tree N. Stem dry weight and N were intermediate between those of leaf and root fractions.

Treatment effects on regrowth. Manual defoliation significantly reduced trunk caliper, total shoot length, and leaf-plus-new-shoot dry weight of trees sampled approximately four months after resumption of growth (Table 4). There were no significant differences among the other treatments in these parameters. There were no significant differences among treatments in leaf N (expressed as NLA or percent N) at time of harvest (Table 5). Manual defoliation accelerated budbreak in comparison with the other treatments (Table 5).

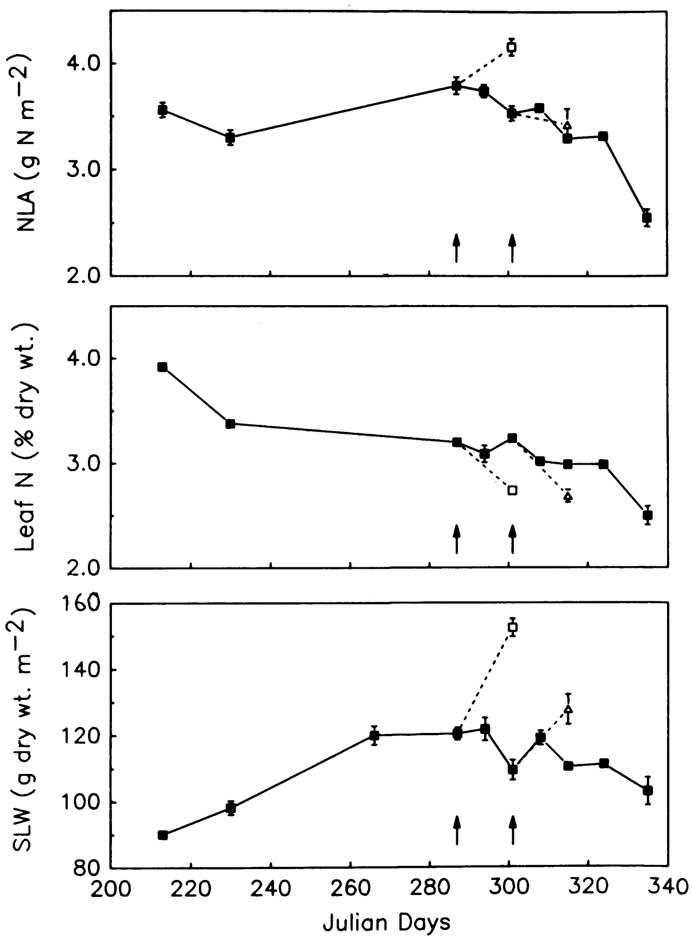

Fig. 1 – Seasonal pattern of leaf N (NLA and % dry weight) and specific leaf weight (SLW) in plum. Defoliation treatments are indicated as follows: 14 October $ZnSO_4$, dashed line, open square; 28 October $ZnSO_4$, dashed line, open traingle; Control, solid line, solid square. The arrows indicate time of spray application. The vertical bars indicate +/- standard error.

Table 2 – Trunk caliper and fresh weight of nursery trees on 15 December, 1986

Treatment	Caliper (mm)	Fresh wt (g)
Manual defoliation	14.3±0.5	330±25
14 Oct. $ZnSO_4$	16.0±0.4	430±30
28 Oct. $ZnSO_4$	17.1±0.4	496±29
Control	15.7±0.5	450±34

Table 3 – Absolute and relative distribution of whole-tree dry weight and N between leaf, stem, and root fractions of nursery trees prior to treatment, i.e., on 14 October, 1986.

Fraction	DW (g)	% Total	N (g)	% Total
Leaf	31.19±5.58	14.21±1.4	1.03±0.19	41.4±3.2
Shoot	134.51±27.10	59.2±1.9	0.71±0.13	28.6±1.5
Root	57.81±7.96	26.6±1.1	0.72±0.09	30.0±2.3
Total	233.51±39.70	— —	2.47±3.72	— —

Table 4 – Mean trunk caliper, total shoot length, and new shoot+leaf dry weight of trees on 24-26 June 1987.

Treatment (1986)	Caliper (mm)	Shoot length (cm)	Shoot+leaf dry wt (g)
Manual defoliation	15.8±0.7	635±65	73.50±8.0
14 Oct. $ZnSO_4$	19.4±0.9	1033±118	132.81±15.6
28 Oct. $ZnSO_4$	20.7±0.9	1139±143	148.77±15.2
Control	20.6±1.3	1184±142	159.19±7.3

Table 5 – Budbreak ratings (see text for details) and leaf N of trees on 25 February and 24-26 June, 1987, respectively.

Spray treatment (1986)	Budbreak rating	NLA (g N m^{-2})	% N (% dry wt)
Manual defoliation	3.7±0.2	2.02±0.10	2.00±0.07
14 Oct. $ZnSO_4$	2.2±0.2	2.18±0.10	2.08±0.08
28 Oct. $ZnSO_4$	2.1±0.2	2.06±0.09	1.95±0.08
Control	1.9±0.2	2.03±0.10	1.95±0.08

4. Discussion

Seasonal trends in leaf nitrogen. Changes in leaf N between midsummer and leaf fall in naturally-defoliated trees were similar to those previously observed for other deciduous fruit species. Leaf N has been expressed on a concentration (percent of dry weight) basis (Taylor and van den Ende, op. cit.; Uriu and Crane, 1977), as milligrams N per leaf (Uriu and Crane, op. cit.), or milligrams N per unit of leaf area (NLA) (Rogers *et al.*, 1953). Generally, with N expressed in any of these ways, there is a trend from high leaf N at mid-season followed by a gradual decrease until late in the season, prior to senescence, when there is a more rapid reduction.

In this experiment, percent N decreased gradually from mid-season until late in the season, prior to senescence, when there was a more rapid reduction. As is apparent from Figure 1, NLA remained high until October and then declined rapidly. This difference in seasonal patterns of percent N and NLA can be explained by changes in SLW. The reduction in percent N prior to the mid-October reduction in NLA appears to be a result of an increase in SLW. These results are in agreement with reports (Murneek, 1942; Taylor, op. cit.) that changes in leaf N concentration may be caused by changes in leaf dry matter content rather than by changes in the absolute N content. These results also support the suggestion by Rogers *et al.* (op. cit.) that leaf N expressed on a leaf area basis more closely reflects the seasonal fluctuations in leaf N. Midsummer leaf N concentration (3.92%) was relatively high. The range of sufficient concentrations reported for Japanese plum in California is 2.3 to 2.8% (Beutel *et al.*, 1983). In deciduous nursery stock production, where vigorous vegetative growth of trees is desired, it is likely that high N fertilizer inputs result in elevated leaf N levels, such as those observed in this study. Under natural defoliation, N remobilization by Japanese plum trees was relatively inefficient as compared with values reported by Titus and Kang (1982), but documentation of the efficiency of N remobilization for Japanese plum is lacking. Leaf N remobilization has been shown to be insensitive to N status in peach (Castagnoli *et al.*, op. cit.); Taylor and van den Ende, op. cit.). Generally, shoot extension and leaf growth of young trees continue later into the season than those of mature trees (Chandler, 1957). Shoots of the Japanese plum trees used in this experiment, grown under conditions of high N and water inputs, did not set terminal buds until early October. In mature peach and nectarine trees shoot elongation ceases prior to 22 July (Castagnoli *et al.,* op. cit.; DeJong *et al.*, 1987). This difference in length of shoot growth period and subsequent difference in leaf age could affect in efficiency of N remobilization during leaf senescence.

Defoliation and nitrogen remobilization. Manual defoliation results in complete loss of leaf N present at time of defoliation. In this experiment, 41% of total tree N, or roughly 60% of above ground N, was lost as a result of manual defoliation. This represents a N loss of 1 g/tree. Because of an increase in NLA following the 14 October spray, that treatment resulted in an even greater loss of tree N on a whole-tree basis than did manual defoliation. Regardless of the cause, these losses represent a reduction in the storage pool N available for subsequent vegetative growth and tree development. It is clear, then, that premature defoliation could reduce vegetative vigor following resumption of growth in the spring. An increase in NLA similar to that which occurred after the 14 October spray in this research was also observed following $ZnSO_4$ foliage application to mature peach trees (Castagnoli *et al.*, op. cit.). This may be the result of a disproportionate flux N into the leaf via the xylem relative to N efflux via the phloem (Weinbaum and Muraoka, 1986). However, a definitive explanation is lacking.

Defoliation and growth in the nursery row. Our data indicate that manual defoliation adversely affected tree performance, and that timing and severity of treatment are important factors in this regard. Early defoliation eliminates the essential photosynthetic organ, shutting down carbon assimilation for the season. Photosynthetic activity after terminal bud formation, could contribute significantly to the carbohydrate available for increase in trunk caliper and fresh weight of trees (Priestley, 1963). It seems likely that the elimination of photosynthesis was related causally to the reduced growth of nursery trees following the October 14 manual defoliation. Reduced vegetative growth in the nursery row, following defoliation, could be of economic importance to nursery operators because trees are graded and sold on the basis of trunk caliper. A reduction in tree size would result in reduced value of the tree. It is curious that the 14 October spray treatment did not significantly decrease tree growth in the nursery row compared to that of the control, especially since it did have substantial effects on N remobilization. It is also difficult to explain why the 28 October spray treatment resulted in significantly greater caliper than did natural defoliation. These results are contrary to what was expected.

Vegetative regrowth. The results of this experiment suggest that reduced N remobilization alone could not be responsible for the reduced performance of manually defoliated trees. The 14 October spray treatment, that caused less N remobilization than did manual defoliation, resulted in significantly better tree performance following resumption of growth. Also, no significant differences in tree performance were found between the 14 October and 28 October spray treatments, and the naturally-defoliated trees despite differences in N remobilization. Still, it is clear that manual defoliation had a severe negative effect on tree performance following resumption of growth.

Reduced storage N following defoliation could have contributed to reduced growth of manually defoliated trees. Other factors, however, can not be ruled out as being important. Because other phloem-mobile mineral nutrients are remobilized prior to leaf abscission (Hill, 1980), premature defoliation may also decrease recovery and storage of these materials. Also, as was discussed above, late-season carbon assimilation is terminated following defoliation. Because leaf function is critical to uptake of NO_3^- (Weinbaum *et al.,* 1978), and presumably the uptake of other mineral nutrients, late season uptake of these mineral nutrients also could have been reduced. These potential effects of premature defoliation could compound the negative impact of reduced N remobilization.

Certain horticultural practices could counteract the impact of reduced N remobilization on later growth and development. Dormant pruning is generally considered to have invigorating effects on vegetative growth (Mika, 1986). Dormant-pruned trees would be expected to be less impacted by premature defoliation than those not dormant pruned. In commercial nurseries, high rates of N fertilization might also counteract the loss of N from premature defoliation. If, however, one objective of nursery management was to make the most efficient use of N resources, premature defoliation would be a practice to avoid. Because later application of $ZnSO_4$ resulted in less reduction in N remobilization, delaying the application date would allow more efficient management of N in nurseries. In practice, all of these factors must be weighed against considerations regarding the effectivess of $ZnSO_4$ applications in preventing Zn deficiencies. Perhaps alternative methods for maintaining good Zn nutrition would eliminate potential deleterious effects of premature defoliation associated with fall foliar application of $ZnSO_4$.

Defoliation and budbreak. There are conflicting reports on the effects of premature defoliation, including manual and chemical defoliation on time of budbreak. Previous research on this topic has been reviewed by Saure (1985). Walser *et al.* (1981) reported that rest intensity may be increased by later retention of leaves. In this experiment, hastened budbreak of manually-defoliated nursery trees may have resulted from decreased intensity of rest and subsequent earlier satisfaction of chilling requirement. This hypothesis does not, however, explain the lack of significant differences between the other treatments in time of budbreak.

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