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Acclimation and Winterhardiness Patterns in the Eastern Thornless Blackberry

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Abstract. **An attempt was made to alter the late-season growth habit of eastern thornless blackberry plants (*Rubus sp.*) with foliar sprays of growth regulators and plant nutrients. While fall applications of ethephon hastened leaf abscission, they did not affect shoot dieback or yield. Cultivar effects were very strong. 'Dirksen' plants had the least cane dieback and highest yield, 'Hull' plants were intermediate, and 'Smoothstem' plants were the least hardy and had the lowest yield. A significant negative correlation was found between the number of leaves retained throughout November and the subsequent yield of these 3 cultivars. Artificial freezing tests throughout the winter demonstrated that buds were less hardy than bark tissue. Bark and pith tissue from plants defoliated 30 Sept. were injured more than those tissues from plants defoliated later in the fall. No apparent relationship between fall defoliation and bud hardiness was observed. 'Dirksen' buds were 0.2° to 5.9°C hardier than were 'Smoothstem' buds. Differential thermal analysis showed that a freezing event occurred in both stems and buds at about −5°. A 2nd exotherm occurred in buds at about the LT_{50}.**

Since 1965, 6 cultivars of the eastern thornless blackberry (*Rubus sp.*), have been released. Their increasing popularity is due to their thornless character, vigorous growth, and high production capacity. A major concern of both growers and breeders of this crop is winterhardiness (6). Numerous studies have been made of the winterhardiness of some species of *Rubus*. Although the crop is known for late-season growth, retention of foliage, and damage at winter temperatures below −20°C, little is known about the mechanism of cold damage to this crop.

Freezing damage to various raspberry cultivars and to a range of *Rubus* species has been associated with persistent late-season growth and leaf retention. Van Adrichem (20, 21), found late summer and fall growth rate, as well as leaf drop, correlated with bud survival. Sako and Hiirsalmi (17) investigated the winterhardiness of 26 cultivars of red raspberry in Finland and found significant positive correlations between early cane ripening and winterhardiness. Jennings et al. (7) found this same cultivar-determined association between early cessation of growth and winterhardiness. In addition, they observed heavy N and manure treatments that prolonged autumn growth resulted in an increase in winter dieback in all cultivars.

Many studies have shown that premature defoliation of deciduous fruit crops can cause an increase in winter damage. This damage has occurred when the defoliation was caused by ethephon (9), mite damage (4), or hand pruning (19). In addition, leaf nutrient status also may affect leaf senescence (10, 12). The importance of ample foliage in late summer and fall has been ascribed to the role of leaves in carbohydrate production and as receivers of a photoperiodic signal that triggers the acclimation process (5, 22, 24).

Dormant flower bud primordia of many fruit crops have been shown to avoid freezing injury by supercooling (1, 2, 13, 15). The exposure of the bud primordium to lethal low temperatures appears to be associated with the sudden freezing of a fraction of supercooled water in the primordium. This sudden freezing of supercooled water appears to be related to death of the primordium (15). Supercooling and the sudden freezing of supercooled water have not been observed in *Rubus* (25).

The purpose of this study was to characterize the role of late-season growth and leaf retention on the winterhardiness of thornless blackberry. In addition, it is of interest to know whether supercooling exists in this crop, since the existence of this process could aid breeders interested in improving the winterhardiness of thornless blackberries.

Materials and Methods

The study was conducted at the Univ. of Maryland Plant Research Farm in Silver Spring, in a planting established in 1979. Plants were set 1.8 m apart within the row with 3 m between rows, on a Beltsville silt loam.

Chemical treatments, 1981–1982. Within the planting, panels 10 m long contained 5 plants of a single cultivar. Each panel, or statistical cell, was assigned a treatment combination based on a 3 cultivar × 5 spray treatment × 4 application date factorial. The 60 test panels were distributed randomly throughout the planting, and unused plots were exploited whenever possible to separate the treated plots. Chemical treatments were applied on windless days with hand-held sprayers. Three thornless blackberry cultivars were used: 'Dirksen', 'Hull Thornless', and 'Smoothstem'. The treatments applied were: 1) ethephon (1500 ppm); 2) $CaCl_2$ (2%); 3) ethephon + $CaCl_2$; 4) urea (0.6%); and 5) a nonsprayed control. A nonionic surfactant, Ortho X-77 (Chevron Chemical Co.) (0.1%) was added to each spray. Sprays were applied on 9 Oct., 21 Oct., 3 Nov., and 17 Nov. 1981.

To test the effectiveness of these defoliation sprays, sample leaves from each plot sprayed on 9 Oct. were analyzed for ethylene evolution. Repeated analyses were made at 12-day intervals from these plots during the fall. Sample leaves were placed immediately in 500-ml canning jars that were fitted with

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air-tight lids and serum bottle stoppers. After 24 hr, 1-ml samples of headspace gas were injected into a Hewlett-Packard gas chromatograph fitted with an alumina column and peak integrator.

In each plant panel, one lateral on each of 3 separate plants was pruned to 10 nodes. The laterals were about the same length and caliper and were located about 1.8 m above the ground level. Beginning 5 days after the first spray date, and continuing at 2-week intervals (until mid-December), the numbers of leaves on these 10-node shoots were counted. The following May, measurements of dieback and flowering were made on these same laterals. Buds producing flowers, leaves only, and those buds that failed to develop were noted. Mean values of these subsample observations were calculated for each panel. In addition, each panel was harvested individually 5 times during a 21-day ripening period to measure total yield.

Statistical analyses of these data were performed using SAS programs (16); means, F values, and correlation coefficients were computed.

Growth, defoliation, and winterhardiness, 1982–1983. During Fall 1982, 'Dirksen' and 'Smoothstem' plants were compared in their pattern of late-season growth and defoliation. Within each panel, one plant was defoliated on 30 Sept. by hand pruning each leaf petiole. A 2nd plant was defoliated 4 Nov. and the remaining 3 plants were allowed to defoliate naturally. Of the 3 naturally defoliated plants, one was chosen randomly for statistical analysis. Thirteen panels in each of the 2 cultivars were used in this study.

On each sample plant, a lateral located about 1.5 m above the ground was selected for observations of leaf retention and shoot elongation. Observations began on 31 Aug. and continued at 2-week intervals until 22 Dec. Temperature data were obtained from a Univ. of Maryland weather station located about 300 m from the experimental plot.

Artificial freezing tests on single-node cuttings were made at 2 week intervals from 19 Nov. until 2 Mar. On each date, 50 midshoot cuttings were taken from each treatment, divided into 5 equal subsamples, and placed in 50-ml polypropylene centrifuge tubes. Freezing tests were made the following day using equipment at the Appalachian Fruit Research Station (Kearneysville, W.Va.). Four of these 5 subsamples were subjected to a series of temperatures to bracket the temperature at which 50% of the buds would be killed (LT_{50}). The 5th subsample was used as a control.

Since the field temperature at collection time was always greater than 0°C, the samples were held overnight at field temperature in a Thermos carrier. This short holding period did not appear to affect the behavior of the buds during the artificial freezing tests. Similar ranges in lethal temperatures as reported here were noted previously in a preliminary study in 1981–1982. At that time, field samples were taken and held on ice prior to testing (data not shown). Samples held at field temperature were also compared to samples held on ice prior to testing in mid-November. These showed similar LT_{50} values ($-7°$ and $-6°$, respectively).

The freeze-testing procedure was a variation of that used by Wu et al. for *Rubus* (25). The stem segments with buds were wrapped in cheesecloth and thoroughly wetted with distilled water. The cheesecloth was then placed on top of ice within the 50-ml polypropylene centrifuge tubes to ensure that ice seeded the tissue. Samples were placed in a circulating ethanol bath at 0°C. The bath was cooled with a cold finger, and bath temperature and cooling rate were controlled using a heating element and temperature programmer (Neslab Instruments, Portsmouth, N.H.).

Samples were cooled at 5°C/hr. At 4 predetermined test temperatures, tubes were removed and placed on ice. The next day samples were put in perlite and kept under an intermittent mist system for 13 days. The viability of buds, bark, and pith tissue were visually evaluated for browning of tissue and tissue development after this period (18). The LT_{50} of buds was estimated using graphic methods (14).

The freezing of water in excised buds, primordia, and stem pieces was investigated by differential thermal analysis (DTA). Studies were conducted using 2 different instruments. In one, the tissue was placed in a small aluminum foil packet that contained a 36-gauge thermocouple junction. Samples were placed in a Kjeldahl flask that was partially submerged in the same ethanol bath used for the freezing tests. The 2nd apparatus used 40-gauge copper-constantan thermocouples. Samples were wrapped in aluminum foil and placed in glass test tubes that were fitted into holes bored into an aluminum block. The aluminum block was placed in a $-70°C$ deep freeze. Block temperature and cooling rate were controlled using a resistance heater and temperature programmer. In both instruments, freeze-dried material was used as a reference. Output of the thermoelectric junctions was monitored using a strip chart recorder (0.5 mV/FS). Samples were analyzed either simultaneously with the freezing tests or stored at 3° and analyzed later. All samples used for DTA were from nondefoliated plants.

To further investigate the relationship between exotherms and lethality to bud primordia, primordia were removed from the bud using a stereoscopic microscope and cooled separately. In 2 of the tests, primordia also were analyzed together with their attached axis tissue.

Results and Discussion

Chemical treatments, 1981–1982. Leaves sprayed with $CaCl_2$ + ethephon or ethephon alone evolved ethylene at a rate 130 and 50 times greater, respectively, than did control leaves. Treatments containing ethephon had a significant effect on leaf retention. Ethephon-sprayed plants lost their leaves earlier than did control plants (data not shown). Adding $CaCl_2$ to the ethephon spray defoliated laterals significantly more than controls, although this treatment was not as effective as ethephon alone. Martin et al. (11) offset ethephon-induced defoliation in pecan by $CaCl_2$. Addition of $CaCl_2$ may have had a similar effect in this study. Calcium chloride was used in this study because its application to apple trees can cause phytotoxic effects. However, when used on apple, $CaCl_2$ is routinely sprayed many times during the season (23). The single application may have been insufficient to increase the defoliation of thornless blackberry.

Although the treatments containing ethephon significantly defoliated the plants, they did not affect yield in the following season (Table 1). This finding is different than that of Ketchie and Williams (9), who used ethephon to defoliate trees of 2 apple cultivars. They reported a marked fluctuation in fruit set and vegetative vigor the following year. Sprays containing urea or $CaCl_2$ alone did not affect leaf retention in our study. These treatments also failed to affect dieback, flowering, or yield (data not shown).

While these treatments were ineffective in altering winterhardiness, large differences in hardiness among cultivars were observed (Table 1). The average dieback of 'Smoothstem' shoots was substantially greater than that observed on either 'Dirksen'

Table 1. Analysis of variance for the main effects of cultivar and fall treatment in the factorial study of winterhardiness and yield of thornless blackberry. Mean separation among cultivars of the variables measured in this study.

	Dieback	Flowers per shoot	Buds on live wood (%) With flowers	Buds on live wood (%) With leaves only	Buds on live wood (%) Dead	Buds[x] (%) With flowers	Buds[x] (%) With leaves only	Buds[x] (%) Dead	Yield per 5 plants (kg)
Analysis of variance				*F values*					
Cultivar	19.28***[z]	6.51***	53.19***	7.97***	55.11***	84.85***	10.85***	99.73***	3.30
Fall Treatments[w]	0.73	0.40	0.51	0.18	0.37	0.39	0.27	0.17	0.36
Cultivar × Treatment interaction	0.78	1.26	1.93	1.35	0.72	1.94	1.24	0.73	0.73
Mean separation among cultivars				*Observed means*					
Dirksen	1.28 a[y]	60 a	67.3 a	24.2 b	8.8 b	65.0 b	23.8 b	10.7 c	24.3 a
Hull	4.35 b	57 a	48.0 b	38.0 a	14.4 b	45.3 b	35.3 a	19.7 b	21.6 ab
Smoothstem	9.93 c	43 b	35.4 c	27.0 b	37.3 a	26.2 c	20.0 b	53.8 a	17.3 b

[z]Analysis of variance F values are significant at 5% level (*), 1% level (**), and 0.1% level (***).
[y]Mean separation within columns by Duncan's multiple range test, 5% level.
[x]Data in "Buds" column taken from entire shoot including dieback.
[w]Falls treatments consisted of $CaCl_2$, ethephon, urea, and $CaCl_2$ + urea.

Table 2. Correlation coefficients among selected dependent variables measured in field study of 1981–1982. Only measurements taken on plants treated with urea, $CaCl_2$, or left untreated are included in these correlations.

	Retained leaves 14 Oct.	Retained leaves 30 Oct.	Retained leaves 14 Nov.	Retained leaves 29 Nov.	Retained leaves 2 Dec.	Dieback	Flowers per shoot	Buds on live wood (%) With flowers	Buds on live wood (%) Leaves only	Buds on live wood (%) Dead	Buds (%) With flowers	Buds (%) Leaves only	Buds (%) Dead	Yield
Variable														
Dieback	−0.005[z]	0.264	0.073	0.060	0.415*	1.000	−0.552**	−0.650**	0.011	0.619**	−0.754**	−0.291	0.775**	−0.327
% Buds with Flowers	−0.092	−0.288	−0.254	−0.294	−0.576**	−0.754**	0.664**	−0.966**	−0.276	−0.705**	1.000	0.007	−0.811**	0.317
Yield	0.125	−0.216	−0.357*	−0.405*	−0.376*	−0.327	0.299	0.324	−0.008	−0.310	−0.317	0.063	−0.291	1.000

[z]Significant at 5% level (*) and 1% level (**). Minimum r values for significance are 0.329 (5%) and 0.423 (1%).

or 'Hull' canes. The average number of flowers/shoot also was significantly lower on the 'Smoothstem' shoots. The small difference in yield among cultivars was probably due to the increased yield potential of 'Smoothstem', caused by its large number of canes/plant and total number of buds/cane.

The proportions of buds with flowers, with leaves only, and with dead buds were determined on entire laterals, as well as on living wood only (Table 1), to determine if there might be compensation in fruit set and yield in response to the winter damage. The 'Smoothstem' laterals had the greatest amount of dieback and also the largest proportion of dead buds on their shoots. There did not appear to be any compensation in fruit set of surviving buds in response to winter damage.

A correlation matrix was generated to test if any of the variables measured were significantly related. Since the treatments containing ethephon affected leaf retention, only data from control, urea-, and $CaCl_2$-treated plants were analyzed (Table 2). Dieback, number of flowers per shoot, number of live buds, and yield were significantly correlated. Again, the retention of leaves at various dates was negatively associated with bud survival, flowering, and yield. Since the delay of fall senescence was associated with a lack of hardiness and vigor in thornless canes, and the progress of senescence was determined by cultivar, it seems that early leaf senescence and the cessation of growth are desirable characteristics in this crop. These data suggest that a blackberry breeder might be able to screen against late-season leaf retention and shoot elongation in order to select for plants with superior cane hardiness.

Growth, defoliation, and winterhardiness, 1982–1983. The patterns of leaf retention and shoot elongation for 'Dirksen' and 'Smoothstem' canes during Fall 1982 are shown in Fig. 1. While both cultivars retained nearly all their leaves through 10 Nov., a large difference was seen on the date when each cultivar ceased its extension growth. On 10 Nov., 'Dirksen' stems were brownish-purple and stiff. Leaves were dark green, large, and full with 3–5 leaflets. Even leaves near the tip were well developed. Buds, although smaller at the shoot tip than were basal buds, were of full size and had visible scales. These buds were prominently raised from the adjacent stem.

'Smoothstem' laterals had not matured at the 10 Nov. date. New growth clearly was visible on many laterals throughout the 'Smoothstem' plants. Apical tips were light brown or green and succulent. The different age of leaves was obvious, as the subapical leaves were smaller and more succulent than older leaves and continued to expand late into the fall. Buds near the tip were less developed than basal buds in this cultivar. No lateral buds on either cultivar made any extension growth as a result of hand-pruning the adjacent petiole for leaf removal on either 30 Sept. or 4 Nov. Consequently, the onset of fall dormancy occurred much earlier in 'Dirksen' canes than it did in 'Smoothstem' canes. The expression of the onset of dormancy appeared to be the cessation of shoot growth, rather than in the date of leaf abscission.

Cultivar differences in mid-winter hardiness of tissue were noted by the artificial freezing tests (Table 3). Total damage to 'Dirksen' samples was less than that observed in stems of 'Smoothstem' after exposure to the same test temperature. The reduced hardiness demonstrated by this test in stem segments

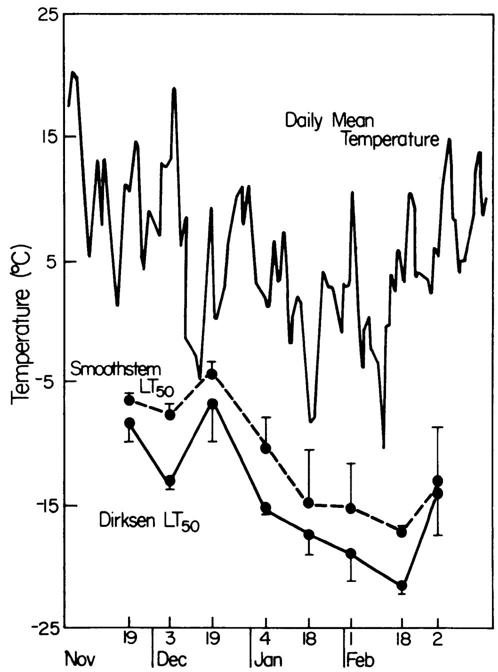

Fig. 1. Changes in the daily mean temperature and the LT_{50} values of 'Smoothstem' and 'Dirksen' blackberry flower buds during the winter of 1982–83.

of basal portions of 'Smoothstem' laterals agrees with the increased dieback of this cultivar observed in the 1981–1982 field trial (Table 1).

Within each cultivar there was an injury response to the wood that appeared to be associated with hand-defoliation. Wood from naturally defoliated 'Dirksen' stems was hardier than wood from defoliated stems, except at the 2 Mar. test date. Wood from stems defoliated on 30 Sept. was the least hardy. Wood from nondefoliated 'Smoothstem' stems generally was the most hardy, while wood from stems defoliated 30 Sept. was usually least hardy. In this test, premature defoliation appeared to decrease mid-winter hardiness of stem tissue. Bark tissue of both cultivars was much hardier than either wood or buds. Differences in hardiness of bark among defoliation treatments were not significant.

No effect of fall defoliation treatment on bud hardiness was noted (Table 3). Consequently, the seasonal hardiness changes of buds were based on the mean LT_{50} values for all 3 defoliation treatments. These measurements were pooled within cultivar on each test date (Fig. 2).

DTA of thornless buds revealed 2 distinct exotherms (Fig. 3). When excised primordia were frozen, a single small exotherm was observed. Although the exotherm was observed at a slightly lower temperature than that observed in intact buds, the size and shape were similar. It was concluded that this low temperature exotherm corresponded to the freezing of water in the primordium, and the high temperature exotherm corresponded to the freezing of water in other portions of the bud. These low temperature exotherms were observed at temperatures close to the LT_{50} values determined by artificial freezing tests (Fig. 3). In addition, both the LT_{50} and the exotherm temperatures increased on the 3 Mar. sampling date (data not presented). Although not conclusive, the data suggest that this 2nd exotherm probably arose from the freezing of supercooled water within the bud primordium. This phenomenon has been observed in several woody-plant species (1, 15). However, stem tissue did not deep supercool (Table 4).

The seasonal hardiness curves (Fig. 2) show that while the pattern of hardiness gain and loss was similar in both cultivars, 'Dirksen' buds were generally hardier. Both cultivars lost hardiness between 3 Dec. and 17 Dec., apparently in response to the warm temperatures on 5 consecutive days during that period. Brierley and Landon (3) observed that cold resistance of raspberry was lost quickly in response to warm spells in mid-winter. Maximum hardiness was attained on 18 Feb. Ketchie and Beeman (8) observed that 'Red Delicious' apple trees attained maximum hardiness after sustained temperatures below 0°C occurred in the field. In their test, trees were hardiest after 7 consecutive days when the mean temperature was about 0°. The continued gain in hardiness with persistent sub-freezing temperatures appears to be due to water loss of bud and stem tissue (3, 15). During the winter of 1981–1982, 'Dirksen' blackberry canes withstood −24.4° on 12 Jan in Silver Spring, Md., and produced yields as high as 9 kg/plant. Noteworthy is the fact that in the 10 days previous to 12 Jan., the minimum daily temperature was lower than −17°, and the high temperatures rarely exceeded 0°.

Shoot dieback and a reduction in the flowering were the primary expressions of winter damage. 'Smoothstem', which continued its extension growth late into the fall, was more winter tender than were other cultivars tested. Extension growth was a better predictor of winterhardiness than was the time of fall defoliation. The hardiness of dormant buds was affected by field

Table 3. Visible injury to wood, bark, and buds of thornless blackberry noted after subjecting them to freezing stress. Tissue values are computed from 7 observations at the representative temperature from 3 Dec. until 2 Mar.[z]

	Tissue score[y]								
	Wood			Bark			Bud		
Cultivar	ND[x]	HD 30 Sept.	HD 14 Nov.	ND	HD 30 Sept.	HD 14 Nov.	ND	HD 30 Sept.	HD 14 Nov.
Dirksen	0.94	0.49	0.64	1.68	1.01	1.44	0.67	0.49	0.43
Smoothstem	0.81	0.01	0.37	1.93	1.56	1.50	0.60	0.66	0.77

[z]Representative temperatures were selected at each date, within each cultivar that preceded the temperature where all wood tissue was killed.

[y]Scoring system used: 0 = brown necrotic tissue, or tissue with watersoaked appearance; 1 = beige color tissue, or tissue speckled with brown; 2 = green, uninjured tissue.

[x]Defoliation treatments: ND = natural defoliation; HD 9/30 = hand defoliated on 9/30; HD 11/14 = hand defoliated on 11/14.

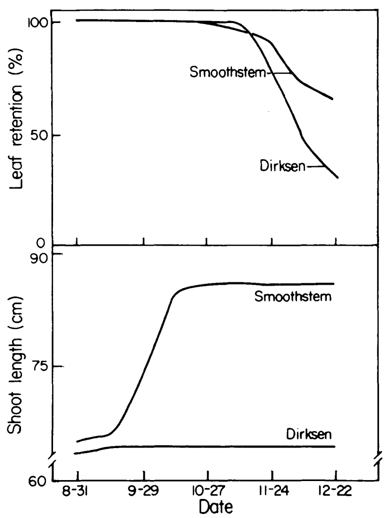

Fig. 2. Changes in leaf retention (upper) and shoot length (lower) of 'Smoothstem' and 'Dirksen' blackberry plants during Fall 1982.

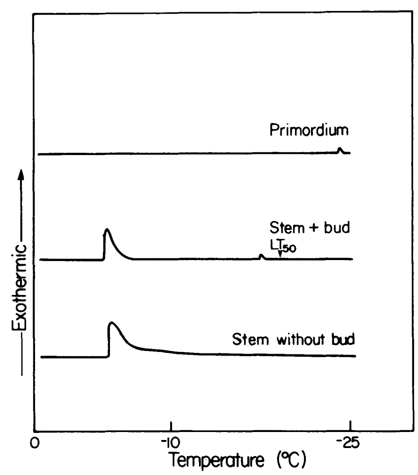

Fig. 3. Freezing curves of 'Dirksen' bud, stem, and primordium produced in differential thermal analysis on 17 Feb. 1983.

Table 4. Differential thermal analysis of bud, stem, and primordial tissue of thornless blackberry.

Date	Cultivar	Tissue	Exotherms (°C)		Samples with 2 exotherms (%)
31 Jan.	Smoothstem	Bud	−4.5[z]	−12.0	100
		Stem	−4.5		0
17 Feb.	Smoothstem	Bud	−4.6	−15.4	100
		Stem	−7.6		0
		Primordia		−26.0	---
	Dirksen	Bud	−4.4	−18.4	100
		Stem	−7.8		0
2 Mar.	Smoothstem	Bud	−4.4	−14.4	88
	Dirksen	Bud	−4.3	−11.1	67

[z]Values presented represent the means of from 2 to 8 replicates.

temperatures. Freezing tests showed that 'Dirksen' and 'Smoothstem' buds lost as much as 5°C of hardiness in mid-December following a period of warm weather.

Dormant 'Smoothstem' and 'Dirksen' buds deep supercooled, but stem tissue did not. The different freezing responses occurring in bud and stem tissue may have led to different responses of these tissues following hand-defoliation treatments. Stem tissue from canes that were hand-defoliated at the end of September showed more injury symptoms after freezing stress than did stem tissue from canes that were hand-defoliated later, or from canes that were naturally-defoliated. However, the amount of mid-winter injury to buds was not related to defoliation treatments.

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The Influence of Fruiting and Shading of Spurs and Shoots on Spur Performance

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Abstract. **Leaves of spurs and/or shoots of small fruiting 'Starkrimson Delicious' apple trees were exposed to light or shade treatments from 60 days after petal fall until fruit maturity. Shading spurs reduced spur leaf photosynthesis (Pn) and transpiration (Tr), but shading shoots had no effect on spur leaf Pn. There was no difference between fruiting and nonfruiting spur Pn and Tr. Shading shoots reduced fruit growth and delayed maturity, but shading spurs had no effect on either. Fruiting reduced—but did not eliminate—spur flowering the following year. Light conditions late in the season had no effect on flowering or spur leaf development the following spring.**

Fruit and spurs may become exposed to changing light environments during the growing season. Vegetative extension growth on the canopy periphery may shade older interior limb sections and limb orientation may change due to crop weight, thereby affecting light exposure of fruits and spurs.

Light is important to fruit color and quality (15, 16, 18), and the light level to which a fruit cluster is exposed after the period of fruit set and cell division is also significantly correlated to fruit size and weight (16, 18), and may affect fruit shape (22). A minimum light level may be necessary for fruit bud formation (12) and to saturate photosynthesis of apple (2, 11). Further, leaves apparently adapt physiologically to changing light levels (3).

Since spur leaves and shoot leaves have different morphological structures and photosynthetic rates (8) and differences in ability to adjust to the fruit-sink demand (21), there may also be differences in the potential importance of spur leaves and shoot leaves to fruit development. The performance of spur leaves and shoot leaves may be dependent on the light environment to which they are exposed. The objectives of this experiment were to study the influence of shade on spur leaves and shoot leaves late in the season and its effects on fruit growth and spur development.

Materials and Methods

Small fruiting trees of 'Starkrimson Delicious' on Malling-Merton 106 (MM 106) were grown in 3-liter pots containing Wooster silt loam soil and Promix-BX (1:1, v/v). Trees were made by whip-and-tongue grafting 3- to 5-year-old spur-bearing limb sections from mature standard trees onto 2-year-old rootstocks grown in pots. Grafts were made during the dormant season (1982), wrapped with cloth adhesive tape, covered with Tree-kote and held at 20° to 25°C for 48 hr. Trees were potted and held for 75 days at 5° (±2°) and 95% relative humidity, and did not fruit the first spring. Trees were grown outside for about 175 days, stored at 5° (±2°) with 80% relative humidity for 145 days, and put into a greenhouse the following spring (23 Mar. 1985). Trees were grown inside the greenhouse to maintain uniform growing conditions and to reduce other environmentally induced problems. Greenhouse temperatures were thermostatically controlled in a range of 8° to 28° and air-cooled by fans and wet aspen pads. Trees were fertilized with 15 g of 14N–6.1P–11.6K put into each pot at the beginning of the growing season. About 500 ml of 20 $g \cdot liter^{-1}$ of 20N–8.7P–16.6K soluble fertilizer was applied with waterings at about 30-day intervals. Pesticides were applied to control insect pests when needed.

About 60 days after petal fall in 1983, relatively uniform trees were selected and all fruiting clusters were hand-thinned to one fruit and 3 fruits per tree. An average of 1.8 fruit per tree were removed and 62% of the fruiting spurs were allowed to retain fruit. Treatments were applied as follows: 1) control; 2) shade spur leaves only; 3) shade shoot leaves only; and 4) shade the entire plant. One treatment per tree was applied to 3 fruiting and 3 defruited sample spurs, with 9 replications (total of 36 trees) in a completely randomly designed split-plot for fruiting and nonfruiting spurs. Shade was created by making bags of black polypropylene 55%-shade fabric (Chicopee Lumite) and completely enclosing the treatment spurs or shoot leaves. Fruit were covered as well as the spur leaves in treatments 2 and 4. Ambient light conditions within the greenhouse were about 35–

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