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

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Additional index words. *Malus* ×*domestica*, photosynthesis, transpiration

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·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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Table 1. The influence of shade and fruiting on net photosynthesis (Pn) and transpiration (Tr) of spur leaves of 'Starkrimson' Delicious apple.

	Pn (mg CO$_2$·dm^{-2}·hr^{-1})				Tr (g H$_2$·dm^{-2}·hr^{-1})			
	Weeks after treatment				Weeks after treatment			
Treatment	2	4	6	Avg	2	4	6	Avg
Shading								
control	13.8 a[z]	17.6 ab	18.8	16.7 a	1.15 a	1.07 b	1.56	1.26
spurs only	7.9 b	13.8 b	16.3	12.7 b	0.52 b	0.51 c	1.25	0.76 c
shoots only	14.5 a	21.2 a	21.3	19.0 a	1.48 a	1.49 a	1.76	1.56 a
all	15.1 a	21.0 a	19.7	18.3 a	1.21 a	1.17 ab	1.45	1.28 b
			NS				NS	
Spur type								
Fruiting	13.0	18.1	18.8	16.6	1.09	1.07	1.51	1.22
Non-fruiting	12.7	18.3	19.3	16.7	1.08	1.03	1.50	1.20
	NS	NS	NS	NS	NS	NS	NS	NS

[z] Mean separation within columns by LSD, 5% level. NS = no significance.

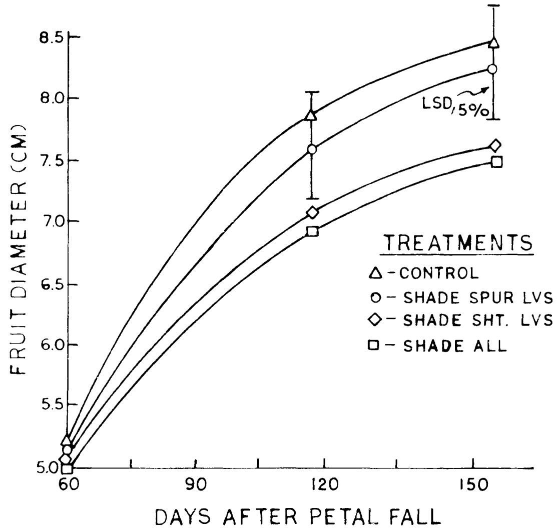

Fig. 1. The influence of shading spurs and shoots late in the season on fruit growth of 'Starkrimson' Delicious apples.

45% of full sunlight, while fabric allowed 20–30% of full sunlight.

Net photosynthesis (Pn) was measured with an infrared gas analyzer (Lira 200, MSA, Pittsburgh, Pa.) and transpiration (Tr) was measured with a dewpoint hygrometer (International EG and G, model 880) after an equilibration period (15–30 mhs) within the leaf chamber with an apparatus and procedure previously described (19). Photosynthetic photon flux of 950 μmol·s^{-1}·m^{-2} inside the leaf chamber was emitted by Sylvania phosphorus-coated metal arc lamps. Leaf chamber temperatures of 25°C (±2°) and air flow rates of 3 liter·m^{-1} were maintained.

Pn and Tr of spur leaves from fruiting and nonfruiting spurs of each tree were measured at 2, 4, and 6 weeks after initiation of treatments. Fruit length and diameter were measured periodically with a vernier caliper. Fruit were harvested at 14 weeks after initiation of treatments (160 days after bloom) and fresh weight, firmness, and soluble solids (percentage) measured. The number of surface cork-spot blemishes were counted and fruit color was subjectively measured using a photographic standard with a rating scale of 1 = 100% red and 5 = 60% red.

Three weeks after fruit harvest, trees were stored at 5°C (±1°) for about 150 days to observe carry-over effects on fruiting the following season. Trees were removed from cold storage the following spring and fertilized (as described above). Diameter and length of the spur and terminal spur bud of each treatment spur were measured with a vernier caliper. Flower number was counted and bloom stage rated every other day during the bloom period. Fruit set per spur was counted 30 days after petal fall and spur leaf area measured using a calibrated area grid (7) made of lucite and placed above the leaf. Fruit were harvested 150 days after bloom.

Results and Discussion

Photosynthesis and transpiration. Shading spur leaves reduced Pn and Tr of a spur leaf (compared to the controls) 2 and 4 weeks after treatment, but shading shoot leaves did not affect spur leaf Pn (Table 1). The response of spur leaves was similar to that of mature shoot leaves which, when shaded (20% full sun), had reduced Pn (3). Six weeks after treatments were applied, the same general trend was apparent and there was a large

Table 2. The influence of shade late in the season on fruit size, shape, and quality of 'Starkrimson' Delicious apples.

	Fruit at harvest							
Shade treat.	Length (cm)	Diam (cm)	Length diam	Weight (g)	Color[y]	Cork per fruit	Firmness (kg)	Soluble solids (%)
Control	7.11 a	8.47 a	0.84 a	263 a	1.6 a	1.8 a	6.03 b	13.2 a
Spurs	6.72 a	8.33 a	0.81 a	233 a	3.4 a	1.4 a	6.22 b	11.3 b
Shoots	6.13 b	7.65 b	0.80 a	184 b	2.4 a	0.8 a	7.08 a	10.9 b
All	6.17 b	7.56 b	0.81 a	176 b	3.4 a	1.1 a	7.45 a	10.5 b

[z] Mean separation within columns by LSD, 5% level.

[y] Color rated by photographic standard: 1 = 100% red; 5 = 60% red.

Table 3. The influence of shade late in the season and fruiting on spur development of 'Starkrimson' Delicious.

Treatment	Spur Growth Diam (cm)	Spur Growth Length (cm)	Terminal Spur Bud Diam (cm)	Terminal Spur Bud Length (cm)
Shading				
Control	0.535^z	2.96	0.450 a	1.67
Spurs	0.528	2.68	0.419 ab	1.70
Shoots	0.485	2.66	0.409 b	1.74
All	0.512	2.88	0.451 a	1.80
	NS	NS		NS
Spur type				
Fruiting	0.584 a	2.89 a	0.419 b	1.71
Nonfruiting	0.446 b	2.71 b	0.449 a	1.73
				NS
Shading interactions				
Fruiting spur				
Control	0.594 a	3.19 a	0.441 bc	1.65
Spurs	0.607 a	2.57 c	0.403 cd	1.68
Shoots	0.549 bc	2.64 bc	0.399 d	1.74
All	0.584 ab	3.15 ab	0.431 bcd	1.75
Nonfruiting spur				
Control	0.476 bc	2.74 abc	0.458 ab	1.68
Spurs	0.448 bc	2.79 abc	0.434 bcd	1.72
Shoots	0.420 c	2.68 abc	0.418 bcd	1.73
All	0.440 bc	2.61 bc	0.484 a	1.84
				NS

[z] Mean separation within columns by LSD, 5% level. NS = nonsignificant.

degree of tree-to-tree variation at the last date. Variation of Pn was greatest with shaded spurs, probably indicating the onset of leaf senescence.

Shading shoots only (with spurs not shaded) did not affect spur leaf Pn (Table 1). These data are in contrast to a report (20) that stated that when all but one leaf of soybean plants were shaded, the nonshaded leaf had increased Pn—responding to the reduction in source ability. The authors indicated that assimilate demand had a strong influence on the remaining source, resulting in increased assimilation and export. Shading the entire plant (''All'' treatment) did not significantly influence Pn of the spur leaves (Table 1). Tree response in this treatment was similar to the control trees, which also had spurs and shoots in a uniform light environment. However, it is interesting to note that the Pn of spur leaves of entirely shaded plants was higher than the shaded spurs of the ''Spur only'' treatment.

The fruiting condition of the spur did not influence Pn or Tr (Table 1) and was consistent with a previous study (17). However, this response was different from other reports that suggest that fruiting results in increased Pn (1, 10). This study was begun with the hypothesis that spurs may behave as a ''physiological unit'' (6). Evidence for spurs acting as an individual entity is supported by the fact that most of the carbon assimilated by spur leaves is retained within the spur (9). Thus, the lack of Pn response to fruiting of individual spurs may be explained by several reasons.

First, all trees were in a fruiting condition. The fruiting spur may have imposed a sink demand away from the fruiting spur on the nonfruiting spur. An alternative situation may have existed if carbohydrates were not limited within the small trees and thus did not require increased photosynthetic activity of spur leaves on fruiting spurs to maintain fruit growth. In either case, both nonfruiting and fruiting spurs would have had similar sink demand and supposedly similar Pn rates. This conclusion suggests that the spur may not act as a unit and is more responsive to other factors than just that in the immediate vicinity. It is possible that the spur leaves do not adjust to sink demand and only shoot leaves respond to the presence of fruit (21). The fact that spur leaves did not have an altered Pn rate when shoot leaves were shaded (effectively reducing total ''sourceness'' of the trees) supports this conclusion.

This experiment did not account for alternative sinks such as shoots, developing leaves, roots, or trunk growth. However, it is important to note that trees were chosen at random and treatments were begun 60 days after bloom—at a time when shoot growth was ceasing. Pn rates at 2 weeks after the beginning of treatments were not correlated to either the amount of fruit on the tree at time of measurement or the initial amount of fruit on the tree prior to thinning. Thus, even though alternative sinks cannot be accounted for, there is no evidence to relate Pn rates to fruit number on a spur or the entire small tree.

Fruit growth. Shading shoots or the entire plant reduced fruit growth (Fig. 1) and, therefore, fruit size at harvest (Table 2). The change in size was an allometric reduction of both length

Table 4. The influence of shade late in the season and fruiting on leaf development, flowering, and fruiting the year after treatment of 'Starkrimson' Delicious apple trees.

1982 treatment	Spurs flowering	Flowers per spur	Spur leaves^z No.	Spur leaves^z Area (cm^2)	Spur leaves^z Avg size (cm^2)	Fruit growth No. per spur	Fruit growth Set (%)	Fruit growth Length (cm)	Fruit growth Diam (cm)	Fruit growth Length Diam	Fruit growth Wt (g)
Shading treatment											
Control	69.6^y	4.4	5.8	101.5	17.6	2.3	52.7	7.49	7.94	0.94	219.4
Spurs	58.8	4.3	7.5	115.8	19.5	2.3	49.2	7.98	8.30	0.96	254.5
Shoots	49.1	3.4	5.6	131.1	23.3	2.1	62.5	7.56	7.93	0.95	230.9
All	53.1	3.8	5.9	107.7	19.7	2.2	63.9	7.40	7.60	0.98	199.3
	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Spur type											
Fruiting	38.7 b	3.4 b	5.6	131.2 a	24.4 a	2.0	58.5	7.44	7.78	0.96	211.7
Nonfruiting	76.5 a	4.5 a	5.0	100.2 b	16.4 b	2.4	55.6	4.78	8.10	0.96	240.4
			NS			NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Spur leaves measured 40 days after petal fall.

[y] Mean separation within columns by LSD, 5% level. NS = nonsignificant.

and diameter and, thus, fruit shape (L/D) was unaffected by shade. Covering apples (shaded spur treatment) did not influence fruit size significantly (Table 2), agreeing with a previous report (15). Apparently, shading shoot leaves reduced their photosynthetic potential (3), similar to that of shading spur leaves (Table 1). Shoot leaves may be more responsive to sink demand (21) and support fruit growth more than the spur leaves later in the season.

Shade also influenced fruit quality (Table 2). Color tended to be reduced by any shade treatment, although the differences were not significant. Fruit firmness was higher and soluble solids lower on trees with the shoot leaves shaded (''Shoots only'' and ''All'' treatments), compared to controls or shading only spur leaves. Severe summer pruning by removing vegetative shoots in August reduced fruit soluble solids (8), similar to shading shoots 60 days after bloom in the study (Table 2). Therefore, shoot leaves have a critical role in fruit development late in the season and in addition to the light in the immediate microenvironment of the fruit may be limiting to growth (16, 18).

Spur development. Spur diameter and length were not affected by shade treatments, but fruiting spurs were larger than nonfruiting spurs (Table 3). The size of the terminal spur bud was not consistently affected by shade treatments. However, buds on nonfruiting spurs were larger than those of fruiting spurs. Consequently, there was an interaction of fruiting and nonfruiting spurs and shade treatments for spur development but no significant trend was apparent.

Growth the season following treatment. Neither shade nor fruiting influenced date of bloom the following season (data not shown). Likewise, shade treatments did not influence the percentage of spurs that flowered the following season nor the number of flowers per spur (Table 4). However, 76% of the spurs that did not have fruit in the treatment year (1982) had flowers the following season (1983), while only 38% of the fruiting spurs had flowers in 1983. Nonfruiting spurs also had more flowers per spur the next season than did fruiting spurs, and no significant interaction between shade treatments and the fruiting condition of the spur was apparent. Therefore, the presence of fruit had a greater effect on flower formation than did the light level later in the season or the assimilate reduction resulting from shade. Chan and Cain (5) have suggested that flower initiation is hormonally controlled and may be limited by seed formation within fruit, but initiation is not limited by carbohydrate supply. The observation has been made that apple trees have a light requirement for flower initiation, and about 30% full sun is a critical threshold (12). Also, it has been clearly demonstrated that as shading was increased, flowering the following season was decreased (13). Spurs in the shade treatments would have been below that critical level, and since shade applied 60 days after bloom did not eliminate or reduce flowering the following year, it is reasonable to assume that flower initiation occurred prior to treatments. Indeed, reports have indicated flower initiation occurs in the early part of the season (4).

The number, area, and average size of spur leaves measured 45 days after bloom in 1983 was not affected by shade treatments the previous season (Table 4). Since initiation and development of the spur buds occurs the season prior to the opening of the bud and the shade treatment during the season did not affect the development the following year, 3 possible causes may be made: 1) shade treatments were made after the initiation of the spur bud and development of leaf primordia, which may have occurred early in the spring during the period of flower bud initiation and differentiation (4, 5); 2) leaf primordia development may have continued to occur in the 3 weeks following harvest when shades were removed and before trees were stored for overwintering; 3) light environment in the year of initiation may have not been as critical to leaf development as was the light environment during the following year.

Spurs that fruited in 1982 had more spur leaf area and larger leaves in 1983 than did spurs that were nonfruiting in 1982 (Table 4). This result was probably due to the great proportion of spurs that fruited in 1982. These spurs did not fruit in 1983 but instead were vegetative or were forming into shoots.

Neither shade treatments nor the fruiting condition of a spur affected fruit set or development the following year (Table 4). Thus, it can be concluded that the light environment in which fruit development occurs may be more important than a light environment the previous season during and after flower initiation.

Shade reduced spur-leaf photosynthesis and transpiration but spur leaves appeared to be unresponsive to changes in sink demand. Shoot leaves are critical for fruit development and quality later in the season. Thus, not only is the light environment to which a fruit is exposed important but so is the light exposure to the vegetative shoot. Fruiting reduced (but did not eliminate) flowering the following season, but there was no carry-over effect of shade treatments on fruiting, bloom date, fruit set, or subsequent fruit development.

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Factors Accounting for the Within-tree Variation of Fruit Quality in Sweet Cherries

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Abstract. **Sweet cherry (*Prunus avium* L.) flower and pistil weight at anthesis decreased at late bloom times. Fruit from early-opening flowers remained larger through harvest and developed higher soluble solids and color than fruit from flowers than opened later. Time of anthesis was delayed and fruit color and soluble solids decreased linearly as flower or fruit location progressed basipetally on one- and 2-year-old wood.**

Maturity and quality are highly variable within and between sweet cherry trees. Exposure to light (14), tree crop load (16), and branch fruit-to-leaf ratio (8) all affect fruit quality. However, not all the variability in cherry quality can be accounted for by these factors. Research on other variables affecting tree fruit quality has been confined mostly to apples.

In apples, the largest and highest-quality fruit come from early-opened or pollinated blossoms (13, 19), the first (terminal) bloom within a cluster (20), the youngest spurs (10, 18), and largest fruit at an early reference date (3). Physiological maturity is more advanced for fruit from interior rather than exterior positions of the tree (9, 11) or near a "ring scar" (bud scale scar) (6).

The objectives of this study were to determine the relationships of 1) bloom time of individual flowers to flower and fruit quality, 2) location of inflorescence to time of anthesis and fruit quality, and 3) early fruit size to fruit quality.

Materials and Methods

Time of anthesis

Expt. 1. The time of anthesis for individual flowers in different positions on one- and 2-year-old wood was measured in 1982 by grouping flower buds into 3 stages of development: open cluster, first white, or full bloom (2). After about 50% anthesis had occurred on the trees, the number of flower buds in each category were counted at 6 positions: the basal bud on one-year-old wood and the first 5 spurs (basipetal direction) on 2-year-old wood. Counts were made on 8-year-old 'Bing' trees.

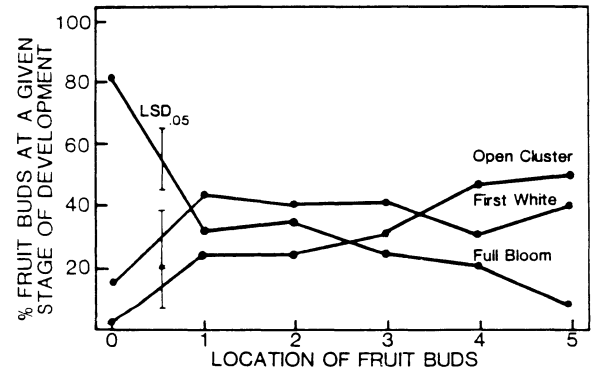

Fig. 1. Relationship between the stage of bud development of 'Bing' sweet cherries and their location on one- and 2-year-old wood. (0 denotes basal buds on one-year-old wood, 1–5 denotes the spur position below the first ring scar). Significant (5% level) linear and cubic trend analysis for full bloom and open cluster, and first white, respectively. Orthongonal analysis of data performed on arcsin square-root transformations.

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