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Canopy Position and Light Effects on Spur, Leaf, and Fruit Characteristics of 'Delicious' Apple

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Abstract. **Spur leaf and fruit characteristics at harvest were measured near the central leader at 1, 2, and 3 m above ground on 17-year-old trees of 'Oregon Spur Delicious' apple (*Malus domestica* Borkh.). Percentages of full sunlight at 1 (bottom), 2 (middle), and 3 m (top) positions were 9, 23, and 48, respectively. Vegetative spurs at the top had greater average leaf dry weight, total leaf number, leaf area, leaf dry weight per spur, specific leaf weight (SLW), and bud diameter than spurs at the bottom. Fruiting spurs at the top had greater leaf dry weight, leaf dry weight per spur, SLW, bud diameter, and spur length than spurs at the bottom. Vegetative spurs had greater values than fruiting spurs for all spur traits except leaf number per spur. Fruit weight, size, and soluble solids were greater at the top than at the bottom. Fruit at the bottom had higher firmness and levels of starch, N, P, K, Zn, Ca, Fe, B, and Mg. SLW, leaf dry weight per spur, and average leaf dry weight of vegetative and fruiting spurs were correlated with percentage of full sunlight. Fruit size, weight, soluble solids, starch, and N content also were correlated with percentage of full sunlight. SLW was correlated with fruit size, weight, soluble solids, and starch, and N, P, Mg, Ca, and Fe content.**

Spurs are the principal fruiting structures on an apple tree. Yeager (26), in 1916, stated "The evidence indicates clearly that strong, vigorous fruit spurs are superior to those that are weak. They flower more frequently, are more prone to set fruit, and produce larger fruits." Unfortunately, spur traits have not been studied sufficiently to be able to characterize spurs quantitatively as "strong" or "weak". Spur length has been associated with flowering and fruit set the following year (1). Leaf area per spur at bloom differed considerably between cultivars and was correlated with fruit production (21).

The light environment within a canopy influences spur characteristics (3). Specific leaf weight has been particularly sensitive to light.

It is necessary to evaluate spur characteristics and factors that influence them, and to understand relationships of specific spur traits with fruiting and fruit quality in order to improve fruit production and quality. The purpose of this study was to characterize vegetative and fruiting spurs and determine their association with canopy light levels and fruit characteristics.

The study was conducted in a commercial orchard in Manson, Wash., with trees of 'Oregon Spur Delicious'/'MM 104' planted in 1969. Trees were spaced 3 × 5.5 m with 600 trees/ha, in north–south rows, and trained to a central leader and pyramid tree shape (10). In 1985, trees were ≈3.5 m wide at the base and 4 m tall. The 12 trees used in the study averaged 899 fruit and 153 kg of fruit per tree. Trees received overhead irrigation and standard commercial cultural practices.

Within the center of each tree there were three data collection positions: 1 m (bottom), 2 m (middle), and 3 m (top) above ground level. Irradiance (400–700 nm) was measured above each tree and at each canopy position at solar noon ± 1 hr on 4 Oct. 1985. Measurements were made with a LI-COR Line Quantum Sensor (LI-191SB) held horizontally in both a north–south and an east–west direction with the center (50-cm point) of the sensor positioned adjacent to the trunk. The north–south and east–west within-canopy readings were averaged and compared to above-canopy readings to calculate percentage of full sunlight for the three canopy positions in each tree.

Spur and fruit samples were collected 1 Oct. from each canopy position in each tree. Five fruiting spurs with fruits attached and five vegetative (nonflowering) spurs were harvested at each canopy position. For each fruiting and vegetative spur, the leaf number, area, and dry weight per spur were determined. From these values, average leaf area, average leaf dry weight, and SLW ($mg \cdot cm^{-2}$) were calculated. Leaf area was measured with LI-COR area meter (LI-3000/LI-3050). Spur length and bud diameter also were measured.

Fruit weight and subjective percent red skin color measurements were made on fruits collected with each spur. In addition, a 50-fruit sample was collected from each canopy position on each tree to determine fruit size distribution by running the fruit over a commercial sizer. After 3 weeks in 0°C storage, fruit from each canopy position in each tree were examined for fruit quality. Firmness was determined using a LC Pressure Tester Model EPT-1 equipped with a 1.11-cm probe. Starch content was rated using the starch–iodine test with scores from 1 to 5, with 1 representing the greatest starch content. An Abbe-type refractometer with a sucrose scale calibrated at 20° was used for soluble solids determination. Red skin color was determined with an Agtron reflectance spectrophotometer, model E5W. Yellow and green flesh colors were measured with an Agtron model 300 reflective spectrophotometer, with high Agtron blue values indicating greater yellow flesh color and low Agtron green values indicating greater green flesh color. Fruit mineral analysis was conducted on fruit after 2 months in 0° storage. A plasma emission spectrometer (Beckman Specter Span V) was used for mineral analysis, and data are presented on a dry weight basis.

Canopy position. All vegetative spur characteristics were greater at the top than at the bottom canopy position except for average leaf area and spur length (Table 1). On a percentage basis reductions from top to bottom position were greatest for total leaf dry weight per spur (−59%), average leaf dry weight (−50%), and SLW (−45%).

All fruiting spur characteristics, except average leaf area and total leaf number and area per spur, were greater at the top than the bottom canopy position (Table 1). On a percentage basis, the reductions were greatest for total leaf dry weight per spur (−37%), SLW (−36%), and average leaf dry weight (−33%).

Fruit weight, size, soluble solids, Agtron blue and green flesh color, and red skin color (subjective) were greater in the top than bottom of the tree canopy (Table 2). Fruit firmness, starch and all element concentrations (Table 3) were significantly greater for fruit in the bottom than in the top canopy position. On a percentage basis, reductions from the bottom of the canopy to the top were greatest for N (−32%), Zn (−27%), Ca (−20%), and Fe (−19%). There was no effect of canopy position on fruit titratable acidity, pH, Agtron red skin color, and levels of Mn, Ca, Al, and Na (data not presented).

Vegetative vs. fruiting spurs. Vegetative spurs had greater mean values for all spur characteristics than did fruiting spurs, with the exception of total leaf number per spur (Table 1). At the top position, vegetative spurs had larger values than fruiting spurs for average leaf dry weight and total leaf dry weight

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Table 1. The influence of canopy position on vegetative and fruiting spur characteristics of 'Oregon Spur Delicious'.

	Per spur			Per leaf				
Treatment	Total leaf no.	Total leaf area (cm^2)	Total leaf dry wt (mg)	Avg. leaf area (cm^2)	Avg. leaf dry wt (mg)	Specific leaf wt (mg·cm^{-1})	Bud diam (mm)	Spur length (mm)
			Vegetative spur characteristics					
Top	10.3 a^z	175 a	1.46 a	15.7 a	137 a	8.0 a	4.2 a	23.0 a
Middle	10.2 a	178 a	1.15 b	18.0 a	115 a	6.1 b	3.9 a	21.0 a
Bottom	8.8 b	129 b	0.60 c	15.1 a	68 b	4.4 c	3.3 b	22.0 a
			Fruiting spur characteristics					
Top	10.8 a	135 a	0.98 a	12.4 a	88 a	7.0 a	3.5 a	8.7 a
Middle	10.9 a	150 a	0.87 a	13.6 a	76 a	5.6 b	3.2 b	8.4 a
Bottom	10.1 a	129 a	0.62 b	12.8 a	59 b	4.5 c	3.0 b	6.9 b
Vegetative	9.8^y	161	1.08	16.5	107	6.1	3.7	22.0
Fruiting	10.5	138	0.82	12.9	74	5.6	3.2	7.9

^{z}Means within a column for canopy position and vegetative or fruiting spur characteristics separated by LSD, $P = 5\%$.
^{y}Mean values within columns for spur type separated by t test, $P = 5\%$.

Table 2. Influence of canopy position on specific fruit traits and mineral content of 'Oregon Spur Delicious'.

Canopy position	Mean fruit wt	Percent fruit in size categories^z		Red skin color (%)	Flesh firmness (lbs)	Starch^y	Soluble solids (%)	Agtron color	
		≤160 g	≥204 g					Blue	Green
Top	203 a^x	32.7 c	29.9 a	88.4 a	18.3 b	2.7 b	13.1 a	38.3 a	75.6 a
Middle	178 b	44.6 b	23.3 b	79.6 b	18.5 ab	3.2 a	12.5 b	36.4 b	73.9 b
Bottom	140 c	67.9 a	5.9 c	80.6 ab	19.0 a	3.5 a	12.5 b	35.1 c	72.9 b

^{z}Commercial box size 125 equals fruit weight of 145–160 g; box size 88 equals fruit weight of 204–227 g.
^{y}Rating of 1 to 5, with 1 representing the greatest starch content.
^{x}Means within a column separated by LSD, $P = 5\%$.

Table 3. Influence of canopy position on apple tissue mineral content.

Canopy position	Percent dry wt			ppm dry wt				
	N	K	P	Zn	Ca	Fe	B	Mg
Top	0.15 b^z	0.62 c	0.040 b	0.93 b	193 b	4.48 b	25.1 b	244 b
Middle	0.20 a	0.65 b	0.044 ab	1.16 ab	225 ab	4.92 ab	26.5 ab	255 ab
Bottom	0.22 a	0.68 a	0.046 a	1.27 a	240 a	5.55 a	27.6 a	264 a

^{z}Means within a column separated by LSD, $P = 5\%$.

per spur, and at the bottom position they had similar values. These interactions were not statistically significant.

Light effects. Mean percent full sunlight levels were 48, 23, and 9 for the top, middle, and bottom canopy positions, respectively. SLW, total leaf dry weight per spur, and average leaf dry weight were correlated with percent full sunlight for both vegetative and fruiting spurs (Table 4). Fruit size, weight, soluble solids, N content, Agtron blue and green flesh color, and starch content were correlated with percentage of full sunlight. Red skin color, Agtron red skin color, firmness, titratable acidity, and tissue levels of K, Mg, Fe, B, Ca, P, Mn, Zn, Na, and Ca were not correlated with light levels.

Correlations of spur leaf and fruit traits. SLW was correlated with fruit N content, size, weight, starch, and soluble solids (Table 5). Several fruit traits also were correlated with total leaf dry weight per spur, although the correlation coefficients were always lower than those for SLW. Total leaf area per spur was correlated only with soluble solids. Correlation coefficients of SLW and total leaf dry weight and leaf area per spur with the following fruit characteristics were not significant at the 5% level: red skin color, Agtron red skin color, titratable acidity, firmness, and content of Mn, B, P, Zn, Na, Cu, and Al.

Spur leaves were sampled at harvest while still green, ≈1 month before abscission. It is not known if spur leaf dry weight changes appreciably from early to late in the growing season. However, reports indicate that SLW of peripheral and interior leaves increased during the growing season at least into October (16).

Most spur traits had larger values for the top and middle canopy positions than at the bottom canopy position. Since canopy position was closely associated with light levels, it is not surprising to find correlations between spur traits and light levels. The association of SLW and light levels for both vegetative and fruiting spurs of spur-type 'Delicious' confirms results with vegetative spur leaves of 'Golden Delicious' (7) and with extension shoot leaves of several other cultivars (2–4, 6, 11, 15). Average leaf dry weight, total leaf dry weight per spur, and SLW decreased as light levels decreased, but leaf area and number per spur did not. For extension shoots of young 'York' trees, leaf number and leaf area were not associated with light levels (3).

Total leaf area per spur, along with most other spur traits, was lower for fruiting spurs than for vegetative spurs. Although vegetative spurs had fewer leaves per spur than fruiting spurs, the former had much larger leaves. Lakso (14), working with 'Empire', and Singh (24) with 'Miller's Seedling', also attributed the reduction in leaf area per spur for fruiting spurs to a reduction in individual leaf area. The reduction in total leaf dry weight per spur for fruiting spurs was due to a reduction in individual leaf dry weight, not to number of leaves per spur. The fact that vegetative spur leaves have higher SLW than leaves of fruiting spurs supports observations that leaves on deblossomed 'Golden Delicious' trees have higher SLW than those on fruiting trees (17). The reduction in SLW with fruiting spurs supports the concept of fruit as a strong physiological sink.

The influences of canopy position and reduced light levels on fruit size and quality have been well-documented (9, 12, 20, 23, 25), but little is known about the influence of individual spur traits on fruit size and quality. Removal of spur leaves reduced fruit

Table 4. Correlation coefficients (*r*) for the relationship between canopy light levels and spur or fruit characteristics of 'Oregon Spur Delicious'.

Spurs and fruit traits	Correlation coefficients (*r*) Vegetative spurs	 Fruiting spurs
	Spur characteristics	
Specific leaf weight	0.650***	0.733***
Leaf dry weight per spur	0.555***	0.542***
Average leaf dry weight	0.533***	0.600***
Leaf area per spur	0.334*	0.046
Leaf number per spur	0.319	0.254
Bud diameter	0.248	0.477**
Leaf area	0.168	−0.201
Spur length	0.102	0.328*
	Fruit characteristics	
Percent small fruit, ≤160 g	---	−0.568***
Soluble solids	---	0.522***
Percent large fruit, ≥204 g	---	0.510**
Nitrogen content	---	−0.506***
Agtron blue	---	0.488**
Starch	---	−0.485**
Agtron green	---	0.426**
Fruit weight	---	0.351*

*,**,***Significant at the 5%, 1%, and 0.1% levels, respectively.

Table 5. Correlation coefficients (*r*) of specific leaf weight, leaf dry weight per spur, and leaf area per spur with fruit characteristics for 'Oregon Spur Delicious' fruiting spurs.

	Correlation coefficients (*r*)		
Fruit characteristics	Specific leaf wt	Leaf dry wt per spur	Leaf area per spur
Nitrogen content	−0.688***	−0.540***	−0.144
Agtron blue	0.552***	0.431**	0.056
Percent small fruit, ≤160 g	−0.549***	−0.467**	−0.139
Soluble solids	0.548***	0.152	−0.362*
Percent large fruit, ≥204 g	0.509**	0.444**	0.177
Potassium content	−0.493**	−0.401*	−0.129
Magnesium content	−0.493**	−0.389*	−0.141
Mean fruit weight	0.442**	0.372*	0.114
Agtron green	0.436**	0.314	−0.019
Starch	−0.395*	−0.204	0.145
Calcium content	−0.377*	−0.328	−0.182
Iron content	−0.330*	−0.324	−0.186

*,**,***Significant at the 5%, 1%, and 0.1% levels, respectively.

size of 'Golden Delicious' (8, 13), and lower leaf area per spur resulted in less Ca in fruit (8, 13). With eight apple cultivars, leaf area/spur at bloom has been associated with fruit production (21). In this study with 'Delicious', leaf area per spur at harvest was not correlated with fruit traits except for soluble solids. Total leaf dry weight per spur was correlated with some fruit traits such as fruit N content and size. However, SLW showed the strongest correlations with fruit characteristics. These relationships are not surprising because SLW had the highest correlation with light levels of any spur trait and SLW has been associated with leaf photosynthetic rate as well as the previous and present light environment (5, 16).

Distinguishing between "strong" and "weak" spurs appears to be more complicated than measuring average leaf area and spur leaf number and area. None of these characteristics was associated with canopy light levels or with fruit traits. The spur characteristics of greatest value in predicting fruit characteristics were those that involved dry weight measurements (e.g., average leaf dry weight, total dry weight per spur, and SLW). Although correlations of SLW and fruit traits were statistically significant, coefficients of determination <50% indicated that other important factors in addition to spur leaf characteristics influence fruit characteristics. Fruit weight was influenced more by late-season shading of shoot leaves than by shading of spur leaves in close proximity to the fruit (22). Late-season summer pruning also has caused reductions in fruit size and soluble solids (18, 19). It appears that, in late season, shoot growth plays a major role in the development of fruit size and quality. However, for much of the growing season, spur leaves are the major source of photosynthate for fruit growth and development. Exposure of spur leaves to light is the primary factor influencing spur leaf characteristics, which, in turn, influence fruit characteristics.

Spur characteristics presented in this study are for a single variety trained to one management system determined at one location and at one time of year. Studies evaluating seasonal trends in spur characteristics and their relationship to end-of-season fruit characteristics as well as the relationship of flowering and fruit set to current season and previous season's spur leaf characteristics are needed.

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Some Factors Associated with Fruit Maturity Range in Cultivars of the Semi-erect, Tetraploid Thornless Blackberry

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Abstract. **Flowering occurred over a 5-week period in semi-erect, tetraploid thornless blackberries (*Rubus* spp.) (cvs. Black Satin, Hull Thornless, and Dirksen Thornless). The harvest durations were slightly longer. The terminal flower bud of the primary axis (A_1) of the inflorescence was first to open, followed by the terminal flower bud on one of basal secondary axes (A_2). Remaining terminal flower buds on A_2 axes opened sequentially in acropetal direction at a constant rate (two flowers/day). However, bloom pattern of flower buds located laterally on A_2 axes was less definite. Within a floricane, the bloom on the primary fruiting laterals began at the distal end and progressed basipetally to the cane base. Ripening sequence of berries in a cluster followed that of the bloom. The time difference in anthesis between fruiting laterals and among flower buds within inflorescences was a major factor affecting the range of fruit maturity.**

Semi-erect, tetraploid cultivars of thornless blackberries (*Rubus*, subgenus *Eubatus*), derived from 'Merton Thornless', are highly productive, and their fruit quality is acceptable for fresh market and processing (3). Berries are large and firm and have good flavor and keeping quality. Many large berries per inflorescence and numerous fruiting laterals per cane contribute to high yielding capacity (4). Another characteristic of these cultivars is a harvest period >5 weeks. In order to develop this crop for the processing industry, a concentrated range of fruit maturity and/or a selective mechanical harvesting system is needed to reduce the cost of labor-intensive harvest.

A modified training system in which primocanes and floricanes are separated so floricanes can be mechanically harvested without interference of primocanes has been recommended (15). In other *Rubus* crops, alternate-year harvesting reduces problems associated with annual straddle harvesting (6, 16). The wide range in fruit maturity encountered in the semi-erect thornless blackberry increases the numbers of passes required to remove the bulk of the crop. This problem has not been addressed. Preliminary work conducted at this station indicated that the separation pull force of thornless blackberries appears to decrease at a rate insufficient to allow adequate mechanical harvest differentiation between the stages of black-ripe and red berries (D.L. Peterson, unpublished data). Morris et al. (9) in Arkansas reported that (2-chloroethyl)phosphonic acid (ethephon) applied prior to harvest accelerated color development and abscission zone formation of thorny blackberries, so the bulk of the crop could be harvested in two pickings. Lipe (5), however, reported that growth regulators produced no beneficial effect in Texas. Thorny blackberries used in these studies yield less than do the semi-erect thornless types, and a complete harvest normally can be accomplished in four or five passes (5, 8–10).

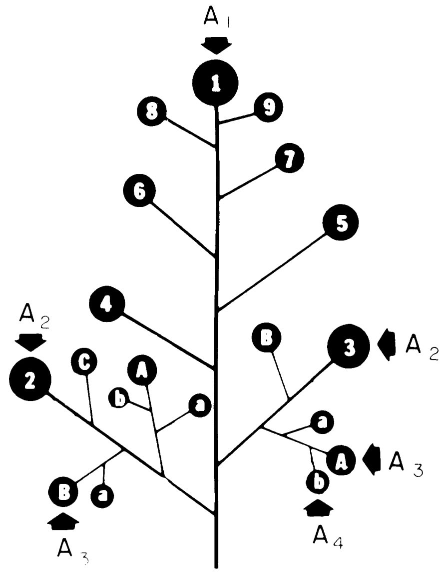

Fig. 1. Illustration of inflorescence structure and bloom pattern in semi-erect tetraploid thornless blackberry. Axes of inflorescence are denoted by A_1 (primary), A_2 (secondary), etc. Tertiary (A_3) and quaternary (A_4) axes were present on many A_2 axes. For clarity, A_3 and A_4 axes are shown only on the two basal A_2 axes. Numerals, uppercase letters, and lowercase letters denote the bloom order of terminal flowers of A_1 and A_2 axes, terminals of A_3 axes, and flowers positioned laterally on A_3 or terminally on A_4 axes, respectively.

The morphology of the raspberry fruiting cane and the relationship between various measurements of lateral vigor, productivity, and the position of the fruiting lateral on the floricane are well documented (2). In contrast, these relationships are not completely understood in the semi-erect thornless blackberry. The purpose of this study was to characterize growth of fruiting laterals, time of flowering, and fruit maturation to determine the growth components associated with fruit maturity range. This information would aid in developing strategies to enhance mechanical harvesting systems of semi-erect thornless blackberries.

'Dirksen Thornless' blackberry growing at the Western Maryland Research and Education Center, Sharpsburg, was used in 1983 and 1984. Fifteen fruiting laterals, each developing from primary axillary buds in the top, middle, and bottom one-third of 2-m-long upright floricanes, were tagged to determine the overall bloom pattern on floricanes as well as the specific pattern within

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