Cultivar and Canopy Position Effects on Seasonal Development of Vegetative Spurs of Apple

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Additional index words. *Malus domestics*, spur leaf area, spur leaf dry weight, spur quality, specific leaf weight

Abstract. Vegetative (nonflowering) spur characteristics of 'Granny Smith', 'Lawspur Rome', and 'Redchief Delicious' apples (*Malus domestics* Borkh.) at two canopy positions (1 and 2 m heights) were examined on eight dates throughout a growing season. 'Granny Smith' had a greater leaf number/spur (LNO/SP) at each date than 'Rome' and 'Delicious'. Area/leaf (LA) and dry weight/leaf (LDW) for 'Delicious' were substantially less than for 'Granny Smith' and 'Rome'. Area/leaf increased rapidly after full bloom (FB) until FB + 21 days for 'Delicious', FB + 35 for 'Granny Smith', and FB + 56 for 'Rome', after which no further changes occurred. For each cultivar, leaf area/spur (LAMP) and leaf dry weight/spur (LDW/SP) increased rapidly from FB until FB + 35 days and then more gradually until FB + 104 days. From FB + 21 onward, 'Granny Smith' had greater LA/SP and LDW/SP than 'Rome', which, in turn, was greater than for 'Delicious'. At harvest (FB + 160), LA/SP was 2.5-fold greater for 'Granny Smith' and 1.7-fold greater for 'Rome' than for 'Delicious'. Cultivar differences for leaf dry weight/leaf area (LDW/LA) were small and canopy position differences were large. LDW/LA declined from 7 days before FB to FB + 7, then gradually increased to the end of the season. Dry weight of the vegetative spur buds (with leaves removed) was lower for 'Delicious' than for 'Rome' or 'Granny Smith'. Total spur dry weight (bud + leaves) was, from FB + 21 onward, greatest for 'Granny Smith', intermediate for 'Rome', and lowest for 'Delicious'.

With apple, fruit develops on spurs and flowers are initiated in the previous growing season (Buban and Faust, 1982; Feucht, 1976). Flower bud formation is associated with factors favoring carbohydrate accumulation and, therefore, with maximum leaf area (Fulford, 1962; Monselise and Goldschmidt, 1982). The quality of the spur during the previous summer is usually determined from estimates of LNO/SP, LA/SP, LDW/LA (often referred to as specific leaf weight), or bud size (Rem and Ferree, 1984a). Shading, which reduces carbohydrate accumulation, also reduces "flowering the following season (Jackson and Palmer, 1977). Shading within tree canopies reduced vegetative spur char-

acteristics, such as LNO/SP, LDW/SP, LA/SP, and LDW/LA, when evaluated in the fall (Barritt et al., 1987). Spurs with reduced leaf number have smaller spur terminal buds and fewer flower buds the next spring (Oh et al., 1987).

There is little information available on the seasonal development of spur leaves or on factors, including cultivar, that may influence spur quality. Spur type (nonflowering vs. fruiting), canopy position, position within

a shoot, and light environment within the canopy influence spur leaf traits (Barritt et al., 1987; Lakso, 1984; Porphiglia and Barden, 1980; Walsh, 1979). Rom and Ferree (1984b) found that LA/SP varied with cultivar and was correlated with cultivar yield. Oh et al. (1987) observed differences between cultivars in LA, LNO/SP, and LA/SP. The purpose of this study was to determine, throughout a growing season, leaf and bud characteristics of vegetative spurs of the three apple cultivars Rome, Granny Smith, and Delicious when sampled at two canopy positions.

Spurs were collected from 'Granny Smith', 'Lawspur Rome', and 'Redchief Delicious' (Campbell strain) trees, each on MM.106 rootstock, that were 9 to 13 years old and located in a commercial orchard near Wenatchee, Wash. The trees carried an average crop load the year before spurs were collected. Thirty trees of each cultivar were used and were chosen in a completely random design. The trees, in north-south rows, were pruned and trained as free-standing, pyramid-shaped central leader trees (Heinicke, 1975). Tree height was between 2.5 and 3 m, and width at the base was between 3 and 3.5 m.

Vegetative spurs, those that did not flower, were collected on eight dates: 13 Apr., 20 Apr. (FB), 27 Apr. (FB + 7), 11 May (FB + 21), 25 May (FB + 35), 15 June (FB + 56), 2 Aug. (FB + 104), and 27 Sept. (FB + 160, harvest). On each spur, the following leaf characteristics were determined: LNO/SP, LA/SP, LDW/SP, LA, LDW, and LDW/LA. Leaf area measurements were made with a LI-COR (Lincoln, Neb.) area meter (LI-3000/LI-30500). In addition, spur bud dry weight was determined and added to LDW/SP to estimate total spur dry weight. Spurs were collected within a 50-cm-radius sphere centered at the trunk at 1 and 2 m heights in each tree. One spur was collected at each canopy position on 30 trees/cultivar

Table 1. The percentage of analysis of variance total sums of squares for vegetative spur characteristics attributable to cultivar, canopy position, and their interaction. (To conserve space, only data for three of eight sampling dates, FB + 7, FB + 35, and FB + 160, are presented.)

Source of variation	Percent of total sums of squares						Per spur	
	LA	LDW	LDW/LA	LNO/SP	LA/SP	LDW/SP	Bud	Total
							dry wt	dry wt
<i>FB + 7, 27 Apr.</i>								
Cultivar (C)	30.1***	24.5***	6.0***	25.5***	30.7***	26.9***	6.0***	26.3***
Position (P)	1.3	0.3	5.1***	<0.1	0.8	0.2	<0.1	0.2
C × P	1.2	0.9	0.5	1.0	1.2	0.9	1.9	1.0
<i>FB + 35, 25 May</i>								
Cultivar (C)	35.5***	31.8**	3.8**	19.3***	38.1***	33.4***	13.9***	29.8***
Position (P)	1.0	0.3	22.6***	2.5*	<0.1	0.8	1.8*	1.1
C × P	0.6	0.5	1.7	2.2	1.1	0.6	0.4	0.6
<i>FB + 160, 27 Sept.</i>								
Cultivar (C)	40.3***	31.1***	6.1**	18.3***	34.0***	22.4***	12.3***	19.1***
Position (P)	0.9	1.7*	25.4***	4.8***	0.6	3.9***	6.2***	5.4***
C × P	<0.1	0.2	1.9*	<0.1	<0.1	0.1	1.3	0.4

***, **, *F test significant at $P = 0.001$, 0.01 , or 0.05 , respectively.

Received for publication 1 Aug. 1989. Horticulture/Landscape Architecture Paper no. 89-20. College of Agriculture and Home Economics Research Center, Washington State Univ., Pullman, WA 99164. The support of the Washington Tree Fruit Research Commission is gratefully acknowledged, as is the cooperation of Cascade Foothills Orchard. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement solely to indicate this fact.

Abbreviations: FB, full bloom; LA, area/leaf; LA/SP, leaf area/spur; LDW, dry weight/leaf; LDW/LA, leaf dry weight/leaf area; LDW/SP, leaf dry weight/spur; LNO/SP, leaf number/spur.

Fig. 1. Effect of cultivar on the vegetative spur traits leaf number/spur (A), area/leaf (B), dry weight/leaf (C) throughout a season. Mean separation within dates by LSD, 5% level. Data points are means of 60 observations. FB was 20 Apr.

on the eight sampling dates. The data were analyzed within dates as a split plot, with cultivar as the whole plot and canopy position as the split plot.

Leaf number/spur. With each cultivar, LNO/SP (mean of two canopy positions) increased from before FB to FB, did not increase from FB to FB + 7, and then continued to increase to FB + 56 (Fig. 1A). End-of-season leaf numbers were similar to those at FB + 56. 'Granny Smith' had greater LNO/SP than both 'Rome' and 'Delicious' throughout the season. 'Rome' and 'Delicious' had similar LNO/SP.

Canopy position significantly affected LNO/SP for the last four sampling dates (Table 1, data for only three dates are presented). On these dates, spurs at the 2-m position had greater LNO/SP than at the 1-m position (data not presented). Similar canopy position effects were observed with vegetative spurs of 'Oregon Spur Delicious' (Barritt et al., 1987). There were no cultivar $\times$ canopy position interactions.

'Redchief Delicious', 'Rome', and 'Granny Smith' at harvest averaged 12, 13, and 18 leaves per vegetative spur, respectively, which compares with 10 leaves/spur for 'Oregon

Spur Delicious' (Barritt et al., 1987), with five to eight leaves/spur for several cultivars over several years in Ohio (Ferree and Schmid, 1987), with seven to nine leaves/spur for 'Starkrimson' over 3 years (Ferree and Forshey, 1988), and with five to eight leaves/spur for six cultivars in Korea (Oh et al., 1987).

Area/leaf and dry weight/leaf. With 'Delicious', LA increased rapidly until FB + 21 and changed little thereafter (Fig. 1B). Increases in LA occurred up to FB + 25 and FB + 56 for 'Granny Smith' and 'Rome', respectively. From FB + 25 onward, LA was greatest for 'Granny Smith' and least for 'Delicious', with 'Rome' generally similar to 'Granny Smith'. At harvest, LA for 'Granny Smith' and 'Rome' was $\approx 30 \text{ cm}^2$ and for 'Delicious' $\approx 18 \text{ cm}^2$. These values compare with 16.5 cm^2 for 'Oregon Spur Delicious' (Barritt et al., 1987) and with 11 to 16 cm^2 for four cultivars in Ohio (calculated from the data of Ferree and Schmid, 1987).

Canopy position did not influence LA in the present study (Table 1) or with 'Oregon Spur Delicious' (Barritt et al., 1987).

Similar cultivar and seasonal trends to those found for LA were observed for LDW, although LDW continued to increase later in the season (Fig. 1C). Canopy position did influence LDW at harvest (Table 1), confirming earlier studies with 'Oregon Spur Delicious' (Barritt et al., 1987), where spurs located higher in the canopy had greater LDW.

Leaf area/spur and leaf dry weight/spur. For each cultivar, LA/SP increased from before FB to FB + 104 and showed a slight decline at FB + 160 (Fig. 2A). The end-of-season decline was due to leaf abscission (Fig. 1A). Leaf area/spur was greatest for 'Granny Smith' and least for 'Delicious', with 'Rome' intermediate and significantly different from both 'Granny Smith' and 'Delicious'. At harvest, LA/SP was 232 cm^2 for 'Delicious', 1.7-fold greater for 'Rome' and 2.5-fold greater for 'Granny Smith', and these LA/SP values were higher than those in earlier reports (Barritt et al., 1987; Ferree and Schmid, 1987; Ferree and Forshey, 1988; Lakso, 1984; Oh et al., 1987). Variation between studies may be due to different cultivars, rootstock, and growing environments. Relatively small year-to-year differences were found in Ohio studies (Ferree and Forshey, 1988; Ferree and Schmid, 1987). Oh et al. (1987) found that LA/SP varied among cultivars by a factor of three, with triploid cultivars Mutsu and Jonagold having the greatest LA/SP and 'Starkrimson' and 'Fuji' less LA/SP. Rom and Ferree (1984b), with fruiting spurs, observed large differences in LA/SP at the pink-bloom stage, with 'Mutsu', 'Idared', and 'Melrose' having the greatest and 'Starkrimson', 'Jonathan', and 'Holiday' the least LA/SP. Directly comparing vegetative with fruiting spur characteristics is not possible, as vegetative spurs have greater LA and LA/SP than fruiting spurs (Barritt et al., 1987; Lakso, 1984).

For LA/SP, the proportion of total sums

Fig. 2. Effect of cultivar on the vegetative spur traits leaf area/spur (A) and leaf dry weight/spur (B) throughout a season. Mean separation within dates by SD, 5% level. Data points are means of 60 observations. For each cultivar, leaf dry weight/leaf area (C) is presented for the 1- and 2-m canopy positions. For each cultivar at each date from FB + 21 to FB + 160 days, canopy position differences were significant, $P = 0.05$. Data points for leaf dry weight/leaf area are means of 30 observations. FB was 20 Apr.

of squares (due to replication, cultivar, canopy position, cultivar $\times$ canopy interaction, and error) attributable to cultivar varied from 30% to 40% (Table 1). The cultivar effect was significant ($P = 0.001$) at each sample date, but canopy position effect was not significant. There was no interaction of cultivar and canopy position. Although differences due to canopy position were small in the present study, when larger trees were studied, LA/SP was greater at the top than at the

bottom canopy position (Barritt et al., 1987; Ferree and Forshey, 1988).

Seasonal trends and cultivar effects for LDW/SP (Fig. 2B) were similar to those observed for LA/SP. However, unlike LA/SP, canopy position effects were significant ($P = 0.001$) for LDW/SP on 27 Sept. (Table 1). There was no interaction of cultivar and canopy position. With 'Oregon Spur Delicious', large canopy position effects were observed, and LDW/SP was positively cor-

related with light levels within the canopy (Barritt et al., 1987).

Leaf dry weight/leaf area. With each cultivar, a reduction in LDW/LA from 7 days before FB to FB + 7 was followed by a gradual increase until harvest (Fig. 2C). This early decline resulted from a rapid increase in LA as the leaves unfolded, with only a modest increase in LDW. After FB + 7 days, LDW increased more than LA, resulting in a gradual increase in LDW/LA to the end of the season. This postbloom increase has been reported with both spur and shoot leaves (Porpiglia and Barden, 1980; Brown et al., 1985; Marini and Barden, 1981, 1982; Wooge and Barden, 1987).

On four of eight sampling dates, there was a significant cultivar effect for LDW/LA, which accounted for < 10% of total sums of squares (Table 1; data for only three dates are presented). A higher proportion of LDW/LA total sums of squares was attributed to canopy position than to cultivar, with canopy position accounting for > 22% of the variability on each of the last four sampling dates (Table 1). At the last five sampling dates, leaves at the 2-m position had higher LDW/LA than leaves at the 1-m position (Fig. 2C). This study confirms that spur leaves from inside canopy positions and/or in areas of reduced light have lower LDW/LA than leaves well-exposed to sunlight (Barritt et al., 1987; Ferree and Forshey, 1988; Porpiglia and Barden, 1980; Rom and Ferree, 1984a).

Bud and total dry weight. Of the two components of total spur dry weight, bud dry weight was substantially less than leaf dry weight (Figs. 2B and 3A). Bud weight for 'Granny Smith' and 'Rome' was similar for the last four sampling dates, and both cultivars had higher bud weight than 'Delicious' at each date. Buds reached their maximum dry weight at FB + 104 (Fig. 3B). Vegetative spur total dry weight showed a steady increase from FB to FB + 104. From FB + 21 onward, 'Granny Smith' had the highest total spur weight, 'Delicious' the least, and 'Rome' intermediate and significantly different from the other two.

Earlier studies (Barritt et al., 1987) have shown that canopy position has a major effect on spur traits. In this study, with the exception of LDW/LA, canopy position had less impact on spur traits than did cultivar. Canopy position did have a marked impact on LDW/LA, and LDW/LA has been shown by various researchers to increase with increased light levels (Barritt et al., 1987; Porpiglia and Barden, 1980; Rom and Ferree, 1984a).

In the present study, canopy position had little effect on leaf area traits, but did influence leaf dry-weight traits. With 'Oregon Spur Delicious' at harvest, canopy position had a greater effect on LDW and LDW/SP than on LA and LA/SP (Barritt et al., 1987). In the same study with fruiting spurs, LDW/SP showed higher correlations with fruit characteristics than did LA/SP. Bud diameter, LA/SP, and LDW/LA of vegetative spurs at various canopy positions were correlated with

Fig. 3. Effect of cultivar on the vegetative spur traits bud dry weight/spur (A) and total dry weight/spur (B) throughout a growing season. Mean separation within dates by LSD, 5% level. Data points are means of 60 observations. FB was 20 Apr.

fruit diameter (Ferree and Forshey, 1988).

A relatively small proportion of total variability in spur characteristics, usually <40%, was attributable to cultivar and canopy position. Because the trees in this study were relatively small, canopy position effects were not as large as would be expected with larger trees. There are other important factors that influence spur leaf development and, thus, the potential for a vegetative spur to develop a strong flower cluster and set fruit the following spring. Among the other factors that influence spur potential and that need further study are current and previous cropping histories of the spur and of the whole tree, spur age, shoot growth, and whole-tree vigor, pruning practices, and limb positioning. With

a better understanding of factors that influence spur development, better control of fruiting and improved fruit quality will be achieved.

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