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Rootstock Affects Ripening, Color, and Shape of 'Starkspur Supreme Delicious' Apples in the 1984 NC-140 Cooperative Planting[1]

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Abstract

In 1984, 'Starkspur Supreme Delicious' apple trees on B.9, MAC.1, MAC.39, P.1, P.22, domestic seedling, M.4, M.7 EMLA, M.26 EMLA, B.490, P.2, P.16, P.18, C6, and A.313 were planted in Belchertown, MA, West Lafayette, IN, Parlier, CA, and Princeton, KY. In Massachusetts, rootstock and year interacted to affect fruit ripening, as measured by internal C_2H_4 concentration, soluble solids concentration, the development of watercore, and starch disappearance. In general, however, ripening was correlated with tree vigor, with the most dwarfing rootstocks resulting in the earliest ripening. The most consistently early ripening fruit were from trees on B.9 and P.16, and the most consistently late ripening fruit from trees on M.4, P.18, and domestic seedling. Soluble solids concentrations from Indiana and California fruit supported this relationship between ripening and vigor; however, no consistent effect of rootstock on soluble solids concentration was measured in Kentucky. Flesh firmness was negatively related to tree vigor in California, positively related to vigor in Indiana, and not related to vigor in Kentucky and Massachusetts. The development of red color was negatively related to vigor in California and not related to vigor in Indiana. The length-to-diameter ratio of fruit was positively related to vigor in Indiana.

To evaluate the full commercial potential of an apple rootstock it is critical to evaluate its effects on fruit characteristics. Autio et al. (2), Autio (1), Barden and Marini (3), and Brown and Wolfe (6) presented results from the 1980/81 NC-140 Cooperative Planting in Massachusetts, Virginia, and Kentucky. They found that rootstocks affected ripening, size, and storability of 'Starkspur Supreme Delicious' apples. The effects of most of the rootstocks studied, however, were not consistent from site to site and year to year. The study reported here expands on that work with a wider range of rootstocks utilizing the 1984 NC-140 Cooperative Planting. The primary objectives of this study were to study over time the effects of rootstock on fruit characteristics, and isolate those effects which were consistent.

Materials and Methods

In 1984, 'Starkspur Supreme Delicious' apple trees on B.9, MAC.1, MAC.39, P.1, P.22, domestic seedling, M.4, M.7 EMLA, M.26 EMLA, B.490, P.2, P.16, P.18, C6, and A.313 were planted in randomized complete blocks in Belchertown, MA, West Lafayette, IN, Parlier, CA, and Princeton, KY. Ten replications were included at each site. Details of these plantings are described elsewhere (8).

In Massachusetts, four fruit from the perimeter of each tree were harvested each week throughout the harvest seasons from 1989 through 1993.

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The internal C_2H_4 concentration of each fruit was assessed via gas chromatography (1) immediately after harvest. All C_2H_4, data (in ppm) were transformed to their corresponding log values, and averages per tree per harvest were used to determine for each tree the date on which the average of the log of the concentrations reached zero. This date is an adjusted estimate of the date on which the internal C_2H_4, concentration reached one ppm, i.e. a date soon after the initiation of the C_2H_4 climacteric. Single harvests of 10 fruit per tree were made each season from 1990 through 1993 (3 Oct. 1990, 3 Oct. 1991, 5 and 6 Oct. 1992, and 11 and 12 Oct. 1993). Flesh firmness was measured with an Effegi penetrometer (Effegi, Alfonsine, Italy) using an 11.1-mm head and two opposing punctures per fruit. The concentration of soluble solids in juice collected during the firmness evaluation (as a bulk sample of the 10 fruit from an individual tree) was measured with a hand refractometer. The severity of watercore was assessed by visual rating (5). Starch disappearance was measured using iodine staining and visual rating (9). Statistical analyses included the assessment of the effects of rootstock and year, as well as the effects of the interaction of year and rootstock. The potentially confounding effects of crop load and crop load within year were removed by analysis of covariance where significant. The confounding effects of fruit weight on flesh firmness also were removed by analysis of covariance.

In Indiana, single 10-fruit samples were harvested from each tree in 1987 and 1990 through 1993 (18 Sept. 1987, 26 Sept. 1990, 13 Sept. 1991, 23 Sept. 1992, and 10 Oct. 1993). Flesh firmness and soluble solids were measured as described above. Additionally, the length and diameter of fruit were determined to give a length-to-diameter ratio, and the percent red color was evaluated visually for each fruit. Statistical analyses were as described above.

In California, bulked samples of 20 fruit from each rootstock (two fruit per tree) were used for fruit assessments in each year from 1987 through 1993 (6 Aug. 1987, 10 Aug. 1988, 2 Aug. 1989, 17 Aug. 1990, 14 Aug. 1991, 5 Aug. 1992, and 10 Aug. 1993). Firmness was measured with a U.C. firmness tester (Western Industrial Supply, San Francisco, CA) using an 11.1-mm head and one puncture per fruit. Juice was extracted from a bulk sample consisting of a wedge from each of the 20 fruit with an ACME Juicerator (ACME Juicer Mfg., Lemoyne, PA), and soluble solids concentration of the juice was assessed with a hand refrac-

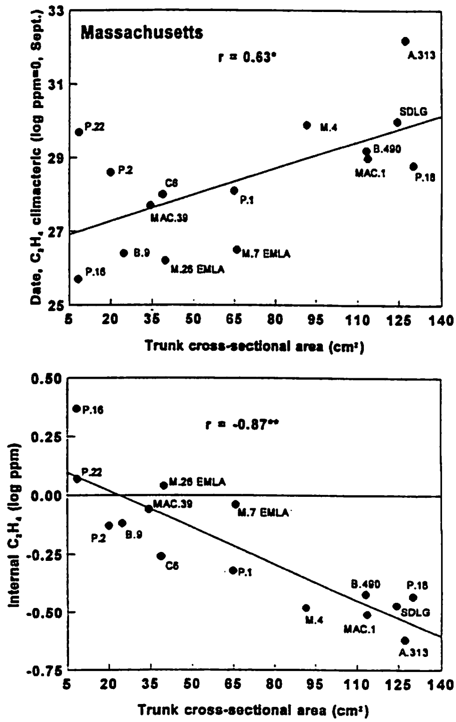

Figure 1. The relationship between trunk cross-sectional area at the end of the 1993 growing season and the average date of the initiation of the C_2H_4 climacteric (date when log C_2H_4 = 0) and the average internal C_2H_4 concentration of 'Starkspur Supreme Delicious' fruit from the 1984 NC-140 Cooperative Planting in Massachusetts. *,**Significant at P = 0.05 or 0.01, respectively.

tometer. Red color was rated visually using a scale from one to four (1 = 0-25% red color, 2 = 26-50% red color, 3 = 51-75% red color, and 4 = 76-100% red color). Because samples were bulked by rootstock, only the main effects of rootstock and year were assessed statistically.

In Kentucky, three-fruit samples were harvested from each tree from 1989 through 1991 (18 Sept. 1989, 14 Sept. 1990, and 4-5 Sept. 1991), and 10-fruit samples were harvested from each tree in 1992 and 1993 (24-28 Sept. 1992 and 22 Sept. 1993). Flesh firmness and soluble solids were measured as in Massachusetts and Indiana. Statistical analyses included the assessment of the effects of rootstock overall and within each year.

Results

In Massachusetts, crop load was a significant covariate for the date of the initiation of the C_2H_4, climacteric. Crop load and crop load within year were significant covariates for all other fruit measurement. Fruit weight additionally was a significant covariate for flesh firmness. In each of these cases, least-squares (or adjusted) means are presented. In all cases, the interaction of rootstock and year was significant. Table 1, however, presents only overall effects, but rootstocks effects which were consistent from year to year are detailed below.

In Indiana, crop load was a significant covariate for soluble solids concentration, and crop load and crop load within year were significant co-

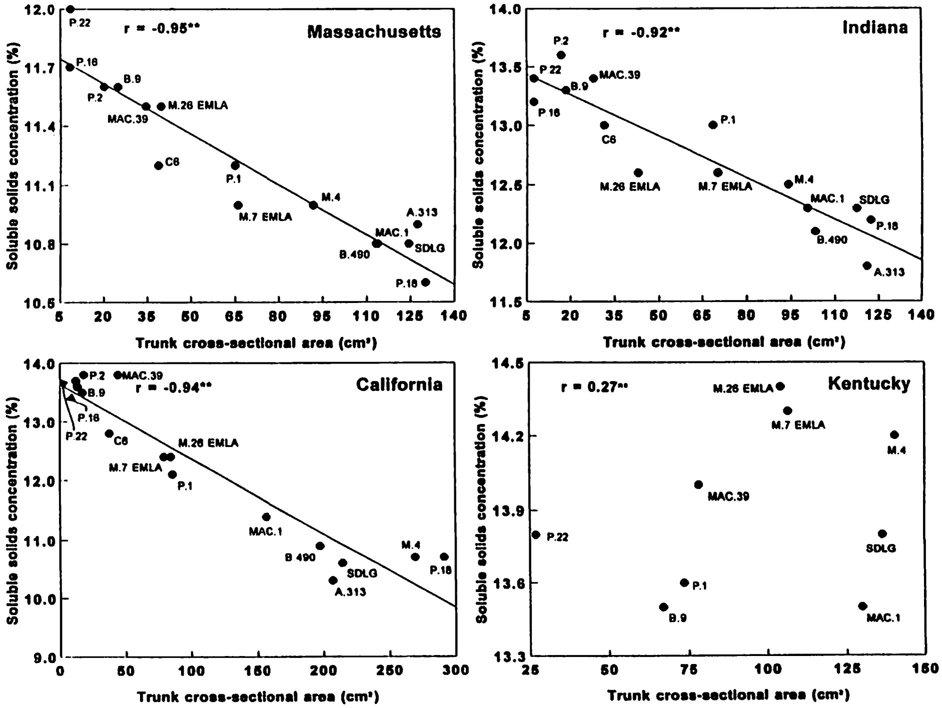

Figure 2. The relationship between trunk cross-sectional area at the end of the 1993 growing season and the soluble solids concentration of 'Starkspur Supreme Delicious' fruit from the 1984 NC-140 Cooperative Planting in Massachusetts, Indiana, California, and Kentucky. ns, **Nonsignificant or significant at P = 0.01, respectively.**

Table 1. Characteristics of 'Starkspur Supreme Delicious' fruit from trees in the Massachusetts planting of the 1984 NC-140 Cooperative Planting. Trunk cross-sectional area was measured at the end of the 1993 growing season. Crop load means represent average values from the years of assessment. Means of all fruit characteristics are least-squares means, adjusted for missing data and appropriate covariates.[z]

Rootstock	Trunk cross-sectional area (cm^2)	Crop load (fruit/cm^2)	Date C_2H_4 climacteric (log ppm = 0, Sept.)	Internal C_2H_4 (log ppm)	Flesh firmness (N)	Soluble solids (%)	Water core index[y]	Starch index[x]
P.16	8.3	6.8	25.7 f	0.37 a	78.2 bc	11.7 ab	2.4 a	4.1 ab
P.22	8.5	5.2	29.7 b	0.07 ab	77.2 c	12.0 a	1.8 cde	4.4 a
P.2	20.0	5.9	28.6 bc	-0.13 bc	78.9 abc	11.6 b	1.9 bcd	3.9 bc
B.9	24.8	5.8	26.4 def	-0.12 bc	78.0 c	11.6 b	2.0 bc	3.8 bcd
MAC.39	34.4	4.5	27.7 cdef	-0.06 bc	78.0 c	11.5 b	2.1 b	3.6 cde
C.6	38.7	6.0	28.0 bcde	-0.26 bcd	79.8 ab	11.2 c	1.6 edg	3.5 def
M.26 EMLA	39.6	5.0	26.2 ef	0.04 b	77.3 c	11.5 b	1.8 cde	3.7 cde
P.1	64.9	4.7	28.1 bcd	-0.32 cde	77.9 c	11.2 c	1.7 def	3.5 def
M.7 EMLA	65.9	5.3	26.5 def	-0.04 b	78.0 c	11.0 cd	1.7 def	3.4 ef
M.4	91.6	5.2	29.9 b	-0.48 de	80.2 a	11.0 cd	1.4 g	3.0 g
B.490	113.1	3.2	29.2 bc	-0.42 de	78.2 bc	10.8 def	1.6 efg	3.4 ef
MAC.1	113.6	3.2	29.0 bc	-0.51 de	77.3 c	10.8 f	1.7 def	3.3 efg
Seedling	124.3	2.7	30.0 b	-0.47 de	79.0 abc	10.8 def	1.4 g	3.2 fg
A.313	127.3	3.6	32.2 a	-0.62 e	77.7 c	10.9 cde	1.7 defg	3.3 efg
P.18	130.1	3.4	28.8 bc	-0.43 de	77.4 c	10.6 ef	1.5 fg	3.2 fg

[z]Mean separation by Duncan's New Multiple Range Test (P = 0.05).
[y]Watercore index: 1 = no watercore, 5 = severe watercore.
[x]Starch index: 1 = least mature, 9 = most mature.

variates for red color and length-to-diameter ratio. Fruit weight was the only significant covariate for flesh firmness. As with Massachusetts data, least-squares means are presented (Table 2). In all cases the interaction of rootstock and year was significant. Rootstocks effects which were consistent from year to year are detailed below.

In California, crop load was a significant covariate for flesh firmness and soluble solids concentration. For these parameters, least-squares means are presented (Table 3).

In Kentucky, the interaction of year and rootstock significantly affected soluble solids concentration and flesh firmness. Overall rootstock means are presented in Table 4.

Fruit Ripening

In Massachusetts, internal C_2H_4 from a single harvest each year and the date of the initiation of the C_2H_4, climacteric were correlated negatively with trunk cross-sectional area (Figure 1, Table 1). B.9, MAC.39, M.7 EMLA, M.26 EMLA, P.2, and P.16 consistently resulted in higher than average internal ethylene levels, while MAC.1, P.1, Seedling, M.4, B.490, P.18, and A.313 consistently resulted in lower than average levels. The ethylene climacteric was consistently earlier than average in fruit from trees on B.9, MAC.39, M.7 EMLA, M.26 EMLA, or P.16 and consistently later than average in fruit from trees on seedling, M.4, B.490, or A.313.

Soluble solids concentration, watercore, and starch disappearance all were

Table 2. Characteristics of 'Starkspur Supreme Delicious' fruit from trees in the Indiana planting of the 1984 NC-140 Cooperative Planting. Trunk cross-sectional area was measured at the end of the 1993 growing season. Crop load means represent average values from the years of assessment. Means of all fruit characteristics are least-squares means, adjusted for missing data and appropriate covariates.[z]

Rootstock	Trunk cross-sectional area (cm^2)	Crop load (fruit/cm^2)	Flesh Firmness (N)	Soluble solids (%)	Red color (%)	Length-to-diameter ratio
P.16	7.4	3.1	68.2 abc	13.2 ab	74 a	0.91 d
P.22	7.5	3.1	66.0 c	13.4 a	76 a	0.91 d
P.2	16.9	3.7	65.6 c	13.6 a	74 a	0.91 d
B.9	18.4	4.8	67.2 bc	13.3 a	72 a	0.93 bc
MAC.39	27.9	4.7	67.9 abc	13.4 a	72 a	0.93 bc
C.6	31.4	4.3	66.1 c	13.0 ab	73 a	0.92 cd
M.26 EMLA	42.9	4.0	67.9 abc	12.6 bc	78 a	0.94 ab
P.1	68.5	4.5	68.4 ab	13.0 ab	75 a	0.94 ab
M.7 EMLA	70.1	4.2	69.5 a	12.6 bc	74 a	0.94 ab
M.4	94.1	4.3	69.4 a	12.5 bc	72 a	0.94 ab
MAC.1	100.6	2.9	69.8 a	12.3 cd	73 a	0.94 ab
B.490	103.2	2.4	68.8 ab	12.1 cd	74 a	0.93 bc
Seedling	117.4	2.5	69.0 ab	12.3 cd	74 a	0.94 ab
A.313	120.9	2.6	69.1 ab	11.8 d	72 a	0.94 ab
P.18	122.2	2.5	69.1 ab	12.2 cd	72 a	0.95 a

[z]Mean separation by Duncan's New Multiple Range Test (P = 0.05).

Table 3. Characteristics of 'Starkspur Supreme Delicious' fruit from trees in the California planting of the 1984 NC-140 Cooperative Planting. Trunk cross-sectional area was measured at the end of the 1993 growing season. Crop load means represent average values from the years of assessment. Means of all fruit characteristics are least-squares means, adjusted for missing data and appropriate covariates.[z]

Rootstock	Trunk cross-sectional area (cm^2)	Crop load (fruit/cm^2)	Flesh firmness (N)	Soluble solids (%)	Red color index[y]
P.22	12.0	4.9	73.7 ab	13.7 a	2.5 ab
P.16	13.2	5.5	75.5 a	13.6 a	2.4 abc
B.9	17.0	5.2	73.7 ab	13.5 a	2.6 a
P.2	18.1	5.2	73.6 ab	13.8 a	2.5 ab
C.6	37.8	4.6	72.8 abc	12.8 b	2.4 abc
MAC.39	44.3	5.5	75.4 a	13.8 a	2.5 ab
M.7 EMLA	79.5	5.2	73.5 ab	12.4 bc	2.4 abc
M.26 EMLA	84.6	4.2	71.3 bc	12.4 bc	2.3 abcd
P.1	86.1	4.1	72.5 abc	12.1 c	2.2 bcd
MAC.1	156.9	3.1	69.9 cd	11.4 d	2.3 abcd
B.490	197.4	2.6	68.4 de	10.9 de	2.2 bcd
A.313	207.0	2.9	68.5 de	10.3 e	2.1 cd
Seedling	214.4	2.7	67.4 de	10.6 e	2.1 cd
M.4	269.5	2.9	67.3 de	10.7 e	2.1 cd
P.18	291.3	2.6	66.5 e	10.7 e	2.0 d

[z]Mean separation by Duncan's New Multiple Range Test (P = 0.05).
[y]Red color index: 1 = 0-25%, 2 = 26-59%, 3 = 51-75%, and 4 = 76-100%.

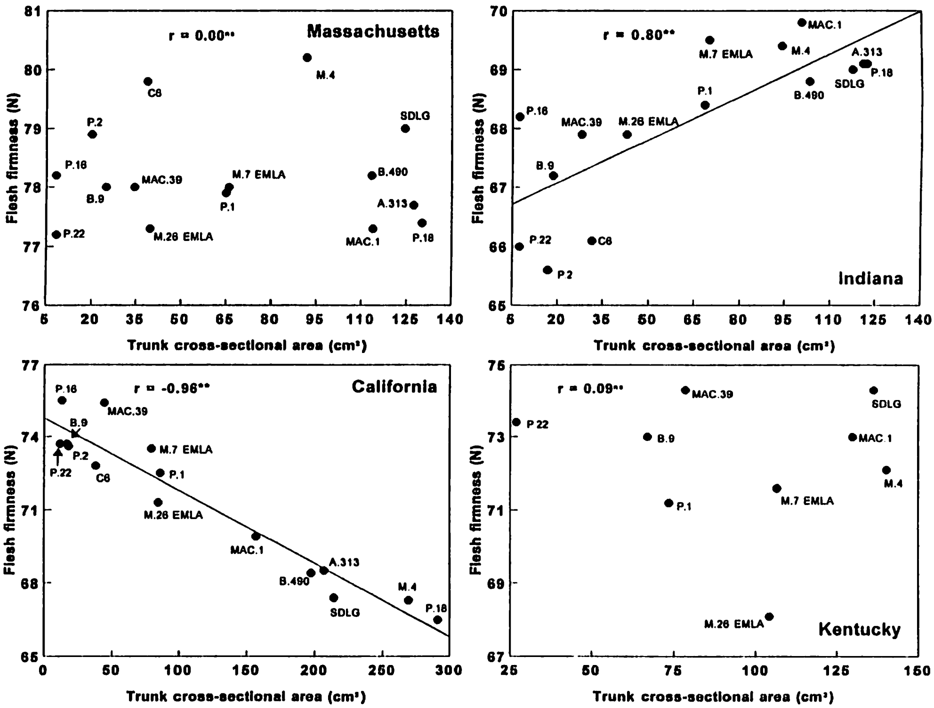

Figure 3. The relationship between trunk cross-sectional area at the end of the 1993 growing season and the firmness of 'Starkspur Supreme Delicious' fruit from the 1984 NC-140 Cooperative Planting in Massachusetts, Indiana, California, and Kentucky. ns,Nonsignificant or significant at P = 0.01, respectively.**

negatively correlated with trunk cross-sectional area in Massachusetts (Figure 2, Table 1). Effects of rootstock varied from year to year, but some rootstocks were consistent in their effects. Specifically, B.9, MAC.39, P.22, P.2, and P.16 consistently resulted in higher than average soluble solids concentration and watercore severity; whereas, seedling, M.4, M.7 EMLA, B.490, and P.18 consistently resulted in lower than average soluble solids concentration. Seedling, M.4, B.490, and P.18 consistently resulted in lower than average watercore severity. B.9, P.22, P.2, and P.16 consistently resulted in the less than average starch levels at the time of sampling, and MAC.1, seedling, M.4, P.18, and A.313 consistently resulted in greater than average starch levels. In Indiana and California, the correlations between soluble solids and

Table 4. Characteristics of 'Starkspur Supreme Delicious' fruit from trees in the Kentucky planting of the 1984 NC-140 Cooperative Planting. Trunk cross-sectional area was measured at the end of the 1993 growing season.[z]

Rootstock	Trunk cross-sectional area (cm^2)	Crop load (fruit/cm^2)	Flesh firmness (N)	Soluble solids (%)
P.22	26.9	4.4	73.4 a	13.8 a
B.9	66.9	3.9	73.0 a	13.5 a
P.1	73.5	3.9	71.2 a	13.6 a
MAC.39	78.5	3.2	74.3 a	14.0 a
M.26 EMLA	104.3	2.3	68.1 a	14.4 a
M.7 EMLA	106.6	2.2	71.6 a	14.3 a
MAC.1	129.9	2.0	73.0 a	13.5 a
Seedling	136.4	1.6	74.3 a	13.8 a
M.4	140.4	2.1	72.1 a	14.2 a

[z]Mean separation by Duncan's New Multiple Range Test (P = 0.05).

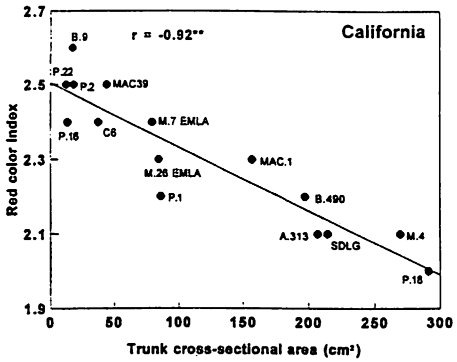

Figure 4. The relationship between trunk cross-sectional area at the end of the 1993 growing season and red color of 'Starkspur Supreme Delicious' fruit from the 1984 NC-140 Cooperative Planting in California (1 = 0-25% red color, 2 = 26-50% red color, 3 = 51-75% red color, 4 = 76-100% red color). **Significant at P = 0.01.

trunk cross-sectional area were similar to that observed in Massachusetts (Tables 2 and 3, Figure 2). In Kentucky, however, very little effect of rootstock on soluble solids concentration was observed (Table 4). Significant differences existed in only two out of five years and there was no correlation with trunk cross-sectional area (Figure 2).

The effects of rootstock on flesh firmness varied dramatically from site to site. In Massachusetts, MAC.39, M.4, and B.490 consistently resulted in firmer than average fruit, and P.22, M.7 EMLA, M.26 EMLA, and P.16 consistently resulted in softer than average fruit (Table 1). There was no correlation between firmness and trunk cross-sectional area (Figure 3). In Kentucky, rootstock affected firmness in only one out of five years (data not shown). B.9, MAC.1, MAC.39, seedling, and M.26 EMLA resulted in the firmest fruit and P.22 and M.7 EMLA resulted in the softest fruit in that year. There was no correlation between firmness and trunk cross-sectional area in Kentucky (Table 4, Figure 3). In Indiana, MAC.1 and M.7 EMLA consistently resulted in firmer than average fruit; whereas, P.22 and P.2 consistently resulted in softer than average fruit (Table 2). There was a strong positive correlation between firmness and trunk cross-sectional area in Indiana (Figure 3). In California, B.9, MAC.39, P.1, P.22, M.7 EMLA, P.2, P.16, and C.6 resulted in the firmest fruit, and seedling, M.4, B.490, P.18, and A.313 resulted in the softest fruit (Table 3). There was a strong negative correlation between firmness and trunk cross-sectional area in California (Figure 3).

Other Fruit Characteristics

The development of red color was assessed in Indiana and in California. In Indiana, rootstock did not affect red color development consistently (Table 2); however, in California there was a strong negative correlation between red color development and trunk cross-sectional area (Table 3, Figure 4).

Length-to-diameter ratio was assessed in Indiana (Table 2). The ratio was positively correlated with trunk cross-sectional area (Figure 5). MAC.39, P.1, seedling, M.7 EMLA, B.490, P.18, and A.313 most consistently resulted in greater than average length-to-diameter ratios, and P.22, P.2, and P.16 consistently resulted in smaller than average ratios.

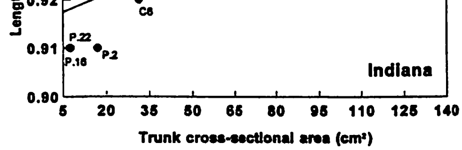

Figure 5. The relationship between trunk cross-sectional area at the end of the 1993 growing season and the length-to diameter ration of 'Starkspur Supreme Delicious' fruit from the 1984 NC-140 Cooperative Planting in Indiana. **Significant at P = 0.01.

Discussion

The specific effects of rootstock on fruit ripening varied from site to site and from year to year, similar to what was reported by Autio et al. (2). Some generalizations can be made, however, from these data. Specifically, under conditions where rootstock affects ripening, there is a relationship between timing and tree vigor. In general, the more dwarfing the rootstock, the earlier the ripening. This generalization is supported by the positive correlation between trunk cross-sectional area and the date of the C_2H_4 climacteric in Massachusetts and the negative correlations between trunk cross-sectional area and the internal C_2H_4 concentration and watercore and starch indices in Massachusetts and the soluble solids concentration in Massachusetts, Indiana, and California.

Although not always discussed specifically, data that supports the relationship between vigor and the timing of ripening have been reported previously. Wallace (10) found that fruit from trees on M.9 ripened earlier than those from more vigorous trees. Lord et al. (7) found that fruit from trees on M.27 ripened earlier than those from trees on M.26, and fruit from trees on M.9 ripened intermediately. In the 1980/81 NC-140 Cooperative Planting, Autio (1) showed that M.27 EMLA, the most dwarfing rootstock in the trial, advanced ripening and M.7 EMLA, the most vigorous rootstock in the trial, delayed ripening. Likewise, the data of Barden and Marini (3) and those of Brown and Wolfe (6) showed a correlation between the timing of ripening and tree vigor.

The reasons for the variation in rootstock effects from year to year and the reasons for the relationship of vigor and ripening are not clear. Both may be related to stress induced changes in the tree. The dwarf trees may be more sensitive to stresses such as a deficiency in water and may respond by initiating ripening sooner (2).

The effects of rootstock on flesh firmness cannot be explained by effects on ripening alone. The inconsistencies among sites with respects to effects on flesh firmness likely relate to a number of factors, such as generally high variability in flesh firmness, effects of rootstock on fruit ripening, effects of rootstock on fruit calcium concentration, effects of shoot vigor on fruit calcium, and effects of fruit size on fruit calcium concentration and directly on firmness. Of these factors, ripening and fruit size may have interacted to provide a seemingly inconsistent picture. Although, analyses of covariance were used to remove the effects of fruit size on flesh firmness, its effects would be removed adequately only if a large enough range of values exists for each rootstock. Apparent effects of size may have existed after this statistical procedure. In Massachusetts, a negative correlation between trunk cross-sectional area and fruit size (data not shown) along with a negative correlation with ripening may have combined to minimize the relationship between trunk cross-sectional area and flesh firmness. In Indiana, no relationship between trunk cross sectional area and fruit size (data not shown) and a negative relationship with ripening may have resulted in a positive correlation between trunk cross-sectional and flesh firmness. In California, a positive relationship between trunk cross-sectional area and fruit size (data not shown) and a negative relationship with ripening may have combined to provide a strong negative correlation between trunk cross-sectional area and fruit size.

In Indiana and California, red color development was assessed. The effects of rootstock were consistent only in California, where the trees were much more vigorous than those in Indiana. There was a negative correlation between vigor and red color, likely due to shading from excessive shoot growth and a large canopy.

Length-to-diameter ratio was measured in Indiana, and there was a positive correlation between tree vigor and the ratio. This relationship also was noted by Barritt et al. (4), who found that there was significant correlation between tree vigor and 'Delicious' fruit shape for a wide range of rootstocks. Assessment of tree vigor accounted for between 40 and 83% of the variation in length-to-diameter ratio. Barritt et al. (4) propose that rootstock may affect the elongation of fruit by influencing the hormonal levels in the fruit.

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Rootstock Effects Terminal Bud Set in 'Starkspur Supreme Delicious' Apples

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Cold hardiness is a major consideration in selecting suitable apple rootstocks as well as scion cultivars for Minnesota and other northern regions. Rootstocks effect many processes in apple tree growth including dwarfing, fruit ripening, and cold hardiness (1). One of the most important ways rootstocks influence hardiness of the scion cultivar is by inducing earlier maturity in the fall and delaying budbreak in the spring. Apple rootstocks, such as M.9 and M.7, have been shown to induce early maturity of the scion cultivar and thus tended to protect trees from fall freezes (7). However, induction of early maturity of the scion does not always translate to an increase in midwinter hardiness. Holubowicz et al. (3) demonstrated apple rootstocks differ in their midwinter hardiness and ability to deacclimate in winter as well as to affect the timing of growth processes in scions.

Howell and Weiser (5) found that leaves of apple scions produced a translocatable promoter of hardiness in response to short days, indicating that apple may be capable of a photoperiod-induced acclimation in late

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