Fruit Count, Fruit Weight, and Yield Relationships in 'Delicious' Apple Trees on Nine Rootstock

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Abstract. Annual yields per tree for 'Starkspur Supreme Delicious' apple (*Malus domestica* Borkh.) trees on nine size-controlling rootstock were related linearly to number of fruit per tree at harvest each year, independent of rootstock. Mean fruit weight was inversely and less closely related to number of fruit per tree when adjusted for tree size (fruit load). Annual yield-fruit count data for 9 years analyzed together showed that the number of fruit per tree was the principal factor determining yield, regardless of rootstock or tree age. A curvilinear relationship between yield and fruit count per tree during 9 years suggests that the sink strength of an apple crop is nearly, but not precisely, proportional to the number of fruit per tree.

The mechanisms by which apple rootstocks influence growth and productivity in scion cultivars are understood poorly (Tubbs, 1973a, 1973b). Apple rootstock genotypes produce large differences in tree size, precocity, yield, and yield efficiency (Elfving and McKibbin, 1991; NC140 Cooperators, 1987, 1991).

Factors influencing apple fruit growth include weather-related phenomena, cultivar, rootstock, fruit load, tree vigor, and carryover effects from previous years (Forshey and Elfving, 1989). Nonetheless, an apple tree's yield is primarily a function of the number of fruit at harvest (Forshey and Elfving, 1977).

The relationship between fruit size and the number of fruit per tree is more variable, a result reflecting differences in tree vigor and growing conditions (Forshey and Elfving, 1977; Volz, 1988).

A linear relationship between number of fruit per tree and yield has been reported in several studies with field-grown (Forshey and Elfving, 1977; Grauslund, 1976; Volz, 1988) and potted (Hansen, 1975) trees, while a curvilinear relationship also has been reported for field-grown (Landsberg et al., 1977) and potted (Hansen, 1977a, 1982) trees. Forshey and Elfving (1977), Grauslund (1976), and Volz (1988) found that a single, linear relationship fit yield-fruit count data from trees on up to three rootstock of similar vigor or on a single rootstock for up to five seasons. However, no studies have examined this relationship by comparing trees grown on size-controlling rootstock of widely different vigor. In addition, we know of no reports that evaluate yield relationships in the same trees over several years from the first year of production to tree maturity.

The detailed harvest data collected annu-

ally for a rootstock trial with 'Delicious' apple at the Horticultural Experiment Station in Simcoe, Ont., Canada, allowed us to explore the relationships among number of fruit, fruit weight, and yield over a wide range of tree sizes during 9 years starting from the first year of production.

'Starkspur Supreme Delicious' apple trees on nine rootstock were planted as whips in 1980 at the Horticultural Experiment Station. The trees were managed according to guidelines established by the NC 140 regional project protocol (NC 140 Cooperators, 1987). The following rootstock were included in this trial: M.7 East Mailing-Long Ashston (EMLA), M.26 EMLA, M.9 EMLA, M.27 EMLA, M.9, Michigan Apple Clone (MAC) 9, MAC 24, Ottawa (O) 3, and Oregon Apple Rootstock 1. The planting was spaced at 3.5 × 5.5 m on a well-drained Tavistock sandy loam consisting of 40 to 100 cm of sandy-loamy material over glaciolacustrine clay (Hohner and Present, 1989). The trial was established with five randomized complete blocks. Trunk diameter was used as the criterion for assigning trees to blocks at planting. The trunks of all trees on M.9 EMLA, M.9, and M.27 EMLA were supported in 1983 with a stake extending 80 cm from the soil surface. The free-standing canopy of each tree was trained to the conventional central-leader system (Tehrani et al., 1988). Fertilizers, pesticides, and herbicides were applied according to commercial practices. One tree each on O 3 and M.9 EMLA was lost before the first year of production in 1983. All trees except those on MAC 24 were thinned chemically in 1985 and 1988 using naphthaleneacetic acid at 5 mg-liter⁻¹. Crop load was not adjusted further. In 1987, a frost at bloom reduced the crop in the portion of the canopy below ≈1 m in height.

Yield and mean fruit weight were determined by counting all fruit on each tree plus any fruit that dropped at harvest and weighing them. Trunk circumference was measured on each tree each year after leaf drop at a premarked location 30 cm above the soil surface.

Annual growth and cropping data for all rootstock combined for each year from 1983 through 1991 were evaluated by analysis of variance on year. Means were separated using Duncan's multiple range test for unbalanced data when the overall F test was significant (Damon and Harvey, 1987). Yield data across rootstock were analyzed further by nonradi-

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sting regression analysis (Snedecor and Cochran, 1980) to compare annual regression parameters between 1983 and 1991. All analyses were carried out with the General Linear Models procedure of the Statistical Analysis System (SAS) program package (SAS Institute, Cary, N.C.).

Although a few trees flowered and set a few fruit in 1982, all trees began cropping in 1983. The nine rootstock produced enormous differences in tree growth, precocity, and productivity throughout the trial (Table 1). By 1991, tree height ranged from that of a small shrub (M.27 EMLA) to >4 m (MAC 24) with nearly equal spread. As expected, yield and number of fruit per tree varied substantially each year, differing by as much as 100-fold or more among individual trees in some seasons. As the trees matured, there was an overall trend toward smaller fruit, although mean fruit weight also varied considerably from tree to tree each year.

Despite the large and changing differences each year in tree size and production, each year a single yield vs. fruit count relationship fit the data for the trees on all nine rootstock. Each year the relationship was linear, the slope was significantly different from zero, and the intercept was not significantly different from zero (Table 2). Annual values for slopes were similar to each other during the 9 years of this study, as were annual values for intercepts.

The overall linear model for the nonradiating regression analysis of the nine annual yield–fruit count relationships had an r^2 value of 0.96, a result indicating clearly that number of fruit per tree was the primary factor determining annual yield for all trees in this planting.

Because of the tree-size effect on the relationship between number of fruit per tree and fruit weight (Forshey and Elfving, 1977), annual mean fruit-weight data were compared with number of fruit per 100 cm² trunk cross-sectional area (fruit load, Table 2). The results of this analysis were similar to those reported by Forshey and Elfving (1977) for ‘McIntosh’ and by Volz (1988) for ‘Gala’. The regressions were less precise in their fit ($r^2 = 0.67$ for the overall model) than the annual yield–fruit count relationships, the slope value each year was negative, annual intercept values varied considerably, and the slope was significantly different from zero in only 5 of 9 years. The negative slope values mathematically represent the well-known fact that mean fruit weight is smaller when fruit load is larger.

When the individual yield–fruit count data pairs for every tree during all 9 years were analyzed together irrespective of rootstock or year, a curvilinear relationship was observed between yield and number of fruit per tree (Fig. 1). Of the total variation in yields during 9 years of production, 96% was explained by this model. Although a curvilinear relation-

ship was observed, the linear component explained 95.5% of the variation described by the model. The quadratic component, although statistically significant, explained only 0.5%.

An apple cultivar displays a characteristic growth response to leaf: fruit ratio (Hansen, 1977b). Rootstock, including those used in this study, are reported to influence fruit size independent of fruit load (Autio et al., 1991; Preston et al., 1981). The extremely close fit of a single yield–fruit count regression to data for nine rootstock during 9 cropping years suggests that fruit growth in this study was influenced to a much greater extent by cultivar characteristics than rootstock effects.

Linear relationships reported for yield vs. number of fruit have included few trees or few production seasons. Annual yield–fruit count relationships observed in this study also were linear. Only when all 9 years of data were combined did the curvilinear component become statistically significant. Hansen (1977b) found that cultivar-specific fruit growth did not increase indirect proportion to increases in the ratio of fruit count to leaf area. Since cropping can decrease leaf count and area per tree (Forshey and Marmo, 1985; Hansen, 1971; Maggs, 1963; Schechter et al., 1991), larger numbers of fruit per tree in this study would likely have been accompanied by increases in number of fruit per unit leaf area. The curvilinear component of the 9-year yield–fruit count

Table 1. Annual means^a and ranges for growth and yield parameters of ‘Starkspur Supreme Delicious’ apple trees on nine size-controlling rootstock.

Year	Per tree		Yield (kg)		Fruit wt (g)		Trunk cross-sectional area (cm ²)		Fruit load ^b (no./100 cm ²)		Yield efficiency ^c (kg/100 cm ²)	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
1983	39 f	4-87	10 e	0.7-18	250 a	180-310	20 gh	4-49	248 e	23-977	62 C	5-234
1984	30 f	1-128	7e	0.2-24	230 b	150-300	31 f-h	5-81	138f	3-744	31 d	0.5-137
1985	193 de	31-396	43 cd	4-89	220 b	140-280	41 e-g	6-118	547 c	61-915	120 a	42-197
1986	129e	1-253	28 d	0.2+1	220 b	160-280	52 d-f	6-158	313 de	15-729	68 bc	3-143
1987	205 de	0-499	45 c	0-106	220 b	140-280	62 c-e	7-202	384 d	0-897	83 b	0-181
1988	449 c	17-1134	81 b	3-200	180c	130-220	70 cd	8-239	726 b	222-1281	126 a	43-186
1989	228 d	0-1100	38 cd	0-165	180c	130-220	84 be	8-276	229 ef	0-1313	38 d	0-165
1990	543 b	42-1228	94 ab	5-210	170c	110-210	97 ab	9-311	640 bc	343-1017	110 a	53-197
1991	724 a	39-1612	108 a	6-215	150d	90-210	107 a	9-331	847 a	248-1 594	117 a	35-200

^aMean separation within columns by Duncan’s multiple range test, $P \leq 0.05$. Each mean contains 43 observations.

^bFruit load = fruit count per 100 cm² trunk cross-sectional area.

^cYield efficiency = yield per 100 cm² trunk cross-sectional area.

Table 2. Annual parameters and their standard errors for yield vs. fruit count and mean fruit weight vs. fruit load relationships for ‘Starkspur Supreme Delicious’ apple trees on nine size-controlling rootstock.

Year	Yield vs. fruit count ^a				Fruit wt vs. fruit load ^b			
	Slope ^c	SE (slope) ^d	Intercept ^e	SE (int.) ^d	Slope	SE (slope) ^d	Intercept ^e	SE (int.) ^d
1983	0.22	0.06	1.0	2.5	-0.008	0.02	253	6.3
1984	0.20	0.05	0.8	2.0	-0.03	0.03	232	5.5
1985	0.22	0.01	-0.1	2.8	-0.05*	0.02	252	12.6
1986	0.21	0.02	1.1	2.6	-0.03	0.02	232	7.6
1987	0.21	0.01	0.8	2.4	-0.08*	0.02	252	9.4
1988	0.19	0.004	-2.5	2.3	-0.05*	0.02	215	12.0
1989	0.16	0.004	2.7	1.5	-0.04*	0.02	186	6.1
1990	0.17	0.003	0.4	2.5	-0.008	0.02	178	16.4
1991	0.15	0.003	4.0	2.6	-0.04*	0.01	184	9.2

^a r^2 for overall model= 0.96.

^b r^2 for overall model = 0.67. Fruit load = fruit count per 100 cm² trunk cross-sectional area.

^cAll values were significant at $P \leq 0.05$.

^dSE(slope) = standard error of estimate for each slope value.

^eAll values were nonsignificant at $P \leq 0.05$.

^fSE (int.) = standard error of estimate for each y-intercept value.

*Significant at $P \leq 0.05$.

Fig. 1. Regression of yield per tree on fruit count per tree for 'Starkspur Supreme Delicious' apple trees on nine rootstocks during 9 years from 1983 to 1991 (n = 387).

relationship probably reflects a small but significant change in cultivar-specific fruit growth rate in response to altered leaf: fruit ratio. The results described here suggest that the collective sink strength of an apple crop changes in nearly, but not precisely, direct proportion to the number of apples on a tree.

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