Does Rootstock Influence Apple Fruit Size?

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Report of IDFTA-supported rootstock research.

Rootstock can have a major impact on the profitability of an orchard. The ideal rootstock should induce good tree survival, high annual yields and acceptable fruit color and fruit size. Fruit size is becoming increasingly important because during just the past few years the minimum size demanded by buyers has increased from 2.25 inches (57 mm) to 2.5 inches (64 mm) in diameter. Even processors demand fruit that is at least 2.5 inches (64 mm) in diameter for sauce and slices. During the last few years several growers have asked if rootstock can affect fruit size. I have always felt that trees on dwarf rootstocks produce larger fruit than trees on more vigorous rootstocks. Some growers have observed small fruit on dwarf trees, probably because the trees have been over-cropped. To obtain more information about rootstock effects on fruit size, I looked through the published data.

Results from dozens of apple rootstock trials have been published during the past 50 years. It is difficult to compare results from these trials because researchers compared different rootstocks with different varieties, and they managed the trees differently and collected different types of data. In addition, they also analyzed the data differently, which may change the interpretation of the data. In general, the effect of rootstock on average fruit size has been inconsistent between experiments and from year to year within experiments. One factor that can have a dramatic effect on average fruit size is crop load, which is usually expressed as number of fruit per tree or as the number of fruit per unit of trunk cross-sectional area (crop density). Most dwarfing rootstocks induce heavier cropping than the more vigorous rootstocks. Because crop load may not be similar for all rootstocks in an experiment, it is difficult to evaluate the direct effect of rootstock on fruit size. Some rootstock researchers have used chemical thinners and hand thinning in an attempt to obtain similar crop loads for all trees within a trial, but there are a number of reports in the literature where crop loads were not similar for all rootstocks.

Researchers can use a statistical technique, called analysis of covariance, to estimate average fruit size that is adjusted for variation in crop load. Two criteria are required for this technique to generate appropriate estimates of average fruit weight. First, there must be a linear relationship between average fruit size and crop load. This seems to be a fairly good assumption because there are several reports in the literature where average fruit size for apple and peach decreased linearly as crop load increased. The second condition is that the relationship between fruit size and crop load is the same for all rootstocks. This means that if the data points were plotted for average fruit size against crop load for each rootstock, the resulting lines would have the same slope and all the lines would be parallel. Both of these criteria should be verified before performing an analysis of covariance. When both assumptions for the analysis of covariance are valid, the adjusted means are values that one would expect for the mean value of crop load observed in that particular experiment. These adjusted means are commonly called least squares means. The second condition for analysis of covariance probably occurs rarely. I have coordinated four NC-140 rootstock trials and in all four trials there are locations where the slopes are not equal for all rootstocks. When this happens, average fruit weight cannot be estimated accurately with analysis of covariance, but means should be estimated for at least three levels of crop load.

The effect of rootstock on fruit size cannot be evaluated without first adjusting for crop load.

The reason it is important to estimate fruit size at more than one crop load is because the slopes are not parallel; therefore average fruit size may be similar for two rootstocks when there is a light crop, but fruit size may differ when there is a heavy crop.

I recently analyzed data from the NC-140 rootstock trial planted in 1990. Gala was the scion variety and there were eight dwarfing rootstocks. Four cooperators (Michigan, New York, Ontario and Virginia) submitted data for individual trees for 2 years. Analysis of covariance was used to determine the effect of rootstock on average fruit weight. Average fruit weight is total weight of harvested fruit per tree divided by the number of fruit per tree. Data for Michigan, Ontario and Virginia are presented in Table 1, and data for New York are presented in Figure 1.

Data in Table 1 show average fruit weight for three locations for 2 years after the means have been adjusted for number of fruit per tree. Therefore, these are the values we would expect if all trees had the same number of fruit. For both years at Michigan, the smallest fruit were harvested from trees on P.1 and M.27 EMLA. In 1998 trees on M.9 EMLA had the largest fruit and in 1999 trees on Mac.39 had the largest fruit. At Ontario, rootstock did not affect average fruit weight in 1998, but in 1999 trees on P.1 and M.27 EMLA produced smaller fruit than did trees on M.9 EMLA, Mac.39, O.3 and B.9. At Virginia in 1998 trees on M.26 EMLA and P.1 produced smaller fruit than trees on M.27 EMLA. In 1999 trees on M.26 EMLA produced smaller fruit than did trees on Mac.39.

Figure 1 contains data for both years at New York. If the slope is negative, then average fruit size decreases as number of fruit per tree increases. If the slope is steep, then average fruit size changes rapidly as the number of fruit per tree increases. Results for the 2 years are slightly different. The slope for Mark was positive; Mark produced the smallest fruit at low crop loads, but fruit size was intermediate at high crop loads.

In 1998 trees on B.9 had the largest fruit regardless of crop load. Slopes were least steep for P.1, O.3 and M.27, so for these rootstocks fruit size decreased slightly as the number of fruit per tree increased. M.9 had the steepest slope; fruit were relatively large at low crop loads, but fruit were relatively small at high crop loads. M.26 produced medium-size fruit at low crop loads, but fruit were small at high crop loads.

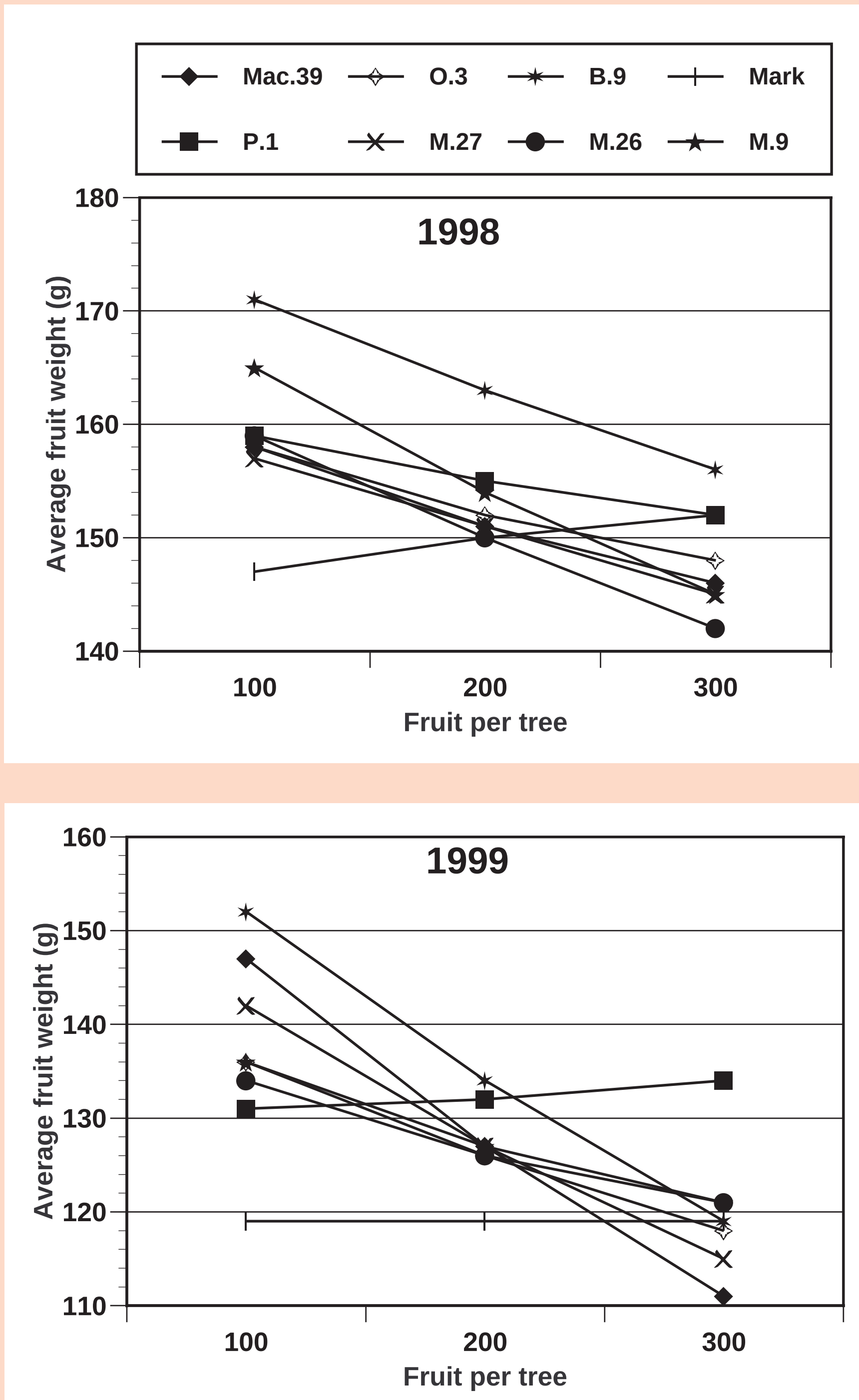
In 1999 B.9 again produced the largest fruit at low and intermediate crop loads, but fruit size was intermediate at the highest crop load. Mac.39 had the steepest slope and produced the second largest fruit at low crop loads and the smallest fruit at high crop loads. Mark and P.1 had positive slopes, whereas Mac.39, B.9 and M.27 had the steepest slopes. M.26, M.9 and O.3 had similar slopes.

Several types of important information can be obtained from these analyses:

1. The relationship between average fruit weight and crop load was not the same for all rootstocks at all four locations.
2. The relationship between average fruit weight and crop load at a given location was not consistent for both years.
3. At three locations (Michigan, Ontario and Virginia) the relationship between average fruit weight and crop load was similar for all rootstocks, so traditional analysis of covariance could be used to adjust fruit weight for crop load. However, the

FIGURE 1

The effect of crop load on average fruit weights at New York during two seasons for Gala trees grown on eight different dwarfing rootstocks. Values are estimates after adjusting for the number of fruits per tree.



adjustment was different for each location, and at each location the adjustment was different for each year.

4. At New York, the relationship between average fruit weight and crop load was not the same for all rootstocks. Therefore, average fruit weight needed to be estimated for several levels of crop load. This is an interesting finding because it means that fruit size declines more rapidly with increasing crop load for some rootstocks than for others. Thus, some rootstocks may be better able to support heavy crops with little loss of fruit size.

Taken together, all this information means that the effect of rootstock on fruit size is not simple to evaluate. The impact of rootstock seems to depend on the location and the year. However, if we look at the data from all four locations, we can see some general patterns.

Before trying to interpret all these seemingly conflicting data, we should first take a look at previously published information. Table 2 is a summary of data obtained from previously published rootstock trials from many locations.

Although these experiments were conducted in different parts of the world with different varieties and different rootstocks were compared, some general trends are apparent. In six of the seven trials, trees on M.9 produced the largest fruit. Trees on Mark usually produced relatively small fruit. Fruit size was usually intermediate for trees on M.26 and B.9. These data generally support the results of the 1990 NC-140 multi-location study with Gala. For the eight combinations of year and location in the NC-140 trial, fruit size for B.9 always ranked in the top half of the eight rootstocks and Mac.39 and M.9 each ranked in the top half seven times. Mark ranked in the top half only once, M.26 and M.27 ranked in the top half only twice and O.3 ranked in the top half three times. In summary, of the commonly used dwarf rootstocks, M.9 generally produced the largest fruit.

SUMMARY

One probably cannot make specific statements concerning the effect of rootstock on average fruit size because results vary from one situation to another. However some general conclusions can be drawn from this mass of data.

1. The effect of rootstock on fruit size cannot be evaluated without first adjusting for crop load.
2. The effect of rootstock on fruit size probably will not be consistent from one year to the next, so several years of data at each location are needed to evaluate fruit size. Before testing the assumptions for analysis of covariance, researchers should avoid trying to adjust average fruit size for crop load when data come from more than one location or more than one season.
3. Data reported for a number of experiments (in some cases values were adjusted for crop load) indicate that, of the commonly planted dwarf rootstocks, M.9 most consistently produced large fruit and O.3 most consistently produced small fruit.
4. The economics of rootstock involving yield/acre, fruit size and fruit packout have not been well studied. Although we may be able to detect a statistical effect of rootstock on fruit size, the effect may not be of economic importance.
5. At this point the effect of rootstock on fruit size does not seem to be consistently large. Therefore, primary considerations for rootstock selection should be tree survival, the desired level of tree vigor and productivity.

TABLE 1

The effect of eight dwarfing rootstocks at three locations on average fruit weight (g/fruit) in 1998 and 1999. Analysis of covariance was used to adjust the means for number of fruit per tree. These least squares means are the means that would be expected if all trees had equal numbers of fruit per tree.

	Michigan		Ontario		Virginia	
Rootstock	**1998**	**1999**	**1998**	**1999**	**1998**	**1999**
Mac.39	145 bc	165 c	165	165 b	140b	122 b
Polish 1	140 b	141 a	157	132 a	119 a	119 ab
Ottawa 3	143 bc	148 ab	157	155 b	122 b	118 ab
M.27 EMLA	128 a	141 a	144	137 a	163 c	112 ab
Budagovsky 9	150 c	155 bc	162	155 b	133 b	120 ab
M.26 EMLA	146 bc	155 bc	156	150 ab	117 a	109 a
Mark	144 bc	152 b	158	148 ab	128 ab	110 ab
M.9 EMLA	152 c	154 b	155	166 b	140 b	116 ab

*Means were adjusted for crop load. Means within columns followed by the same letter do not differ at the 5% level of significance.

TABLE 2

A summary of data from previous rootstock trials. Average fruit size is ranked from largest to smallest. These data are averages over the entire experiment.

Author and date	Location	Variety	Ranking	Adjusted for crop load
NC-140, 1996	Many	Several	M.9>B.9>M.26>Mark>O.3	No
Autio, 2001	Many	Several	M.9=M.26>B.9>O.3>Mark	Yes
Jackson & Blasco, 1975	UK	Cox's	M.9>M.26=M.7+MM.106	Yes
Preston et al., 1981	UK	Bramley's	M.9>M.26+M.27+MM.106	?
Marini et al. 2000	Many	Gala	M.9>M.26>B.9>O.3>M.27>Mark	No
Webster & Hollands, 1999	UK	Cox's	M.27>M.9>Mark=B.9	No
Autio, 1991	MASS	Delicious	M.9=O.3>M.26=Mark>M.27>OAR1	Yes

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CONVERSION FACTORS ENGLISH VS. METRIC

To convert Column 1 into Column 2, multiply by:	Column 1	Column 2	To convert Column 2 into Column 1 multiply by:
	Length		
.621	kilometer, km	mile	1.609
1.094	meter, m	yard	.914
3.281	meter, m	foot, ft	.3048
39.4	meter, m	inch	.0254
.03281	centimeter, cm	foot, ft	30.47
.394	centimeter, cm	inch	2.54
.0394	millimeters, mm	inches	25.40

metric: 1 km = 1000 m; 1 meter = 100 cm; 1 meter = 1000 mm
English: 1 mile = 5280 ft; 1 mile = 1760 yards; 1 yard = 3 ft; 1 ft = 12 inches

	Area		
247.1	kilometers^2, km^2	acre	.004047
2.471	hectare, ha	acre	.4047
.4047	trees/hectare	trees/acre	2.471

metric: 1 ha = 10,000 m^2 = .01 km^2
English: 1 acre = 43,560 ft^2

	Volume		
1.057	liter	quart (US)	.946

English: 1 US gallon = 4 quarts

	Mass—Weight		
1.102	ton (metric), MT	ton (English)	.9072
2.205	kilogram (kg)	pound, lb	.454
52.5	ton (metric) of apples	apple packed box, *carton	.01905

metric: 1 metric ton = 1000 kg
English: 1 ton = 2000 lb; 1 packed box or carton* of apples = 42 lb

	Yield or Rate		
0.446	ton (metric)/hectare, MT/ha	ton (English)/acre	2.242
.892	kilogram/hectare, kg/ha	pound/acre	1.121
.991	ton (metric) of apples/hectare, MT/ha	bins* of apples/acre	1.009
.4047	trees/hectare	trees/acre	2.471
0.107	liter/hectare	gallon (US)/acre	9.354

metric: 1 metric ton = 1000 kg; 1 hectare = 10,000 m^2
English: 1 ton = 2000 lb; apple bin* = 900 lb; 1 acre = 43,560 ft^2

	Temperature		
1.8 C + 32	Celsius, C	Fahrenheit, F	.555 (F-32)

**Commercial cartons (packed boxes) of fruit and field/storage bins of fruit do not have universal weights. The weight of fruit in a packed box or carton varies around the world and with the type of fruit, but is here taken for apples as 42 lbs (19.05 kg); the weight of fruit in a bin also varies but is here taken for apples as 900 lbs (408.2 kg).*