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Comparison of Methods to Express Growth, Size, and Productivity of Apple Trees

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Abstract

Data from an 18-year rootstock trial with 'RedChief' and 'Red Prince' strains of 'Delicious' and 'Goldspur' and 'Smoothee' strains of 'Golden Delicious' were used to compare multiple ways to express tree productivity and efficiency. Our data confirm the close relationship between trunk cross-sectional area (TCA) and scion weight across a wide range of tree sizes. In addition, our data show that cumulative yield increased at a decreasing rate as tree size increased, whether expressed on the basis of scion weight or TCA. The regression between pruning time and TCA was linear for both strains of both cultivars. The cumulative crop-weight-to-final-scion- weight ratio (C/S ratio) varied widely with rootstock, but much less with cultivar and strain. Trees on M.9 rootstocks had a C/S ratio of about 15, indicating that the average annual production of fruit for each of the 14 fruiting years was equal to the final scion weight. With M.7 and MM.111, the annual yields of fruit were equal to about 50% of the final scion weights. The relative differences in C/S ratio were considerably greater than the cumulative yield efficiencies reported earlier.

Introduction

As we evaluate the many rootstock candidates that become available, we strive to generate the most useful information as to their relative merits. Certainly, one of the most important types of data is some measure of productivity. Over the past six to seven decades, there have been multiple ways developed to characterize tree fruitfulness. In the 1950s and 1960s, Preston suggested the ratio of crop weight to the weight of the scion, trunk cross-sectional area (TCA), canopy height, and canopy spread (3, 4, 5). Westwood and Roberts (9) reported a strong linear relationship between TCA and scion weight and concluded that TCA could be used to estimate potential bearing surface of any orchard tree as long as it has not been heavily pruned. Most reports on rootstock performance since 1970 have included data on TCA as well as yield efficiency (YE) which is expressed as kg fruit per cm^2 TCA. The completion of a long-term evaluation of a standard and a spur-type strain of two cultivars on several dwarfing and semi-dwarfing rootstocks provided the opportunity to reevaluate the relationships among cumulative crop weight, TCA, and scion weight, as well as pruning time and pruning weight. Because of the pruning required to restrict the trees to their allotted space, we were also able to evaluate, at least to some degree, the effect of pruning severity on the scion weight-TCA relationship.

Materials and Methods

A rootstock trial was established in 1976 near Blacksburg, Va. Rootstocks and interstocks were M.9, M.9/MM.106, M.9/MM.111, M.26, M.7, and MM.111. Scion cultivars were 'RedChief Delicious', 'Red Prince Delicious', 'Goldspur Golden Delicious', and 'Smoothee Golden Delicious'. All 'Delicious' were in three-tree plots; 'Golden Delicious' were in single-tree plots. Row spacing was a standard 6.1 m. Tree spacing was varied with anticipated tree vigor and ranged from 1.8 to 5.5 m. Three rows of 'Delicious' alternated with single rows of 'Golden Delicious'. Because of the diversity of anticipated tree sizes, the rootstocks were divided into dwarf (M.9, M.26, M.9/MM.106, and M.9/MM.111) and semi-dwarf to vigorous (M.7,

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MM.106, MM.111) groups and each group was treated as a separate experiment. Also, because of expected differences in tree size, the spur-type and standard-growing strains of each cultivar were put in separate experiments. The net result was that we had four separate experiments, each of which was a randomized complete block with five replications. The tree growth and cropping data were presented previously (1, 2).

In January, 1990 we recorded the time required to prune all 'Golden Delicious' and 'Redchief Delicious' trees and one tree per replication of 'Red Prince Delicious'. In January, 1992, we recorded time of pruning as in 1990, and in addition, weighed the prunings from each tree in the pruning study.

When the study was terminated, after leaf fall in November 1993, the trees were cut off just above the ground (close to the bud union) with a chainsaw. After each tree was cut, it was weighed immediately by attaching a chain around the trunk and lifting the tree with a small crane with a digital scale attached. Cumulative yield and TCA data had been measured previously.

Results and Discussion

The strong linear relationship between scion weight and TCA is apparent in Fig.1. We calculated regression lines for each of the four strains separately and the r^2 values ranged from 0.95 to 0.98 and the intercepts and slopes varied slightly (data not shown). The regression line for the entire data set has an r^2 value of 0.96 and describes the data well, but the variation around the line increases with the larger trees. It is worth noting that these regressions are calculated from either individual-tree data ('Golden Delicious') or means for three-tree plots ('Delicious') rather than cultivar means. These data strongly support the conclusion made by Westwood and Roberts (9) that TCA is an excellent predictor of scion weight.

As expected, cumulative per-tree yields increased with increasing tree size, whether expressed on a scion-weight basis (Fig, 2) or a TCA basis (Fig. 3). In both cases, the regressions were second order polynomials. Both the slopes and the intercepts varied among cultivars. Whether expressed on a TCA or scion weight basis, the yields were higher for 'Golden Delicious' than 'Delicious', especially with the larger tree sizes (Fig. 2 and 3). As would be expected from the close relationship between TCA and tree weight (Fig.1), the regression coefficients are similar for the two methods of expression (Fig. 2 and 3).

The relationship between TCA and pruning time was linear for all cultivars and was somewhat stronger for 'Delicious' than for 'Golden Delicious' (Fig.4). As TCA increased, the pruning time increased rapidly, especially for 'Red Prince'. The slopes for the two strains of 'Golden Delicious' were similar, and quite similar to that for 'RedChief'.

The ratio of cumulative crop to scion weight (C/S ratio) varied widely with rootstock but varied much less with cultivar and strain (Table 1). Excluding MM.106 as either a rootstock or interstock (because of poor survival), the overall means for 'Red Chief', 'Red Prince', 'Goldspur', and 'Smoothee' were 11.1, 9.1, 10.6, and 11.1, respectively. Although 'Golden Delicious' is usually considered more productive than 'Delicious', the mean C/S ratios in this study do not support that contention. Again, omitting MM.106 as a rootstock or interstock, the overall means for trees on M.9, M.26, M.9/MM.111, M.7 and MM.111 were 15.2, 10.9, 11.2, 7.9, and 7.2, respectively. Among the dwarf rootstocks, trees on M.9 tended to have higher C/S ratios than trees on M.26 or M.9/MM111, both of which were intermediate between trees on M.9 and those on the semidwarfs M.7 and MM.111.

In a series of papers on long-term rootstock studies (3, 4, 5), Preston published data on C/S ratios. He reported that the C/S ratios at 20 years for 'Cox's Orange Pippin' /M.9 and 'Jonathan'/M.9 were 13.9 and 27.0, respectively (4). In our study, the average C/S ratio for two strains each of 'Delicious'/M.9 and 'Golden Delicious'/M.9 were 16.2 and 14.2 Also of interest is

Table 1. Ratio of cumulative fruit weight to final scion weight (kg/kg) of 'Delicious' and 'Golden Delicious' apple trees after 18 years as influenced by strain, rootstock, and interstock.

Rootstock/Interstock	'Delicious'[z]		'Golden Delicious'[y]	
	'Redchief'	'Red Prince'	'Goldspur'	'Smoothee'
DWARF				
M.9	18.2 a[x]	14.3 a	13.5 ab	15.0 ab
M.26	11.1 b	8.2 c	12.6 b	11.7 b
M.9/MM.106	21.2 a	—[w]	20.1 a	16.9 a
M.9/MM111	12.8 b	10.4 b	9.5 b	12.3 b
Significance (P≤F)	*0.001*	*0.0001*	*0.039*	*0.038*
SEMI-DWARF				
M.7	6.9	7.4	8.9	8.4
MM.106	—[v]	—[v]	9.7	9.2
MM.111	6.7	5.4	8.4	7.9
Significance (P≤F)	*0.519*	*0.268*	*0.579*	*0.194*

[z]Delicious - means of 3-tree plots.
[y]Golden Delicious - single tree plots.
[x]LS means; separation within columns and size groups by PDIFF, 0.05.
[w]Not calculated due to low (43%) tree survival.
[v]Not calculated due to low (13%) tree survival.

that after 15 years (5), 'Cox Orange Pippin'/M.9 had a C/S ratio of 10.6 whereas on M.7 it had a C/S ratio of 5.0 (47% of M.9). Our data show a similar relationship with M.9 having an overall average C/S ratio of 15.2 and M.7 having an average of 7.9 (52% of M.9).

In our study, the C/S ratio of both strains of 'Delicious' and 'Golden Delicious' on M.9 averaged 15.2. Since significant yields began in 1980 (1, 2), during the 14 years of cropping (1980-1993), annual fruit yields of trees on M.9 approximated the final weight of the scion. On the other hand, the C/S ratio of trees on the semi-dwarf rootstocks averaged about 7.5 indicating an annual yield of only about 54% of the final weight of the scion. As an interstock on MM.111, M.9 increased the C/S ratio by more than one-half, (7.1 to 11.2), compared to MM.111 with no interstock. These data provide strong evidence of the effectiveness of M.9 as a rootstock or an interstock in increasing the partitioning of photosynthate

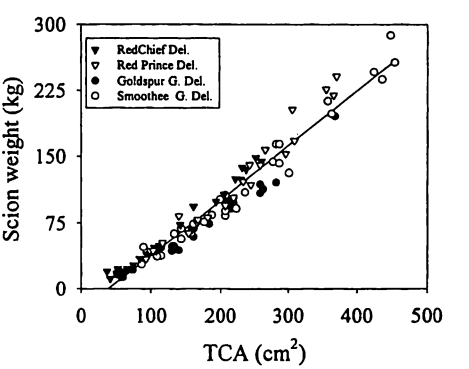

Figure 1. The relationship between scion weight and trunk-cross-sectional area (TCA) of two strains eeach of 'Delicious' and 'Golden Delicious' on several rootstocks at 18 years. Regression: y=-35.6 + 0.70x; r^2 = 0.96.

Table 2. Annual weights (kg) of prunings removed from 14-year-old 'Delicious' and 'Golden Delicious' apple trees as influenced by strain, rootstock, and interstock and pruning weights as percent of scion weight at 18 years.

	'Delicious'[z]				'Golden Delicious'[y]			
Rootstock/Interstock	'Redchief'		'Red Prince'		'Goldspur'		'Smoothee'	
DWARF	kg	%	kg	%	kg	%	kg	%
M.9	0.3 b[x]	1.7	6.4	8.2	1.7	3.4	2.4 b	3.9 c
M.26	2.6 a	3.5	13.7	10.1	4.1	6.1	11.4 a	12.0 a
M.9/MM.106	0.5 ab	2.6	—[w]	—	0.7	3.4	3.3 b	6.7 bc
M.9/MM111	1.2 ab	3.1	7.6	9.1	4.1	3.9	7.7 a	9.2 ab
Significance (P≤F)	*0.04*	*0.21*	*0.17*	*0.85*	*0.17*	*0.45*	*0.01*	*0.03*
SEMI-DWARF								
M.7	8.4	7.1	13.8	12.6	5.7	8.2	9.8	7.7
MM.106	—[v]	—[v]	—[v]	—[v]	5.0	6.5	7.2	6.2
MM.111	8.6	6.8	21.2	10.0	8.7	6.4	14.6	6.7
Significance (P≤F)	*0.98*	*0.47*	*0.18*	*0.26*	*0.44*	*0.62*	*0.07*	*0.49*

[z]Delicious - means of 3-tree plots.
[y]Golden Delicious - single tree plots.
[x]LS means; separation within columns and size groups by PDIFF, 0.05.
[w]Not calculated due to low (43%) tree survival.
[v]Not calculated due to low (13%) tree survival.

into fruit rather than into wood.

Strong and Azarenko (7) studied the partitioning of dry matter in ten-year-old 'Starkspur Supreme Delicious' trees on nine rootstocks, and reported that trees on M.9 as well as M.9EMLA, MAC.9, M.27EMLA, and O.3 partitioned a greater percentage of dry weight to fruit than did trees on the more vigorous rootstocks such as M.26 and M.7. Direct comparison of their data with ours is impossible, however, because they included fruit weight for only the final year of the study.

The data from the pruning study provide additional insight on the effects of cultivar, strain, and rootstock on the relative partitioning of photosynthate to fruit and wood (Table 2). In the actual pruning-weight data, there were large differences among the cultivars, strains, and rootstocks which might lead one to conclude that pruning severity varied considerably among the various cultivar/rootstock combinations. If, however, we look at the pruning weight as a percent of the final scion weight (Table 2) the differences decline dramatically. On

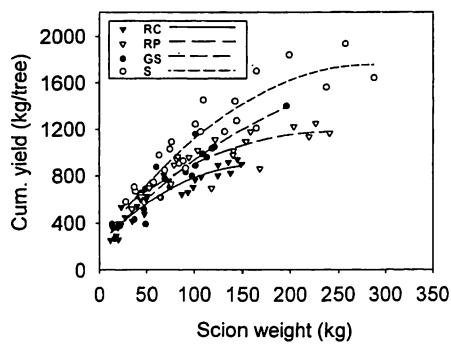

Figure 2. Cumulative yield (1976-1993) of two strains each of 'Delicious' and 'Golden Delicious' on several rootstocks as related to 1993 scion weight. 'Red Chief Delicious' (RC): $y = 227.1 + 7.9x - 0.02x^2$, $R^2 = 0.90$; 'Red Prince Delicious' (RP): $y = 362.7 + 6.8x - 0.01x^2$; $R^2 = 0.75$; 'Goldspur Golden Delicious' (GS): $y = 212.2 + 8.5x - 0.01x^2$; $R^2 = 0.88$; 'Smoothee Golden Delicious' (S): $y = 231.7 + 10.8 - 0.02x^2$; $R^2 = 0.85$.

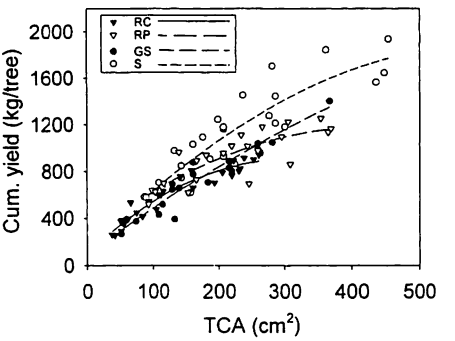

Figure 3. Cumulative yield (1976-1993) of two strains each of 'Delicious' and 'Golden Delicious' on several rootstocks as related to 1993 trunk cross-sectional area (TCA). 'Red Chief Delicious' (RC): y = 147.3 + 4.2x - 5.3x², R² = 0.87; 'Red Prince Delicious' (RP): y = 237.9 + 4.4x - 5.1x²; R² = 0.68; 'Goldspur Golden Delicious' (GS): y = 91.8 +4.1x - 1.9x²; R² = 0.87; 'Smoothee Golden Delicious' (S): y = 102.3 + 5.7x - 4.0x²; R² = 0.81.

the basis of these data, expressed as a percentage, it appears that although we had to prune trees of the standard strains on the semi-dwarfs much more severely than the spur-type strains on the dwarfing rootstocks, the relative proportion of the tree removed was not dramatically different. We are, therefore, unable to support or question the validity of the statement by Westwood and Roberts (9) that severity of pruning could modify the relationship between TCA and tree weight.

The concept of harvest index (HI) has been widely used in research with field crops and is calculated by dividing the dry weight of economic product (i.e. grain) by the total above-ground plant dry weight. Strong and Azarenko (8) calculated HI for apple as the current years' yield (dry weight of fruit) divided by total plant dry weight (including roots). In our opinion, this method of calculating HI has several inherent problems. By using only one years' yield, the resulting HI values likely could vary widely, depending of the size of the crop in the particular year when the trees were sacrificed. After a tree fills its allotted space, its weight will continue to increase, but its annual crops likely will not; therefore one might anticipate that the HI calculated this way would decline over time. Also, the HI values will vary with crop density. It is well known that the maximum yield (total kg of fruit) results from a heavy fruit set with no thinning. However, such fruit is of little or no value due to inadequate fruit size; therefore thinning is practiced to both increase fruit size and increase return bloom, even though it reduces total yield. The trees used by Strong and Azarenko were non-thinned (6) and had crop densities of 10.5 to 16 (8) - much higher than the crop density which would lead to annual cropping. Such excessive crop densities lead to a high HI, but are not realistic for continued cropping. We also suggest that to include the roots in the calculation is somewhat problematical. First, it is difficult if not impossible to get complete root capture, and secondly, root excavation of mature trees is rarely attempted, so very few data are available. We suggest that it is much more informative to divide the cumulative yield over the life of the trees by the final above-ground tree (scion) weight. Since the tree weight is cumulative over the life of the tree, cumulative crop weight would

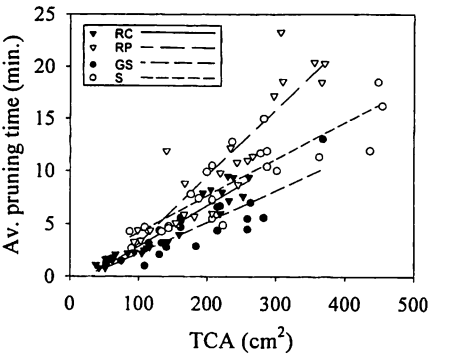

Figure 4. Average pruing time per tree (1990-91) of two strains each of 'Delicious' and 'Golden Delicious' on several rootstocks as related to 1993 trunk cross-sectional area. 'Red Chief Delicious' (RC): y = -1.02 + 0.04x; r² = 0.93; 'Red Prince Delicious' (RP): y =y-3.21 + 0.06x; r² = 0.81; 'Golden Spur Delicious' (GS): y = -0.75 + 0.03x; r² = 0.75; 'Smoothee Golden Delicious' (S): y = 0.73 + 0.03x; r² = 0.77.

seem far more appropriate as the numerator in calculating the ratio of fruit to wood production.

Routinely recorded data in rootstock evaluation studies include yield and TCA. To increase the potential usefulness of such studies we suggest that final scion weights also be recorded. The amount of labor required is significant, but considering the time and effort going into a long term year study, the additional effort is relatively small.

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