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Various Measures of Tree Vigor, Yield, and Yield Efficiency of Apple Trees in the 1990 NC-140 Systems Trial as Influenced by Location, Cultivar, and Orchard System

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Abstract

In the 1990 NC-140 Apple Systems Trial (4, 5), the treatments included Slender Spindle (SS)/ M.9EMLA, B.9, and Mark; Vertical Axis (VA)/ P.1, M.26EMLA, O.3, M.9EMLA, and Mark; and Central Leader (CL)/ M.26EMLA and Mark. In the Illinois and Ontario trials the cultivars were 'Empire'and 'Jonagold'; in North Carolina and Virginia the cultivars were 'Empire' and 'Early Red One Delicious'(a non-spur strain). At the termination of the trial in 1999, above-ground tree weight data were collected by cooperators at four sites. In combination with data collected previously, these data provided the opportunity to evaluate the relationship between scion weight and trunk cross-sectional area (TCA) as well as to calculate the ratio of cumulative crop (C) to scion weight (S). Although the regression equations varied somewhat among sites, at each location TCA explained from 94 to 97% of the variation in scion weights. Scion weights in North Carolina were approximately one-half of the mean for the other three sites. Compared to cumulative yield in Virginia, yields at the other three sites ranged from 45-55%. The C/S ratio, calculated by dividing the cumulative crop by scion weight, was more than twice as high in North Carolina and Virginia as in Illinois and Ontario. The treatments were ranked within each site from high to low for both C/S ratio and yield efficiency (YE). The relationships among the treatments were very similar at all sites using either the YE or C/S ratio as the basis of comparison. A logical conclusion is that the readily obtained and commonly utilized parameter YE is essentially as informative as the more destructive and difficult to obtain and therefore rarely measured parameter C/S ratio.

Introduction

The evaluation of apple rootstocks continues to be a research priority in most apple-growing regions of the world. Many characteristics of rootstock candidates are evaluated, but certainly one of the most important is a measure of productivity. Over the past several decades various measures of fruiting and tree efficiency have been used. Preston (6, 7, 8) suggested several possibilities including the ratio of crop weight to tree weight, trunk cross-sectional area (TCA), canopy height, and canopy spread. A strong linear relationship between TCA and scion weight was reported by Westwood and Roberts (10), and they suggested that TCA could be used to estimate potential bearing surface of any orchard tree. They did, however, express a concern that severe pruning might alter this relationship. Barden and Marini (3) provided additional evidence of the strong relationship between TCA and scion weight. Recent research reports on rootstock evaluations have typically contained data on TCA and also yield efficiency (YE) which is calculated as cumulative kg of crop per cm^2 final TCA. Barden and Marini (3) calculated cropping efficiency both on the basis of YE and crop/scion ratio (C/S ratio), and reported that the relative differences in C/S ratio were considerably greater than the differences in YE. An advantage of the C/S ratio is that it allows for the comparison of annual yields to final scion weights. The termination of the 1990 NC-140 Orchard Systems Trial in multiple sites (4,5) offered the opportunity to further evaluate the various measures of tree size, yield, and yield efficiency.

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Materials and Methods

In 1990 an apple orchard systems trial was established at nine sites across North America. The details of the experiment as well as the resulting data are presented in reports published in 1997 (4) and 2001 (5). There were two cultivars at each location and the cultivars varied among locations. In Illinois and Ontario the cultivars were 'Empire' and 'Jonagold'; in North Carolina and Virginia the cultivars were 'Empire'and 'Early Red One Delicious' (a non-spur strain). The training systems consisted of a cental leader (CL), vertical axis (VA), and slender spindle (SS). The rootstocks varied with the training system as follows: CL/M.26EMLA, CL/Mark , VA/P.1, VA/M.26EMLA, VA/M.9EMLA, VA/O.3, and VA/Mark; SS/M.9EMLA, SS/B.9, and SS/Mark.

At the end of the trial, four of the cooperators obtained data on above-ground tree (scion) weight. During the dormant season following the tenth growing season, trees were cut just above the bud union and the fresh weight determined. These data were combined with the data on TCA and yield to calculate additional measures of tree efficiency.

Results and Discussion

Trunk cross-sectional area. Because O.3 was not planted at all locations, the data for VA/O.3 are not included in calculating the various treatment means (Tables 1- 5). TCA varied with location, cultivar, and the system/rootstock treatment, hereafter referred to as treatment (Table 1). On the basis of decreasing TCA, the locations ranked as follows: Virginia > Illinois > Ontario > North Carolina. Trees of 'Jonagold' had larger trunks than trees of 'Empire' in both Illinois and Ontario. In North Carolina, trees of 'Empire' had larger trunks than trees of 'Delicious', but in Virginia, 'Empire' and 'Delicious' trunk sizes did not differ.

Only in Ontario was there a significant cultivar x treatment interaction. Rankings of treatments were quite similar with 'Jonagold' and 'Empire'. The interaction was likely significant because the range among treatment means was greater for 'Empire' than for 'Jonagold'. The range of TCA for 'Empire' was 71.5 cm^2 for VA/P.1 to 25.3 cm^2 for SS/Mark, and for 'Jonagold' was 77.2 cm^2 for VA/P.1 to 39.5 cm^2 for VA/Mark (data not shown).

The ranking of the treatments varied to some degree among the four locations, but the overall trends were similar. The largest trunks were consistently on VA/P.1 followed by CL/M.26 and VA/M.26, which on average, were approximately equal. Differences among the other treatments were neither large nor consistent across locations.

Scion weight. Scion weights were influenced by location, cultivar, and treatment (Table 2). Mean tree weights in Illinois, Ontario, and Virginia were relatively similar, but those in North Carolina were about 50% lower. For comparison, mean TCA of trees in North Carolina was about 35% lower than the mean for the other three locations. The smaller trees in North Carolina likely resulted from the extensive summer and dormant pruning done at that location in attempts to control vigor.

In both Illinois and Ontario, trees of 'Jonagold' weighed more than trees of 'Empire', whereas trees of 'Empire' and 'Delicious' did not differ in either North Carolina or Virginia. Ontario was the only location in which there was a significant treatment x cultivar interaction. The interaction was likely due to the greater range among treatment means for 'Empire' than with 'Jonagold'. The range in scion weight for 'Empire' was from 50.0 kg for VA/P.1 to 11.0 kg for SS/Mark and for 'Jonagold' was from 48.3 kg for VA/P.1 to 20.9 kg for VA/Mark (data not shown).

The trees of VA/P.1 and CL/M.26 were the heaviest at all four locations and were followed by VA/M.26. The other treatments did not differ consistently nor in most cases, significantly.

Cumulative yield. Cumulative yield per tree was strongly affected by location, cultivar, and treatment (Table 3). There were no significant interactions between cultivar and treatment. Yields were greatest in Virginia and lowest in Ontario; those in Illinois and North Carolina were interme-

Table 1. Influence of location, training system/rootstock, and cultivar on trunk cross-sectional area (TCA) of apple trees after 10 years in the 1990 NC-140 Orchard Systems Trial.

Treatment System/Rootstock (S/R)	TCA (cm^2) at following locations				
	IL	ONT	NC	VA	S/R Mean
SS/M.9EMLA	53.3 c[z]	41.0 cd	26.5 c	55.5 de	44.1
SS/B.9	55.0 c	37.9 de	27.7 c	42.6 fg	40.8
SS/Mark	44.2 c	33.5 e	30.2 c	39.4 g	36.8
VA/P.1	95.0 a	74.2 a	64.2 a	116.6 a	87.5
VA/M.26EMLA	69.3 b	57.8 b	58.3 a	91.4 b	69.2
VA/O.3	-	46.2 c	49.9 b	71.3 c	-
VA/M.9EMLA	46.5 c	44.8 c	34.5 c	59.7 d	46.4
VA/Mark	39.5 c	34.1 e	26.2 c	47.2 efg	36.8
CL/M.26EMLA	85.3 a	60.7 b	49.3 b	99.0 b	73.6
CL/Mark	51.3 c	44.4 c	27.9 c	51.7 def	43.8
Location Mean[y]	59.9	47.6	38.3	67.0	
Cultivar (CV)					
'Empire'	51.8 b	38.0 b	41.5 a	66.8 a	
'Jonagold'	68.1 a	54.0 a	-	-	
'Delicious'	-	-	37.4 b	68.1 a	
ANOVA P-value					
S/R	<0.0001	<0.0001	<0.0001	<0.0001	
CV	<0.0001	<0.0001	0.03	0.58	
S/R x CV	0.36	0.004	0.95	0.59	

[z]Mean separation within columns and groups by Duncan's multiple range test, P=0.05.
[y]Location means do not include data for VA/O.3.

diate (Table 3). In Illinois 'Empire' yields exceeded those of 'Jonagold', but in Ontario, the reverse was true. As a means of evaluating yield differences among sites, the number of years (from 1992-1999) in which average yield was less than 19 kg (one bushel) per tree was counted. Averaging the two cultivars at each site, the number of such years was 6, 7, 7, and 1 for Illinois, Ontario, North Carolina, and Virginia, respectively. The reasons for the low yields at three sites varied but were related to low precocity, overcrowding, spring frosts, problems with chemical thinning, alternate bearing, and in North Carolina with heavy pruning resulting from high vigor and low precocity.

At all locations CL/M.26 was among the most productive treatments. In two of four locations CL/Mark, VA/M.9, and VA/M.26 were not different than CL/M.26. The other treatments were generally lower in production. Averaged over

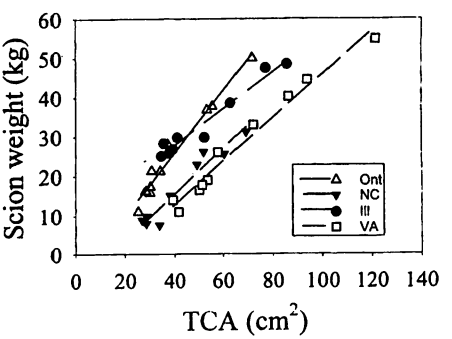

Figure 1. The relationship between scion weight and trunk-cross-sectional area (TCA) of ten-year-old 'Empire' apple trees on multiple rootstocks and in different training systems in four locations. Regressions as follows: Ontario: y = -5.98 + 0.80x; r^2 = 0.97; North Carolina: y = -7.66 + 0.58x; r^2 = 0.94; Illinois: y = 9.12 + 0.47x; r^2 = 0.96; Virginia: y = -9.66 + 0.55x; r^2 = 0.97.

Table 2. Influence of location, training system/rootstock, and cultivar on scion weight (kg/tree) of apple trees after 10 years in the 1990 NC-140 Orchard Systems Trial.

Treatment System/Rootstock (S/R)	Scion weight (kg/tree) at following locations				
	IL	ONT	NC	VA	S/R Mean
SS/M.9EMLA	32.8 c[Z]	22.6 de	10.0 bc	21.4 de	21.7
SS/B.9	31.2 cd	22.6 de	9.4 bc	15.6 ef	19.7
SS/Mark	26.4 cd	18.9 e	8.1 c	11.0 f	16.0
VA/P.1	51.5 a	49.2 a	30.6 a	50.6 a	45.5
VA/M.26EMLA	39.8 b	38.5 b	25.9 a	40.6 b	36.2
VA/O.3	-	32.6 c	26.2 a	34.2 c	-
VA/M.9EMLA	31.5 cd	27.3 cd	14.7 b	25.1 d	24.6
VA/Mark	24.8 d	18.6 e	8.1 c	16.0 ef	16.9
CL/M.26EMLA	49.5 a	40.2 b	25.1 a	47.1 a	40.5
CL/Mark	28.4 cd	25.2 d	10.3 bc	18.2 e	20.5
Location Mean[Z]	35.1	29.2	15.8	27.3	26.8
Cultivar (CV)					
'Empire'	33.4 b	24.2 b	16.4 a	27.8 a	
'Jonagold'	36.8 a	32.7 a	-	-	
'Delicious'	-	-	17.3 a	28.2 a	
ANOVA P-value					
S/R	<0.0001	<0.0001	<0.0001	<0.0001	
CV	0.02	<0.0001	0.484	0.71	
S/R x CV	0.59	0.04	0.99	0.62	

[Z]Mean separation within columns and groups by Duncan's multiple range test, P=0.05.
[Y]Location means do not include data for VA/O.3.

all four locations, CL/M.26 produced about twice the yield of each of the three SS treatments which were all very similar.

It must be kept in mind that in this paper we are evaluating cumulative yield per tree. When calculated on a per hectare basis, the much higher tree populations of the SS treatments dramatically altered the relationship among treatments (5).

Crop/scion-weight ratio. The cumulative crop to scion-weight ratio (C/S ratio) was strongly influenced by location, cultivar, and treatment (Table 4). The only significant interaction between cultivar and treatment was at Ontario and appeared to be due to a greater spread among treatment means with 'Empire' than with 'Jonagold'. The C/S ratio for 'Empire' ranged from 4.9 for VA/Mark to 1.7 for VA/P.1 and with 'Jonagold' was from 5.0 for VA/Mark to 2.7 for VA/P.1 (data not shown).

In Illinois and Ontario the C/S ratios were similar (Table 4) because the somewhat larger trees in Illinois (Tables 1, 2) produced proportionally more fruit than did the smaller, lower yielding trees in Ontario (Table 3). Although yields in North Carolina were only about 56% as high as in Virginia (Table 3), the C/S ratio in North Carolina was similar to that in Virginia because the mean tree size in North Carolina was also proportionally smaller (Tables 1, 2). Of particular interest is the greater than 2:1 difference in C/S ratios in North Carolina and Virginia compared to those in Illinois and Ontario. This difference is due largely to the relatively large trees and relatively low cumulative yields in Illinois and Ontario. Perhaps most noteworthy of all is that in spite of the large differences in C/S ratio among the four sites, the relative ranking of treatment means for the C/S ratio is quite similar. This would seem to be good evidence that the C/S ratio is an excellent means of ranking relative productivity of rootstock/training system

Table 3. Influence of location, training system/rootstock, and cultivar on cumulative yield (kg/tree) of apple trees after 10 years in the 1990 NC-140 Orchard Systems Trial.

Treatment System/Rootstock (S/R)	Cumulative yield (kg/tree) at following locations				
	IL	ONT	NC	VA	S/R Mean
SS/M.9EMLA	81.1 b[Z]	71.5 c	68.6 d	132.0 c	88.3
SS/B.9	80.3 b	67.8 c	66.9 d	125.9 c	85.2
SS/Mark	79.7 b	62.8 c	76.6 cd	124.4 c	85.9
VA/P.1	96.1 b	91.3 b	79.4 cd	202.5 b	117.3
VA/M.26EMLA	122.8 a	102.8 a	140.2 ab	227.4 b	148.3
VA/O.3	--	93.4 ab	110.2 bc	226.9 b	--
VA/M.9EMLA	121.5 a	101.9 a	116.3 bc	239.3 ab	144.8
VA/Mark	97.6 b	86.0 b	113.6 bc	201.2 b	124.6
CL/M.26EMLA	141.8 a	102.0 a	175.4 a	271.5 a	172.7
CL/Mark	132.4 a	101.7 a	144.8 ab	219.7 b	149.6
Location Mean[Y]	105.9	87.5	109.1	193.8	124.1
Cultivar (CV)					
'Empire'	132.8 a	68.3 b	124.3 a	210.4 a	
'Jonagold'	79.0 b	101.3 a	-	-	
'Delicious'	-	-	94.0 b	183.7 b	
ANOVA P-value					
S/R	<0.0001	<0.0001	<0.0001	<0.0001	
CV	<0.0001	<0.0001	0.007	0.002	
SR x CV	0.28	0.27	0.59	0.66	

[Z]Mean separation within columns and groups by Duncan's multiple range test, P=0.005.
[Y]Location means do not include data for VA/0.3.

treatments in both high- and low-yielding sites.

The C/S ratio was higher for 'Jonagold' than 'Empire' at Illinois, primarily due to much higher yields for 'Jonagold'. The C/S ratio for the two cultivars did not differ in Ontario. In both North Carolina and Virginia the C/S ratio was higher for 'Empire' than for 'Delicious', due primarily to higher yields for 'Empire' while tree sizes differed little.

Data on C/S ratios from multiple long-term rootstock studies were published by Preston (7). He reported that after 20 years, the C/S ratios for Cox's Orange Pippin/M.9 and Jonathan/M.9 were 13.9 and 27.0, respectively. In our study, the C/S ratio differences between cultivars were relatively large in Illinois and North Carolina, but smaller in Ontario and Virginia (Table 4). In comparing the Virginia C/S data herein with that published earlier from an 18-year study with 'Golden Delicious' (1) and 'Delicious' (2), only two rootstocks are common to both studies. The C/S ratio for VA/M.26 was about 68% of that for VA/M.9; in the earlier study, trees on M.26 had C/S ratios about 72% as large as trees on M.9. Considering the differences in cultivars, training systems, and ages, the relationships between M.9 and M.26 are quite similar.

Since trees in this study were defruited until the third year, the trees potentially cropped for eight years. On the basis of C/S ratios, trees in all treatments in Virginia and North Carolina averaged annual yields of approximately the final scion weight. This compares favorably with the M.9 data published earlier by Barden and Marini (3). In comparison, average annual yields in Illinois and Ontario were less than one-half of the final scion weight. Averaged across all sites, trees on Mark had higher C/S ratios than M.9, to a large degree because they essentially stopped

Table 4. Influence of location, training system/rootstock, and cultivar on cumulative crop/scion ratio (C/S ratio)(kg/kg) of apple trees after 10 years in the 1990 NC-140 Orchard Systems Trial.

Treatment System/Rootstock (S/R)	Crop/scion ratios at following locations				
	IL	ONT	NC	VA	S/R Mean
SS/M.9EMLA	2.65 cd[Z]	3.49 bc	7.27 bc	6.48 e	4.97
SS/B.9	2.83 c	3.17 cd	7.47 bc	8.62.cd	5.52
SS/Mark	3.21 bc	4.00 bc	10.00 b	11.22 ab	7.09
VA/P.1	2.03 d	2.16 e	2.66 d	3.95 f	2.70
VA/M.26EMLA	3.23 bc	2.74 d	5.61 cd	5.74 ef	4.33
VA/O.3	--	3.01 cd	4.49 cd	6.68 de	--
VA/M.9EMLA	3.84 b	3.87 b	7.97 bc	9.64 bc	6.33
VA/Mark	3.93 b	4.94 a	15.96 a	12.91 a	9.43
CL/M.26EMLA	3.09 bc	2.80 d	7.67 bc	5.82 ef	4.84
CL/Mark	4.82 a	4.50 ab	14.51 a	13.15 a	9.13
Location Mean[Y]	3.29	3.51	8.79	8.61	6.05
Cultivar (CV)					
'Empire'	2.38 b	3.46 a	9.75 a	8.93 a	
'Jonagold'	4.20 a	3.45 a	-	-	
'Delicious'	-	-	6.98 b	7.91 b	
ANOVA P>F					
S/R	<0.0001	0.55	<0.0001	<0.0001	
CV	<0.0001	<0.0001	0.0002	0.03	
SR x CV	0.27	0.006	0.98	0.65	

[Z]Mean separation within columns and groups by Duncan's multiple range test, P=0.05.
[Y]Location means do not include data for VA/O.3.

growing but continued to fruit. The overly vigorous P.1 had very low C/S ratios and trees on M.26 were intermediate. Because only the final year's crop was included by Strong and Azarenko (9), no direct comparison can be made between our data and theirs.

The relationship between TCA and scion weight for 'Empire' trees in the four locations is shown in Fig. 1. The slopes were very similar for North Carolina and Virginia. The slopes for Ontario and Illinois were somewhat different from each other as well as from North Carolina and Virginia. Within each site, however, the linear relationship is very strong, offering additional support to the findings of Westwood and Roberts (10). The similarity of the relationships in Virginia and North Carolina are particularly interesting in relation to the statement by Westwood and Roberts (10) that pruning severity may alter the scion weight/TCA relationship. In comparing the Virginia and North Carolina data, it appears that pruning severity may not greatly alter this relationship. When the data for all four sites were combined, the resulting regression equation was as follows: $y = 0.71 + 0.50x$; $r^2 = 0.72$.

From the summary paper for the NC-140 1990 Systems Trial (5), the YE data for the two sites with low C/S ratios (Illinois and Ontario) and the two sites with high C/S ratios (North Carolina and Virginia) were ranked and are presented in Table 5. Likewise the C/S ratio data for the same pairs of sites were also ranked and are presented in Table 5. In comparing YE between the low and high C/S ratio sites, the mean YE at the high C/S sites averaged 50% greater at the low C/S sites. Using the C/S ratios, this relationship was 2.5 : 1. Although the relationships between the pairs of sites varied with the measure of productivity, when the treatments were ranked from high to low, the array was surprisingly similar whether using YE or C/S ratio (Table 5). We can also make the observa-

Table 5. Ranking[Z] (from high to low) of treatments based upon yield efficiency (YE)[Y] and crop/scion ratio (C/S ratio)[X].

Treatment (system/rootstock)	YE IL+ONT	YE NC+VA	YE All 4 sites	C/S ratio IL+ONT	C/S ratio NC+VA	C/S ratio[X] All 4 sites
SS/M.9EMLA	6.0	6.0	6.0	6.5	6.5	6.5
SS/B.9	5.5	5.0	5.2	6.5	5.5	6.0
SS/Mark	3.5	5.0	4.2	4.0	3.0	3.5
VA/P.1	9.0	9.0	9.0	9.0	9.0	9.0
VA/M.26EMLA	6.0	8.0	7.0	6.0	8.0	7.0
VA/O.3	-	-	-	-	-	-
VA/M.9EMLA	2.0	3.5	2.8	3.5	4.0	3.8
VA/Mark	2.5	1.5	2.0	1.5	1.5	1.5
CL/M.26EMLA	6.5	5.0	5.8	6.5	6.0	6.2
CL/Mark	1.5	1.5	1.5	1.5	1.5	1.5

[Z]When means were the same, they were assigned the same rating.
[Y]YE = Kg fruit/cm^{2}TCA; data from Table 6 in (5).
[X]C/S ratio = kg fruit/kg scion; data used are from Table 4, herein.

tion that even though the second cultivars differed between the low and high C/S sites, the rankings are surprisingly consistent. On the bases of these observations, certain conclusions seem justified. One is that both the YE and C/S ratio data provide essentially the same overall conclusion as to the relative production efficiency of different system/rootstock treatments. It is certainly easier to obtain TCA data than to obtain scion weight data and there are also many TCA data already in the literature for comparative purposes. It seems therefore, that the additional time and effort in weighing trees may not be routinely justified.

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