Performance of 'Golden Delicious,' 'Jonagold,' 'Empire,' and 'Rome Beauty' Apple Trees on Five Rootstocks Over Ten Years in the 1990 NC-140 Cultivar/Rootstock Trial[1]

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Abstract

At 12 sites in the United States, trials were established in 1990 which included four apple (*Malus* X *domestica* Borkh.) cultivars ('Smoothee Golden Delicious,' 'Nicobel Jonagold,' 'Empire,' and 'Law Rome Beauty') in all combinations on five rootstocks (M.9 EMLA, B.9, Mark, O.3, and M.26 EMLA). After ten growing seasons, rootstock and scion cultivar interacted significantly to affect trunk cross-sectional area (TCA), root suckering, yield efficiency, and fruit size but not survival or yield per tree. In all cases these statistically significant interactions contributed minimally to the variability among rootstocks and were relatively unimportant in determining tree performance. Comparing cultivars after 10 years, survival was greatest for 'Empire' and poorest for 'Rome.' 'Jonagold' had the largest TCA, and 'Empire' and 'Rome' had the smallest. Root suckering occurred most prevalently with 'Empire.' 'Rome' yielded the most, and 'Jonagold' and 'Empire' yielded the least. 'Rome' trees also were the most yield efficient, and 'Jonagold' trees were the least efficient. Largest fruit were 'Rome' and 'Jonagold.' Comparing rootstock effects over 10 years, B.9 resulted in the greater tree survival than did O.3. M.9 EMLA, and Mark, and M.26 EMLA resulted in intermediate survival. Trees with the greatest TCA were on M.26 EMLA. Trees on M.9 EMLA and those on O.3 were similar and significantly smaller. Trees on B.9 and those on Mark were similar in size and the smallest in the trial. The greatest root suckering developed from B.9, Mark, and O.3, and the least came from M.26 EMLA. Trees on M.26 EMLA, O.3, and M.9 EMLA yielded similarly and significantly more than those on B.9 or Mark. The most yield efficient trees, however, were on B.9 and Mark, and the least were on M.26 EMLA. M.26 EMLAand M.9 EMLA resulted in the largest fruit size, and Mark resulted in the smallest.

Researchers have studied the effects of rootstock on apple tree performance for more than 100 years. The NC-140 Technical Committee has organized a number of these studies, including more than 30 different rootstocks (e.g., 8, 9). Relative performance of rootstocks has not always been consistent. Some variation in performance may be attributed to the interaction of rootstock with cultivar, but only a few studies have assessed this interaction directly.

Schupp (12) compared 'Pioneer Mac,' 'Marshall McIntosh,' 'Ginger Gold,' and 'Empire' in all combinations on M.26 and Mark rootstocks. Rootstock and cultivar interacted, such that, the trunk

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cross-sectional area (TCA) of 'Pioneer Mac' on M.26 was approximately 25% greater than comparable trees on Mark, but 'Empire' trees on Mark were about 61% larger than those on M.26. Schupp and Koller (13) found 'Dayton' and 'Williams Pride' trees to have similar TCA when on M.27 EMLA and Mark, but 'Dayton' trees were significantly larger than 'Williams Pride' trees with both on M.26 EMLA. Barden and Marini (3) observed that MM.111, MM.106, and M.7 resulted in similar yield efficiency of 'Red Prince Delicious' trees, but with 'Redchief Delicious,' MM.106 resulted in significantly more efficient trees than did MM.111 or M.7. Czynczyk and Piskor (6) showed P.59 to result in greater yield efficiency than B.9 or P.60 with 'Gloster,' but these three rootstocks resulted in similar yield efficiency with 'Melrouge.' Sadowski et al. (11) compared four strains of M.9 rootstock (EMLA, NAKBT337, NAKBT339, and Burgmer 984) and found that the largest 'Jonagold' trees were on M.9 EMLA and M.9 Burgmer 984. However, the largest 'Holiday' trees were on M.9 EMLA, and the largest 'Fiesta' trees were on M.9 NAKBT337 and M.9 NAKBT339. These studies show some potential for different rootstock effects depending on the scion cultivar.

On the other hand, studies by Barritt et al. (4), Barritt et al. (5), Ferree et al. (7), and Schupp and Koller (14) found only small variation in the relative effects of rootstock on tree size or yield of several different cultivars.

The objective of the study reported here was to compare rootstock effects on tree performance utilizing cultivars ranging in growth habit from the spur-type and basitonic 'Empire' to the tip-bearing and acrotonic 'Rome' in an attempt to predict variability in rootstock response with different cultivars. Several articles are included in this issue of the *Journal of the American Pomological Society*. The first will address overall cultivar and rootstock effects and interactions. The second will report variation in response as affected by location. Another will discuss cold damage, and a fourth will present data from additional cultivars and rootstocks at a few locations

Materials & Methods

Details regarding the initiation of this trial were presented previously (10). Seventeen locations were included initially; however, five plantings were removed during the trial. The twelve locations remaining in the trial through the tenth growing season are listed in Table 1. Trees were planted in 1990 from February through May, depending on site. All trees were spaced 3 x 5.5 m. The entire trial was a randomized-complete-block/split-split plot design, with location and replication nested within location as the whole plot, cultivar as the split plot, and rootstock as the split-split plot. Each site had six replications. Each replication included a single tree of each cultivar-rootstock combination. All trees were supported with an individual stake and were trained as slender spindles. Pests, fertility, fruit thinning, and water were managed according to local recommendations.

Trunk circumference was measured each October at approximately 25 cm above the graft union. Trees were defruited in 1990 and 1991, and total yield per tree was assessed each year from 1992 through 1999. Each fruiting year, 25 fruit were sampled randomly from each tree and weighed to estimate average fruit weight.

Data collection and analyses were organized by the Massachusetts site cooperator. Analyses of variance were conducted with the MIXED procedure of the SAS software package (SAS Institute,

Cary, NC). For the results presented in this article, cultivar, rootstock, and the interaction of cultivar and rootstock were considered fixed effects. Location, replication nested within location, and all additional interactions were considered random. Considering location to be a random effect allowed calculation of overall cultivar, rootstock, and cultivar x rootstock least-squares means; however, it must be noted that locations with completely missing rootstocks or combinations of rootstock and cultivar reduced the accuracy of these least-squares means. Tukey's HSD ($P = 0.05$) was used to separate overall rootstock and overall cultivar least-squares means. In cases where significant interactions between cultivar and rootstock existed, the sums of squares for rootstock and the interaction were repartitioned into units representing the effects of rootstock within each cultivar utilizing the SLICE option of the LSMEANS statement. Where rootstock within cultivar was significant, a t test ($P = 0.05$) was used to separate rootstock least-squares means; however, a Bonferroni adjustment was applied prior to determining the significance of each pairwise comparison (i.e., $P = 0.005$ was used as the critical value to declare significance).

Results & Discussion

Tree survival. Cultivar and rootstock did not interact to affect tree survival. 'Empire' trees survived to the end of the trial to a significantly greater extent than did 'Rome' trees (Table 2). 'Golden Delicious' and 'Jonagold' trees were intermediate between the two other cultivars. The reduced survival of 'Rome' appears to be due primarily to its sensitivity to fireblight and resultant tree loss in a few locations. Locational variation is shown in the second article of this series (1). Trees on B.9 survived significantly better than did trees on O.3, with M.9 EMLA, Mark, and M.26 EMLA resulting in survival intermediate to B.9 and O.3 (Table 2). Similarly poor survival of trees on O.3 was noted by NC-140 (8) in the 1980/81 NC-140 Apple Rootstock Trial.

Tree size. Over all rootstocks, 'Jonagold' trees had significantly greater TCA than 'Empire' and 'Rome' trees (Table 3). 'Golden Delicious' trees were intermediate. Over all cultivars, trees on M.26 EMLA had significantly greater TCA than trees on any of the other rootstocks (Table 3). Among the others, trees on M.9 EMLA and those on O.3 were significantly larger than trees on B.9 or Mark. Although cultivar and rootstock interacted significantly to affect TCA, the relative differences among rootstocks did not vary dramatically among cultivars (Table 3). Specifically, M.26 EMLA resulted in the greatest TCA, and B.9 and Mark resulted in the smallest TCA, regardless of cultivar. Trees on M.9 EMLA had similar TCA to those on O.3, also regardless of cultivar. Similar rootstock effects were presented by NC-140 (8).

Rootstock and cultivar did not interact significantly to affect tree height at the end of 10 growing seasons. Furthermore, cultivar did not affect tree(Table 3). Trees on M.26 EMLA were significantly taller than those on O.3, with trees on M.9 EMLA intermediate to the two (Table 3). All three resulted in taller trees than those on B.9, which were taller than those on Mark. NC-140 (8) reported similar relative height differences caused by M.9 EMLA, M.26 EMLA, O.3, and MAC.9 (later named Mark).

Cultivar also did not affect canopy spread (Table 3). M.26 EMLA resulted in greater canopy spread than did M.9 EMLA, with trees on O.3 intermediate between the two (Table 3). All three resulted in greater spread than did B.9, which in turn resulted in greater spread than Mark. As with

TCA, cultivar and rootstock interacted significantly to affect canopy spread, but relative effects of rootstock were not dramatically different. Specifically, M.26 EMLA resulted in the greatest spread, and B.9 and Mark resulted in the smallest spread, regardless of rootstock (Table 3). M.9 EMLA and O.3 resulted in similar spread, regardless of rootstock.

Root suckering. 'Empire' produced more root suckers over the 10-year life of this trial than any of the other cultivars (Table 4). Autio and Southwick (2) also reported cultivar effects on root suckering, but in their study, a spur-type cultivar produced fewer root suckers than did a standard cultivar. Over all cultivars, B.9, Mark, and O.3 produced more suckers than did M.26 EMLA, with M.9 intermediate between these two groups (Table 4). However, cultivar and rootstock interacted to affect suckering. Specifically, M.26 EMLA produced the fewest suckers regardless of cultivar, but the differences among all rootstocks were nonsignificant with 'Jonagold' and 'Rome.' With 'Golden Delicious,' B.9 and Mark produced more root suckers than did M.26 EMLA. With 'Empire,' O.3 produced more suckers than did B.9 and M.9 EMLA, with Mark intermediate and M.26 significantly less than all others.

Yield per tree. Cultivar and rootstock did not interact significantly to affect yield per tree during the cropping years (1992-99) of this trial. 'Rome' trees yielded significantly more than 'Jonagold' and 'Empire' trees (Table 5). 'Golden Delicoius' trees were intermediate. Trees on M.26 EMLA, O.3, and M.9 EMLA yielded similarly and significantly more than trees on Mark or B.9 (Table 5). Relative differences among rootstocks were similar to those reported by NC-140 (8).

Yield efficiency. Cumulatively (1992-99), 'Rome' trees were significantly more yield efficient than were 'Jonagold' trees (Table 5). 'Golden Delicious' and 'Empire' were intermediate. Trees on B.9 were more efficient than those on M.9 EMLA, with trees on Mark intermediate (Table 6). Trees on B.9 and those on Mark were more efficient than trees on O.3, and trees on M.26 EMLA were the least efficient. Minor variation in the relative effects of rootstock occurred across cultivar. Specifically, trees on B.9 and those on Mark were similarly efficient with 'Golden Delicious,' 'Jonagold,' and 'Empire,' but 'Rome' trees on B.9 were significantly more efficient than comparable trees on Mark. Trees on M.9 EMLA and those on Mark were similarly efficient with 'Golden Delicious,' 'Jonagold,' and 'Rome,' but 'Empire' trees on M.9 EMLA were more efficient than those on O.3.

Barritt et al. (4) reported a similar general relationship among rootstocks for cumulative yield efficiency to the one reported in this study, also with some interaction between cultivar and rootstock. 'Golden Delicous,' trees on Mark were more efficient than those on B.9, and with 'Delicious,' the reverse was true. 'Granny Smith' trees were similarly yield efficient on the two rootstocks. They also reported that 'Delicious' trees on O.3 were significantly more efficient than comparable trees on Mark. Ferree et al. (7) also reported a similar general relationship among rootstocks over eight seasons, but with very little interaction between cultivar and rootstock

Fruit Size. 'Rome' and 'Jonagold' had the largest average fruit size over the life of the study, followed by 'Golden Delicious' and 'Empire' (Table 6). Over all scion cultivars, M.26 EMLA and M.9 EMLA resulted in significantly larger fruit than did B.9 or O.3 (Table 6). Trees on these four rootstock all produced significantly larger fruit than trees on Mark. Rootstock and cultivar interacted significantly, but variation existed only in the magnitude of the rootstock effect.

Conclusions

As trees in this study have matured, the interactions among scion cultivar and rootstock have declined. After five years, the interaction affected nearly all measured parameters (10). After ten years, some of these interactions still were statistically significant, but they were less important. Specifically, the interaction of cultivar and rootstock did not affect tree survival. Differences in TCA caused by rootstock were relatively consistent across cultivar, with trees on M.26 EMLA being the largest and those on Mark and B.9 being the smallest. Yield per tree was not affected by the interaction of cultivar and rootstock. M.26 EMLA, O.3, and M.9 EMLA produced the greatest cumulative yield per tree, and Mark and B.9 resulted in the least. Yield efficiency, although affected significantly by the interaction, did not vary greatly from cultivar to cultivar. B.9 and Mark resulted in the most efficient trees, and M.26 EMLA resulted in the least efficient trees. Trees on M.9 EMLA and those on O.3 were intermediate. Cultivar affected only the magnitude of the rootstock affect on fruit size, such that fruit from trees on M.26 EMLA and from trees on M.9 EMLA were the largest, and fruit from trees on Mark were the smallest, across cultivars.

These results from a study conducted over 12 locations throughout the U.S. suggest that the relative importance of the interaction of cultivar and rootstock is low. Earlier NC-140 studies utilizing these rootstocks with 'Delicious' as the cultivar (8, 9) predicted relative performance adequately.

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Table 1. Site locations and cooperators in the 1990 NC-140 Apple Cultivar/Rootstock Trial.

State	Planting location	Cooperator
Colorado	Hotchkiss	Alvan Gaus
Iowa	Ames	Paul Domoto
Indiana	West Lafayette	Peter Hirst
Kansas	Wichita	Alan Erb
Kentucky	Princeton	Gerald Brown
Massachusetts	Belchertown	Wesley Autio
Maine	Monmouth	James Schupp
Ohio	Wooster	David Ferree
Pennsylvania	University Partk	Robert Crassweller
Tennessee	Crossville	Charles Mullins
Utah	Logan	J. LaMar Anderson
Virginia	Blacksburg	John Barden

Table 2. Survival as affected by cultivar and rootstock after 10 years in the 1990 NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing subclasses.[z]

Rootstock	Golden Delicious	Jonagold	Empire	Rome	Mean
			Survival (%)		
M.9 EMLA	93	80	91	77	85 ab
B.9	97	83	97	90	92 a
Mark	89	82	96	78	86 ab
O.3	82	83	83	63	78 b
M.26 EMLA	91	87	96	77	88 ab
Mean	90 ab	83 ab	93 a	77 b	

[z]Separation among overall rootstock means and among overall cultivar means by Tukey's HSD (P = 0.05).

Table 3. Trunk cross-sectional area, tree height, and canopy spread as affected by cultivar and rootstock after 10 years in the 1990 NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing subclasses. Cultivar and rootstock interacted significantly to affect trunk cross-sectional area and canopy spread, so mean separations are presented for rootstock within each cultivar.[z]

Rootstock	Golden Delicious	Jonagold	Empire	Rome	Mean
			Trunk cross-sectional area (cm^2)		
M.9 EMLA	80 bc	111 ab	68 bc	86 b	86 b
B.9	61 cd	59 c	54 cd	50 c	56 c
Mark	43 d	49 c	42 d	47 c	45 c
O.3	90 b	92 b	84 b	84 b	88 b
M.26 EMLA	117 a	132 a	110 a	111 a	118 a
Mean	78 ab	89 a	72 b	76 b	
			Tree height (m)		
M.9 EMLA	3.5	3.6	3.2	3.6	3.5 ab
B.9	3.2	2.9	2.9	2.9	3.0 c
Mark	2.7	2.6	2.5	2.6	2.6 d
O.3	3.5	3.3	3.4	3.5	3.4 b
M.26 EMLA	3.8	3.8	3.6	3.7	3.7 a
Mean	3.4 a	3.2 a	3.1 a	3.2 a	
			Canopy spread (m)		
M.9 EMLA	3.2 ab	3.6 a	3.2 b	3.5 a	3.4 b
B.9	3.0 bc	3.0 b	3.0 b	3.0 b	3.0 c
Mark	2.6 c	2.6 b	2.6 c	2.6 c	2.6 d
O.3	3.4 a	3.4 a	3.5 ab	3.5 a	3.4 ab
M.26 EMLA	3.6 a	3.6 a	3.9 a	3.7 a	3.7 a
Mean	3.2 a	3.2 a	3.2 a	3.2 a	

[z]Separation among overall rootstock means and among overall cultivar means by Tukey's HSD (P = 0.05). Mean separation among rootstocks within cultivars by t test (P = 0.05) with a Bonferroni adjustment (adjusted P = 0.005).

Table 4. Root suckering as affected by cultivar and rootstock after 10 years in the 1990 NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing subclasses. Cultivar and rootstock interacted significantly to affect suckering, so mean separations are presented for rootstock within each cultivar.[z]

Rootstock	Golden Delicious	Jonagold	Empire	Rome	Mean
			Cumulative root suckers (no./tree)		
M.9 EMLA	5 ab	9 a	39 b	8 a	15 ab
B.9	29 a	18 a	34 b	10 a	23 a
Mark	26 a	16 a	43 ab	10 a	24 a
O.3	22 ab	2 a	64 a	14 a	25 a
M.26 EMLA	2 b	2 a	6 c	1 a	3 b
Mean	17 b	9 b	37 a	9 b	

[z]Separation among overall rootstock means and among overall cultivar means by Tukey's HSD (P = 0.05). Mean separation among rootstocks within cultivars by t test (P = 0.05) with a Bonferroni adjustment (adjusted P = 0.005).

Table 5. Cumulative yield per tree and cumulative yield efficiency as affected by cultivar and rootstock after 10 years in the 1990 NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing subclasses. Cultivar and rootstock interacted significantly to affect cumulative yield efficiency, so mean separations are presented for rootstock within each cultivar.[z]

Rootstock	Golden Delicious	Jonagold	Empire	Rome	Mean
		Cumulative yield per tree (1992-99, kg)			
M.9 EMLA	195	188	158	230	193 a
B.9	169	140	117	177	151 b
Mark	131	118	96	158	126 b
O.3	212	175	174	236	199 a
M.26 EMLA	216	200	182	244	210 a
Mean	184 ab	164 b	145 b	209 a	
	Cumulative yield efficiency (1992-99, kg/cm^2 trunk cross-sectional area)				
M.9 EMLA	2.50 ab	1.95 b	2.79 a	2.80 bc	2.51 bc
B.9	2.85 a	2.73 a	2.73 ab	3.75 a	3.02 a
Mark	3.10 a	2.67 a	2.91 a	3.07 b	2.94 ab
O.3	2.54 a	1.97 b	2.27 b	2.84 bc	2.40 c
M.26 EMLA	1.98 b	1.65 b	1.70 c	2.33 c	1.92 d
Mean	2.49 ab	2.19 b	2.48 ab	2.96 a	

[z]Separation among overall rootstock means and among overall cultivar means by Tukey's HSD (P = 0.05). Mean separation among rootstocks within cultivars by t test (P = 0.05) with a Bonferroni adjustment (adjusted P = 0.005).

Table 6. Average fruit size (adjusted for annual yield) as affected by cultivar and rootstock after 10 years in the 1990 NC-140 Cultivar/Rootstock Trial. All values are least-squares means, adjusted for missing subclasses. Cultivar and rootstock interacted significantly to affect fruit size, so mean separations are presented for rootstock within each cultivar.[z]

Rootstock	Golden Delicious	Jonagold	Empire	Rome	Mean
			Fruit size (1992-99, g)		
M.9 EMLA	180 ab	226 a	154 ab	209 a	192 a
B.9	173 b	210 b	155 ab	203 ab	185 b
Mark	158 c	197 c	149 b	196 b	175 c
O.3	173 b	206 bc	150 ab	196 b	181 b
M.26 EMLA	186 a	225 a	158 a	206 a	194 a
Mean	174 b	213 a	153 c	202 a	

[z]Separation among overall rootstock means and among overall cultivar means by Tukey's HSD (P = 0.05). Mean separation among rootstocks within cultivars by t test (P = 0.05) with a Bonferroni adjustment (adjusted P = 0.005).