Performance of trees in the 1990 NC-140 apple cultivar/rootstock planting: additional cultivars and rootstocks[1]

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Abstract

In 1990, up to 10 apple (*Malus* X *domestica* Borkh.) cultivars were planted on four to seven rootstocks at six sites in the midwestern and eastern United States. The growth and field performance of these trees was measured over 10 years. Although some cultivar x rootstock interactions were evident, tree growth and performance was primarily due to the main effects of cultivar and rootstock. Cultivar had no effect on tree size at three sites, while at other sites 'Rome Beauty', 'Jonagold' and 'McIntosh' trees were the largest. 'Stayman' and 'Empire' trees were among the smallest trees across sites. Trees growing on M.26 EMLA were among the largest trees at all sites, although trees on M.9 EMLA were similar in size at two sites. The smallest trees were produced by B.9, Mark, P.22 and M.27 EMLA rootstocks. No single cultivar produced the highest yield at all sites. 'Golden Delicious' was among the most productive cultivars at three sites, but performed only moderately or poorly at other sites. 'Empire' and 'McIntosh' trees had the lowest yields per tree at most sites. Yields per tree tended to be closely related to tree size, therefore rootstocks producing the largest trees (M.26 EMLA, M.9 EMLA) also produced the largest yields. 'York Imperial' and 'Stayman' trees were highly efficient, and although 'Rome' trees were efficient in some sites, they were inefficient in others. Consistently the most efficient rootstocks were B.9, P.22, and Mark. M.26 EMLA was among the least efficient trees at each site. A significant negative relationship between tree size and yield efficiency was evident at each site, but the relationship differed among sites.

There is a plethora of reports of rootstock performance in the literature, but in most instances, these were conducted with one test cultivar. Studies comparing a number of cultivars growing on a range of rootstocks have produced differing results. Some studies showed that rootstock performance varied depending on the scion cultivar (8, 9) whereas in other studies the rootstock x scion interactions were either insignificant or contributed little to the overall effects (2, 3, 5, 10).

The objective of this study was to compare the growth and performance of a number of apple cultivars growing on up to seven rootstocks across six sites. This paper is one of a series appearing in this issue of the Journal of the American Pomological Society describing results from a NC-140 cultivar/rootstock trial planted at a number of

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sites in 1990. Some of the cooperating sites in this planting included cultivars and/or rootstocks additional to those on the main planting (1), and the performance of these additional trees is reported here.

Materials & Methods

An apple planting was established in 1990 as previously described (1, 7). Briefly, the planting consisted of four cultivars ('Smoothee Golden Delicious', 'Nicobel Jonagold', 'Empire', 'Law Rome Beauty') growing on five rootstocks (M.9 EMLA, B.9, Mark, O.3, M.26 EMLA) in 12 sites (CO, IA, IN, KS, KY, MA, ME, OH, PA, TN, UT, VA). The performance of these trees was reported by Autio et al. (1). Additional trees of a range of cultivars and rootstocks were included in the plantings at six of the sites (Table 1). These were generally combined in a factorial arrangement where each cultivar was growing on each rootstock. For example, in Iowa, the trees additional to the main planting were 'Jonathan' and 'Chieftain' growing on M.9 EMLA, B.9, Mark, O.3, and M.26 EMLA rootstocks.

Each year during October, trunk circumference was measured approximately 25 cm above the graft union, and trunk cross-sectional area was calculated. After defruiting the trees in the first two growing seasons, annual yield per tree was measured. Data collection and analyses were performed by the Massachusetts site cooperator (1). The MIXED procedure of SAS (SAS Institute, Cary, NC) was used to analyze the data. For a more complete description of statistical procedures, see Autio et al. (1).

Results & Discussion

Tree size. Tree size was the product of cultivar, rootstock, and their interaction, although this was not consistent across all sites. At three sites (IN, KY, ME) cultivar had no effect on tree size while the interaction between cultivar and rootstock was significant at some sites (IA, IN, ME, PA) but not at others (KY, VA) (Tables 2- 7). 'Jonagold', 'Rome' and 'Golden Delicious' consistently ranked among the largest trees at each site, while 'Empire' and 'Stayman' tended to be the smallest. As expected, trees on M.26 EMLA rootstock ranked as the largest at each site, although at two sites, those on M.9 EMLA and O.3 were similar in size. Trees growing on Mark, B.9, P.22, and M.27 EMLA were similar in size and were consistently in the smallest category at every site. At all sites, trees on B.9 were smaller than those on M.9 EMLA.

Yield per tree. In ME, cultivar had no effect on yield per tree, but cultivar differences were evident at all other sites. There was no cultivar that produced high yields at all sites. 'Golden Delicious' was among the most productive in three sites (IA, IN, KY) but at other sites, was intermediate (PA) or low (VA) in terms of yield per tree of other cultivars. 'Rome' was relatively productive in IA, IN, PA, and VA but was among the lowest yielding cultivars in KY. 'York' was also quite productive at the two sites where this cultivar was included (PA and VA). Trees growing on M.26 EMLA and M.9 EMLA rootstocks tended to be the highest yielding at each site, except in Iowa where trees on M.26 EMLA were relatively unproductive. The smallest trees also tended to have the lowest yields per tree, therefore typically trees growing on Mark, B.9, P.22, and M.27 EMLA rootstocks had the lowest yields at each site.

Yield efficiency. There were no cultivars that had consistently high yield efficiencies across all sites. For example, 'Rome' was among the most efficient cultivars in IN, ME, PA, and VA but was among the least efficient in IA and KY. 'York' and 'Stayman' trees were highly efficient while 'McIntosh' trees had low efficiency, although these cultivars were only planted at two sites. Overall, trees on B.9 were the most efficient, although trees growing on P.22 rootstock were similar at the two sites where this rootstock was included. Trees growing on Mark were also consistently efficient, as opposed to M.26 EMLA, which was the least efficient rootstock at each site.

At each site, there was a significant negative relationship between tree size and yield efficiency (Figure 1). The slopes defining these relationships were broadly similar across sites. Trees in VA were generally much more efficient than those at other sites, due to higher yields from trees of similar sizes. Strong relationships between tree size and yield efficiency have previously been described where smaller trees were more efficient (3, 4, 6).

When trees were grouped by cultivar (across all sites and rootstocks) or by rootstock (across all sites and cultivars), there were not significant relationships between cumulative yield efficiency and tree size in most cases (data not presented). This suggests that site was the predominant influence on tree performance in this study. Site also had a much larger effect than rootstock on tree performance in a recent study with 'Gala' growing on 18 dwarf and 4 semi-dwarf rootstocks (6). This reiterates the importance of conducting coordinated trials such as this to enable the response of cultivars and/or rootstocks to be measured across widely varying sites. Such trials are a necessary pre-requisite to making appropriate site-specific recommendations to growers.

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Table 1. List of cultivars and rootstocks at each of the six sites. Shaded areas indicate cultivars and rootstocks that formed the main planting described by Autio et al. (1).

Site	IA	IN	KY	ME	PA	VA
Cutlivars						
Jonathan	X					
Chieftain	X					
Liberty			X			
McIntosh				X	X	
York					X	X
Stayman					X	X
Golden Delicious	X	X	X	X	X	X
Jonagold	X	X	X	X	X	X
Empire	X	X	X	X	X	X
Rome	X	X	X	X	X	X
Rootstocks						
P.22		X	X			
M.27 EMLA		X				
M.9 EMLA	X	X	X		X	X
B.9	X	X	X	X	X	X
Mark	X	X	X	X		X
O.3	X	X	X	X	X	X
M.26EMLA	X	X	X	X	X	X

Table 2. Trunk cross-sectional area and yield as affected by cultivar and rootstock after 10 years in the 1990 NC-140 Cultivar/Rootstock Trial in **Iowa**. All values are least-squares means, adjusted for missing subclasses. Cultivar and rootstock interacted significantly to affect trunk cross-sectional area, yield per tree, and yield efficiency so mean separations are presented for rootstock within each cultivar.[z]

Rootstock	Golden Delicious	Jonagold	Empire	Rome	Jonathan	Chieftain	Mean
			Trunk cross-sectional area (cm^2)				
M.9 EMLA	89 b	105 ab	65 b	86 b	94 a	81 b	87 b
B.9	48 c	51 c	35 c	58 c	49 b	44 c	47 c
Mark	40 c	44 c	29 c	50 c	36 b	44 c	41 c
O.3	95 ab	88 b	83 ab	101 ab	94 a	78 b	90 b
M.26 EMLA	116 a	124 a	94 a	114 a	109 a	121 a	113 a
Mean	78 ab	82 a	61 b	82 a	76 ab	74 ab	
			Cumulative yield per tree (1992-99, kg)				
M.9 EMLA	122 ab	99 a	121 a	107 a	102 ab	104 a	109 a
B.9	105 bc	83 ab	74 b	103 a	89 b	89 a	90 bc
Mark	84 c	57 b	70 b	89 a	80 b	96 a	79 c
O.3	137 a	85 ab	131 a	104 a	122 a	108 a	115 a
M.26 EMLA	96 bc	78 ab	93 b	99 a	90 b	105 a	94 b
Mean	109 a	81 b	98 ab	100 a	97 ab	100 a	
			Cumulative yield efficiency (1992-99, kg/cm^2 TCA)				
M.9 EMLA	1.39 b	0.95 bc	1.91 bc	1.27 bc	1.14 b	1.29 bc	1.33 b
B.9	2.28 a	1.67 a	2.22 ab	1.80 ab	1.91 a	2.11 a	2.00 a
Mark	2.08 a	1.29 ab	2.58 a	1.87 a	2.29 a	2.25 a	2.06 a
O.3	1.46 b	1.07 bc	1.61 c	1.05 c	1.32 b	1.39 ab	1.32 b
M.26 EMLA	0.83 c	0.65 c	1.02 d	0.88 c	0.84 b	0.89 c	0.85 c
Mean	1.61 ab	1.12 c	1.87 a	1.38 bc	1.50 bc	1.59 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 3. Trunk cross-sectional area and yield as affected by cultivar and rootstock after 10 years in the 1990 NC-140 Cultivar/Rootstock Trial in **Kentucky**. All values are least-squares means, adjusted for missing subclasses. Cultivar and rootstock did not interacted significantly to affect trunk cross-sectional area, yield per tree, or yield efficiency, so separations are presented only for overall rootstock and cultivar means.[z]

Rootstock	Golden Delicious	Jonagold	Empire	Rome	Liberty	Mean
			Trunk cross-sectional area (cm^2)			
M.9 EMLA	---	---	63	104	112	99 a
B.9	61	---	37	63	60	56 b
Mark	32	20	29	35	35	35 b
O.3	---	103	46	---	---	86 ab
M.26 EMLA	176	162	108	128	118	132 a
P.22	---	42	19	36	24	33 b
Mean	85 a	82 a	54 a	74 a	74 a	
			Cumulative yield per tree (1992-99, kg)			
M.9 EMLA	---	---	142	122	268	197 a
B.9	168	---	104	128	158	139 b
Mark	96	76	83	67	98	90 b
O.3	---	181	131	---	---	173 ab
M.26 EMLA	252	220	182	179	269	219 a
P.22	---	116	60	78	93	86 b
Mean	175 ab	154 ab	119 b	122 b	184 a	
			Cumulative yield efficiency (1992-99, kg/cm^2 TCA)			
M.9 EMLA	---	---	3.17	1.25	2.52	2.21 ab
B.9	2.72	---	3.59	2.26	3.69	3.04 a
Mark	2.75	3.10	3.13	1.92	3.74	2.89 a
O.3	---	1.78	2.65	---	----	1.99 ab
M.26 EMLA	1.57	1.55	1.94	1.36	2.43	1.76 b
P.22	---	2.72	3.28	2.22	3.90	2.99 a
Mean	2.22 ab	2.38 ab	2.90 ab	1.75 b	3.13 a	

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

Table 4. Trunk cross-sectional area and yield as affected by cultivar and rootstock after 10 years in the 1990 NC-140 Cultivar/Rootstock Trial in **Maine**. All values are least-squares means, adjusted for missing subclasses. Cultivar and rootstock interacted significantly to affect trunk cross-sectional area, yield per tree, and yield efficiency so mean separations are presented for rootstock within each cultivar.[z]

Rootstock	Golden Delicious	Jonagold	Empire	Rome	McIntosh	Mean
			Trunk cross-sectional area (cm^2)			
B.9	---	29 b	33 bc	28 a	35 b	32 c
Mark	40 b	63 a	31 c	47 a	42 ab	44 b
O.3	61 ab	---	57 ab	46 a	---	58 ab
M.26 EMLA	69 a	65 a	61 a	41 a	71 a	61 a
Mean	51 a	54 a	45 a	40 a	52 a	
			Cumulative yield per tree (1992-99, kg)			
B.9	---	95 b	99 b	123 a	103 a	103 b
Mark	138 a	209 a	102 b	160 a	89 a	138 ab
O.3	191 a	---	184 a	160 a	---	182 a
M.26 EMLA	165 a	184 a	151 a	133 a	129 a	152 a
Mean	152 a	173 a	134 a	146 a	114 a	
			Cumulative yield efficiency (1992-99, kg/cm^2 TCA)			
B.9	---	3.32 a	3.30 a	4.43 a	2.75 a	3.44 a
Mark	3.53 a	3.33 a	3.18 a	3.49 ab	2.25 a	3.15 ab
O.3	3.13 ab	---	3.36 a	3.48 ab	---	3.14 ab
M.26 EMLA	2.39 b	2.98 a	2.63 a	3.24 b	1.85 a	2.63 b
Mean	3.13 a	3.22 a	3.12 a	3.71 a	2.28 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 $P = 0.008$).

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

Rootstock	Golden Delicious	Jonagold	Empire	Rome	McIntosh	York	Stayman	Mean
				Trunk cross-sectional area (cm^2)				
M.9 EMLA	70 b	86 a	52 b	72 b	90 a	62 bc	41 b	67 b
B.9	45 c	51 b	39 b	52 b	51 b	45 c	40 b	46 c
O.3	68 b	62 b	57 b	69 b	45 b	78 ab	60 b	63 b
M.26 EMLA	96 a	97 a	88 a	119 a	110 a	85 a	85 a	97 a
Mean	70 ab	74 ab	59 b	78 a	74 ab	67 ab	56 b	
				Cumulative yield per tree (1992-99, kg)				
M.9 EMLA	149 a	124 a	102 a	327 ab	131 a	206 a	122 b	166 a
B.9	121 a	103 a	77 a	265 c	113 ab	179 a	134 b	142 b
O.3	162 a	114 a	127 a	311 bc	77 b	203 a	201 a	171 a
M.26 EMLA	147 a	115 a	127 a	368 a	112 ab	184 a	169 ab	175 a
Mean	145 cd	114 de	108 e	318 a	108 e	193 b	156 c	
				Cumulative yield efficiency (1992-99, kg/cm^2 TCA)				
M.9 EMLA	2.20 ab	1.50 a	1.98 a	4.57 a	1.52 b	3.37 b	3.00 a	2.59 b
B.9	2.74 a	2.09 a	1.99 a	5.16 a	2.58 a	4.42 a	3.58 a	3.22 a
O.3	2.42 ab	1.90 a	2.22 a	4.53 a	1.81 ab	2.69 bc	3.43 a	2.71 b
M.26 EMLA	1.57 b	1.24 a	1.47 a	3.13 b	1.07 b	2.19 c	2.05 b	1.82 c
Mean	2.24 bc	1.68 c	1.91 c	4.35 a	1.74 c	3.17 b	3.01 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 $P = 0.008$).

Table 6. Trunk cross-sectional area and yield as affected by cultivar and rootstock after 10 years in the 1990 NC-140 Cultivar/Rootstock Trial in **Virginia**. All values are least-squares means, adjusted for missing subclasses. Cultivar and rootstock did not interacted significantly to affect trunk cross-sectional area, yield per tree, or yield efficiency, so separations are presented only for overall rootstock and cultivar means.[z]

Rootstock	Golden Delicious	Jonagold	Empire	Rome	York	Stayman	Mean
			Trunk cross-sectional area (cm^2)				
M.9 EMLA	109	125	96	126	106	112	112 b
B.9	64	65	52	63	57	45	58 c
Mark	58	69	65	86	81	44	67 c
O.3	104	132	125	110	114	92	113 b
M.26 EMLA	117	153	155	153	161	144	147 a
Mean	90 ab	109 a	99 abc	108 ab	104 abc	88 b	
			Cumulative yield per tree (1992-99, kg)				
M.9 EMLA	348	417	331	498	396	472	410 ab
B.9	241	309	218	309	273	238	264 c
Mark	200	262	201	310	247	202	237 c
O.3	314	353	343	412	431	390	374 b
M.26 EMLA	355	456	371	553	439	439	435 a
Mean	291 c	360 ab	293 c	416 a	357 ab	348 bc	
			Cumulative yield efficiency (1992-99, kg/cm^2 TCA)				
M.9 EMLA	3.23	3.47	3.84	3.94	3.84	4.26	3.76 bc
B.9	3.82	4.79	4.22	4.88	4.87	5.24	4.64 a
Mark	3.48	4.03	3.91	3.66	3.23	4.52	3.81 b
O.3	2.99	2.62	2.86	3.65	3.78	4.21	3.35 cd
M.26 EMLA	3.09	2.99	2.47	3.67	2.83	3.08	3.02 d
Mean	3.32 b	3.58 ab	3.46 b	3.96 ab	3.71 ab	4.26 a	

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

Table 7. Trunk cross-sectional area and yield as affected by cultivar and rootstock after 10 years in the 1990 NC-140 Cultivar/Rootstock Trial in **Indiana**. All values are least-squares means, adjusted for missing subclasses. Cultivar and rootstock interacted significantly to affect trunk cross-sectional area and yield per tree 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	---	122	113	74	103 ab
B.9	65	59	34	36	47 c
Mark	44	41	55	43	47 c
O.3	66	74	87	71	76 b
M.26 EMLA	117	136	129	109	123 a
M.27 EMLA	---	25	11	17	19 c
P.22	45	39	22	22	31 c
Mean	68 a	70 a	64 a	52 a	
		Cumulative yield per tree (1992-99, kg)			
M.9 EMLA	---	125	113	157	142 a
B.9	132	74	73	96	95 bc
Mark	85	52	52	71	67 cd
O.3	172	78	126	158	131 ab
M.26 EMLA	155	131	111	194	141 a
M.27 EMLA	---	36	21	29	39 d
P.22	85	69	38	45	60 cd
Mean	121 a	84 b	77 b	104 ab	
		Cumulative yield efficiency (1992-99, kg/cm^2 TCA)			
M.9 EMLA	---	1.08 a	1.16 bc	2.06 a	1.53 ab
B.9	2.16 ab	1.26 a	2.23 a	2.61 a	2.15 a
Mark	1.95 ab	1.28 a	1.20 bc	1.79 a	1.53 ab
O.3	2.89 a	1.03 a	1.41 abc	2.25 a	1.80 ab
M.26 EMLA	1.45 b	1.03 a	0.88 c	1.79 a	1.25 b
M.27 EMLA	---	1.34 a	1.71 abc	1.83 a	1.72 ab
P.22	1.75 b	1.65 a	1.92 ab	1.91 a	1.83 ab
Mean	1.93 a	1.30 b	1.51 b	2.02 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 $P = 0.003$).

Figure 1. Relationships between trunk cross-sectional area and cumulative yield efficiency (1992-99) of various apple cultivars growing on a range of rootstocks in six sites. The relationships were: IA, y=2.79-0.017x, r^2=0.85***; IN, y=2.076-0.006x, r^2=0.21*; KY, y=3.44-0.012x, r^2=0.52***; ME, y=4.15-0.022x, r^2=0.30*; PA, y=3.89-0.019x, r^2=0.15*; VA, y=5.19-0.015x, r^2=0.56***.