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Performance of Three Apple Cultivars with 18 Vigorous Rootstocks During Nine Seasons in Washington[1]

BRUCE H. BARRITT, BONNIE S. KONISHI AND MARC A. DILLEY[2]

Abstract

The performance of 18 apple rootstocks was evaluated with scion cultivars 'Golden Delicious,' 'Granny Smith' and 'Delicious' during nine seasons. Rootstocks in the trial, listed in order of increasing tree vigor, measured as trunk cross-sectional area (TCA), were M.7A, M.7 EMLA, MM.111 EMLA, P.13, A.306, MM.106 EMLA, MM.106, M.2 EMLA, B.490, MAC.16, MM.104 EMLA, M.4, MAC.1, B.118, P.18, MAC.4, A.313 and MAC.24. There was little change in the ranking of rootstocks for TCA after year 5, and the influence of rootstocks on TCA was generally similar with each cultivar. The occurrence of root suckers with each cultivar was low with most rootstocks, moderate with M.7 EMLA, M.4, A.313 and M.7A, and extremely high with MAC.24. Trees showing the greatest trunk leaning and, therefore, poorest anchorage were P.13, M.7 EMLA, M.4, B.118, M.7A and M.2 EMLA. The most precocious rootstocks were B.118, MM.106 EMLA and MM.106, and the least precocious were B.490, A.306, MAC.16, MAC.1, A.313 and MAC.24. Cumulative yield efficiency (kg/cm^2) at the end of year 9 was greatest for M.7A, MM.106, P.13, MM.106 EMLA and M.7 EMLA, and lowest for MAC.16, MAC.24, MAC.1, B.490, A.313 and A.306. The influence of rootstocks on cumulative yield efficiency at year 9 was generally similar with each cultivar.

Rootstocks are a key component with all apple orchard management systems because they determine the size of the tree and, therefore, tree density but also because they influence precocity and yield for the life of the orchard (2, 10). With a worldwide trend to higher tree density there has been extensive evaluation of the performance of dwarfing and semi-dwarfing rootstocks. However, for weakly growing cultivars, e.g., 'Braeburn' and spur types of 'Delicious,' and for sites with low fertility soils or soils with replant disease or contaminated with lead arsenate, rootstocks imparting greater vigor than dwarfing rootstocks are required. This study evaluates 1) the performance during nine years of 18 rootstocks imparting more vigor than dwarfing rootstocks, 2) the influence of three scion cultivars on the performance of rootstocks, and 3) the number of years required to accurately assess rootstock influence on tree growth and productivity. A companion study with the same scion cultivars planted in the same site and year evaluated 23 dwarfing rootstocks (3).

Materials and Methods

An apple rootstock trial was established in May 1986 on a sandy loam soil (Birchmount Series) at the Tree Fruit Research and Extension Center, Wenatchee, Washington. The site had been in apple production for over 50 years, resulting in the presence of apple replant disease and lead arsenate soil contamination. An old apple orchard was removed from the site the previous fall. Tree growth at this site, which is adjacent to earlier NC-140 plantings, has been relatively weak in comparison with other North American sites (18, 20, 22). Trees of 'Smoothee Golden Delicious,' 'Granny Smith' and 'Redchief Delicious' (Campbell Strain) were prepared in a single commercial nursery with the following 18 clonal rootstocks: Antonovka 306 (A.306), Antonovka 313 (A.313), Budagovsky 118 (B.118), Budagovsky 490 (B.490), Malling 7A (M.7A), Malling 7 EMLA

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[2]Washington State University Tree Fruit Research and Extension Center, Wenatchee, WA 98801.

(M.7 EMLA), Malling 2 EMLA (M.2 EMLA), Malling 4 (M.4), Malling-Merton 104 EMLA (MM.104 EMLA), Malling-Merton 106 (MM.106), Malling-Merton 106 EMLA (MM.106 EMLA), Malling-Merton 111 EMLA (MM.111 EMLA), Michigan Apple Clone 1 (MAC.1), Michigan Apple Clone 4 (MAC.4), Michigan Apple Clone 16 (MAC. 16), Michigan Apple Clone 24 (MAC.24), P.13 and P.18.

The experimental design was a split plot with cultivars as the main plot and rootstock as subplots with 10 individual tree replications for each cultivar/rootstock combination arranged in a randomized complete block design. Cultivar/rootstock combinations with fewer than five surviving trees were not included in the analysis. Although the experimental design allowed for the separation of main effect means (for rootstock and for cultivar), significant rootstock X cultivar interactions occurred for almost all traits. Therefore, most rootstock data are presented as within-cultivar means.

Trees were spaced 2.7 m x 5.5 m, a density of 665 trees/hectare (9′ x 18′, 269 trees/acre). The pyramid-shaped trees were freestanding and trained to the central leader system. The trial received regular irrigation from a solid-set undertree system. The driveways were grass sod and the trees were in the center of a 1.5 m wide herbicide strip. Insect and disease control and fertilizer applications were based on local recommendations (26). Both chemical and hand thinning were used to encourage annual cropping and adequate fruit size.

The following characteristics were measured annually: trunk circumference (at 20 cm above bud union), yield/tree (kg) and number of fruit/tree. Using these data, the following traits were calculated: trunk cross-sectional area (cm^2) (TCA), mean fruit weight (kg/tree ÷ fruit number/tree), yield efficiency (kg fruit/tree ÷ cm^2 TCA), and crop load (number of fruit/tree ÷ cm^2 TCA). Mean fruit weight was adjusted for the covariant crop load. Biennial bearing index was calculated according to Hoblyn et al. (15). The number of root suckers/tree was recorded in years 5, 6 and 7. As an estimate of tree anchorage, in year 9 the angle of trunk leaning was measured in 10° increments as degrees from vertical.

Table 1. Influence of cultivar and rootstock on trunk cross-sectional area and cumulative yield efficiency at years 5 and 9.

		Year 5		Year 9	
Source	df	MS	% of total sums of squars	MS	% of total sums of squares
		Trunk cross-sectional area			
Cultivar	2	29,237**	40.4	409,618**	54.5
Rootstock	17	2,488**	29.2	20,151**	22.8
Cultivar X Rootstock	34	176**	4.1	1,444**	3.3
Error	142	86		623	
		Cumulative yield efficiency			
Cultivar	2	12.567**	39.4	26.377**	50.6
Rootstock	17	.993**	26.4	1.531**	25.0
Cultivar X Rootstock	34	.075*	4.0	.150**	4.9
Error	142	.044		.034	

*, **Significant at P ≤ 0.05 and P ≤ 0.01, respectively.

Table 2. The number of root suckers recorded for 18 rootstocks with three cultivars during three seasons.

	No. root suckers/tree[z]		
Rootstock[y]	Golden Delicious	Granny Smith	Delicious
B.490	.1	0	.1
P.18	0	0	.7
MM.106	.7	0	.2
A.306	.4	.1	.9
MM.106 EMLA	.6	1.1	.6
B.118	1.8	0	.7
M.2 EMLA	.7	.3	1.5
MM.111 EMLA	1.4	0	2.1
MAC.16	.8	.1	4.6
MM.104 EMLA	1.4	.1	5.3
MAC.1	.8	.2	5.9
MAC.4	1.0	.1	10.3
P.13	2.4	.1	3.0
M.7A	9.6	1.3	11.3
A.313	3.6	1.3	16.2
M.4	2.7	1.4	23.7
M.7 EMLA	15.9	3.3	11.6
MAC.24	68.6	24.8	84.8
LSD (P = .05)	8.7	4.1	9.3
Cultivar mean	6.4	2.1	10.4

[z]Means of years 5, 6 and 7.
[y]Rootstocks listed in estimated order of increasing incidence of root suckers.

Results and Discussion

Cultivar accounted for a greater proportion of variation in TCA and cumulative yield efficiency than did rootstock at years 5 and 9 (Table 1). This was not surprising as the rootstocks included were all relatively vigorous and there was substantial difference in growth and fruiting habit of the three cultivars, e.g., 'Redchief Delicious' is a compact spur type and 'Granny Smith' is a vigorous tip bearer. The interaction of cultivar and rootstock was statistically significant with each trait. Preston (24) also reported significant rootstock x cultivar interaction. However, in the present study only a small portion of total sums of squares was attributed to interaction compared to either cultivar or rootstock. The relatively small interaction compared to the large rootstock effect indicates that the ranking of rootstocks for TCA and for cumulative yield efficiency was generally similar with each cultivar. This conclusion is supported by numerous reports worldwide which include a wide range of scion cultivars that consistently rank rootstocks for TCA from dwarf to vigorous as follows: M.27 < M.9 < M.26 < MM.106.

Tree loss. The following rootstocks had the highest tree losses (30% or greater) with both 'Granny Smith' and 'Delicious': M.7 EMLA, A.306, P.18 and MM.104 EMLA. With 'Golden

Table 3. The incidence of trees with leaning trunks in year 9 for 18 rootstocks with three cultivars.

		% of trees with trunk leaning of	
Rootstock[x]	No. of trees[y]	10-20°[z]	>20°[z]
A.313	23	0	0
MAC.16	25	4	0
MAC.1	24	4	0
MM.104 EMLA	22	5	0
MAC.4	20	5	0
P.18	17	6	0
MM.111 EMLA	28	4	4
MAC.24	32	9	0
MM.106 EMLA	27	11	4
MM.106	26	12	4
A.306	22	18	0
B.490	22	13	5
P.13	24	25	0
M.7 EMLA	18	33	0
M.4	36	19	17
B.118	26	23	19
M.7A	30	30	20
M.2 EMLA	28	21	32
Total	450	14	6

[z]Degrees from vertical.
[y]Total of 3 cultivars.
[x]Rootstocks listed in estimated order of increasing trunk leaning.

Table 4. The influence of 18 rootstocks on tree size, measured as trunk cross-sectional area (TCA), with three scion cultivars in the 9th year.

	Trunk cross-sectional area year 9			
Rootstock	Golden Delicious (cm^2)	Granny Smith (cm^2)	Delicious (cm^2)	Mean (% of MM.106 EMLA)[z]
M.7A	98	141	40	73
M.7 EMLA	120	163	48	89
MM.111 EMLA	116	165	63	95
P.13	130	181	56	97
A.306	115	164	70	99
MM.106 EMLA	127	198	57	100
MM.106	133	147	70	100
M.2 EMLA	128	154	72	102
B.490	137	180	76	111
MAC.16	157	208	82	124
MM.104 EMLA	158	222	--	
M.4	151	227	80	125
MAC.1	185	165	93	131
B.118	167	200	93	132
P.18	172	203	103	139
MAC.4	176	189	109	142
A.313	173	214	104	142
MAC.24	220	256	151	189
LSD P = .05	24	38	19	
Cultivar mean[y]	147	186	80	

[z]A % of MM.106 EMLA was calculated for each cultivar/rootstock combination and the mean of the cultivars is listed for each rootstock. These values were used to establish the overall ranking of the 18 rootstocks for their influence on tree size.
[y]Mean for 17 rootstocks common to all three scion cultivars.

Delicious,' tree losses were 30% or greater with P.18 and MM.111 EMLA. With each cultivar, tree losses were low (less than 10%) with M.7A and MM.106 EMLA. Tree losses were also low (less than 10%) for MM.111 EMLA with 'Delicious' and 'Granny Smith' and for B.118 and MAC.1 with 'Delicious' and 'Golden Delicious.' Relatively high tree loss in year 1 (11.5% of all trees) may have been due to unusually high temperatures at planting time and a relatively late planting date in May. The cause of subsequent tree death was not determined; however, neither fire blight infection nor winter injury appeared to contribute to tree death.

Root suckers. Rootstocks having the greatest number of root suckers with each cultivar were MAC.24, M.7 EMLA, M.4, A.313 and M.7A (Table 2). With each cultivar, the rootstocks with few root suckers, less than 2 per tree, were B.490, P.18, MM.106, A.306, MM.106 EMLA, B.118 and M.2 EMLA. The extremely high number of root suckers with MAC.24, the moderate number with M.7A, M.7 EMLA and M.4 and the relatively low number of root suckers for P.18, B.490, MM.106 and MM.106 EMLA have been reported previously (5, 13, 14, 18, 19, 24).

Anchorage. Of 450 trees (total of 3 cultivars), 20% showed trunk leaning of 10° or greater (Table 3). The proportion of leaning trees was similar for the 3 cultivars. The following rootstocks had the poorest anchorage with more than 25% of the trees with trunks leaning more than 10° from vertical: P.13, M.7 EMLA, M.4, B.118, M.7A and M.2 EMLA. From 17 to 32% of the trees with M.4, B.118, M.7A and M.2 EMLA leaned more than 20° from vertical. Relatively poor anchorage also

Table 5. Correlation among cultivars for trunk cross-sectional area, cumulative yield/tree and cumulative yield efficiency at the end of years 3, 5, 7 and 9.

	Correlation coefficient[z]		
Year	Golden Delicious with Granny Smith	Golden Delicious with Delicious	Granny Smith with Delicious
	Trunk cross-sectional area (cm^2)		
3	.761**	.869**	.614**
5	.803**	.906**	.749**
7	.808**	.919**	.741**
9	.727**	.939**	.701**
	Cumulative yield/tree (kg)		
5	.603**	.829**	.609**
7	.582*	.884**	.403[NS]
9	.551*	.853**	.345[NS]
	Cumulative yield efficiency (kg/cm^2)		
5	.870**	.329[NS]	.471[NS]
7	.870**	.558*	.535*
9	.865**	.898**	.855**

[z]**significant P = .01; *significant P = .05; [NS]not significant; n = 16 to 18 rootstocks.

Table 6. Coefficients of determination (%) with three apple cultivars for the relationship of TCA at planting and at end of years 1 to 8 with TCA at the end of year 9.

Cultivar	No. of Root-stocks	Coefficients of determination (%) for the relationship of TCA in year 9 with TCA at: Planting	the end of years 1	2	3	4	5	6	7	8
Golden Delicious	18	22	35	53	69	78	91	93	98	99
Granny Smith	18	10	21	43	63	67	86	78	95	99
Delicious	18	7	13	31	54	70	89	94	98	99

has been reported for M.7, M.2 and M.4 (4, 6, 11) while good anchorage has been reported for A.313, MAC.1 and B.490 (5, 18).

Tree size. In comparison with the standard rootstock MM.106 EMLA, only M.7A, with two of three cultivars, had smaller TCA (Table 4). MAC.24 produced the largest trees in the trial, being larger than MM.106 EMLA with each cultivar. The following rootstocks produced trees larger than MM.106 EMLA with two of three cultivars: MAC.16, MAC.1, B.118, P.18, MAC.4 and A.313. The ranking of rootstocks for TCA with 3 cultivars in the present study was generally similar to earlier reports with a range of cultivars (6, 13, 16, 18, 21, 24, 25).

Influence of rootstocks on tree size (TCA) from year 3 onward was generally similar with each cultivar, e.g., in year 7, r = .808 ('Golden Delicious'/'Granny Smith'), r = .919 ('Golden Delicious'/'Delicious') and r = .741 ('Granny Smith'/'Delicious') (Table 5).

TCA in the early years of the trial was correlated with TCA at the end of year 9 with each cultivar (Table 6). By year 5, over 86% of the variation (coefficient of determination) in year 9 TCA could be accounted for with the three cultivars, indicating that little change in the ranking of rootstocks for TCA occurs after year 5. Carlson and Tukey (6) found that the ranking of rootstocks for trunk circumference with 'McIntosh' and 'Courtland' at year 5 was similar to the ranking at the end of the 14th year. In 'Delicious' trials with 9 rootstocks (17, 19) and with 15 rootstocks (18, 21), the ranking of rootstocks for TCA at year 5 and at year 10 was similar.

Precocity. With 'Golden Delicious' and 'Delicious,' B.118 was the only rootstock that had more blossom clusters/tree than MM.106 EMLA in year 3 (Table 7). With 'Granny Smith,' B.118, MM.106 and MM.106 EMLA had the highest number of blossom clusters/tree. For cumulative yield efficiency to year 5, also an indicator of precocity, no rootstock had greater efficiency than MM.106 EMLA with the three cultivars (Table 8). Two rootstocks, B.118 and MM.106, were the only rootstocks not lower than MM.106 EMLA with all three cultivars.

Table 7. The number of blossom clusters/tree in year 3 for three cultivars each with 18 rootstocks.

Rootstock[y]	No. blossom clusters/tree[y] Golden Delicious	Granny Smith	Delicious
M.7A	52 [13]	50 [10]	11 [6]
M.7 EMLA	102 [4]	45 [11]	23 [2]
MM.111 EMLA	119 [2]	53 [8]	18 [4]
P.13	60 [9]	38 [13]	16 [5]
A.306	28 [17]	14 [17]	3 [16]
MM.106 EMLA	91 [7]	111 [3]	11 [7]
MM.106	106 [3]	117 [2]	18 [3]
M.2 EMLA	91 [6]	37 [14]	9 [9]
B.490	17 [18]	2 [18]	1 [18]
MAC.16	35 [16]	38 [12]	3 [17]
MM.104 EMLA	57 [10]	64 [5]	7 [14]
M.4	62 [8]	59 [7]	5 [15]
MAC.1	38 [15]	14 [16]	9 [11]
B.118	201 [1]	126 [1]	27 [1]
P.18	54 [12]	51 [9]	7 [13]
MAC.4	51 [14]	104 [4]	11 [8]
A.313	54 [11]	60 [6]	7 [12]
MAC.24	94 [5]	16 [15]	9 [10]
LSD (P = .05)	55	50	11
Cultivar mean	74	55	11

[y]Ranks are included in brackets.
[y]Rootstocks listed in order of increasing tree size (TCA).

Table 8. The influence of 18 rootstocks on cumulative yield efficiency for three scion cultivars to year 5 and to year 9.

	Cumlative yield efficiency to year 5 (kg/cm²)ᶻ			Cumulative yield efficiency to year 9 (kg/cm²)ᶻ		
Rootstockʸ	Golden Delicious	Granny Smith	Delicious	Golden Delicious	Granny Smith	Delicious
M.7A	.97 [8]	.51 [3]	.89 [7]	1.38 [1]	.73 [2]	1.87 [2]
M.7 EMLA	1.00 [6]	.46 [6]	.73 [11]	1.19 [5]	.57 [5]	1.66 [6]
MM.111 EMLA	.87 [10]	.29 [11]	.75 [10]	1.17 [7]	.49 [8]	1.69 [4]
P.13	.96 [7]	.38 [8]	.97 [3]	1.26 [3]	.59 [4]	1.84 [3]
A.306	.74 [14]	.16 [13]	.26 [16]	1.02 [9]	.40 [12]	1.01 [14]
MM.106 EMLA	1.30 [1]	.56 [2]	1.00 [2]	1.29 [2]	.62 [3]	1.66 [5]
MM.106	1.09 [4]	.58 [1]	1.16 [1]	1.26 [4]	.73 [1]	1.91 [1]
M.2 EMLA	1.09 [3]	.34 [10]	.85 [8]	1.17 [6]	.49 [9]	1.30 [7]
B.490	.80 [12]	.15 [14]	.62 [13]	.77 [14]	.30 [14]	1.10 [13]
MAC.16	.51 [17]	.09 [16]	.09 [17]	.58 [17]	.15 [17]	.88 [16]
MM.104 EMLA	.75	.21	--	1.04	.33	--
M.4	1.02 [5]	.47 [5]	.91 [4]	.99 [11]	.46 [10]	1.19 [10]
MAC.1	.70 [16]	.17 [12]	.62 [12]	.71 [16]	.39 [13]	.92 [15]
B.118	1.25 [2]	.50 [4]	.90 [6]	1.00 [10]	.55 [7]	1.27 [8]
P.18	.81 [11]	.35 [9]	.90 [5]	.85 [13]	.45 [11]	1.11 [12]
MAC.4	.88 [9]	.41 [7]	.77 [9]	1.08 [8]	.55 [6]	1.22 [9]
A.313	.74 [13]	.14 [15]	.44 [15]	.87 [12]	.22 [15]	1.13 [11]
MAC.24	.73 [15]	.08 [17]	.46 [14]	.77 [15]	.17 [16]	.74 [17]
LSD P = .05	.23	.19	.25	.22	.18	.33
Cultivar meanˣ	.91	.33	.73	1.03	.46	1.33

ᶻRanks are included on brackets for rootstocks common to all cultivars.
ʸRootstocks listed in order of increasing tree size (TCA).
ˣFor rootstocks evaluated with all scion cultivars.

With 'Golden Delicious' and 'Granny Smith,' B.490, A.306 and MAC.16 had fewer blossom clusters/tree in year 3 than MM.106 EMLA and also had the fewest blossom clusters/tree with 'Delicious' (Table 7). These three rootstocks, plus MAC.1, A.313 and MAC.24, had lower cumulative yield efficiency to year 5 than MM.106 EMLA with each cultivar (Table 8).

In a 30-site trial with spur 'Delicious,' precocity was similar for M.7 EMLA, MAC.1, M.4, B.490, A.313 and P.18 (18). However, in the present study, number of blossom clusters/tree with at least two cultivars was less for MAC.1 and B.490 than for M.7 EMLA. Carlson (5) reported MAC.1 was precocious, but in the present study it lacked precocity in comparison with M.7 EMLA and MM.106 EMLA. Cummins and Aldwinckle (7) reported that B.490 was as precocious as MM.106, but B.490 had the fewest blossom clusters/tree in year 3 and among the lowest cumulative yield efficiency to year 5 in this study. They also reported that B.118 was not precocious, but in this study with three cultivars it was as precocious as MM.106 EMLA.

Yield/tree. The highest cumulative yield/tree at the end of years 5 and 9 occurred with rootstocks MAC.4, B.118, MM.106 and MM.106 EMLA. These rootstocks were ranked in the top 5 for cumulative yield/tree at year 5 and year 9 with all three cultivars (B.118 and MAC.4) or with two cultivars (MM.106 and MM.106 EMLA) (Table 9). With MAC.16, B.490, A.306 and MAC.1, cumulative yield/tree at year 5 and year 9 was lower than for MM.106 EMLA with both 'Golden Delicious' and 'Granny Smith' and for

Table 9. The influence of 18 rootstocks on cumulative yield/tree for three apple cultivars to year 5 and to year 9.

	Cumlative yield/tree (kg)[z]					
	to year 5			to year 9		
Rootstock[y]	Golden Delicious	Granny Smith	Delicious	Golden Delicious	Granny Smith	Delicious
M.7A	33 [15]	23 [8]	17 [14]	126 [14]	96 [7]	75 [15]
M.7 EMLA	48 [11]	23 [7]	16 [15]	136 [11]	92 [8]	78 [14]
MM.111 EMLA	43 [13]	15 [11]	20 [10]	132 [12]	80 [10]	104 [7]
P.13	52 [8]	21 [9]	29 [6]	160 [6]	101 [5]	101 [8]
A.306	33 [16]	9 [14]	7 [16]	114 [15]	64 [12]	69 [17]
MM.106 EMLA	62 [3]	32 [1]	24 [8]	160 [5]	120 [1]	91 [11]
MM.106	58 [5]	28 [5]	34 [2]	166 [4]	97 [6]	127 [2]
M.2 EMLA	55 [6]	16 [10]	29 [5]	146 [10]	73 [11]	92 [10]
B.490	34 [14]	8 [15]	17 [13]	106 [16]	55 [14]	85 [13]
MAC.16	28 [17]	5 [17]	3 [17]	92 [17]	32 [17]	70 [16]
MM.104 EMLA	45	14	18	161	72	--
M.4	54 [7]	31 [2]	22 [9]	149 [7]	101 [4]	96 [9]
MAC.1	45 [12]	9 [13]	20 [11]	131 [13]	61 [13]	86 [12]
B.118	77 [1]	28 [4]	32 [3]	166 [3]	107 [2]	117 [4]
P.18	52 [9]	25 [6]	32 [4]	147 [9]	90 [9]	113 [5]
MAC.4	61 [4]	29 [3]	35 [1]	190 [1]	104 [3]	131 [1]
A.313	49 [10]	11 [12]	19 [12]	150 [8]	50 [15]	119 [3]
MAC.24	62 [2]	7 [16]	27 [7]	169 [2]	43 [16]	112 [6]
LSD P = .05	15	11	9	28	26	23
Cultivar mean[x]	50	19	23	145	81	98

[z]Ranks are included in brackets for rootstocks common to all cultivars.
[y]Rootstocks listed in order of increasing tree size (TCA).

MAC.16 and A.306 was also lower with 'Delicious' in year 5.

The influence of rootstocks for cumulative yield/tree to years 5, 7 and 9 was not always similar for each cultivar (Table 5). In year 9, the 'Golden Delicious'/'Delicious' correlation was high (r = .853) but the correlations including 'Granny Smith' were relatively poor ('Golden Delicious'/'Granny Smith' r = .551 and 'Granny Smith'/'Delicious' r = .345).

By year 6 cumulative yield/tree accounted for 87, 94 and 88% (coefficients of variation) of the variability in yield/tree at year 9 with 'Golden Delicious,' 'Granny Smith' and 'Delicious,' respectively (Table 10). Therefore, the four years of production data collected up to and including year 6 are a reasonable estimate of cumulative production/tree over the longer period to year 9.

Cumulative yield/tree generally increases as tree size increases when rootstocks vary in tree size from dwarfing M.9 to semi-dwarfing M.7 (3, 12, 19, 23, 27). However, with the more vigorous rootstocks in this study as TCA increased with each cultivar there was not a consistent increase in cumulative yield/tree (Table 9).

Yield efficiency. Cumulative yield efficiency at year 9 was highest for M.7A, MM.106, P.13, MM.106 EMLA and M.7 EMLA. These rootstocks (except for M.7 EMLA) were ranked in the top 5 for cumulative yield efficiency at year 9 with all three cultivars (Table 8). M.7 EMLA was ranked in the top 5 with both 'Golden Delicious' and 'Granny Smith.' Rootstocks with the lowest cumulative yield efficiency to year 9 were MAC.16, MAC.24, MAC.1, B.490, A.313 and A.306. Each of these rootstocks had lower cumula-

Table 10. Coefficients of determination (%) with three apple cultivars for relationships in the early years (4 through 8) versus in year 9 for cumulative yield/tree and cumulative yield efficiency.

Cultivar	No. of Root-stocks	Coefficients of determination (%) for the relationships of year 9 with years 4	5	6	7	8
	Cumulative yield/tree					
Golden Delicious	18	56	73	87	94	93
Granny Smith	18	49	90	94	93	99
Delicious	17	49	71	88	96	97
	Cumulative yield efficiency					
Golden Delicious	18	40	51	68	93	95
Granny Smith	18	41	84	82	93	99
Delicious	17	61	51	60	77	93

tive yield efficiency to year 9 than MM.106 EMLA with all three cultivars. In addition, P.18, B.118 and M.4 had lower cumulative yield efficiency than MM.106 EMLA with 'Golden Delicious' and 'Delicious.' With each cultivar cumulative yield efficiency to year 9 tended to decline as TCA increased, a trend observed in earlier studies (3, 12, 18, 19, 21).

In the present study and in a multi-site NC-140 trial with spur 'Delicious' the ranking of rootstocks for cumulative yield efficiency was similar (1, 18, 21). Autio (1), as in the present study, found P.18, A.313, MAC.1 and B.410 to have lower cumulative yield efficiency than M.7 EMLA. In another multi-site trial (19), cumulative yield efficiency at year 10 for M.7 EMLA and MAC.24 was similar, but in the present study M.7 EMLA and M.7A had greater cumulative yield efficiency to year 9 than MAC.24 with three cultivars.

Correlations among cultivars for cumulative yield efficiency to year 9 were high ($r \geq .85$) (Table 5). However, correlations including 'Delicious' were generally lower when yield accumulations were for fewer harvest seasons.

Of the variation in year 9 cumulative yield efficiency, 93, 93, and 77% (coefficients of determination) could be accounted for by yield efficiency in year 7 for 'Golden Delicious,' 'Granny Smith' and 'Delicious,' respectively (Table 10). It appears that cumulative yield efficiency can be assessed accurately when trees are approximately 7 years of age and have had five cropping seasons.

Biennial bearing index. The ranking of rootstocks for biennial bearing was not consistent with the three cultivars nor was the extent of biennial bearing related to rootstock vigor (TCA) (Table 11). In a companion study (similar

Table 11. The influence of rootstock on biennial bearing index through 6 growing seasons (1989-1994) with three cultivars.

Rootstock[y]	Biennial bearing index (x 100)[z] Golden Delicious	Granny Smith	Delicious
M.7A	69 [4]	54 [6]	46 [11]
M.7 EMLA	76 [8]	51 [2]	51 [14]
MM.111 EMLA	89 [16]	54 [7]	45 [8]
P.13	70 [5]	48 [1]	41 [6]
A.306	68 [3]	53 [5]	46 [10]
MM.106 EMLA	83 [14]	57 [9]	58 [16]
MM.106	82 [13]	53 [4]	37 [4]
M.2 EMLA	87 [15]	57 [10]	52 [15]
B.490	81 [12]	51 [3]	38 [5]
MAC.16	67 [2]	56 [8]	48 [12]
MM.104 EMLA	76 --	59 --	-- --
M.4	80 [10]	75 [16]	45 [9]
MAC.1	73 [7]	58 [11]	49 [13]
B.118	80 [11]	65 [12]	35 [3]
P.18	77 [9]	70 [13]	43 [7]
MAC.4	62 [1]	73 [15]	33 [1]
A.313	81 --	-- --	40 --
MAC.24	72 [6]	72 [14]	33 [2]
LSD (P = .05)	13	13	14
Cultivar mean[x]	76	59	44

[z]The larger the biennial bearing index, the greater the tendency toward biennial bearing. Ranks are included in brackets for 16 rootstocks common to all scion cultivars.
[y]Rootstocks listed in order of increasing tree size (TCA).
[x]Means of 16 rootstocks common to all 3 cultivars.

Table 12. Mean fruit weight (MM.106 EMLA = 100) for 18 rootstocks during 6 seasons with three apple cultivars.

	Adjusted mean fruit weight (MM.106 EMLA = 100)[z]																	
	Golden Delicious						Granny Smith					Delicious						Grand
Rootstock	1989	1990	1991	1992	1993	1994	1990	1991	1992	1993	1994	1989	1990	1991	1992	1993	1994	mean
MM.106	100	94	122	104	101	104	99	105	101	105	104	110	114+	114	107	98	104	105+
M.7 EMLA	107	92	121	97	101	102	101	108	101	104	104	117	101	118	105	91-	88-	103
B.118	102	95	107	104	110	92-	98	114	95	99	98	110	111+	104	105	101	104	103
P.18	110	97	117	105	101	93	97	110	95	94	99	106	106	112	104	98	98	102
P.13	120+	91	101	97	98	106	102	104	99	103	102	106	108	101	100	92	96	102
M.7A	107	92	112	101	100	103	106	100	100	105	103	99	112+	114	97	87-	88-	102
MAC.24	100	96	112	104	105	92-	96	102	92-	87-	102	106	107	113	100	100	102	101
A.306	115	89	105	96	98	102	98	101	95	95	101	122+	101	107	100	91-	97	101
MAC.4	114	92	115	108	99	110	98	98	90-	96	89-	99	110	109	98	89-	94	100
A.313	110	97	113	105	100	103	93	106	88-	91	93	93	102	128+	104	92-	88-	100
M.4	103	104	96	108+	105	100	98	105	93-	94	101	105	113+	99	100	86-	95	100
MM.106 EMLA	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
MAC.1	93	92	111	101	94	93	89	112	93	93	100	95	103	111	103	95	99	98
B.490	102	91	107	100	96	89	90	105	94	94	102	91	108	103	100	90-	95	97
MM.111 EMLA	112	87-	102	93	90	111	90	94	96	95	100	97	94	117	101	91-	95	97
MM.104 EMLA	90	85-	110	99	99	98	98	104	88-	94	100	93	110	89	99	101	--	97
M.2 EMLA	91	89-	118	97	87-	99	101	98	96	102	100	100	91	74-	93	95	97	96
MAC.16	103	86-	114	103	92	98	90	107	88-	87-	100	83-	86	97	100	87-	88-	95-
MM.106 EMLA mean fruit weight (g)	259	206	195	182	183	225	228	207	202	193	219	231	238	209	238	236	278	--
CV (%)	17	12	21	8	11	9	10	19	8	9	9	14	12	19	8	7	8	--

[z]Least-squares means adjusted for crop load and presented relative to MM.106 EMLA. Plus (+) and minus (-) indicate means significantly different from MM.106 EMLA (LSD, P = .05). Grand mean separation based on ANOVA of 16 or 17 adjusted means (as % of MM.106 EMLA) per rootstock.

planting date and site) with dwarfing and semi-dwarfing rootstocks, the incidence of biennial bearing increased as tree vigor increased with 'Golden Delicious' and 'Granny Smith' but decreased as rootstock vigor increased with 'Delicious' (3). Average biennial bearing index during 7 seasons with 'Golden Delicious' was not influenced by 6 rootstock and interstem combinations (9). Rootstock influenced biennial bearing index with 'Starkspur Supreme Delicious' but the effect was not related to rootstock vigor (8).

Fruit weight. Mean fruit weight was influenced by rootstock during six seasons with three cultivars (Table 12). Based on the mean of 17 year/cultivar evaluations, only one rootstock, MM.106, had greater mean fruit weight than MM.106 EMLA, and only one rootstock, MAC.16, had lower mean fruit weight than MM.106 EMLA. MAC.16 had significantly lower mean fruit weight than MM.106 EMLA in 6 of 17 evaluations. In earlier studies, differences in mean fruit weight among vigorous rootstocks have been relatively small (1, 24).

Preston (24) noted in a 15-year trial of 19 new and 7 older rootstocks that it was possible by year 7 to select among the 19 new rootstocks those with the greatest promise. In the present study, the ranking of rootstocks for TCA at year 9 was accurately predicted by data collected in year 5. The ranking of rootstocks for cumulative yield/tree and cumulative yield efficiency at year 9 was accurately predicted by data collected up to year 6 or 7. It appears that four or five years of cropping data are required to establish relative productivity of rootstocks. A companion study of 23 dwarfing and semi-dwarfing rootstocks reached similar conclusions (3). The ranking of rootstocks for precocity, root suckering and anchorage can be reliably estimated by year 7. For traits such as drought and cold tolerance, soil-line swelling and insect and disease resistance, the longer the trial is in place the more likely stress situations and infestations will occur and it will be possible to determine relative rootstock performance. However, by having multiple sites for replicated rootstock trials, for example, the North American NC-140 plantings, the opportunity to evaluate these traits in relatively few years increases as the number of sites increases. The present data support the conclusion that seven years is sufficient time for replicated rootstock trials, particularly if several cultivars are included or if there are multiple sites.

Of the rootstocks in this trial, none surpassed MM.106, MM.106 EMLA, M.7A and M.7 EMLA in overall suitability for commercial use. MM.106 and MM.106 EMLA have shown excellent precocity and productivity in their vigor class and, although susceptible to collar rot, are widely grown commercially. M.7A and M.7 EMLA had relatively poor anchorage and suckered moderately, but they are commercially popular rootstocks due to their semi-dwarfing vigor class, productivity and fireblight resistance. B.118 showed promise due to its precocity and winter hardiness; however, it was in the vigorous class and was poorly anchored. P.13 had high yield efficiency and its precocity and anchorage were similar to M.7 EMLA. Rootstocks which performed poorly in this trial include (major weaknesses listed in brackets): MAC.24 [lacked precocity, low yield efficiency, suckered badly, extreme vigor], MAC.16 [lacked precocity, low yield efficiency, small fruit size], MAC.1 [lacked precocity, low yield efficiency, vigorous], B.490 [lacked precocity, low yield efficiency], A.313 [lacked precocity, low yield efficiency, suckered badly, vigorous], and A.306 [lacked precocity, low yield efficiency].

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Flower Bud and Shoot Hardiness of Southern Highbush Blueberry Cultivars

JOHN R. CLARK,[1] ROBERT BOURNE[2] AND EDWARD GBUR[3]

Abstract

The southern highbush blueberry (*Vaccinium* spp.) cvs. 'Blue Ridge,' 'Cape Fear,' 'Cooper,' 'Georgiagem,' 'Gulf Coast' and 'O'Neal,' and selections A-109 and G-616, the rabbiteye (*V. ashei* Reade) cv. 'Climax' and the northern highbush (*V. corymbosum* L.) cvs. 'Bluecrop' and 'Sierra' were evaluated in December 1993 and January and February 1994 for shoot and flower bud damage following exposure to 0, -5, -10, -15, -20, -25 and -30C in a programmable freezer. All cultivars were hardier than 'Climax' at all sample dates. Hardiness among several southern highbush clones was similar to that for northern highbush at several dates and temperatures. The hardier southern highbush clones were A-109, 'Blue Ridge' and 'Cape Fear.' 'Sierra' exhibited equal or greater hardiness than 'Bluecrop,' depending on date of sampling and temperature.

Evaluations of hardiness of flower buds have been done on several species of blueberries, including northern highbush (*Vaccinium corymbosum* L.) (4, 5), lowbush (*V. angustifolium* Ait.) (6) and rabbit eye (*Vaccinium ashei* Reade) (7, 13, 15). Cultivars with comparatively higher levels of flower bud hardiness have been determined, including 'Northland,' 'Jersey' and 'Bluecrop' highbush and 'Tifblue' rabbiteye (8).

The southern, or low-chill, highbush blueberry consists of cultivars that were developed for areas of the United States that have fewer chilling hours than northern blueberry production regions. These cultivars resulted from hybridizing the highbush blueberry with other *Vaccinium* species, primarily *V. darrowi* Camp (11). A lower level of flower bud hardiness of southern

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[1]Dept. of Horticulture, University of Arkansas, PTSC 316, Fayetteville, AR 72701.
[2]Fruit Substation, Clarksville, Ar 72830.
[3]Agricultural Statistics Laboratory, University of Arkansas, Fayetteville, AR 72701.