Fruit Varieties Journal 51(3):183-191 1997

Performance of Dwarfing Apple Rootstocks In Five Trials in British Columbia, Canada

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Abstract

Five trials of dwarf and semi-dwarf apple rootstocks were conducted, with the objective of identifying hardy, yield-efficient rootstocks adapted to the regional climate, and suitable for the newer tree training methods used in high-density plantings. The rootstocks tested were: Jork 9 (J.9), Mark, Ottawa 3 (O.3), Budagovsky 9 (B.9), the Polish rootstocks P.2, P.16 and P.22, and the Malling rootstocks M.4, M.9 EMLA, M.26 EMLA and M.27 EMLA. The scion varied among trials and included 'Macspur McIntosh,' 'Summerland McIntosh,' 'Jonagold' and 'Shamrock.' Mark, J.9 and P.16 produced trees similar to M.9 EMLA in size and productivity. P.16 was slightly more yield-efficient than M.9 EMLA, and average fruit weight on Mark was slightly lower than on M.9 EMLA or J.9. Mark and J.9 were more precocious than M.9 EMLA, as judged by early blossom production. Trees of this size would be most suitable for high density plantings on most sites in British Columbia. O.3, B.9 and P.2 produced trees larger than M.9 EMLA and similar to M.26 EMLA in size. P.2 was lower in yield and yield efficiency than trees of similar size on O.3 and B.9. O.3 and B.9 were similar in all respects, except that O.3 was more yield-efficient in one trial. M.26 EMLA was slightly more precocious than O.3. O.3, B.9 and M.26 EMLA would be useful on cold sites or where site or scion vigor is too low for M.9. P.22 and M.27 EMLA produced trees that are probably too small for conventional slender spindle and vertical axe training. Vertical axe trees were more precocious than supported central-leader trained trees, but not slender spindles.

Introduction

The chief apple-producing regions of British Columbia (B.C.) are characterized by a continental arid climate, with warm dry summers and cold winters. Winter temperatures of –30C create the risk of winter injury to rootstocks, particularly if snow cover is lacking (19). Soils of the region are highly variable, but many are shallow, coarse-textured, and low in organic matter. Orchards must be irrigated. Crown rot (caused by *Phytophthora cactorum*) is a problem in many areas, but woolly apple aphid *(Eriosoma lanigerum)* and fireblight *(Erwinia amylovora)* have not been serious historically.

In the early 1980s, most apple orchards in B.C. were planted at low densities on cold-hardy, vigorous or semi-vigorous rootstocks such as Antonovka seedling. A dramatic shift to high-density plantings and newer training systems requiring dwarfing rootstocks began in the mid- to late 1980s (21). Several rootstock trials were initiated at that time to identify hardy, yield-efficient rootstocks adapted to the region that would give good performance with the newer methods of tree training. Rootstocks ranging from M.27 to M.26 in size control were desired to provide choices appropriate for sites and scions varying in vigor. We tested Jork 9 (J.9), Mark, Ottawa 3 (O.3), Budagovsky 9 (B.9), and the Polish rootstocks P.2, P.16 and P.22, along with one or more of the Malling (M) rootstocks M.4, M.9 EMLA, M.26 EMLA and M.27 EMLA as standards.

Materials and Methods

Experimental units were single trees in all trials. Trial 1 was located at the Pacific Agri-Food Research Centre substation in Kelowna, B.C. Trials 2 to 4 were planted at the Pacific Agri-Food Research Centre in Summerland, B.C. and Trial 5 was in Creston, in the Kootenay Valley of southeastern B.C.

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Cultural Practices and Experimental Measurements

For all trials, the trees were budded and grown for one year in the nursery, then planted in the field at the same depth as in the nursery. The rootstocks and scions came from virus-indexed sources and were free of known viruses. All trees were headed at planting. Herbicide strips were present in the tree row, with alleys seeded to grass. All plantings were drip-irrigated during the growing season, except the Kelowna site (Trial 1), which had micro-jet irrigation. Pest and disease control were consistent with standard commercial practices for the region. In Trials 1-4, fruit was chemically thinned with a follow-up hand thinning; in Trial 5, only chemical thinning was done. Trees were pruned annually in the dormant season according to the philosophy of the training system used.

Tree height, maximum canopy spread and trunk diameter were recorded annually. Trunk diameter was measured at 10 cm above the graft union and used to calculate trunk cross-sectional area (TCA). Yield (kg) was measured annually and used to calculate cumulative yield and cumulative yield efficiency (CYE = cumulative yield in kg/final TCA in cm^2). In some years (noted in tables), apples were counted during picking to obtain average fruit weight. Fruit size was not recorded at the Summerland sites in 1992 because of hail damage reducing the crop. Blossom clusters were counted in the first 1 or 2 years as a measure of precocity (5) in all trials except Trial 5. Blossoms were removed after counting in the first year, in order to prevent undesirable stunting of ultimate tree size with precocious rootstocks. Variables were analyzed with the procedure GLM of the SAS v. 6.03 software package (SAS Institute, Cary, NC). Means were separated with the Waller-Duncan K-ratio t-test, K-ratio = 100

Description of Trials

Trial 1. A 10-year trial of 'Macspur McIntosh' budded on B.9, M.26 EMLA, M.27 EMLA or O.3 was planted in Kelowna on sandy loam soil in 1985. The design was a randomized complete block with 10 replications. Trees were spaced at 3 m x 1.8 m and trained as vertical axe.

Trials 2 to 4 (Summerland). Trial 2 was planted on sandy loam soil at a spacing of 4 m x 2 m in 1988 and studied for 7 years. The scion was 'Shamrock' budded onto M.4, M.26 EMLA and O.3. The trees were planted in a randomized complete block design with 6 replications, and were trained as vertical axe.

A 10-year trial (Trial 3) of J.9, M.9 EMLA, M.26 EMLA, M.4 and Mark rootstocks was planted on a 4.5 m x 3 m spacing on sandy loam soil in 1986. The experimental design was a split-plot with 7 replications, with rootstocks assigned to the main plots and training system (vertical axe or supported central leader) to the sub-plots. Each rootstock was therefore represented by 14 trees (7 replications x 2

Table 1. Final tree size (10 years), cumulative yield, yield efficiency, blossom density and fruit weight of 'Macspur' trees trained as vertical axes on four rootstocks (Trial 1).

Rootstock	TCA (cm^2)[z]	Tree height (m)	Maximum canopy spread (m)	Blossom density (no,•cm^{-2})[y]	Cumulative yield (kg)	CYE (kg•cm^{-2} TCA)[x]	Mean fruit weight (g)[w]
M.26 EMLA	52.3 a	3.27 a	2.34 a	10 c	153.6 a	4.23	200
O.3	43.7 a	3.39 a	2.43 a	17 b	123.0 b	3.35	180
B.9	40.3 a	3.10 a	2.30 a	16 bc	118.7 b	4.09	198
M.27 EMLA	15.6 b	2.38 b	1.58 b	27 a	49.3 c	3.61	179

[z]TCA = trunk cross-sectional area.
[y]Cumulative number in first three years.
[x]CYE = cumulative yield efficiency.
[w]Average in 1987-90 inclusive.

Table 2. Final tree size (7 years), cumulative yield, yield efficiency, fruit size and blossom production of 'Shamrock' trees trained as vertical axes on three rootstocks (Trial 2).

Rootstock	TCA (cm²)[z]	Tree height (m)	Maximum canopy spread (m)	Blossom cluster no.[y]	Blossom density (no.•cm⁻²)[y]	Cumulative yield (kg)	CYE (kg•cm⁻² TCA)[x]	Mean fruit weight (g)[w]
M.4	36.9 a	3.36 a	2.80 a	3.5 b	0.48 b	76.0 a	2.09 b	175
O.3	17.5 b	2.92 b	2.35 b	1.2 b	0.26 b	47.4 b	2.99 a	162
M.26 EMLA	23.4 b	3.02 ab	2.38 b	7.8 a	1.39 a	46.9 b	1.93 b	165

[z]TCA = trunk cross-sectional area.
[y]Taken the year after planting.
[x]CYE = cumulative yield efficiency.
[w]Average of 4 years (1990-91, 1993-94).

training systems). The scion was 'Summerland McIntosh.' After 10 years the trees were cut off at ground level after leaf fall and the aboveground portion weighed.

Trial 4 was planted on sandy loam soil at 4 m x 2 m in 1988 and studied for 7 years. The trees were 'Jonagold' scions on M.9 EMLA and O.3 rootstocks. This trial was a split-plot design with 9 replications. Rootstocks were assigned to main plots and training systems (vertical axe or slender spindle) to sub-plots; thus each rootstock was represented by 18 trees.

Trial 5. A commercial orchard in Creston, B.C. was the site of a trial initiated in 1990. This trial consisted of 10 replicate trees per rootstock with 'Summerland McIntosh' as the scion, laid out in a ran-

Table 3. Performance of 'Summerland McIntosh' trained as vertical axe or central leader trees on five different rootstocks over 10 years (Trial 3).

Treatment	Final TCA (cm²)[z]	Final tree height (m)	Maximum canopy spread (m)	Above-ground tree fresh weight (kg)	Blossom cluster number[y]	Bloom density (no.•cm⁻² TCA)[y]	Cumu-lative yield (kg)	CYE (kg•cm⁻² TCA)[x]	CYE (kg•kg tree weight)[x]	Mean fruit weight (g)[w]
Rootstock										
M.4	97.49 a	3.86 a	3.28 a	28.6 a	99 c	5.2 d	241.5 a	2.52 b	8.91 c	213 a
M.26 EMLA	46.90 b	3.15 b	2.39 b	10.2 b	183 ab	16.2 c	142.0 b	3.18 b	15.38 b	187 b
M.9 EMLA	19.43 c	2.53 c	1.81 c	4.2c	152 b	21.6 b	99.4 c	5.23 a	25.57 a	192 b
Mark	19.17 c	2.57 c	1.69 c	3.8 c	187 ab	30.6 a	78.2 c	4.77 a	28.11 a	174 c
J.9	18.78 c	2.69 c	1.93 c	4.0 c	206 a	29.0 a	102.9 c	5.48 a	26.19 a	196 b
Training system										
Vertical axe	39.70	3.25	2.16	10.0	189	23.1	139	4.43	21.7	187
Central leader	41.00	2.67	2.28	10.3	142	17.9	126	4.04	20.0	197
***P* values:**										
Rootstock	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
System	0.60	<0.01	0.10	0.05	<0.01	0.01	0.05	0.10	0.20	0.06
Rootstock* System	0.15	0.14	0.13	0.38	0.15	0.02	0.39	0.90	0.66	0.85

[z]TCA = trunk cross-sectional area.
[y]Data from first two years after planting.
[x]CYE = cumulative yield efficiency.
[w]Mean over 7 years (1988-95 inclusive, except 1992).

domized block design at a spacing of 5 m x 1.5. m. The central leader was treated according to slender spindle training, but the side branches were left unheaded to make better use of alley space. Drip irrigation (one point emitter per tree at the trunk, delivering approximately 4 liters per hour) was scheduled by atmometer. The rootstocks were B.9, O.3, M.9 EMLA, J.9, P.2, P.16 and P.22. A few of the trees on P.2 and P.22 became scion-rooted or were identified as off-types after several years; these trees were therefore eliminated from the statistical analysis.

Results

Trial 1. 'Macspur' trees trained as vertical axe on M.26 EMLA, O.3 and B.9 were all about the same size after 9 years, but those on M.27 EMLA were much smaller, whether size was estimated by TCA, tree height or maximum canopy spread (Table 1). Cumulative yield was highest on M.26 EMLA, and by far the lowest on M.27 EMLA, but none of the rootstocks differed significantly in cumulative yield efficiency (Table 1). The performance of O.3 and B.9 was similar for all variables examined, and M.26 EMLA differed from them only in having greater cumulative yield. Fruit size was unaffected by rootstock (Table 1).

The biennial bearing index was calculated for the six pairs of years covering the period from 1988 to 1994, according to the method of Hoblyn et al. (12), where trees with a pronounced alternate bearing tendency have high indices. Although significant differences among rootstocks were observed in 4 of the 6 analyses, no consistent patterns were found (data not shown).

Blossom cluster density in the first one or two years did not vary among rootstocks ($p = 0.12$ year 1, $p = 0.22$ year 2). Cumulative blossom cluster counts over the first three years divided by TCA in year 3 suggested that trees on M.27 EMLA had the highest bloom density, while those on M.26 EMLA tended to have the lowest (Table 1).

Trial 2. 'Shamrock' trees on M.26 EMLA and O.3 were about the same size in their seventh year, as measured by

Table 4. Performance of 'Jonagold' over 7 years on two rootstocks and two training systems (Trial 4).

Rootstock	Final TCA (cm^2)[z]	Tree height (m)	Maximum canopy spread (m)	Blossom cluster no.[y]	Bloom density ($no.\cdot cm^{-2}$)[y]	Cumulative yield (kg)	CYE ($kg\cdot cm^{-2}$)[x]	Mean fruit weight (g)[w]
O.3								
All trees on O.3	25.1	2.52	2.60	5.8	1.1	64.7	2.74	247
Slender spindle	23.8	2.41	2.56	5.9	1.3	68.5	2.96	248
Vertical axe	26.7	2.64	2.65	5.7	0.9	60.9	2.44	247
M.9 EMLA								
All trees on M.9	17.2	2.34	2.17	11.2	3.1	48.1	2.73	250
Slender spindle	16.6	2.11	2.16	9.7	2.6	44.9	2.48	259
Vertical axe	17.6	2.64	2.19	12.8	3.6	51.3	2.93	242
***P* values:**								
Rootstock	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	0.86	0.93
System	0.95	<0.01	0.20	0.60	0.66	0.81	0.73	0.30
Rootstock x system	0.63	0.30	0.56	0.54	0.36	0.02	0.05	0.34

[z]TCA = trunk cross-sectional area.
[y]Data from year after planting.
[x]CYE = cumulative yield efficiency.
[w]Average from 3 years (1990, 1993-94).

Table 5. Performance of 'Summerland McIntosh' on 7 rootstocks over 7 years (Trial 5).

Rootstock	Final TCA (cm^2)[z]	Tree height (m)	Canopy spread (m)	No. of suckers[y]	Cumulative Yield (kg)	CYE ($kg{\bullet}cm^{-2}$)[x]	Mean fruit Weight (g)[w]
O.3	29.0 a	2.62 ab	2.88 a	3.7	40.6 a	1.44 c	132
B.9	24.5 ab	2.78 a	2.78 a	2.1	33.1 b	1.43 c	138
P.2	23.4 ab	2.73 ab	2.69 ab	0.8	23.4 c	1.13 d	132
J.9	19.0 bc	2.56 ab	2.66 ab	3.5	34.8 ab	1.81 b	144
M.9 EMLA	17.1 c	2.40 bc	2.39 bc	3.4	33.1 b	2.00 b	128
P.16	16.0 c	2.47 abc	2.58 ab	1.6	35.7 ab	2.31 a	136
P.22	14.2 c	2.14 c	2.14 c	2.7	23.7 c	1.71 bc	131

[z]TCA = trunk cross-sectional area.
[y]Cumulative count 1993-96.
[x]CYE = cumulative yield efficiency.
[w]Mean over 1994-96.

TCA, tree height and canopy spread (Table 2). Trees on M.4 had larger TCA and spread. On average, trees on M.26 EMLA were more precocious than on O.3 or M.4, as judged by blossom counts and blossom density in the year after planting (Table 2), but observed differences were not large in absolute terms. Cumulative yield was highest on M.4. Although the cumulative yield and TCA of trees on M.26 EMLA and O.3 were similar, small but non-significant differences in both led to a higher cumulative yield efficiency (CYE) for O.3 (Table 2). Fruit size was unaffected by rootstock (Table 2).

Trial 3. In the Summerland trial of 5 rootstocks with two training systems, the trees fell into three distinct size classes. Trees on M.4 were the largest, followed by trees on M.26 EMLA; trees on Mark, J.9 and M.9 EMLA were the smallest and did not differ significantly from each other (Table 3). The same pattern was found whether tree size was estimated by TCA, height, canopy spread or above-ground tree weight. The size difference between M.4 and the others was proportionally larger for tree weight or TCA than for height or spread, undoubtedly because of containment pruning. The average TCA of trees on J.9, M.9 EMLA and Mark was about 20% of that for trees on M.4, tree weight 14% of M.4, spread 55% and height 67% of M.4.

Training system did not affect TCA or canopy spread significantly (Table 3), but trees on all rootstocks were slightly taller with vertical axe than with central leader training. This finding is not surprising in view of the different treatment of the central leader in the two training systems. Rootstock and system did not interact for any of the tree size parameters (Table 3).

Both rootstock and training system, affected precocity, as evaluated by cumulative blossom cluster counts and bloom density in the first two years (Table 3). Trees on M.4 were the least precocious. Despite their larger size, they produced fewer blossom clusters, so their blossom cluster density was much lower than any of the other trees. Trees on Mark and J.9 had higher bloom densities than trees on M.9 EMLA or M.26 EMLA. Trees trained as vertical axe had more blossom clusters and higher bloom density than 'trees trained to the central leader system, reaffirming that annual pruning of the leader delays flowering. The system x rootstock interaction was significant for bloom density, but not for blossom cluster number (Table 3). The central leader training system had a much more pronounced deleterious effect on bloom density for J.9 and M.4 than for the other rootstocks.

Trends in cumulative yield closely paralleled differences in tree size. Trees on

M.4 produced the highest cumulative yield, followed by trees on M.26 EMLA (Table 3). The cumulative yield of trees on the other 3 rootstocks was similar within the group and only 32-43% that of M.4. The mean yield of vertical axe trees was slightly higher than central leader-trained trees, underlining the detrimental effect on productivity of annually pruning the leader.

CYE was calculated as cumulative yield per tree divided by: (a) final TCA, or (b) final aboveground wood fresh weight. M.4 trees were bigger, but they were just as efficient as M.26 EMLA on a TCA basis, although not on a tree weight basis (Table 3). M.26 EMLA and M.4 were only 50-60% as yield-efficient as the other three rootstocks on a TCA basis. Overall, TCA and aboveground tree weight were closely correlated (r = 0.96***), yet the low CYE of M.4 was more pronounced on a tree weight basis, being only about one-third as great as the mean of M.9 EMLA, J.9 and Mark. Training system had no effect on CYE, and did not interact with rootstock (Table 3).

Fruit size was slightly larger on M.4 and smaller on Mark than on the other rootstocks (Table 3). A small training system effect on fruit size was observed, with central leader trees tending to have slightly larger fruit. However, this observation was probably a function of crop load, since the axe trees were almost the same size but had greater cumulative yields.

Trial 4. 'Jonagold' trees trained as vertical axe or slender spindles were slightly larger on O.3 than on M.9 EMLA in terms of TCA, tree height and canopy spread after 7 years (Table 4). Vertical axe trees were slightly taller than slender spindles on both rootstocks, as might be expected, but training system did not affect maximum canopy spread or final TCA. Precocity was unaffected by training system, but M.9 EMLA was more precocious than O.3 in terms of both number of blossom clusters and bloom density (Table 4). Although M.9 EMLA was more precocious than O.3, its cumulative yield was significantly lower (Table 4). A significant rootstock by training system interaction was present, in that cumulative yield was about 12% lower on spindles for M.9 EMLA and about 12% higher on spindles for O.3. The interaction was also seen for CYE (Table 4). Reasons for this difference are unclear. The rootstocks did not differ in average fruit size.

Trial 5. At Creston, only trees on O.3, B.9 and P.2 had larger final TCA than M.9 EMLA (Table 5). Trees on B.9 were also taller, and both B.9 and O.3 trees had greater canopy spread than those on M.9 EMLA. None of the trees on the other rootstocks (J.9, P.16, P.22) differed from M.9 EMLA in any of these size attributes, although P.22 ranked last in all cases (Table 5). All rootstocks sporadically produced a low and variable number of suckers; the cumulative means did not vary with rootstock [p = 0.37 on transformed data i.e. the square root of (cumulative number of suckers + 0.5)] Untransformed mean counts appear in Table 5.

Cumulative yield was not a simple function of tree size in the Creston trial. Trees on O.3, B.9 and P.2 did not differ in TCA, height or spread, but their cumulative yields all differed significantly (Table 5), with O.3 yielding the most. Trees on J.9, P.16 and P.22 were similar in size to those on M.9 EMLA, but the cumulative yield of P.22 was significantly lower than the others (Table 5). The most yield-efficient trees were those on P.16, followed by M.9 EMLA, J.9 and P.22. All other rootstocks were inferior to M.9 EMLA in yield efficiency, with P.2 being especially inefficient. Fruit size did not vary among rootstocks (p = 0.64).

Discussion

None of the rootstocks tested was demonstrably superior to M.9 EMLA in performance, but Mark, J.9 and P.16 were equal to M.9 EMLA in many respects and possess certain useful traits. J.9 is reportedly hardier than M.9 (21, 24) and may provide an advantage on cold sites. J.9 is also easier to propagate than M.9 (8, 9, 24). In excised shoot assays, J.9 was as resistant as M.9 to *P. cactorum*, and more resistant than M.26 (23). Here it also conferred greater precocity to the scion than did M.9 EMLA. The vertical axe training system appeared to take better advantage of this ability than did the central leader system. Because J.9 is highly susceptible to fireblight (1, 8) it has not been used extensively in many regions. Its propensity to form root suckers was similar to M.9 EMLA in the present study (Table 5).

The performance of P.16 has been variable in rootstock trials. Czynczyk and Omiecinska (6) found trees on P.16 to be similar to those on M.9 EMLA in size, but Ferree et al. (10) found them to be much smaller, similar to trees on M.27. In an NC-140 trial, trees on P.2, P.16 and P.22 were all similar to each other and to B.9 in size (15). The degree of vigor control on P.16 is altered by soil water status, as is P.22 (2, 4), which may account for this inconsistency. The Polish rootstocks have also varied in root suckering. In some trials (10, 25) suckering is unacceptably high, especially on P.16, whereas in others (3 and here) no problems were encountered. Tree survival has been poor in some locations on the P series stocks (3, 16).

In the Creston trial, P.16 was similar to M.9 EMLA in size-controlling ability, more yield-efficient, and it produced few root suckers (Table 5). P.2 and P.22 were inferior in cumulative yield and CYE to rootstocks with similar vigor control (e.g. compare the cumulative yield and CYE of P.2 to O.3 and B.9, and compare cumulative yield of P.22 to J.9, M.9 EMLA and P.16 in Table 5). An NC-140 trial also found P.16 to be more yield-efficient than P.2 or P.22, although the trees did not vary in size in that trial (15). The greater vigor and lower efficiency of P.2 relative to M.9 were also mentioned by Ferree and Carlson (9). P.16 is similar to M.9 in crown rot resistance (23), fireblight resistance (10, 24), ease of propagation (20) and cold hardiness (20). Nevertheless, none of the trees on M.9 or P.16 showed obvious symptoms of winter injury during the period of study at Creston. They are probably sufficiently hardy to withstand average winter soil temperatures in B.C. if snow cover is adequate (as is typical in the Kootenay Valley, but not the Okanagan Valley).

Mark performed as well as M.9 EMLA in most respects in the studies described here. Mark induced greater early blossom production in the scion than did M.9 EMLA, in agreement with previous studies (18, 22). The performance of Mark has been inconsistent in rootstock trials, varying in dwarfing potential and productivity with different scions and in different locations (1, 22). Reported tree size on Mark varies from similar to trees on M.27 (10) to bigger than on M.26 (22). Its sole disadvantage in our trial was smaller average fruit weight, a trait that has been observed previously (17), even when fruit size is adjusted for crop load (3). Mark is easy to propagate and has good anchorage (1, 18, 24). Although Mark is more flood-tolerant than M.9 or M.26 (1) and is highly resistant to *P. cactorum*-induced crown rot (2, 4), it tends to perform poorly in dry soils and with low-vigor or small-fruited scion cultivars (18). It is susceptible to fireblight (10, 18), and sometimes produces many root suckers (3, 10). The cold hardiness of Mark is not well-characterized, but is believed to be similar to M.9 or slightly less hardy (7, 24). Domoto (7) indicates that Mark acclimates early but does not attain a high degree of mid-winter hardiness. Major problems with winter survival in the field have not been commonly reported, however.

In these trials, trees on O.3 and B.9 were consistently similar to M.26 EMLA in size, and significantly larger than trees on M.9 EMLA. Previous reports indicate that trees on O.3 are about the size of trees on M.26 (9), or somewhere between M.9 and M.26 (3, 25). Trees on O.3 did rank behind M.26 EMLA in final TCA (Tables 1 and 2). Possibly we did not have a sufficient number of replicate trees to detect any difference between O.3 and M.26 EMLA statistically.

Literature reports conflict as to the relative size of trees on B.9. In some cases, trees are similar to M.9 or Mark in size (10, 15, 17), but sometimes they are significantly larger than M.9 (6) or between M.9 and M.26 (3, 25). In the absence of any demonstrated clonal differences in B.9, these variations must be attributable to differences in management, tree quality at planting, or the interactions of rootstock performance with site and scion cultivar.

In our trials, trees on O.3 and B.9 did not differ from each other in any of the measured performance variables (Tables 1 and 5), except, that the yield of trees on O.3 was greater than on B.9 at Creston (Table 5). O.3 was less precocious than either M.26 EMLA or M.9 EMLA in our trials (Tables 2 and 4), but Barritt et al. (3) found O.3 to be more precocious than M.26 EMLA. 'Jonagold' trees on O.3 were larger than on M.9 EMLA, but just as yield-efficient (Table 4). Relative to M.26 EMLA, trees on O.3 were similar, in size and equal or superior in yield efficiency (Tables 1 and 2). Yield per tree was similar to M.26 EMLA in one of our trials (Table 2) and lower in another (Table 1). B.9 and O.3 are more cold-hardy than M.9 and M.26 (19). Neither O.3 nor B.9 is resistant to fireblight or easy to propagate by conventional means (9, 21). O.3 is better anchored than M.9 (9). O.3 and B.9 have been found to be similar to or greater than M.26 in crown rot resistance in excised shoot assays (2,13,23), and O.3 was more resistant than B.9 in one study (13). Browne and Mircetich (4) did not test O.3, but reported that B.9 was highly resistant (similar to M.9), using excised shoot assays and plants grown in *P. cactorum*-infested soil. In pot studies, Wilcox (26) found O.3 to be less resistant than M.26 to *P. cactorum*, but more resistant than M.7 or MM.111. The susceptibility of O.3 varied with species of *Phytophthora;* it was highly susceptible to *P. cryptogea*, but among the most resistant of the rootstocks to *P. cambivora* and *P. megasperma* (26). These rootstocks may be useful in cold sites, for weak scions, or where soil conditions are too unfavorable for trees in the M.9 vigor-controlling range. They are probably too vigorous for fertile soils or vigorous cultivars under present high-density management systems.

M.27 EMLA and P.22, in contrast, probably produce trees too short and canopies too small for high cumulative yields at spacings typical for slender spindle, Y- or V-trellis or vertical axe training systems as used in B.C. Their use in very high density "super spindle" systems on fertile sites with vigorous scions may merit further study.

None of the rootstocks we tested affected fruit size, except for M.27 EMLA and Mark. Fruit size problems are sometimes encountered on P.22 without irrigation (15). Trees on Mark and M.27 seem particularly susceptible to small fruit size, and require irrigation and aggressive thinning (3 and references therein,14, 18, 24).

In Creston, cumulative yields and yield efficiencies of all the trees were low compared to other trials, and average fruit size was small. The Creston site suffered from heavy bird and hail damage early in the study, and the orchard had been re-planted on an old apple-growing site without fumigating. A strip of persistently problematic soil ran through the center of the trial. Although the planting was blocked appropriately, average yields were affected. The crop was chemical-thinned but not hand-thinned, and trees tended to alternate-bear and have smaller average fruit size. Early fruit yields were especially low on the Polish stocks. Blossom counts at Creston were not available, but the Polish rootstocks are reportedly precocious (3, 11, 24), so perhaps their disappointing early performance was due to poor establishment or rooting, or less resistance to any potential replant problems.

Among the performance variables we measured, tree training affected only final tree height and early blossom production. Vertical axe trees were more precocious than supported central leader trees, but not slender spindles (Tables 3 and 4), at least with the rootstock-scion combinations we studied. The relative performance of rootstocks was similar regardless of training system, with two exceptions. The vertical axe system took greater advantage of the precocity-inducing potential of J.9, and encouraged earlier flowering on M.4 than did central leader training (Table 3). Second, the yield performance of O.3 was better on spindles than on vertical axe trees (Table 4). Perhaps the spindle training encouraged earlier bearing on O.3. Further trials would be needed to demonstrate whether this effect is consistent. In any case, the difference in cumulative yield was not large.

Acknowledgments

We wish to thank A. Hoag of Creston, B.C. for the use of his orchard.

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