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Early Performance of 'Red Fuji' on M.9 Clones and Other Dwarfing Rootstocks

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In 1993, trees of 'Red Fuji' (T.A.C. 114) apple (*Malus x domestica* Borkh.) on 16 dwarf rootstocks were planted in New Franklin, Missouri (MO) to evaluate tree growth and precocity in a midwestern climate. Rootstocks in this study included 11 M.9 clones, as well as B.9, M.27 EMLA, V.1, and V.3. Tree loss was minimal for all rootstocks in spite of heavy rainfall immediately preceding and following planting. By 1997, trees on M.9 NAKB T340, V.1, Mark, and M.9 EMLA had greater trunk cross-sectional areas (TCAs) than those on B.9, M.9, M.9 Janssen 337, V.3, and M.27 EMLA. Trees on M.9 NAKB T340 were also taller than those on M.9 Burgmer 984, M.9 NAKB T337, M.9 Pajam 1, B.9, M.9 Janssen 337, V.3, and M.27 EMLA. V.3 trees produced the greatest number of flower clusters per tree in 1995. Of the M.9 clones, M.9 NAKB T340 produced more flower clusters than M.9 RN 29, M.9 Burgmer 756, M.9, and M.9 Janssen 337. However, fruit yield of all trees was low due to rainfall and high winds during bloom in 1995 and frost when flowers were at full pink stage in1996. By 1997, trees on M.27 EMLA had lower cumulative yield (CY) than those on all other rootstocks. Although yield efficiency (YE) was statistically similar during the early years of tree growth, differences may become apparent as trees mature and regular cropping is achieved.

Introduction

M.9 rootstock is the most commonly planted rootstock in orchard systems where dwarf apple trees are desired (23). M.9 has several positive attributes: 1) it produces a small tree size, 2) trees can produce a crop in the third leaf after fall budding, 3) fruit size is generally larger than that of trees on other rootstocks, and 4) it is resistant to crown rot (*Phytophthora* spp.) and tolerant of common latent viruses (7, 23). One major negative trait of M.9 rootstock is the need for tree support due to its brittle roots. In addition, trees perform poorly when planted in droughty soils (without irrigation) and are susceptible to low temperature injury, woolly aphid damage, crown gall, and fireblight (1, 23). Nurserymen have also had difficulty propagating M.9 rootstocks from stool beds and by hardwood cuttings. Because of these problems and viruses in the original M.9 selection, several European researchers and nurseries have heat-treated M.9 rootstock to eliminate viruses and made their own selections of M.9 clones with improved rooting in stool beds (Table 1) (4, 8). Some of these newer selections of M.9 have also shown variation in tree vigor, yield efficiency, and fruit size, but are often cultivar and site dependent (2, 10, 22, 24).

B.9 is another dwarfing rootstock often planted on sites where apple trees are susceptible to low winter temperatures (Table 1) (15). Pieniazek et al. (15) reported that B.9 roots and shoots can tolerate –13 °C and –35 °C, respectively. B.9 has other attributes such as few suckers and burrknots and crown rot resistance. However, B.9 is susceptible to fireblight and woolly apple aphid (1, 6, 23).

Mark has performed well when planted in heavy soils that are susceptible to crown rot (14) and woolly apple aphid (1). Various cultivars on Mark rootstock have been precocious and trees had high YE (12, 14, 16, 17). However, propagation problems (14, 20, 21), poor performance on water-stressed sites (5, 12), susceptibility to fireblight (1), and soil-line swelling on the rootstock (11) have limited extensive use of Mark.

V.1 and V.3 , which originated from the hardy 'Kerr' crabapple (Table 1), may be useful in cold climates. In a North American trial (NC-140) with 'Gala' as the scion cultivar, V.1 trees were more productive during the early years of cropping when compared to those of a similar tree size (10).

Tree losses of V.1 due to fireblight were less than those of M.9.EMLA in Ohio (6).

Because rootstock performance is often cultivar and site specific, the objective of this study was to evaluate early tree growth and precocity of a cultivar of worldwide interest on various M.9 clones and other dwarfing rootstocks in MO. Midwestern sites typically have productive soils, but trees are often subject to stressful environmental conditions, including temperature and moisture extremes as well as intense disease pressure (10, 13). Thus, a 'Fuji' sport was selected as the scion cultivar due to its relative tolerance to fireblight and its popularity in domestic and international markets.

Materials and Methods

'Red Fuji' (T.A.C. 114) trees on 11 clones of M.9 rootstock and B.9 , Mark, V.1, V.3, and M. 27 EMLA (Table 1) were obtained from a commercial nursery (TRECO, INC., Woodburn, OR). Trees were planted in a Menfro silt loam soil at the University of Missouri Horticulture and Agroforestry Research Center near New Franklin on May 20, 1993. Trees were spaced 1.8 x 4.9 m with the bud union ≈5 cm above the soil surface. Ten single-tree replications of each rootstock were planted in a randomized complete block design. Thirty pollinizer trees of 'Stark UltraGold'/Mark were included throughout the planting. Trees were headed at 76 cm and trained in a vertical axis system (1). Immediately after planting, a 3-cm-diameter conduit pipe was placed adjacent to each tree for leader training and support. Stakes extended 2.7 m above the soil surface. A wire connecting the stakes at 1.3 m was used for additional support. Pruning cuts on the central leader were minimized, allowing leaders to grow above the 2.7 m stakes used for support. Drip irrigation scheduling and pest and fertility management followed local recommendations.

Data collected annually included tree survival, number of rootstock suckers, and trunk circumference at 30 cm above the soil surface. TCA was calculated from trunk circumference measurements. Because there was no bloom in 1994 due to low temperature injury to floral buds, the number of flower clusters per tree was recorded in April 1995. The total number of fruit per tree and yield (kg/tree) were recorded in 1995-1997 and were used to calculate average fruit weight. Tree height and spread were measured in November 1997. Data were subjected to analysis of variance using the GLM procedure of SAS (SAS Institute, Cary, N.C.). Bloom count data were square root transformed for analysis because of heterogeneous variance (18). Means were separated by Duncan's new multiple range test.

Results and Discussion

After five growing seasons, tree loss was minimal (Table 2). This result was unexpected due to the late planting date and the water-saturated soil condition at planting. Apple trees are generally planted in late March in Missouri. However, in the 40 days preceding planting, rainfall (20.5 cm) was recorded on 19 of these days. In the 40 days following planting, an additional 19.8 cm of rainfall was recorded. Orchards at lower elevations were flooded by heavy and continuous rainfall. One tree each on Mark and M.9 NAKB T338 rootstock did not survive vole damage.

Root suckers were absent on M.9 Burgmer 751, M.9 Burgmer 984, M.9 NAKB T337, B.9, and M.27 EMLA trees (Table 2). Few trees (≤30%) of other rootstocks produced suckers. In most cases, trees produced only one sucker per year, except for one M.9 Burgmer 756 tree that averaged four suckers per year. Ferree et al. (6) reported that root sucker production was cultivar dependent with M.27 EMLA, B.9, V.3, and M.9 EMLA producing few suckers with scion cultivars 'Macspur McIntosh,' 'Lawspur Rome Beauty,' and 'Redchief Delicious.' During the first five years of a NC-140 rootstock trial with the scion 'Gala,' M.9 EMLA and M.27 EMLA have produced few root suckers, whereas M.9 RN 29 and Mark produced the most suckers (10). However, root sucker production of rootstocks was strongly influenced by site. By 1997, trees on M.9

Table 1. Origin of M.9 rootstock clones and other dwarfing rootstocks.

Rootstock	Origin
B.9	A cross of M.8 x 'Krasnayi Standart' which was introduced by Michurinsk College of Horticulture to provide adaptability to the severely cold climate of central Russia. Also known as Red-leaved Paradise No. 9 (15).
M.9	Selected as a chance seedling in 1879 in France and named 'Jaune de Mertz.' Introduced as one of the Malling series in 1917 at the East Malling Research Station at Kent, England. Infected with latent viruses (19).
M.9 EMLA	Developed cooperatively from East Malling and Long Ashton Research stations in England. Released in 1969 as a M.9 clone that was free of known viruses (J. Palmer, personal communication).
M.9 Burgmer 751, 756, 984	M.9 selections from the Klein-Altendorf Experiment Station (University of Bonn) in cooperation with the J. Burgmer Nursery in Straellen, Germany (B. Barritt, personal communication).
M.9 RN 29	M.9 selection from R. Nicolai Nursery in Alken, Belgium (24).
M.9 Janssen 337	A clone of NAKB T337 supplied by Janssen Brothers Nurseries Ltd., Nederweert, Netherlands to TRECO, INC.,Woodburn, OR (B. Barritt, personal communication).
M.9 Pajam 1 (Lancep)	M.9 selections resulting from a collaborative effort of the Technical Interprofessional Center for Fruit and Vegetables and the Nurseries Experimentation Center in France.
M.9 NAKB T337, T338, T340	M.9 selections from the Dutch Inspection Service for Woody Nursery Stock (NAKB) (7, 23).
M.27 EMLA	Developed cooperatively from East Malling and Long Ashton Research stations in England. Released in 1969 as a M.27 clone that was free of known viruses. M.27 was a cross of M.13 x M.9 originally made in 1929 at the East Malling Research Station, Kent, England (7, J. Palmer, personal communication).
Mark	An open-pollinated seedling of M.9 developed by Michigan State University in 1979 (1).
V.1, V.3	Open-pollinated seedlings of 'Kerr' crabapple ('Dolgo' x Haralson') selected at McGill College in 1959 and subsequently evaluated at the Horticultural Research Institute of Ontario in Vineland. Propagated by Oregon Rootstock, Woodburn, Oregon in 1979 (3).

NAKB T340, V.1, Mark, and M.9 EMLA had greater TCAs than those on B.9, M.9, M.9 Janssen 337, and V.3 (Table 2). Trees on M.27 EMLA had the smallest TCAs of all rootstocks. In similar 'Fuji' trials in Washington, V.1 trees also had large TCAs, while those of M.27 EMLA were small (9). However, in contrast to MO, trees on M.9 clones, Mark, and B.9 were intermediate in TCAs in Washington. The ranking of TCAs of trees grown in Washington was V.1 > M.9 Burgmer 756 > M.9 EMLA > Mark > M.9 RN 29 > M.9 NAKB T340 > M.9 Pajam 1 > M.9 Janssen 337 > M.9 NAKB T337 > B.9 > M.9 Burgmer 984 > M.9 NAKB T338 > M.9 Burgmer 751 > V.3 > M.9 > M.27 EMLA.

Tree height among all rootstocks varied by 127 cm. However, among the M.9 clones, tree height varied by only 49 cm (Table 2). M.9 NAKB T340 trees were taller than those on M.9 Burgmer 984, M.9 NAKB T337, M.9 Pajam 1, B.9, M.9 Janssen, V.3, and M.27 EMLA. In Ohio, Ferree et al. (6) grouped rootstocks as follows: B.9, V.1, V.3, M.9 EMLA = M.9 tree size and Mark = M.27 size with the scion cultivars 'Macspur McIntosh,' 'Lawspur Rome Beauty' and 'Redchief Delicious.' In a NC-140 trial, Marini et al. (10) ranked tree height with the scion 'Gala' as: M.9 RN 29 > M.9 EMLA > M.9 Pajam 1 > NAKB T337. In a study comparing 'Cox's Orange Pippin' on 24 M.9 clones at East Malling Research Station, England, tree sizes were similar in most cases (22). However, Dutch T.337 (M.9 NAKB T337) and Pajam 1 were 10 and 30% smaller than M.9 EMLA.

All M.9 clones in this study were similar in tree width (Table 2). However, M.9 NAKB T340 and V.1 had greater tree spread than B.9, and M.27 EMLA had the smallest spread. Trees on all rootstocks except M.27 EMLA filled their allotted space (1.8 m) by 1997. Based upon average width of M. 27 EMLA trees, they could be planted a maximum of 1.25 m within the row, resulting in a higher tree density than was used in this study.

In 1995, at least 9 of 10 trees of each rootstock produced flower clusters (data

Table 2. Vegetative and reproductive characteristics of 'Fuji' on selected dwarfing rootstocks in the New Franklin, MO trial planted in 1993.

Rootstock	Tree loss (%)	Trees with root suckers (%)	1997 TCA (cm^2)	1997 Tree size (cm) height	1997 Tree size (cm) width	1995 Flower clusters (No./tree)	1995 Fruit yield (kg/tree)	1996 Fruit yield (kg/tree)	1997 Fruit yield (kg/tree)	1997 Avg. fruit weight (g)	Cumulative yield (kg/tree)	Cumulative yield efficiency (kg/cm^2)
M.9 NAKB T340	0	10	38.8 a[z]	345 a	228 a	77 abcd	0.74	0.39	20.8 a	201 abcd	21.9 a	0.59
V.1	0	30	37.9 ab	332 ab	227 a	47 bcde	0.17	0.00	19.8 a	215 abcd	20.0 a	0.62
Mark	10	20	36.3 abc	313 abc	211 ab	82 ab	0.28	0.71	24.3 a	196 abcd	25.3 a	0.75
M.9 EMLA	0	20	36.2 abc	326 ab	222 ab	43 cdef	0.51	0.00	18.6 a	212 abcd	19.1 a	0.57
M.9 RN 29	0	10	33.8 abcd	326 ab	201 ab	28 ef	0.36	0.00	20.3 a	221 ab	20.7 a	0.64
M.9 Burgmer 756	0	20	33.2 abcd	330 ab	224 ab	24 ef	0.29	0.00	21.8 a	230 a	22.1 a	0.70
M.9 Burgmer 751	0	0	31.3 abcd	313 abc	202 ab	51 bcde	0.66	0.19	18.6 a	210 abcd	19.5 a	0.68
M.9 Burgmer 984	0	0	30.4 bcd	311 bc	201 ab	46 bcde	0.48	0.10	22.3 a	191 bcd	22.9 a	0.80
M.9 NAKB T337	0	0	30.1 cd	296 bcd	204 ab	62 abcd	0.69	0.00	18.9 a	187 bcd	19.6 a	0.69
M.9 Pajam 1	0	10	30.1 cd	296 bc	218 ab	39 def	0.50	0.22	17.8 a	196 abcd	18.5 a	0.70
M.9 NAKB T338	10	10	29.0 cd	324 ab	223 ab	47 bcde	0.37	0.22	23.8 a	191 bcd	22.0 a	0.88
B.9	0	0	28.0 d	296 bc	193 b	76 abc	0.49	0.30	25.8 a	178 cd	26.6 a	0.94
M.9	0	10	27.8 d	320 abc	199 ab	26 ef	0.18	0.31	19.1a	224 ab	19.6 a	0.74
M.9 Janssen 337	0	10	27.2 d	304 bc	217 ab	29 ef	0.47	0.33	19.5 a	188 bcd	20.3 a	0.80
V.3	0	10	25.9 d	287 c	205 ab	102 a	0.94	0.18	24.1 a	177 d	25.2 a	0.98
M.27 EMLA	0	0	8.3 e	218 d	127 c	16 f	0.00	0.07	4.6 b	215 abc	4.7 b	0.54

[z]Mean separation within columns by Duncan's new multiple range test, $P \leq 0.05$.

not shown). Trees on Mark, B.9, and V.3 produced more flower clusters than M.9 RN 29, M.9 Burgmer 756, M.9 Pajam 1, M.9, M.9 Janssen 337, and M.27 EMLA (Table 2). In spite of the differences in the number of flower clusters, fruit yields (< 1 kg per tree) were similar among rootstocks in 1995. The reason for similar yields is attributed to poor pollination conditions (rainfall and high winds) during bloom.

In 1996, the temperature dropped to –3.3 °C when most flowers were at full pink stage. None of the trees on V.1, M.9 EMLA, M.9 RN 29, M.9 Burgmer 756, or M.9 NAKB T337 produced any fruit in 1996 (Table 2). Other rootstocks produced little fruit with similar yields. This result may indicate that some of these rootstocks influence the low temperature tolerance of the scion cultivar and warrants further investigation.

Although a substantial harvest occurred in 1997, fruit yields were similar among all rootstocks except M.27 EMLA (Table 2). Also, average fruit weight was similar among trees of M.9 clones. However, fruit from M.9 RN 29, M.9 Burgmer 756, and M.9 trees had greater average weight than those of B.9 and V.3 trees. In other studies, M.9 clones did not influence fruit weight (9, 22).

Cumulative yield from 1995 to 1997 was similar among all rootstocks except M.27 EMLA (Table 2). Low YE for all rootstocks was due to poor fruit set in 1995 and crop loss in 1996. Although YE of rootstocks was not statistically significant among rootstocks, M.9 EMLA had relatively low efficiency compared to other rootstocks, except M.27 EMLA.

In conclusion, results from this study represent preliminary data indicating differences in TCA, tree size, and average fruit weight among rootstocks. However, M.9 clones varied in TCA, height, and width by only 30%, 14%, and 13%, respectively. In some locations, differences in vigor among most M.9 clones may be perceived as small and inconsequential (9, 22), with the exception of M.9 Fleuren 56 (selected from the H. Fleuren nursery at Baarlo, The Netherlands). M.9 Fleuren 56 has consistently produced smaller trees than other M.9 clones (9, 10, 24).

Due to the inclement weather in the early years of this trial, it is difficult to make conclusive statements concerning precocity. In spite of climatic conditions, this trial is located on a site that historically produces relatively vigorous tree growth with moderate yields (13). Thus, as trees mature and more regular cropping is achieved, differences in CY and YE may be elucidated and more productive M.9 clones or other dwarfing rootstocks than M.9 EMLA may be recommended for planting in midwestern orchards.

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The Utilization of Related Prunus Species for Almond Variety Improvement

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Abstract

Germplasm from a range of Prunus species in the subgenus Amygdalus, sections Euamygdalus, Spartoides, and Lyciodes has been evaluated for potential value to almond (*P. dulcis*) breeding through an international, U.S.-Spain cooperative project. Species evaluated include *Prunus argentia*, *P. bucharica*, *P. fenzliana*, *P. mira*, *P. persica*, *P. scoparia* and *P. webbii*. The absence of severe crossing barriers in the initial hybridization and in subsequent backcrosses demonstrates a direct accessibility of this rich germplasm to almond breeding. The performance of interspecific hybrids, as well as their subsequent backcrosses to cultivated almond, further demonstrate valuable opportunities for transferring useful traits including self-compatibility, resistance to important pests and diseases, the improvement of seed oil quality, tree growth architecture and bearing habit, and tolerance to aberrant environments. The international collaboration has allowed a more thorough evaluation of related germplasm and avoids quarantine restrictions on the U.S. importation of new Prunus accessions.

Introduction

Almond (*Prunus dulcis* Miller, syn. *P. amygdalus* Batsch, syn. *Amygdalus communis* L.) in the subgenus *Amygdalus*, section Euamygdalus is an important tree crop of worldwide distribution (38). In 1999, California production was estimated at over 800 million pounds from plantings of approximately 500,000 acres. Spain, with the second largest commercial production has plantings of over 1,480,000 acres, but with the total production of less than 200 million pounds due to the widespread practice of low-input, dryland agriculture. The cultivated almond is thought to have originated in the arid mountainous regions of Central Asia (Fig. 1) (19, 31). Several wild species are also found in these mountainous areas, from the Tian Shan mountainous in western China, through Afghanistan, Kurdistan, and Turkestan, and into Iran and Iraq (5, 18, 19, 20, 29). The *Prunus* species *P. fenzliana*, *P. bucharica* and *P. argentia* (of the Section Euamygdalus) from these regions are described as the wild species most closely related to almond (5, 19, 20), and may be the ancestral species of the modern cultivated almond (29). Ladizinsky (31), however, identifies only *P. fenzliana* as the wild ancestor of almond. *P. webbii*, which is thought to have originated on the Balkan peninsula, and *P. persica* and *P. mira* from China are also described as closely related to almond (19, 20, 29). The limited genetic base for cultivated almond has been well documented using molecular markers (3), distribution of self-incompatibility alleles (27) and related genetic studies (32). Environmental limitations, particularly almond's vulnerability to frosts during its early spring flowering, and its susceptibility to foliar diseases under humid production conditions, have limited its cultivation to geographicareas with the characteristic Mediterranean type climate of moderate winter temperatures and low summer rainfall.

While inter-specific gene transfer has

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