on eight rootstocks and compared with own-rooted 'Redhaven' propagated by cuttings. Rootstocks included are seedlings of Halford, Lovell, Bailey, and Siberian C, and vegetatively propagated GF (Grande Ferrade) 677 ('Amandier'), GF 1869 ('Damas') GF 655-2, and 'Citation'. In these plantings, 'Redhaven'/'Citation' trees were dwarfed but weak, suggesting an incompatible combination or perhaps virus infection. The 'Damas' stocks are beginning to sucker excessively. Trees on GF 655-2 and 'Damas' have the highest survival ratings among all sites.

In addition to support of the local agricultural experiment stations in maintaining these plantings, industry support has been provided for the peach planting by Hilltop Nurseries, Dave Wilson Nursery, and Oregon Rootstock, Inc. Grower support for these cooperative tests has been provided through the International Dwarf Fruit Tree Assn., which paid shipping costs for all cooperators. The NC-140 cooperative rootstock plantings have gained wide support across the fruit-producing regions of North America, and hold promise for greatly shortening the time required to evaluate new rootstock candidates.

Individual cooperators are encouraged to collect additional data for specific interests. In the annual meetings, cooperators have reported on observations or studies related to treatment responses to low temperature exposure, calcareous and other adverse soil conditions, nematode infestations, inoculation with specific pathogens, and other more site-specific problems.

The intent of the NC-140 uniform rootstock trials is to provide bases for communicating rootstock performance and characteristics over a wide range of conditions. Limitations exist among sites due to scion adaptation. However, each site can only be considered a preliminary test plot, and researchers are encouraged to establish other trials that may be more applicable to regional conditions.

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Criteria and Procedures for Evaluating Apomictic Rootstocks for Apple

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Breeding apomictic apple seedling rootstocks in a country where vegetatively propagated material is grown nearly exclusively is a tremendous challenge. When the program was started 25 years ago, virus infection was widespread in apples. Used as rootstocks, seedlings have the advantage of being free from viruses, because these viruses are not seed-transmitted. In Germany, a functional system has been developed to produce and distribute pomologically valuable, virus-free (VF) plant material in quantities sufficient for the nurseryman. The standard of orchard performance for apple rootstocks is high, with the dwarfing M.9 being the most important rootstock in our country. Apomictic seedlings have to compete with this and other horticulturally excellent stocks.

Apomixis is widespread in many rosaceous species, especially among the polyploids; in none of them is apomixis obligate. Progenies from open-pollination (o.p.) always contain a certain proportion of hybrids together with the maternal seedlings. The form of apomixis in the *Rosaceae* is apospory, by which embryos do not develop directly in the nucellus. An unreduced embryo sac is formed. Under favorable conditions, the unreduced egg can be fertilized, giving rise to hybrids of high polyploidy. Apomixis is present in some triploid and tetraploid *Malus* species of eastern Asiatic origin. In the research program reported here, the 3x *M. hupehensis* (Pamp.) Rehd. and the two 4x species *M. sargentii* Rehd. and *M. sieboldii* (Regel) Rehd., which seem to be closely related, have been used. Our *M. hupehensis* was identical with that at the Swedish Fruit Breeding Institute, Balsgård, and the Fruit Institute at Hannover Univ., but quite different from *M. hupehensis* used at Angers, France and two seed samples that I received from China, although all of them were obviously related. At least the Chinese seedlings are highly apomictic also. None of the apomictic species mentioned above is satisfactory as a rootstock, although *M. sieboldii* has been used in Japan (2).

Crosses with *M.* ×*domestica Borkh.*, including M.9, were made. The percentage of hybrids from artificial pollination usually is higher than that from open pollination. These hybrids were selected and grown for seed production. Seedlings from the hybrid trees were screened for maternal types. Trees producing high percentages of apomictic seedlings were selected for seed production, and seedlings were raised for budding with apple cultivars. With few exceptions, the percentage of apomictic seedlings from open pollination was lower in the hybrids than in the species from which they were derived (Fig. 1). An explanation could be that the cytological balance of apomixis is disturbed by recombination during meiosis in the apomict. Recombination is the rule when pollen-fertile apomicts are used as pollinators. Apomixis is preserved, at least partly, when apomicts are used as seed parents, and unreduced eggs are fertilized

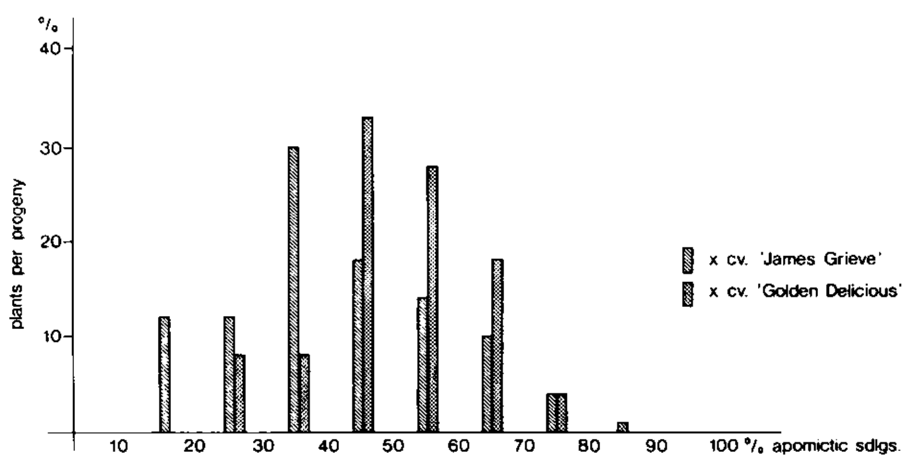

Fig. 1. Frequency distribution for degree of apomixis in the two progenies *Malus hupehensis* x 'James Grieve' and *M. hupehensis* x 'Golden Delicious'.

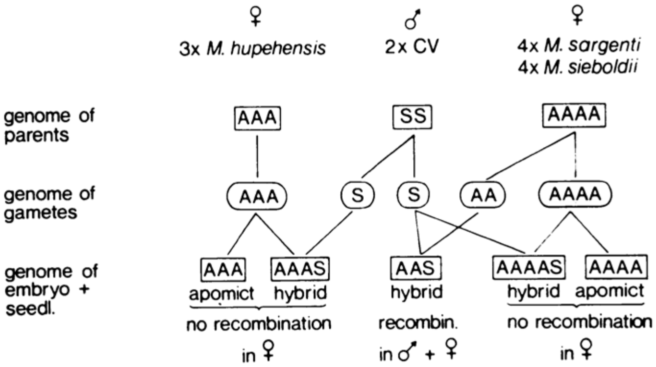

Fig. 2. Patterns of inheritance of apomixis in apomictic *Malus* species pollinated by a diploid non-apomictic cultivar. (A = apomixis, S = sexual).

by pollen of a non-apomict. The more the number of unreduced genomes from the apomict exceeds the number of genomes from the non-apomict, the better are the chances for a high rate of apomictic reproduction in the hybrid (Fig. 2). Whereas *M. hupehensis* forms unreduced eggs nearly exclusively, the two tetraploid species produce both reduced and unreduced gametes. Consequently, two kinds of hybrids can arise, triploids and pentaploids (3).

From about 1100 seedlings, 124 trees with a high degree of maternal types were selected from open pollination. Seedlings from these trees were budded with apple cultivars and were tested for their capacity as rootstocks. The failure of budtake in the nursery during the early trials proved to be due to virus infection (4). Many of the apomictic selections were highly sensitive to the common latent viruses. Even if the scions grew, trees in the orchard stayed extremely small, whereas the VF combinations grew quite vigorously (Table 1). When VF scion material was used, budtake of seedlings from selected apomicts was ≈90%. Only a few apomicts had to be discarded because of true graft incompatibility. In the orchard, no losses that could be attributed to disturbed rootstock–scion relations were recorded in the VF combinations. Results from orchard trials showed the best dwarfing potentiality in hybrids derived from *M. sargentii* (Table 2).

Rootstocks from *M. sieboldii* and *M. hupehensis* were more vigorous than M.9, comparable to MM.106 (Fig. 3). With increased vigor, anchorage of trees improved (Fig. 4). Rootstock–scion interactions were observed in some combinations (Table 3). The induction of vigor by the rootstock was generally similar in different

Table 1. The influence of latent viruses in apple scion material on the growth of 'Ingrid Marie' during 7 years in the orchard.

	Weight of roots (kg)		Crown volume (m³)	
Rootstock	+Vi[z]	−Vi[y]	+Vi	−Vi
M. 9	2.1	2.0	2.7	4.2
4556	8.8	6.7	13.3	11.8
4637	1.8	14.6	1.6	14.5
CO725	1.0	11.5	1.8	12.9
GO138	1.0	12.3	0.4	16.9

[z] +Vi: infected with latent viruses.
[y] −Vi: virus free.

cultivars; CO311, however, produced large trees of 'Ingrid Marie' and severely dwarfed trees of 'Cox's Orange Pippin'. It is not possible to predict such interaction, so rootstocks must be tested under a series of cultivars. During the extremely dry summers of 1982 and 1983, apomictic mother trees and other seedlings budded with 'Cox's Orange Pippin' and 'Golden Delicious' were screened for their reaction. No correlation could be found between drought susceptibility of mother trees and their seedling rootstocks. Among the mother trees, the vigorous *M. hupehensis* hybrids suffered most; M.9 and vigorous as well as more dwarfing rootstocks were damaged, generally more with the susceptible 'Cox's Orange Pippin' than with 'Golden Delicious'.

Yields of trees on apomictic stocks have not been satisfactory. Since most rootstock candidates induced more vigorous growth in the scion cultivars than does M.9, standard trees of the semi-dwarf and semi-vigorous classes should have been included for comparison. Trials were usually not run longer than 7 to 10 years, with many tree losses during this period. None of the apomictic rootstocks was as precocious as M.9. The shorter the period of cumulative yields, the greater the advantage of the precocity-inducing M.9. The most dwarfing trees on *M. sargentii* hybrids cropped like those on M.9 in the early years. They later produced many thin and weak branches, which led to lower yields. The best crops were obtained among the apomicts inducing intermediate vigor.

Among the 124 apomicts, about 20 have been selected for further trial on the basis of their behavior as rootstocks for 'Cox's Orange Pippin', 'Golden Delicious', 'Ingrid Marie', and 'Laxton's Superb'. These selections, with M.9 and MM.106 as standards, were budded in 1985 with 'Gloster', 'Jamba', and 'Jonagold' and were planted in 1987.

If these last trials indicate that some of the apomicts are worthy

Fig. 3. Root crowns of virus-free 'Golden Delicious' on M.9 stock (**left**) and on the apomict GI 0138 (**right**).

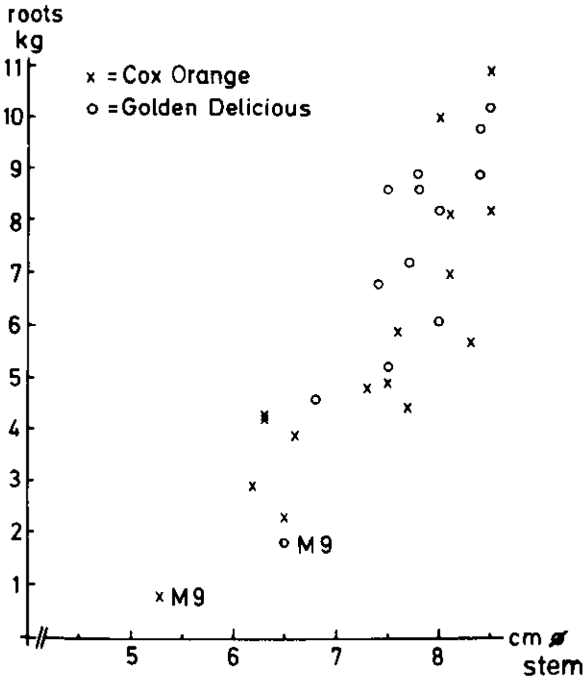

Fig. 4. Weight of roots and stem diameter of scion cultivars related to apomictic rootstocks after 6 years in the orchard.

of release for commercial production, some nursery characteristics must be studied again. These characteristics include seed production, germination rate, percentage of maternal seedlings and the ease of recognizing them, and vigor and health of plants in the nursery and orchard. Good seed production depends on the fruit set of the mother tree and the number of seeds per fruit. Fruit set in the apomicts generally is good. Seed number, however, is low in many apomicts, usually in the range of 0.7 to 1.5 seeds per fruit, staying fairly stable over the years. The germination rates of seeds from apomictic sources vary with weather conditions, as do those of other seed-propagated stocks (Table 4).

The percentage of maternal seedlings is highest in *M. hupehensis* forms with more than 90%. This stock cannot be recommended as rootstock because of compatibility problems and susceptibility to *Erwinia amylovora* (Burr.) Winslow et al. (fire blight). *M. sargentii* and *M. sieboldii* produce 70% to 80% maternal seedlings from open

Table 2. Vigor classes of apomictic apple rootstock selections.

Species or cross from which rootstock derived	No. rootstocks	No. rootstocks in vigor classes: Very invigorating	Invigorating	Intermediate	Dwarfing	Very dwarfing
Species						
M. hupehensis	35	1	7	21	6	---
M. sargentii	28	---	---	15	11	2
M. sieboldii	47	---	13	25	9	---
Hybrids						
(*M. hupehensis* x *M. sargentii*)	3	---	---	3	---	---
(*M. sieboldii* x *M. sargentii*)	7	---	---	5	2	---
Various species	4	---	3	1	---	---
Standards						
M. 9	1	---	---	---	1	---
Bittenfelder OPS	1	1	---	---	---	---

pollination. Seedlings grow slowly, so selection is not always easy. In many of the hybrids, the percentage of apomicts is between 65% to 75%, with considerable variation from year to year. Certain years seem to increase or reduce the proportion of maternal seedlings. In 1973, germination was good, and a high percentage of apomictic seedlings was recorded in many progenies. Weather conditions, thus, must have been favorable for both in 1972.

Healthy growth in the nursery is best in *M. hupehensis* and hybrids derived from this species. *M. hupehensis* is immune to powdery mildew [*Podosphaera leucotricha* (E. & E.) Salmon] and transmits this immunity to all F_1 hybrids. Some of the *M. sieboldii* hybrids are fairly mildew-susceptible and must be sprayed. The *M. sargentii* hybrids are intermediate. Scab rarely has been seen in any of the apomicts. Investigations on the resistance to collar rot (*Phytophthora cactorum* Leb. and Cohn) in some of the apomictic selections revealed the best resistance in *M. sargentii* and its hybrids, intermediate resistance in *M. hupehensis* and its derivatives, and varying degrees of susceptibility in the various *M. sieboldii* hybrids (1). Testing for resistance to *Nectria* canker revealed a fairly high resistance in some *M. sieboldii* hybrids compared to 'Cox's Orange Pippin' (A. Schmidle, personal communication). *M. sargentii* has some resistance against fire blight (J.N. Cummins, personal communication). *M. hupehensis* is susceptible to fire blight (W. Zeller, personal communication).

Vigor of seedlings in the nursery row varies with species of origin. The *M. hupehensis* derivatives and some *M. sieboldii* hy-

Table 3. Apple rootstock–scion interactions of crown volume and root weight in virus-free combinations.

Rootstock	Weight of roots (kg): Ingrid Marie	C.O.P.[z]	Crown volume (m^3): Ingrid Marie	C.O.P.[z]
M. 9	2.0	1.5	4.2	4.2
4556	6.7	5.5	11.8	10.7
CO311	10.4	1.1	13.0	3.1

[z]'Cox's Orange Pippin'.

Table 4. Year-to-year variation in germination rate and percentage of maternal seedlings from selected apomictic mother trees.

Rootstock	Germination (%): 1971	1973	1983	Maternal seedlings (%): Average	Maximum	Minimum
D 1718	18		71	67 (5)[z]	91	48
D2009	16	75	66	66 (5)	82	37
D2032	32		82	51 (5)	76	36
C1825	13	76		72 (5)	94	59
C1810	18	49	75	53 (6)	60	47
C0725	15	81	76	58 (7)	81	33
4556	26	81	84	79 (6)	90	63
D 2212	48	80	85	73 (4)	86	60
Gi 460/9	15	12	57	65 (6)	69	58
4637		90	76	76 (3)	82	73

[z]Number of years recorded in parentheses.

brids generally grow well and are ready for budding in the year of sowing. Most of the *M. sargentii* hybrids, however, need to grow a second year before they can be budded.

DISCUSSION AND SUMMARY

What are the chances for commercial production of apomictic apple rootstocks? Apomictic apple rootstocks have several advantages. They are easily seed-propagated. Seedlings are virus-free. Grafted trees generally are well-anchored. They are comparable to vegetatively propagated rootstocks in budtake and compatibility in the orchard when VF scion material is used. Several disadvantages, however, cannot be denied. The seedlings must be selected for maternal types. In some years, the proportion to be discarded can be as much as half the plants (Table 4). The nurseryman must be able to distinguish between apomicts and hybrids. Although identification is not difficult in most of the progenies, it requires time and some patience. Finally, the more dwarfing *M. sargentii* hybrids need 2 years to be ready for budding.

Most of these rootstocks are more vigorous than M.9, the best "croppers" being more like MM.106. The generally high variability in yield data among the trees of the same rootstock–scion combination in a trial can have many different causes. I would like to demonstrate some of the problems with trial 12/77. Variances (s%) between accumulated yields of trees 6 years after budding were 18 with 'Cox's Orange Pippin' on M.9 and varied from 14 to 102 on the apomicts. The trees with the lowest yields were those with the highest drought damage in 1982 and 1983. Whereas most 'Cox's Orange Pippin' trees on the apomicts reacted with lower yields and normal fruit size, 'Cox's Orange Pippin' on M.9 produced fairly high yields, although with an average fruit diameter of only 43 mm. The high variances may be partly due to incomplete removal of hybrid seedlings in the nursery. Further, it must be determined whether the thin, unfruitful branches in 'Cox's Orange Pippin' and 'Golden Delicious' by *M. sargentii* hybrid rootstocks was the result of inadequate pruning, which can be overcome. The insufficient branch system obviously was the reason that cultivars on *M. sargentii* hybrids decreased in yield with increasing age.

Commercial propagation of apomictic rootstocks by raising seedlings may prove too difficult for the nurseryman. Vegetative propagation is possible. We multiplied one of our clones easily by micropropagation. Rooting of softwood cuttings was successful with some of the apomicts.

Fire blight and collar rot resistances (1) in *M. sargentii* make this species valuable for rootstock breeding. When this species or any of its hybrids are used in a program for breeding vegetatively propagated rootstocks, apomixis will not be a problem when the species is used as pollinator. The 3x and 5x hybrids may not be good pollinators. Hybrids with *M. sargentii* can be produced freely. If apomictic seedling rootstocks were wanted, the use of *Malus sargentii* is recommended because it has the best percentage of maternal seedlings.

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Progress in Breeding Rootstocks in Romania

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For the past 10 years, new attention has been given in Romania to the development of improved fruit tree rootstocks by hybridization and mutation breeding. Prior to 1976, rootstock improvement was focused primarily on selection in seedling populations derived from both wild and cultivated forms, with emphasis on adaptation to local soil and climatic conditions. The rootstocks now in commercial use in Romania come from these sources.

The more aggressive rootstock research programs have resulted in the release of 25 new rootstocks (20 seed and five vegetatively propagated). Five of these new stocks are of particular interest because they have a marked capacity for producing dwarf trees.

It may be asked, "Why has there been such a major change in rootstock research in Romania"? One reason is the need to reduce the total acreage of good soils and sites devoted to fruit production and to shift this land, in part, to agronomic crops. At the same time, it is necessary to increase fruit production on lands unsuitable for agronomic crops. Such a change in the fruit production pattern puts a new set of pressures on the root systems of our trees. A second factor is the development of orchard replant problems. As new fruiting cultivars become available, old orchards are removed and replaced. Need for size-controlling rootstocks is now more widely recognized, so this has become a more important objective. We have also become more conscious of the need for root systems that are either tolerant or resistant to disease, especially to problems such as plum pox.

SELECTION PRINCIPLES AND PRACTICES

For both seed-propagated rootstocks and vegetatively propagated stocks alike, 3 to 6 years of observation in the nursery are followed by at least 5 years of full production in the orchard. For seed-propagated stocks, a hortitype is isolated from a population; this may be a set of seedlings from the wild, or perhaps a seedling from cultivated fruit, or even a root sucker from an outstanding tree. Such a potential candidate is evaluated in the nursery, examined for its responses to the diseases common in the environment, for its capacity to remain thrifty without special management, and for its capacity to produce an abundance of good seed. Of course, the behavior of the seedlings of the candidate must be examined in the orchard for its effects on production, stature, and longevity.

Candidates of interest as vegetatively propagated rootstocks are examined for propagability as layers, by hardwood cuttings, and by softwood cuttings. Nursery tests last 2 or 3 years, maiden trees are produced, and orchard trials follow. In the orchard, the standard observation period is 5 years of full production. However, candidates derived by interspecific hybridization are observed for 3 to 5 years longer in case delayed incompatibility should appear.

APPLE ROOTSTOCKS INTRODUCED

Pătul (*Malus* ×*domestica* Borkh.) is a seed-propagated stock named in 1968. It was selected from the natural swarm of *Malus* common in the foothill regions of Transylvania. Trees on Pătul seedlings are quite vigorous, long-lived, somewhat late to begin bearing, and are annually productive. The stocks are resistant to ground frost, have good anchorage, and are adapted to a wide range of soils. Pătul seedlings are graft-compatible with all apple cultivars that are commercially important in Romania. This stock is suited for spur-type