Precocious, Dwarfing, and Productive—How Will New Cherry Rootstocks Impact the Sweet Cherry Industry?

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ADDITIONAL INDEX WORDS. *Prunus avium*, *Prunus* hybrids, high density, virus sensitivity, orchard management

SUMMARY. Sweet cherries (*Prunus avium* L.) can be one of the most profitable tree fruits cultivated in temperate climates. While cherry trees grow naturally to relatively tall heights (≈35 ft [≥10 m]), new size-controlling cherry rootstocks similar to those used in high-density apple (*Malus domestica* Borkh.) orchards are now a reality. The Gisela (GI.) and Weiroot (W.) series from Germany, the Gran Manier (GM.) series from Belgium, the P-HL series from Czech Republic, 'Tabel Edabriz' from France, and others of international origin are at various stages of scientific and field testing in North America, with some now being used for commercial fruit production. These stocks confer several advantageous traits besides vigor control, including precocious fruiting and high productivity. While these beneficial traits are exciting, serious problems also have been documented on occasion, such as small fruit size and tree decline. As many of these rootstocks are interspecific *Prunus* L. hybrids, might there be significant limitations for fruit quality and orchard longevity? What is known about their tolerance to various soil types and / or climatological stresses? What is known about their susceptibilities to pathogens and pests? Further, with the U.S. and worldwide orchard area planted to fresh-market sweet cherries already expanding to record levels throughout the 1990s and a time-honored agricultural tendency toward overproduction until grower profits are minimized (e.g., recent international apple markets), what might be the future impact of such precocious, productive rootstocks on sweet cherry profitability and sustainable production? This overview addresses these topics, providing some answers and some areas for future scientific investigation and industry discussion.

Sweet cherries are among the most highly prized temperate tree fruit by consumers, a fact reflected in their having one of the highest economic returns per acre on a seasonal basis. They are flavored intensely and, typical of *Prunus* species, can be stored for only a couple of weeks, thereby intensifying the apparent special allure (and value) to consumers due to their ephemeral availability during the summer. However, sweet cherries are not easy to produce, being subject to numerous serious diseases and pests (Blodgett, 1976) and susceptible to numerous vagaries of climate (severe winter cold, spring frost, rain during ripening, summer heat).

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Further, profitable orchard management can be challenged by the inefficiencies associated with large tree size, a long establishment period before first fruiting, and relatively small, delicate fruit, which must be harvested by hand for fresh markets. The potential production efficiencies conferred by dwarfing, precocious rootstocks have long eluded sweet cherry growers (Toyama et al., 1964; Webster, 1996).

Beginning in the late 1980s, several series of promising dwarfing cherry rootstocks (Table 1), developed largely from European breeding and selection programs, were tested widely in North America (Perry et al., 1996) and Europe (Kemp and Wertheim, 1996). Some of these have shown great potential to promote precocious fruiting and high productivity, as well as provide a range of tree vigor levels to better match sweet cherries to different training systems and soil characteristics. Yet, many questions remain before commercial adoption of such rootstocks into high density cherry orchards is widespread, not the least of which include whether large fruit size can be attained in spite of increased crop loads, and a pervasive concern about more readily facilitating overproduction and depressing orchard economics as sweet cherries become easier to manage. With horticultural selection of this first wave of improved rootstocks occurring only recently, more advanced study of their adaptabilities, susceptibilities, and management dynamics is still relatively early.

Sweet cherry tree vigor

Genetic control of vigor is the driving force in the development and selection of new rootstocks for sweet cherry. *Prunus avium* is a forest tree in its native environment, therefore a challenge to maintain in an orchard. Labor to prune vigorous shoot growth and to harvest small fruit by the cluster is a major production cost made even more inefficient by the time spent climbing and moving ladders. Smaller trees have the potential to, at a minimum, double labor efficiency, as well as facilitate other possible orchard efficiencies. For example, protective chemical spray volumes can be reduced and coverage improved as tree size is decreased, benefitting both the orchard and the surrounding environment. Orchard covering systems for small trees can be developed at significantly lower costs to minimize potential damage from rain, birds, or hail. With a proper understanding of vegetative and reproductive growth relationships, small trees are easier to facilitate the even distribution of light throughout the canopy and the optimal balancing of crop loads to leaf area.

Conversely, smaller trees also present some new challenges for orchardists. With less permanent structure and less inherent vigor, balancing leaf area and storage reserves with fruiting capacity becomes more critical to achieve high quality fruit. As the proportion of the crop that can be picked from the ground increases, so does the vulnerability of the crop to spring frost damage. With high density orchards having open alleys between tree rows rather than a closed canopy over the tractor alley, less light interception per acre and possibly lower yields may result.

The results of about 10 years of NC-140 (Perry et al., 1996) and other trials in North America revealed that a wide range of rootstock-influenced tree vigor is possible, from very dwarfing to very vigorous (Table 2). In these initial trials, the most dwarfing rootstocks, 'Inmil' (tested as 'GM.9') from Belgium and 'Gisela 1' ('GI.1', tested as 'Giessen 172 / 9 [Gi.172 / 9]') from Germany, have not been satisfactory, for reasons that will become apparent later in this review. However, quite a few rootstocks were classified in the very useful dwarfing to semidwarfing vigor ranges, most notably 'GI.5' (tested as 'Gi.148 / 2') and 'GI.12' (tested as 'Gi.195 / 2'). In France, 'MaxMa 14 / Brokforest' (a virus-free clone of 'MxM.14') has become an important semidwarfing rootstock; widespread comparative trials of the 'MaxMa 14' have yet to occur in either North America or Europe, though some early North American trials of 'MxM.14' have been reported (Perry, 1987). While a number of these new rootstocks equal or exceed the vigor of Mazzard, further evaluation has revealed some to be significantly more precocious (e.g., 'GI.6', tested as 'Gi.148 / 1'), more productive (e.g., 'GI.6', 'MxM.2'), or more adaptable to specific conditions (e.g., 'Colt' in replant sites, [Webster, 1996]) that might be of specialized interest in more traditional orchard systems.

Having a range of vigor levels available to growers will likely be important for matching higher density orchard objectives with different soil types and / or scion variety growth habits. For instance, high density orchards of strong-growing varieties on fertile soils would be good candidates for a

Table 1. Cherry rootstocks tested across North America in the 1987–88 NC-140 regional project trials (Perry et al., 1996).

Prunus parentage	Rootstock
P. avium L.	Mazzard seedling (standard vigor control)
P. avium x *P. pseudocerasus* Lindl.	'Colt'
P. canescens Bois.	'GM. 79' ('Camil')
P. canescens x *P. avium*	'Gi.196 / 4'
P. canescens x *P. cerasus*	'Gi.195 / 1' ('GI.11'), 'Gi.195 / 2' ('GI.12')
P. cerasus x *P. avium*	'Gi.169 / 15'
P. cerasus x *P. canescens*	'Gi.148 / 1' ('GI.6'), 'Gi.148 / 2' ('GI.5'), 'Gi.148 / 8' ('GI.7'), 'Gi.148 / 9' ('GI.8')
P. cerasus x *P. fruticosa* Pall.	'Gi.154 / 4', 'Gi.154 / 7'
P. x *dawykensis* Sealy	'GM.61 / 1' ('Damil')
P. fruticosa x *P. avium*	'Gi.172 / 7', 'Gi.172 / 9' ('GI.1')
P. fruticosa x *P. cerasus*	'Gi.173 / 9' ('GI.10')
P. incisa Thunb. x *P. serrulata* Lindl.	'GM.9' ('Inmil')
P. mahaleb L.	Mahaleb seedling (standard vigor control)
P. mahaleb x *P. avium*	'MxM.2', 'MxM.39', 'MxM.46', 'MxM.60', 'MxM.97'

Table 2. General tree size (based on trunk cross-sectional area) and vigor classifications of sweet cherry on various rootstocks, relative to that on Mazzard seedling, under irrigated conditions in the Pacific northwestern United States.

Classification	Relative size (% of Mazzard)	Rootstock
Very dwarfing	35 to 50	‘Inmil’, ‘GI.1’
Dwarfing	50 to 65	‘Damil’, ‘GI.5’, ‘GI.7’, ‘GI.8’, ‘Gi.172 / 7’, ‘GI.10’
Semidwarfing	65 to 80	‘Gi.154 / 7’, ‘Gi.169 / 15’, ‘GI.11’, ‘GI.12’, ‘Camil’, ‘MxM.14’
Vigorous	80 to 100	Mazzard, mahaleb, ‘MxM.39’, ‘MxM.60’, ‘GI.6’, ‘Gi.196 / 4’
Very vigorous	100 to 120	‘Colt’, ‘MxM.2’

Table 3. Rootstock classification for tolerance of or sensitivity to the pollenborne viruses prune dwarf (PDV) or prunus necrotic ringspot (PNRSV).

Classification	Rootstock
Tolerant	Mazzard, mahaleb, ‘Colt’, ‘GI.5’, ‘GI.6’, ‘GI.12’, ‘Gi.169 / 15’, ‘Gi.196 / 4’, ‘Inmil’, ‘Damil’, ‘MxM.2’, ‘MxM.60’
Sensitive	‘GI.7’, ‘GI.8’, ‘Camil’
Hypersensitive	‘GI.1’, ‘GI.4’, ‘GI.10’, ‘GI.11’, ‘Gi.154 / 4’, ‘Gi.154 / 7’, ‘Gi.172 / 7’

Table 4. Cherry rootstocks tested across North America in the 1998 NC-140 regional project trials (Kappel et al., 1998).

***Prunus* parentage**	**Rootstock**
P. avium	Mazzard seedling (standard vigor control)
P. avium x *P. fruticosa*	‘Gi.473 / 10’ (‘GI.4’)
P. cerasus	‘Tabel Edabriz’; ‘Weiroot 10’ (‘W.10’), ‘W.13’, ‘W.53’, ‘W.72’, ‘W.154’, ‘W.158’
P. cerasus x *P. canescens*	‘GI.5’ (dwarf control), ‘GI.6’, ‘GI.7’, ‘Gi.209 / 1’
P. canescens x *P. avium*	‘Gi.318 / 17’
P. canescens x *P. cerasus*	‘Gi.195 / 20’
P. mahaleb	Mahaleb seedling (standard vigor control)
P. pseudocerasus (presumably)	‘P-50’

dwarfing stock like ‘GI.5’, whereas moderate density orchards with otherwise similar conditions may be better planted with a semidwarfing rootstock like ‘GI.12’. On poorer soils, the high density orchard could be planted with a somewhat more vigorous stock like ‘GI.12’ and the moderate density orchard with a vigorous stock like ‘GI.6’. It should be noted that, in the NC-140 trial reported by Perry et al. (1996), ‘GI.6’ produced full-size ‘Bing’ trees on fertile, irrigated soils in Washington, Oregon, and British Columbia, but produced very dwarf trees of ‘Hedelfingen’ on poorer soils in Michigan and New York. Consequently, in addition to soil type and management factors, scion varietal differences may also have a significant impact on orchard rootstock decisions.

Screening for virus sensitivity

While screening rootstocks for susceptibilities or tolerances to various important diseases is valuable (and will be discussed further below), it has been recognized only recently that one of the earliest rootstock screening tests should be for reaction to ilarviruses, such as prune dwarf (PDV) and prunus necrotic ringspot (PNRSV). These viruses are prevalent throughout most cherry-growing regions, can be transmitted via infected pollen, and indeed are often found in sweet cherry orchards causing no negative symptoms on trees growing on Mazzard (*P. avium)* or *P. mahaleb* L. (mahaleb or perfumed cherry) rootstocks. However, some genotypes of *P. cerasus* L. (sour cherry), *P. canescens* Bois. (grey leaf cherry), and *P. fruticosa* Pall. (steppe or ground cherry) are known to exhibit varying levels of sensitivity to these viruses, and hence so do some of the new rootstocks that have been selected or hybridized from these species. Lang et al. (1997, 1998) have shown that the virus can pass from the point of infection (young flowering shoots) to the graft union within 10 weeks, whereupon a hypersensitive rootstock may begin exuding gum, followed by yellowing and premature abscission of leaves. During the second growing season following infection, hypersensitive trees collapse and die. Sensitive trees, which may only reveal a bronze leaf color during the initial season of infection, subsequently put out small, pale green leaves and minimal new growth, which eventually lead to tree collapse and death after several growing seasons. The rootstocks that have been screened for PDV and PNRSV sensitivity thus far are listed in Table 3. It is likely that this virus sensitivity may explain several of the cases of tree loss in the European trials (Wertheim et al., 1998) that were ascribed to delayed graft incompatibility.

As there are no protective measures to be taken to halt these viruses once they infect a tree, the NC-140 regional project scientists have concluded that virus tolerance should be a primary screening criteria for new cherry rootstocks. Indeed, of the new rootstocks screened thus far, 50% have been eliminated from further commercial consideration (Table 3) and

Table 5. 'Bing' sweet cherry precocity (cumulative yield, orchard years 4 to 7) and productivity (cumulative yield, orchard years 7 to 10) on four rootstocks with commercial potential (results from the NC-140 regional project trial at Washington State University, Prosser).

Rootstock	Vigor Class	Precocity: 4th–7th Year Cumulative Yield [lb(kg)]	Precocity: Relative Yield (% of Mazz.)	Productivity: 7th–10th Year Cumulative Yield [lb(kg)]	Productivity: Relative Yield (% of Mazz.)
Mazzard	vigorous	82 (37)	100	273 (124)	100
'GI.5'	dwarfing	101 (46)	124	267 (121)	98
'GI.12'	semidwarf	108 (49)	132	346 (157)	127
'GI.6'	vigorous	174 (79)	213	405 (184)	148

Table 6. Productivity and fruit quality (weight, diameter, and soluble solids) of unpruned 'Rainier' sweet cherry trees on the dwarfing rootstock 'GI.7', following crop load management by flower bud removal at bloom (5th leaf), in an irrigated orchard at Washington State University, Prosser.

Crop load treatment	Yield/tree [lb (kg)]	Fruit (g)[z]	Size distribution (% ≥24 mm)[y]	Soluble solids (°Brix)
unthinned	43 (19.5)	6.9	49	21.4
3 buds / spur	47 (21.3)	7.1	61	21.2
2 buds / spur	36 (16.3)	9.0	82	22.7
1 bud / spur	32 (14.5)	9.9	87	24.2

[z]r28.4 g = 1.0 oz.
[y]Fruit diameter of 24 mm (0.94 inches) or larger is equivalent to 11-row or greater.

preliminary results from screening of the most recent group of rootstocks under test (Table 4) have indicated a similar percentage will be eliminated (G. Lang and W. Howell, unpublished). The new project to identify potential cherry rootstocks from the *P. cerasus*-based hybridization program at Michigan State University has made virus sensitivity screening a selection criteria that precedes any orchard testing for horticultural traits (A. Iezzoni, personal communication).

Effects on precocity, productivity, and fruit quality

Sweet cherry trees on Mazzard or mahaleb rootstocks often do not flower significantly until the 6th or 7th leaf. Some of the new hybrid rootstocks begin flowering in the 3rd leaf (2nd year in the orchard), with economic crop potential in the 4th to 5th leaf. Such precocity is a tremendous economic advantage, helping to recover orchard establishment costs much earlier and thereby advancing the financial breakeven point in the life of the orchard by several years. In the 1987 NC-140 trial, the Gisela rootstocks were the most precocious, with first flowering ranging from the 3rd to the 5th leaf (Perry et al., 1996). The Gran Manier rootstocks were not quite as precocious, averaging about a year longer, followed by mahaleb and the MxM rootstocks, Mazzard, and 'Colt'. While the most vigorous rootstocks generally were the least precocious, 'GI.6' exhibited strong vigor in the Pacific northwestern U.S. yet was as precocious as the more dwarfing 'GI.5' and 'GI.7' (tested as 'Gi.148 / 8'). A measure of precocity for three virus-tolerant Gisela rootstocks having different vigor classes in Washington state, compared to Mazzard, can be determined from the cumulative yields over years 4 to 7 in the orchard (Table 5). For full-size 'Bing' trees on 'GI.6', the cumulative yields were more than twice that of trees on Mazzard, and even trees on the semidwarfing 'GI.12' and dwarfing 'GI.5' had yields about 25% to 30% higher, on a per tree basis. Planting such rootstocks at higher densities to best utilize their reduced size will increase early yields, on a per acre basis, even more.

In addition to earlier formation of flower buds, the precocious Gisela rootstocks also promote a higher number of flowering nodes and ultimately higher spur formation. This results in the potential for continued high productivity, compared to Mazzard, even after the impact of precocious flowering is factored out. The Productivity column in Table 5 reveals the higher yields possible during orchard years 7 to 10 on the three Gisela rootstocks currently recommended for commercial trial. Yields were similar, on a tree basis, between the dwarf trees on 'GI.5' and the full-size trees on Mazzard, yet in commercial orchards the dwarf trees would be planted at up to twice the density of the full size trees. This bodes well for maintaining good production levels even as some reduction in total light interception per acre may be expected due to open alleys in high density orchards. The semidwarfing and vigorous Gisela rootstocks maintained yields of about 25% and 50% higher than Mazzard, respectively. These productivity traits can be used to particular advantage in promoting higher crop loads on lighter-bearing varieties like 'Tieton' and 'Cavalier'.

With respect to rootstock influence on fruit quality—a matter of critical importance as worldwide cherry production increases market competition—in the NC-140 trials, the largest fruit size generally was attained from the most vigorous trees. A caveat to this parameter is that the management of trees in the NC-140 trials was relatively minimal, in order to document natural rootstock influences without the impact of horticultural management. Since balancing crop loads to leaf area is a critical factor in sweet cherry fruit size variation, potential genetic and physiological effects of rootstocks on fruit size can only truly be examined by comparative experiments that tightly regulate leaf-to-fruit ratios across rootstock genotypes (such trials are now underway).

Observations and interpretations of the NC-140 data during years in

Table 7. Cherry rootstocks now being screened for virus sensitivity and potential inclusion in the next North American NC-140 regional project trial.

Parentage	Origin	Designation
P. avium x [*P. canescens* x *P. kurilensis* (Miyabe) Wils.]	Germany	'PiKu 4.11', 'PiKu 4.13', 'PiKu 4.15'
P. avium x [*P. canescens* x *P. tomentosa* Thunb.]	Germany	'PiKu 4.17', 'PiKu 4.20'
P. avium x *P. cerasus*	Czech Republic	'P-HL A', 'P-HL B', 'P-HL C'
P. cerasus x [*P. cerasus* x *P. maacki* Ruprecht]	Russia	'LC-52', 'VC-13'
P. fruticosa x *P. serrulata* va. *lannesiana* Carrière	Russia	'VSL-2'
P. serrulata var. *lannesiana*	Russia	'L-2'
P. pseudocerasus x [*P. cansecens* x *P. incisa*]	Germany	'PiKu 4.83'
Unknown	Russia	'Bz-3-II'

which spring frosts altered crop loads, however, lead to some preliminary conclusions regarding rootstock effect on fruit size. Fruit from trees on 'Inmil', and sometimes 'Damil' (tested as 'GM.61 / 1') and 'Camil' (tested as 'GM.79'), most often were noted across all sites and across various years to be smaller than fruit on the other rootstocks (Perry et al., 1996). Fruit from trees on the Gisela rootstocks generally were smaller than fruit on Mazzard in heavy cropping years, but similar in size (except for 'GI.1') to fruit on Mazzard when crop loads were moderated by spring frost. Hence, the hypothesis that good fruit size can be attained, even on these highly productive rootstocks, via intensive orchard management remains valid and in need of proof. A preliminary study (Lang and Ophardt, 2000) that thinned flower buds just before bloom to alter crop loads on unpruned trees of a very productive variety, 'Rainier', on a very productive dwarfing rootstock, 'GI.7', resulted in highly significant differences in fruit size, yet respectable yields (Table 6). Compared to the control crop load, which was similar to those under low management in the NC-140 trials, altering the crop by leaving 1 or 2 flower buds per spur reduced total yields by up to 25%, but increased fruit size by up to 43%. Fruit were of higher flavor quality as well, with significantly higher soluble solids, and up to 87% of the crop was packable for fresh markets compared to only half the crop of the unthinned control. On a per acre basis, the minimally managed trees would have yielded about 3.5 tons (3.2 t) of marketable fruit, while the crop load-managed trees would have yielded about 5 tons (4.5 t) of marketable fruit, a significant achievement in the 5th leaf.

Thus, the challenging aspect to those new rootstocks that are both precocious and highly productive is that overcropping is a strong possibility as early as the 5th leaf, before a typical tree on Mazzard would even have a crop. Yet, in the case of those rootstocks from this first wave that are being recommended for grower trial ('GI.5', 'GI.6', and 'GI.12'), this does not appear to be a genetic limitation of the rootstock, but rather a challenge to develop new ways to manage cherry orchards now that precocity and excessive vigor are less of a problem. Matching varieties and training and management systems to rootstock traits is therefore likely to become more important as the number of suitable rootstocks and their diversity of unique traits offers growers a greater set of orchard tools from which to choose.

Soil and climatic adaptations

In general, seedling rootstocks like Mazzard and mahaleb are deep-rooted and tolerate drought conditions better than clonally propagated rootstocks that tend to be more shallow-rooted. This may be the reason 'Colt' is considered semidwarfing under nonirrigated conditions, as often occurs in European orchards, while on the irrigated fertile loam soils of the western U.S., it can be at least as vigorous as Mazzard. 'Colt' also appears to be less vigorous on clay soils (R. Perry, personal communication). However, some of the MxM series, which are propagated clonally, develop extensive root systems (such as MxM.2 and MxM.60 [Longstroth and Perry, 1996]) and have been noted to be drought-tolerant (Wertheim, 1998). Rootstocks derived from *P. cerasus* tend to have shallow roots and are sensitive to drought, such as 'Tabel Edabriz' (Webster, 1996). The *P. avium* x *P. cerasus* hybrid rootstocks from the Czech Republic, 'P-HL A', 'P-HL B', and 'P-HL C', also are sensitive to drought (Wertheim, 1998). Experience at Washington State University with inadvertent irrigation problems in one trial block suggests that 'GI.1', 'GI.5', and 'GI.7' are fairly sensitive to drought stress. The Russian rootstocks 'L-2', 'LC-52', 'VC-13', and 'VSL-2' were selected under nonirrigated conditions and are presumed to drought tolerant, though they are noted to perform poorly on rocky soils (G. Eremin, personal communication).

As for some of the other species that have been used to create new cherry rootstocks through selection or hybridization, *P. canescens* and *P. cerasus* tend to have shallow roots and are sensitive to anaerobic conditions, though some deep-rooting has been found (Perry, personal communication). Although the *P. cerasus*-based Weiroot series are recommended for well-drained soils not subject to flooding (Wertheim, 1998), *P. cerasus* in general has been reported to be quite tolerant of heavy soils (Perry, 1987). *P. fruticosa* has shallow roots and is somewhat tolerant of anoxia. With regard to specific rootstocks, 'Colt' and 'Damil' are reported to be somewhat tolerant of anoxia, as are 'GI.4' (tested as 'Gi.473 / 10'), 'GI.6', and 'Gi.169 / 15' (ASHS, 1997; Franken-Bembenek, 1996; Webster, 1996). 'Gi.196 / 4' does not tolerate anoxia well. The Russian rootstocks noted above are reported to tolerate heavy soils and excessive soil moisture (G. Eremin, personal communication).

There has been very little North American research on rootstock interactions with different soil chemistries. The Belgian rootstocks, 'Inmil' and 'Damil', as well as 'Colt' and 'Tabel Edabriz', are sensitive to calcareous, high pH soils, whereas *P. mahaleb*-based rootstocks are well-suited to such soils (ASHS, 1997; Callesen, 1998; Webster, 1996). Callesen (1998) summarized several reports that 'Colt' and 'Damil' take up nitrogen and potassium poorly, one of which (Ystaas and Froynes, 1998) also showed that trees on 'GI.1' had low N and trees on 'Colt' also had lower P levels and higher levels of leaf Ca and Mg. Some of these reports are contradictory, requiring more study before many useful conclusions can be made. Of particular interest, in the matter of soil relations, is the tolerance of 'Colt' to replant disease (Webster, 1996), which normally causes decline and, possibly, death of young trees on Mazzard or mahaleb that have been planted on old cherry orchard soils.

Cold hardiness tests conducted by Strauch and Gruppe (1985) revealed good hardiness of *P. avium* selections from mountainous regions, *P. cerasus* x *P. subhirtella* Miq., *P. mahaleb* ['St. Lucie 64' ('SL.64')], 'GI.6', 'GI.8' (tested as 'Gi.148 / 9'), 'GI.12', and 'Gi.196 / 4'. Cummins et al. (1986) found good early winter hardiness with 'GI.6' and 'GI.10', but mixed results with 'GI.11' (tested as 'Gi.195 / 1') and 'GI.12'. Strauch and Gruppe (1985) rated 'GI.5' as similar in hardiness to the 'F.12 / 1' clone of Mazzard, though Cummins et al. (1986) found 'GI.5' to be very cold-hardy with respect to early winter freezes. Lang et al. (1997) reported that Bing flower buds on 'GI.5' were equally hardy to those on seedling Mazzard in January, but that deacclimation occurred more rapidly on 'GI.5' during February and March, a characteristic also evident in the data of Strauch and Gruppe (1985). 'GI.6', 'GI.8', 'GI.12', and 'Gi.196 / 4' remained similarly hardy in Jan and Feb, with slightly accelerated deacclimation in March (but not as much as 'GI.5'). Least hardy is 'Colt', for both early winter and midwinter freezes (Strauch and Gruppe, 1985; Cummins et al., 1986; Perry et al., 1996). This would suggest caution in planting 'P-50' (Table 4), which appears to be derived from *P. pseudocerasus* Lindl. (false cherry), in climates with potentially severe winter cold until it can be evaluated accordingly. In addition to losing several trees on 'Colt' to a severe December freeze, the NC-140 trial in Utah also lost trees on 'Camil', 'Damil', 'Inmil', and 'Gi.196 / 4' (Perry et al., 1996).

Other disease sensitivities

Little research has been conducted on the disease susceptibilities of these new rootstocks in North America, with the exception of bacterial canker (*Pseudomonas syringae* pv. *syringae* van Hall) (Krzesinska and Azarenko, 1992), Phytophthora (see below) and Armillaria (see below) root rots (Cummins et al., 1986; Proffer et al., 1988), and the ilarvirus sensitivity described above (Lang et al., 1997, 1998). While the severity and longevity of bacterial canker infections vary with climate and can sometimes be managed, selection of rootstocks that are less susceptible is a high priority in certain areas like Oregon's Willamette valley. Cherry rootstocks that have been reported previously (ASHS, 1997; Webster, 1996; Wertheim, 1998) to be somewhat tolerant or less susceptible to bacterial canker include the vigorous rootstocks 'F.12 / 1', 'Colt', and the MxM series, although only 'Charger' (*P. avium*) is noted to be "resistant". Krzesinska and Azarenko (1992) found 'GI.10' (tested as 'Gi.173 / 9') and 'Gi.169 / 15' to be more sensitive to bacterial canker than 'F.12 / 1'; 'GI.5' and 'GI.6' were similar in susceptibility to 'F.12 / 1'.

Avoidance of root rot caused by infection with *Phytophthora megasperma* Dreschler, *P. cambivora* (Petri) Buisman, *P. drechsleri* Tucker, *P. cryptogea* Pethyb. & Laf., *P. cinnamomi* Rands, *P. citricola* Sawada, *P. syringae* (Kleb.) Kleb., and *P. cactorum* (Lebert & Cohn) Schroet. is important in many California and eastern U.S. cherry growing areas (Mink and Jones, 1996). Some resistance to Phytophthora root rots has been reported for the MxM series, 'Damil', 'GI.10', and 'Gi.169 / 15' (Cummins et al., 1986). The seedling-derived *P. mahaleb* rootstocks common in North America are known for being sensitive to various *Phytophthora* sp., and tests have suggested the following are also sensitive: 'Inmil', 'Camil', 'GI.1', 'GI. 6', 'GI.11', 'GI.12', 'Gi.196 / 4', and several new Hungarian mahaleb seedling selections (CT500 and CT2753) that are just now entering trials in North America (Wertheim, 1998).

Resistance to Armillaria root rots, caused by *Armillaria mellea sensu stricto* (Vahl ex Fr.) Kummer, *A. ostoyae* (Romagn.) Herink., and / or *A. bulbosa* (Barla) Kile & Watling, would be an important rootstock trait in cherry-growing regions of Michigan and on other sandy soils in eastern North America (Mink and Jones, 1996). Some reports (Proffer et al., 1988; ASHS, 1997; Webster, 1996) have indicated sensitivity to Armillaria by 'Colt', 'Inmil', 'MxM.2', 'Gi.196 / 4', mahaleb seedling, and some *P. cerasus*-derived rootstocks, with less sensitivity by Mazzard, 'GI.11', and 'MxM.60'.

Wilt caused by *Verticillium dahliae* Kleb. can be a problem in parts of Washington state where *Verticillium*-harboring crops such as potatoes (*Solanum tuberosum* L.) and mints (*Mentha* sp. L.) are prevalent. There has been little or no research conducted on rootstock tolerance to verticillium wilt. Likewise, little work has been done on crown gall [*Agrobacterium tumefaciens* (E.F. Smith & Townsend) Conn.] susceptibility or resistance, with notes only on tolerance exhibited by 'GI.10' and sensitivity exhibited by 'F.12 / 1', 'Colt', North American seedling mahaleb, the Hungarian mahalebs (CT500, CT2753), 'Damil', and 'Gi.196 / 4' (ASHS, 1997; Webster, 1996; Wertheim, 1998). Western X disease, caused by leafhopper-transmittal of a mycoplasma-like organism (MLO), causes a slow decline in trees on Mazzard and 'Colt', and a rapid decline on mahaleb due to a hypersensitive resistant response that prevents transmittal of the MLO from the infected scion into the rootstock (Uyemoto et al., 1991). All of the Gisela rootstocks and 'Damil' were as susceptible to Western X disease as Mazzard, while 'MxM.2' and 'MxM.46' exhibited responses similar to mahaleb.

Conclusions

The first wave (Table 1) of new sweet cherry rootstocks for North American trial has yielded at least 3 precocious, highly productive genotypes ('GI.5', 'GI.6', and 'GI.12') with differing vigor levels worthy of grower trial in more intensive orchard management strategies. The outstanding productivity of some very vigorous rootstocks, like 'MxM.2', also may be worthy of trial by growers interested in more traditional orchard systems. The precocity of the next wave (Table 2) will become evident in 2000–01, and the virus sensitivity of the second and third (Table 7) waves will also become known during the next couple of years.

These regional and institutional trials hold great promise for discovering new traits that progressive cherry growers may utilize to meet some of the production challenges of the future.

Sweet cherry production is bound to undergo significant change in the new millennium, with a diversity of new rootstock traits altering the foundations of orchard management that changed little during the 20th century. The induction of precocious cropping is an extremely strong economic incentive that will become common, via either rootstocks or new cultural manipulation of standard rootstocks, to remain competitive as orchard capitalization costs increase. Similarly, smaller tree stature and higher density orchards will become common as experience in crop load management on highly productive, vigor-controlling rootstocks increases. Rather than focus management decisions on minimal early pruning to hasten cropping and later pruning to manage excessive vigor, as are current practices, high quality intensive cherry orchards likely will be pruned and fertilized more aggressively throughout their existence to generate new leaf area and balance cropping potential, resulting in a more labor efficient orchard that can also be better protected from some of the many risks inherent in sweet cherry production.

As dwarfing, precocious rootstocks have revolutionized apple production in North America and worldwide, the late 1990s have seen concomitant apple production levels in North America, New Zealand, Europe, and China outpace market demand, with disastrous effects on sustainable profits. Some traditional cherry growers have expressed concern that rootstocks which confer greater orchard efficiency and ease of production may lead this currently profitable industry down similar paths. The history of modern agriculture suggests that eventual overproduction is almost an inherent outcome of a free market system comprised of independent producers. Certainly, any orchard innovation that promotes more sustainable production in a milieu typically subject to numerous serious climatic and pathological challenges will make production of that commodity more attractive to new growers and / or expansion by existing growers, and hence require greater planning and / or partnering between producers and marketers to better balance demand with anticipated supplies. However, it also is clear that the future of labor-intensive traditional sweet cherry production cannot be sustained in North America and Europe as agricultural labor forces continue to concomitantly shrink and become more expensive. In the logical hierarchy of sustainable production challenges, high density labor-efficient orchards (based on a combination of improved rootstock genetics and more intensive management) will clearly be a factor in maintaining the potential economic viability of North American sweet cherry production. Grower-packer-marketer communication and coordination to anticipate market demand and possible saturation will clearly be related, but separate, factors.

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