NEW YORK'S FOOD AND LIFE SCIENCES BULLETIN NO. 41, MAY 1974

PLANT SCIENCES

POMOLOGY AND VITICULTURE (GENEVA) • 15

NEW YORK STATE AGRICULTURAL EXPERIMENT STATION, GENEVA, A DIVISION OF THE NEW YORK STATE COLLEGE OF AGRICULTURE AND LIFE SCIENCES, A STATUTORY COLLEGE OF THE STATE UNIVERSITY, CORNELL UNIVERSITY, ITHACA

# Apple rootstock problems and potentials

J. N. Cummins[1] and Richard L. Norton[2]

In the fruit grower's future, nothing is more constant than change. Change is being forced on the industry by a number of social and economic factors, especially by those related to the work force. These pressures are now driving the orchardist toward higher density plantings of smaller trees.

This publication is designed to assist the grower in anticipating problems which can occur with higher density orchards; such anticipation should enable the grower to avoid these pitfalls, to minimize the total effects of shortcomings, and to maximize the total utilization of the potential of modern orchard design. The rootstock-related problems described should not be interpreted as negating the value of dwarfing rootstocks and high density plantings.

Modern clonal rootstocks are an essential factor in the new technology of apple orcharding. By utilizing these stocks, growers have been able to develop orchards of relatively small trees, closely planted, bearing commercial crops much earlier than had been possible in former times. Aside from the advantages, important problems have arisen also which are root-stock related. However, the convenience and profitability of those small trees will continue to push the industry in the direction of size controlled rootstocks.

1 Associate Professor of Pomology, New York State Agricultural Experiment Station, Cornell University, Geneva, New York 14456

2 Cooperative Extension Specialist, Cornell University, 249 Highland Avenue, Rochester, New York 14620

## PROBLEMS ASSOCIATED WITH SEEDLING STOCKS

Rootstock problems are neither new nor unique to the newer size-controlling clones; problems of the old, standard seedling-rooted tree have not, however, been recognized as rootstock-related.

The most conspicuous problem of the seedling rootstock was its failure to limit tree vigor and size. The tools used to combat this problem have included long ladders and "steel squirrels," ever more powerful sprayers, pneumatic pruners and giant hedging machines, and now shake-and-catch harvesters (Fig. 1). The excessive vigor of the seedling-rooted tree has been largely responsible for the excessive capital requirement for the fruit farm.

Traditionally, the fruit grower has waited half a lifetime for his orchard to begin profitable commercial production. Now we recognize that this delayed bearing was also a rootstock-caused problem. Early production is not limited to the small tree; the very vigorous Mailing (M.) 25 and Malling-Merton (MM.) 109 clonal stocks cause early bearing, yet make full-sized trees (2,9).

Associated with delayed production is limited tonnage. Annual yields of 1,000 to 1,200 bushels per acre are commonly reported from the best York, Mclntosh, and Golden Delicious blocks, but these are mature orchards 20, 30, or more years old. These excellent annual yields of mature trees have blinded us to the much lower *average* annual yields measured over the entire lifetime of the orchard—truly a much more appropriate criterion (1).

*Figure 1.—Large, "standard" apple trees require large machinery and large investments.*

The waiting period, from the date of planting until the first cash returns are received, is one of the costliest items in the business of bringing an apple orchard into commercial production. This long delay of onset of commercial production associated with the seedling rootstock has made the orchard enterprise relatively inflexible. Once the "apple factory" has reached commercial production, the grower has so much time, effort, and capital invested that he can ill afford to retool to take advantage of new technological developments or to meet changes in the market or labor pictures.

Fruit color and quality are directly related to the exposure of leaves and fruit to the sun. Exposure decreases as tree size increases. Percentage fancy fruit from the large tree is typically less than percentage fancy fruit from the smaller tree. The increasing emphasis on fruit size and color by the produce buyer has been a major factor in New York's shift to the smaller tree.

### Assets of Seedling Rootstocks

That we have lived so long (and so well) with seedling stocks suggests that they must have some significant assets, along with their liabilities. Most seedlings came from the Pacific Northwest, suggesting that almost all have Red Delicious as one parent. These seedlings tend to be somewhat tolerant of fire blight, collar rot, and woolly apple aphids (WAA), and reasonably winter hardy. Selection in the seedling nursery, and again in the budling nursery, has tended to give uniform trees despite the original genetic diversity of the seedling stocks. In the orchard, we always planted our trees with the bud union 2 or 3 inches below soil level; after a few years, we had both the seedling roots and a new adventitious root system from the scion variety. Anchorage has been excellent; the roots have been suitable for a wide variety of soil types (2).

Both the nurseryman and orchardist liked seedling-rooted trees because they were cheap and simple to handle. The nurseryman never had to worry about confusing rootstock clones; the seedling stocks grew vigorously in the nursery with minimal care, took buds well, and made fine maiden trees (Fig. 2).

Our traditional seedling stocks, then, have been satisfactory for disease and pest tolerance, for nursery behavior, and for anchorage under the conditions of our past orchard technology.

*Figure 2.—In the nursery, budding onto seedling liners leads to excellent stands of vigorous, uniform trees.*

## DISEASE AND PEST PROBLEMS OF CLONAL ROOTSTOCKS

With the clonal rootstocks, there is a potential for catastrophic problems from fire blight and collar rot and for chronic difficulties with woolly apple aphids, viruses, and nematodes. If these possible difficulties are recognized, though, they can be prevented or the dangers reduced.

Fireblight

This disease was not ordinarily a rootstock-related problem with the standard tree for several reasons:

1. Since on trees with standard roots, flowering did not begin until the trunk and scaffold system be came quite large, a blight lesion then developing on the trunk or scaffolds was relatively unlikely to result in girdling.
2. Heavy shading limited the development of fruit spurs on the trunk and main scaffolds. This virtual absence of blossoms on the primary tree structure reduced the possibility of initial infec tions occurring there and therefore there was little chance of a girdling lesion developing.
3. With the wide spacing between trees and be tween rows, inoculum had to be transferred considerable distances between source and infec tion court.
4. Most seedling roots are inherently somewhat resistant to fire blight. Perhaps more important, by the time flowering began, shade was so dense that rootstock suckers were succulent for only a short period each spring.

Our change to the new rootstocks has altered the picture: (1) Trees on most of the clonal stocks begin bearing at an early age, when the tree is still small enough that a single canker on the rootstock can girdle and kill it (Fig. 3). (2) Many vigorous fruit spurs are set on the lower trunk and scaffolds while these are still of small circumference. Fire blight cankers are likely to develop from infected flowers, and these cankers can extend laterally enough to kill a substantial part of the tree. (3) With closer spacings, bees tend to work down a row, rather than on a single tree; inoculum may thus be distributed much more efficiently. (4) Most serious, some of the rootstock clones are themselves extremely susceptible to the fire blight bacteria (4). Even if the scion portion of a tree is quite resistant, M.9 or M.26 roots are highly susceptible (Fig. 4). MM.106 is moderately susceptible (Fig. 5), while M.7 and MM.lll (Fig. 6) are relatively resistant (4). On M.9 and M.26, an infection of a sucker on a tree less than perhaps 3 inches diameter is quite likely to lead to a girdling lesion. M.9 suckers freely, so it is especially important to control M.9 root suckers under commercial orchard conditions. Lesions on suckers of M.7 and MM.lll Usually terminate well above the main root (Fig. 7). At this stage, we can only suggest that trees on susceptible rootstocks can best be protected from fire

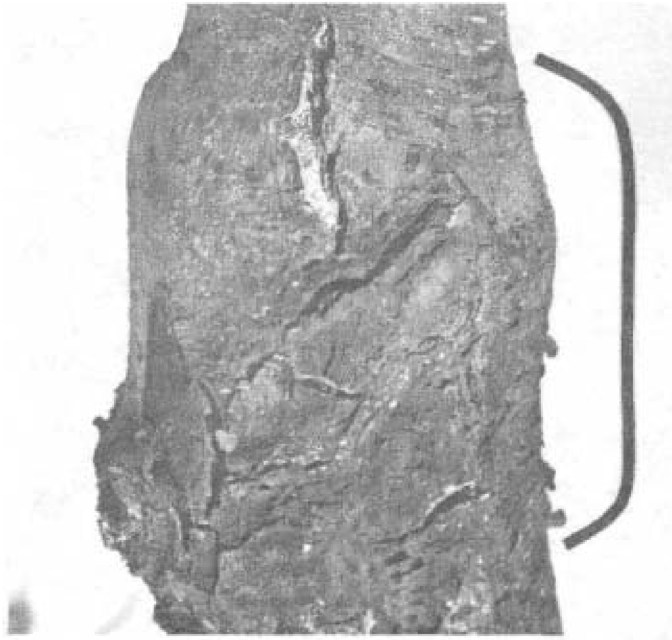


*Figure 3.—Fire blight lesion (bracket) in the rootstock portion of this 3-year-old Empire/M.26 girdled and killed the tree.*

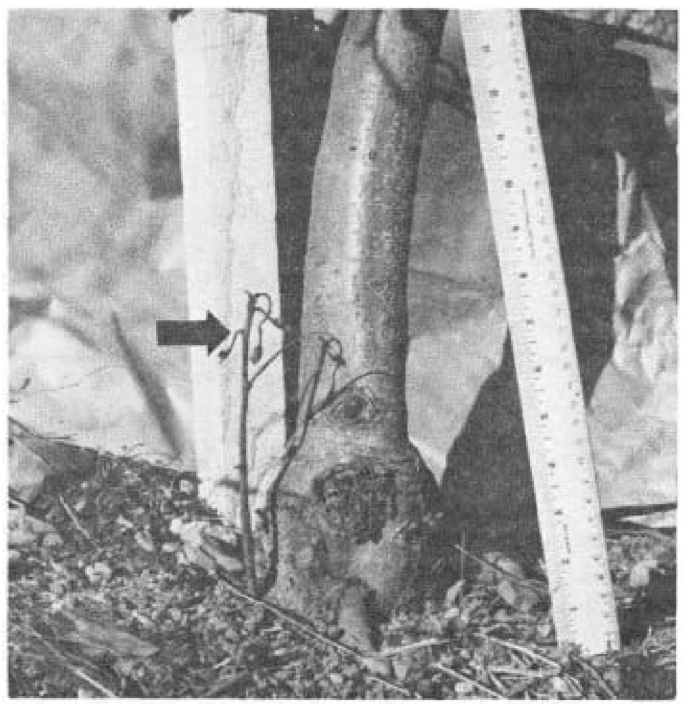
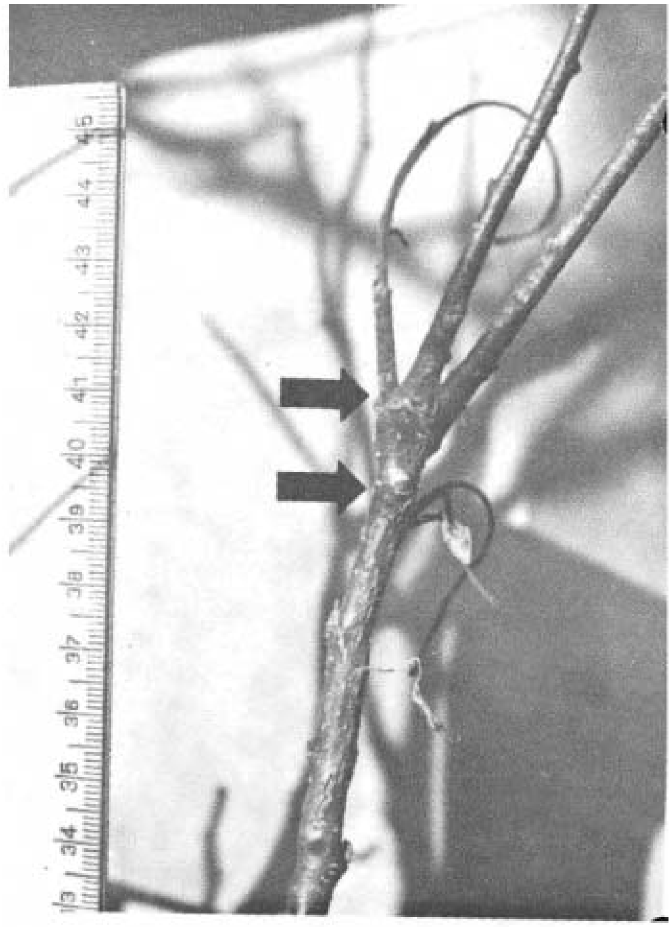


*Figure 4.—Base of 5-year-old McIntosh/M.26 tree. Tip of the rootstock shoot (arrow) was naturally infected with fire blight. During the growing season, the lesion progressed basipetally through this shoot to the original M.26 stem tissue and then laterally in the stock until the 10-inch circumference was girdled. In the planting which included 10 McIntosh/M.26 trees, only this tree produced a shoot from the rootstock.*

*Figure 5.—Fire blight lesion in rootstock tissue of 7-year-old Monroe/MM.106 tree. Lesion terminated during the growing season of initial infection without girdling either lower trunk or a lateral root; the lesion did not become active the following season.*



blight by

*Figure 7.—Fire blight lesions in succulent shoot tips of this M.7 rootstock sucker terminated at the junctions with 2-year-old tissue (arrows). No symptoms were observed below this point. This buffer zone of older tissue reduces the likelihood of a fire blight lesion extending basipetally into the root system or the base of the rootstock trunk.*

*Figure 6.—Few of the suckers under this 14-year-old McIntosh/M.7 tree displayed fire blight symptoms; on the McIntosh there were many flower and twig infections.*

preventing infection in the scion variety. Measures which lead to earlier maturation of wood-fertilizer timing and herbicide management-can be helpful. A well-integrated control program for fire blight is outlined in the current *Tree-Fruit Production Recommendations* and in a special bulletin on fire blight; this program should be carefully followed.

Management of rootstock suckers should also be reconsidered. Under our present system of cutting suckers back to ground level, or even deeper if possible, a fresh crop of vigorous suckers arises each year; these are succulent; susceptible to the pathogen; and the lesions tend to move all the way to the bases of the suckers and sometimes into the roots. On the other hand, if suckers are trimmed only lightly, well above ground level, there will be several re weak shoots produced from each lative cut; these much earlier than the vigorous suckers, ligni are susceptible to blight for a much shorter time, and the lesions tend to be stopped within the "buffer zone" of older wood (Fig. 7).

The severity of fire blight on the fruiting variety varies with the rootstock. Severity is usually greatest on MM. 106 stocks, high on MM. 104, lower on M.2 and M.7, and at a minimum on M.9.

At least three mechanisms may be identified by which certain rootstocks contribute to severity of fire blight in the fruiting variety:

1. Most of the clonal stocks, especially M.9, M.26, and MM. 106, accelerate the onset of flowering in the scion variety. Therefore, more infection courts are available earlier in the life of the tree.
2. The downward extension of a fire blight lesion is limited, in part, by the "hardening" of the stem. Shoots of trees on MM. 106 rootstocks tend to grow relatively late in the summer and to be come "hardened" weeks after trees on M.9 stocks. Fire blight lesions in trees on MM. 106 roots tend to continue basipetal extension for a much longer period than in trees on M.9 roots; in addition, shoots are susceptible to initial infection for a longer time.
3. Empire, Mclntosh, Idared, Monroe, and Jona than are examples of fruiting varieties which typically produce fruit buds on 1-year-old spurs. When one of these varieties is grown on M.9, M.26, and (sometimes) on MM.106 rootstocks, many of the lateral buds on new growth differ entiate into fruit buds. These lateral fruit buds open 3 to 7 days later than the normal spur buds. This phenomenon prolongs the bloom period—the period during which the blossom blight phase of the disease is initiated. In addi tion, weather during this late bloom tends to be warmer and therefore more conducive to the development of the disease. Additional sprays may be indicated when considerable lateral flow ering occurs.

**Collar Rot**

This term is supposed to refer to a set of symptoms caused by *Phytophthora cactorum;* unfortunately, this label has been applied to conditions arising from a number of other causes as well: fire blight, winter injury, girdling by wire rabbit guards, and girdling by field mice. Except on the worst sites, true collar rot (Fig. 8) has not been a significant rootstock problem with standard trees, although very susceptible scion varieties such as Grimes Golden and Twenty Ounce have taught us the need for resistant trunks. Probably most important is the fact that by the time the standard tree began bearing, it was so large that the physiological stress of fruiting was relatively low.

It may well be that most of our tree losses commonly attributed to collar rot are really more

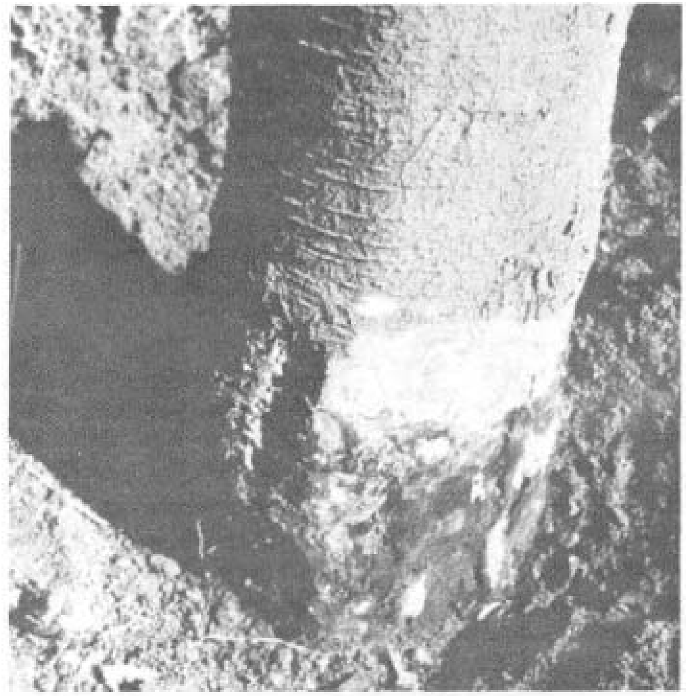


*Figure 8.—Collar rot at base of McIntosh/MM.104 tree.*

directly related to soil management and soil drainage. The late maturing of trees on MM.106 is much accentuated when the fruiting variety is also late maturing. For example, on a site that is moderately to poorly drained, after a wet autumn, the following tree losses were recorded in the spring of 1973:

| | |
|---|---|
| Twenty Ounce (late maturing) | 60% |
| Red Rome (late maturing) | 40 |
| Idared (intermediate) | 0 |
| Golden Delicious (early) | 0 |
| McIntosh (early) | 0 |

These and other observations suggest that winter damage to poorly matured crown tissue may be a major cause of the "collar rot" on many marginal sites. That M.7, which is genetically susceptible to *P. cactorum,* has been grown successfully on marginal sites in western New York, lends support to this concept.

The commercially available rootstocks rank in approximately the following order of susceptibility to *Phytophthora cactorum*: M.9 (resistant); M.2 and MM.111 (moderately resistant); M. 7, MM.106, M.26, and domestic seedling (susceptible); MM.104 (very susceptible) (2, 11).

**Woolly Apple Aphids (WAA)**

Under our present spray programs, WAA have been a minor problem on the large, poorly pruned tree. Colonies develop late in the season in the top center of such trees, but there is little economic loss because most of the fruit in this section is of low quality for other causes. On smaller trees, WAA are rarely seen above ground.

With a pest management system that is based on monitoring of the major pests, WAA can build up in such numbers on the fruiting parts of the tree that pickers find it impossible to work (Fig. 9). Special sprays, particularly of systemic materials, may be required for control.

*Figure 9.—Woolly apple aphids multiply rapidly under some pest management programs. The white wax and sticky exudate can make picking a distasteful chore.*

Although the Malling-Merton stocks are highly resistant to the WAA race(s) now found in New York, a resistant stock does not impart resistance to the fruiting variety it supports. M.9, M.26, and M.7 are highly susceptible to WAA; on these stocks, under some soil conditions a large WAA population on the roots will stop tree growth.

## Replant Problems

In experiments conducted by Mai and Parker in western New York, tree growth and performance after preplanting fumigation strongly suggested that shallow-rooted rootstocks such as M.2 and M.9 benefit more from fumigation than deep-rooted stocks such as M.7. This appeared to be related to the fact that a greater percentage of the M.7 root system is below the level of maximum nematode infestation.

On a soil with a fragipan at 12 to 18 inches, both M.7 and M.2 responded to fumigation; this suggests that since the M.7 roots were restricted in depth to the nematode zone, a reduction in the nematode population was effective.

In western New York, neither M.9 nor M.26 has performed well without irrigation on the typical nematode-prone site without preplant fumigation. Similar reports have been made for plantings in England and Europe.

Particularly when planning to set the clonal stocks in light soil, the grower should remove all possible, roots from the proposed site, have the soil analyzed and apply the indicated nutrients, grow a cover crop such as sudan grass for at least one season, and fumigate the fall before planting. Fumigation may confer benefits in addition to nematode control. Especially when replanting an old apple site, a broad-spectrum fumigant is usually recommended; the grower should consult his Extension Plant Pathologist.

## Viruses

Most of the apple varieties in commercial cultivation are infected with one or more viruses, yet ill effects are seldom seen. Similarly, the older clonal rootstocks, especially M.7 and M.9, are infected with four or more latent viruses. The lack of discernible orchard effects from such a complex of viruses suggests that the fruiting varieties, the older clonal rootstocks, and the seedling stocks have much tolerance for these common viruses. M.26, MM.106, and MM.lll also appear to be highly tolerant of the common viruses.

A few varieties are sensitive. For example, cropping of Golden Delicious may be significantly reduced by rubbery wood virus (M.7 and M.9 stocks carry rubbery wood virus; the strains vary in virulence). We have some instances of Idared/M.7 trees infected with flat limb, transmitted to the Idared from the infected but tolerant M.7 stocks (Fig. 10). Some strains of rubbery wood virus have also been shown to reduce the production of rooted shoots in the stool bed.

*Figure 10.—Symptoms of flat limb virus on 4-year-old Gravenstein.*

Virus-free selections of both fruiting varieties and rootstocks are rapidly becoming available. In preliminary work at Geneva and also reported by numerous nurserymen, the virus-free strains of M.9 appear to be somewhat more difficult to root than the standard, virus-infected M.9 strains. In the nursery, trees budded on virus-free M.9 are somewhat more vigorous than those on infected M.9 roots. In one trial in Orleans County, Mclntosh on M.9a (which is infected with only chlorotic leaf spot, stem pitting, and stem grooving viruses) were much more vigorous than those on M.9 (9). It is conceivable that the virus content of M.9 is producing some horticultural benefits, possibly including vigor reduction; if further experimentation confirms the tendency of "clean" trees to be more vigorous, then this will have to be regarded as a liability.

## CULTURAL AND MANAGEMENT PROBLEMS OF CLONAL STOCKS

### Anchorage

In the past, anchorage of the seedling rootstock has seldom been a problem. However, with the size-controlling rootstock, we find anchorage can become a problem of major dimension. Since so much of our rootstock anchorage problem stems from the soil type, it becomes critically important to fit rootstock choice to orchard site.

Coming as we have from the traditional large, independent tree to the typical Red Delicious/M.7 "leaner" (Fig. 11), it is no wonder that so many orchardists have rejected the size-controlling root-stock or approached with excess caution. Even so, on the right sites we have seen many free-standing M.7 trees. For example, at Geneva on a deep well-drained soil there were no leaners during 18 years of heavy production of Mclntosh/M.7, Delicious/M.7, and Cortland/M.7.

Regardless of soil type, variety or varietal strain, of the stocks that have gained recent popularity, only MM.lll can be depended on to produce a well-anchored tree. For M.9, we must simply accept the fact that providing tree support is commercially necessary. Trees on M.9 have been grown without support on some soil types, but with some varieties this is at the expense of reduced production (Fig. 12). On certain soils and/or with certain varieties, it is also necessary to support M.26 and M.7. Four different types of support systems can be considered; each attacks a particular set of support problems:

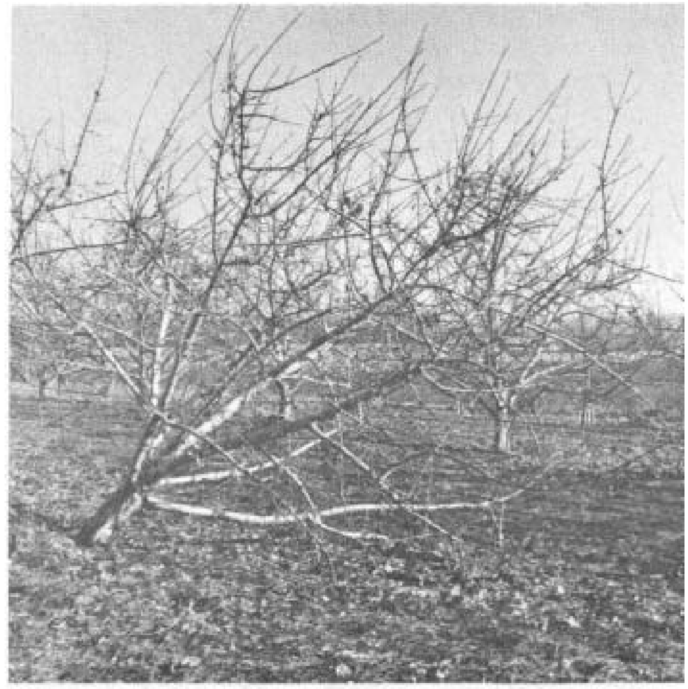


*Figure 11.—This 15-year-old McIntosh/MM.109 tree carrying 18 bushels of apples toppled after a soaking rain. The root system had developed in only one direction.*

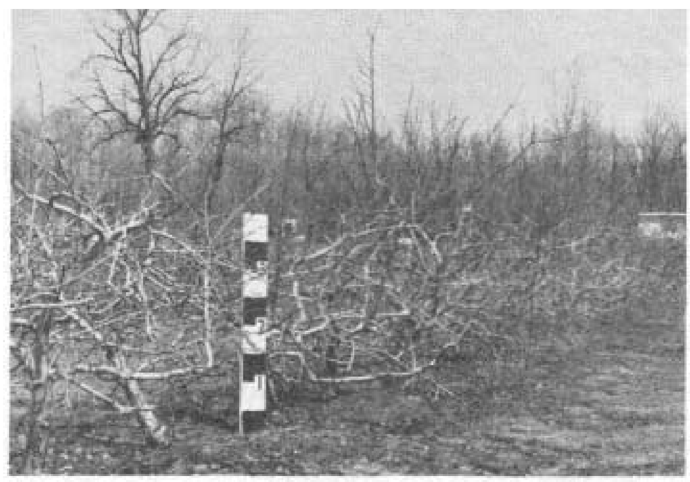


*Figure 12.—Unsupported Golden Delicious/M.9, 17 years old. Although the trees are now about 6 feet tall, for most of the orchard life, the production was limited by the inadequate surface exposure. Pickers object to having to pick much of the crop at ankle level.*

1. Temporary basal support may be needed on trees using the M.7 rootstock. A stake driven 2 feet in the ground, with a foot or more above ground, is adequate to prevent "pocket formation" and to permit the root system to stabilize (Figs. 13, 14).
2. Permanent basal support should be provided trees of vigorous varieties on M.26 roots on strong growing soils. A 6-foot creosoted pole can

be cut into two excellent 3-foot stakes. 3. Permanent "artificial trunks" should be provided trees on M.9 roots as in the "slender spindle" of the Dutch (8, 10, 12); such a program may also be appropriate for trees on M.26 roots (Fig. 15). This 8- or 9-foot pole supports the crop during years when the developing central leader lacks diameter for structural strength. For high density systems involving perhaps 800 trees per acre, the capitalization is considerable; the capital is amortized surprisingly rapidly under proper management (3,6,8,9). The expense of a pole and its installation generally can only be economically practical when the planting approaches 500 or more trees per acre. It is very important with this system that the top of the tree not overgrow the bottom. Therefore, the tree top is pruned out each year, and a weak lateral is tied to the pole to serve as the leader.

*Figure 13.—Combination of wind and rain in June caused a deep "pocket" in the soil at the base of this 4-year-old Tydeman's Early Worcester/M.7 tree. This type of action seriously impairs anchorage, and, if not corrected, presents an open invitation to mice and to winter injury.*

4. An alternative support for trees on M.9 is wire trellis. Trellis systems support the bearing scaffolds and also make it easier to keep scaffolds in a narrow row. This requires substantially smaller capitalization per acre than does the pole system, but certain inconveniences are introduced. Trellis may be especially attractive with very, vigorous cultivars, such as Mutsu, on M.9 (8, 9).

*Figure 14.—The 3-foot stake stabilized this 4-year-old Tydeman's Early Worcester/M.7 enough that severe wind and rain did not produce a "pocket" around the base. Note upper roots washed free of soil.*

**Soils**

Working with trees on seedling roots, growers have long recognized interactions between soil and tree. Excessive vegetative growth, long delay in onset of bearing, and poor fruit color taught us to avoid the "good" soils of the grain farmer. On thin, droughty sites, trees grew poorly, but production began early and fruit was well colored. The clonal rootstocks/soils interactions have added a new dimension to orchard planning. In general, two types of soil problems are accentuated with the clonal stocks: (1) All of the common clonal rootstocks except M.I3 are sensitive to "wet feet"; M.26 and MM.106 appear to be especially sensitive. (2) A fragipan 12 to 24 inches below the surface stops the downward extension of the root system; M.7 is especially sensitive to such a barrier.

*Figure 15.—A permanent pole such as these 8-foot creosoted posts provides a base for training the central leader of a modified "slender spindle" tree and support for the crop when the leader is structurally immature. This Rhode Island Greening/M.9 tree in third leaf carried 18 pounds of premium fruit.*

For M.26 and MM.106, the Ontario, Madrid, and Honeoye glacial tills and the Schoharie, Hudson, Dunkirk, and Arkport lake-laid silts and clays are ideally suited.

Some of our poorly drained soils are high in organic matter and nutrient holding capacity, yet cannot support certain rootstocks at all. For example, M.26 and MM.106 die within a few years on Lyons and Canandaigua soils; yet, with systematic tile drainage, these soils are very well suited for M.9. Other soils which are suitable for M.9, M.2, and MM.lll when systematically tiled include Appleton and Kan-daia (glacial till), Fredon (glacial outwash), and Minoa and Niagara (lake-laid).

Several glacial outwash and beach soils are excellent for all these stocks if irrigation can be supplied during drought; Palmyra, Howard, Alton, and Otis-ville are productive if water supply is well managed. Even with supplemental irrigation, though, truly droughty types such as Colonie, Wassaic, and Elnor are not suitable for M.9, M.26, and M.7. MM.lll is more tolerant of droughty sites than are the other stocks.

A soil type with a shallow bedrock or fragipan barrier, such as Farmington, Benson, Sodus, or Ira, should never be planted to M.7, which has a tap-root tendency. However, if the site is appropriately drained and if the tree is permanently staked, MM.106, which has horizontally-oriented roots, will usually succeed (9).

## Variety/Rootstock Interactions

Poor anchorage has commonly been reported for Delicious/M.9 and Delicious/M.7 trees, particularly when grown on marginal sites. However, on the same rootstocks and the same sites, Mclntosh trees were well anchored. Even on precocity-inducing stocks, Delicious tends to begin production relatively late, and the dwarfing effects of fruitfulness are delayed. The vegetative shoot growth of the Delicious trees is relatively much greater than the root growth. Mclntosh, in contrast, begins fruiting early and heavily on these stocks; the fruiting reduces vegetative growth, and the ratio of top growth to root growth is in better balance.

Most reported cases of stock/scion incompatibility are now known to have been virus-related; many thousands of trees on the hardy Virginia Crab trunk stock were killed by stem pitting virus introduced by the scion variety. Most spur-type Golden Delicious grow very poorly on MM. 104 roots; this is thought to be a response of MM. 104 to rubbery wood virus carried by the scion. A "trunk-twisting" occurs in a number of Golden Delicious/M.7 plantings, and we have observed this in a Spartan/M.2 planting in Wayne County; usually this is seen on poorly drained micro-sites, and usually the trees were budded low in the nursery and were given no initial support in the orchard.

Clean breaks at the union have been observed in some Wayne/M.9 and Wayne/M.26 plantings. Dis-oriented vascular tissues, the typical symptom of genetic incompatibility, are usually conspicuous in such breaks. The disorder seldom appears in trees more than 4 or 5 years old. Breaks are rare in staked trees; during their first 5 years, none occurred among 48 Wayne/M.9 trees trained to modified slender spindles at Geneva.

## Longevity and Rotation

Under proper management, orchards on these clo-nal stocks are long-lived. At Geneva, we have trees on M.9 planted in 1931 (Fig. 16). A block of Mclntosh/M.2 was very vigorous, with a solid stand of trees in heavy production, when we removed them at age 29. Red Delicious, Cortland, Mclntosh, and Monroe on M.7 were obviously in their prime when removed at age 18 (2).

The potential longevity of such trees could pose the same rotation difficulty we have long experienced with seedling-rooted orchards; it is difficult to decide to remove a heavily-producing block of apples, even if the market has lost its respect for that particular variety. The fact that it is now possible to replace a block and have commercial production in a reasonably short period of time is of significant assistance in arriving at the demolition decision.

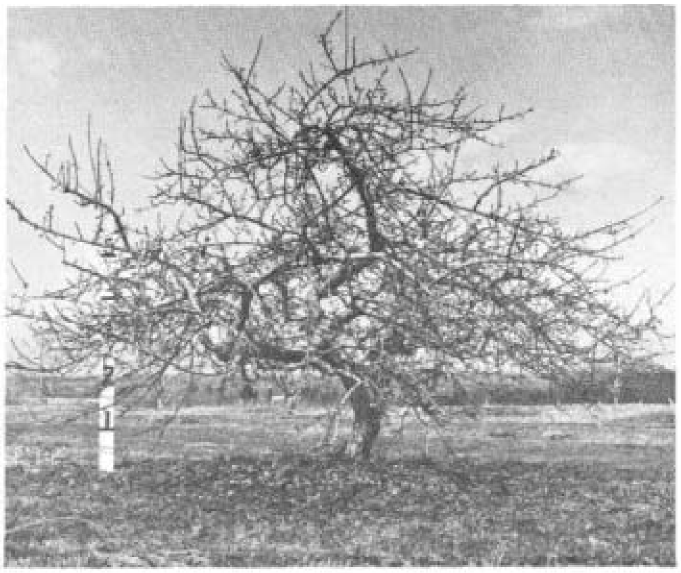


*Figure 16.—This 43-year-old Rhode Island Greening/M.9 tree has survived severe winters at Geneva. Unpruned since age 35, the tree shown is 9 feet high x 14 feet wide. Now in biennial bearing habit, the tree produces about 9 bushels in "on" years, and 3 in "off" years. No support was provided the tree.*

*Figure 17.—Senescent spur system of 16-year-old Golden Delicious/M.9 tree. Fruit from such trees matures late, sizes poorly, and tends to be of low quality. Rejuvenative pruning is required.*

**Winter Hardiness**

In most western New York orchards that lie near a lake, dependable and persistent snow cover greatly lessens the likelihood of direct winter injury to the rootstock. On most hilly sites, though, portions of an orchard are often swept completely free of snow. Such exposure may permit low temperatures at considerable depths in the soil. At Sodoma Orchards in Orleans County, trees on MM. 104 were killed and some on MM. 106 were seriously injured by such low temperatures in 1968.

Of the commercial clonal stocks available, M.26 has been reported to be the hardiest; M.7 the least hardy; and MM.Ill, M.9, and MM.106 of intermediate hardiness. Still hardier clonal stocks, not otherwise considered here, include Ottawa 3, Hibernal, and Antonovka. Robusta 5 is extremely resistant to midwinter cold, but its tendency to start activity early in the spring makes it unsuitable for western New York conditions (5).

**Tree Senescence**

Heavily fruiting trees on seedling roots commonly become "old" after 30 or 40 years; little shoot extension, many-branched spurs, poor fruit set, and small, late-maturing fruit are common symptoms. With a very dwarfing rootstock, such as M.9, and a very precocious variety, such as Idared, we commonly observe the symptoms of aging in plantings only 6 to 10 years old (Fig. 17).

In these small, early-bearing, highly productive trees, a high proportion of total assimilates are channeled into bud and fruit production and relatively little into vegetative growth. Even in the nursery row, many lateral fruit buds are formed on Idared/M.9 budlings. On the other hand, stions such as Northern Spy/M.9 have long periods of vegetative growth before fruiting commences; senescence is very seldom a problem with such combinations.

There is a razor-edge balance between fruit production and tree growth for a few of the very precocious varieties on the very precocious stocks. In high density systems, heavy, early cropping of such trees can cause such a loss in initial tree vigor that future yields and fruit quality may be sacrificed. Invigorative pruning is necessary to maintain a reasonable balance between fruitfulness and growth; this will not only prevent senescence but will also contribute to better fruit quality and to avoidance of alternate bearing.

**Tree Training and Pruning**

Tree design requirements are very different between low density and high density plantings. In the low density orchard on seedling roots, it was important to fill the allocated floor space as rapidly as possible. Because scaffolds would eventually be quite long, it was important that the crotch angles be wide and the scaffolds themselves stiff. Attempts to achieve these objectives tended to be counterproductive; most growers tried to develop good scaffold systems with pruning shears, and this heavy pruning in the formative years led to delayed production. As the tree on seedling roots matures, continuous inten-tive pruning becomes necessary to keep the tree within the assigned space limits, to permit penetration of sunlight and of spray materials, and to facilitate harvest. Although this pruning is necessary for economic cropping, it does encourage such unfavorable effects as reduced tonnage, increased vegetative growth, and unbalanced production. Hedges and pneumatic pruners are common now in low density orchards.

In medium density orchards, especially those on M.2, MM. 106, and MM.Ill, spring-type clothespins or wooden toothpicks are used to establish good crotch angles during the first two summers in the orchard (Fig. 18). Limb placement during the third and fourth winters is of significant help in inducing heavy, early fruiting and to bring the tree spread to desired limits (7). Evidence is accumulating which seems to indicate that major reductions in pruning requirements for the bearing orchard may be expected when such good tree-training practices are followed in the formative years (9).

*Figure 18.—On this Vermont Spur Delicious/MM.106 tree, spring-type clothespins applied to succulent shoots when 4 to 8 inches long help to establish strong, wide-angled crotches.*

The high density orchard employs small trees set dose together in order that high, early production may be obtained. Much less attention to tree structure is required in the early years. In turn, this diminished pruning of the tree on dwarfing stocks leads to earlier fruit bud formation and much heavier production during the early years. With densities of 500 to 800 trees per acre, the grower cannot rely on pruning to correct overcrowding, because heavy pruning in such a planting brings about a major reduction in yield. High density systems favor top growth of the tree; this top growth is carefully removed each year or so and a 2-year-old scaffold is tied up to the post to serve as a new leader. This treatment minimizes growth response in the top of the tree and stimulates a modest growth in the lower parts. Pruning emphasis is on renewal and on slowing the growth of the central leader. The high density orchard requires far less pruning time per bushel (Table 1). Almost all the cuts are made with hand shears, so no elaborate pruning machinery is needed, and brush disposal is not a problem (9,10,12).

Table 1.—Pruning performance in McIntosh on dwarfing, semi-vigorous, and seedling rootstocks.

| Stock | Age | Trees/ Acre | Bu/Acre | Hours/ Acre | Min/ Bushel |
|---|---|---|---|---|---|
| M.9 | 6 | 454 | 901 | 9 | .6 |
| MM.106 | 6 | 113 | 340 | 12½ | 2.2 |
| M.9 | 7 | 454 | 1,190 | 8 | .4 |
| MM.106 | 7 | 113 | 940 | 17½ | 1.1 |
| M.9 | 8 | 454 | 1340 | 8 | .4 |
| MM.106 | 8 | 113 | 1786 | 28 | .9 |
| Seedling | 25 | 27 | 400 | 31½ | 4.7 |

## Tree Spacing

With seedling rootstocks, only two factors were usually considered in determining spacing: whether the soil was shallow, droughty, or fertile, and whether the fruiting variety tended to be small; e.g., Rome Beauty and Idared, or large; e.g., Northern Spy and Delicious. Allocated space was seldom filled before the orchard was 15 to 18 years old, and many trees never filled their assigned spaces.

The clonal rootstocks have introduced additional factors; rootstock/soil interactions, the vegetative growth aspects of variety/rootstock interaction, and the dwarfing effect of precocity-inducing stocks on varieties which usually begin bearing late (11).

In high density plantings, miscalculation in spacing can ruin the production potential in a few years. If the spacing is so close that intertree competition takes place before any significant production occurs, then considerable pruning is necessary to hold the trees in their allocated spaces. Such pruning stimulates vegetative growth, reduces fruit bud formation, and leads to a depression of yield (1,8). Spacing of Delicious/M.9 trees frequently is too close because

Delicious comes into bearing relatively late and grows vigorously in the early years. Golden Delicious/M.9 and Idared/M.9 begin bearing very early, and the trees grow very little after the fourth or fifth year. On a given soil, Golden Delicious/M.9 and Idared/M.9 may do quite well at a 5-foot x 12-foot spacing, while Delicious/M.9 might require a 10-foot x 18-foot space.

### High Investment Requirement

As the apple industry continues to move toward higher density plantings of smaller trees, with wire or pole support provided, the initial cost per acre increases dramatically (Table 2). However, this high initial capitalization is rapidly amortized in the well-managed high density orchard. Rapid amortization increases in importance as land values and interest rates continue to rise (3,8,9).

Table 2.—Initial establishment costs of four orchard planting systems (land values not included).

| Density Category | Trees/Acre | Initial Establishment Cost/Acre |
|---|---|---|
| Low | 121 | $ 321 |
| Medium | 218 | 504 |
| High | 454 | 1402 |
| Ultra-high | 792 | 2329 |

Table 3.—Production of McIntosh during fifth through tenth years in the orchard on three stock systems.

| Year | MM.111 116 Trees/Acre | MM.106 116 Trees/Acre | M.9/MM.106 454 Trees/Acre |
|---|---|---|---|
| | | Bu/Acre | |
| 5 | 12 | 93 | 1135 |
| 6 | 232 | 845 | 1180 |
| 7 | 418 | 313 | 1226 |
| 8 | 487 | 940 | 1725 |
| 9 | 1473 | 1786 | 1407 |
| 10 | 626 | 870 | 1544 |
| Cumulative | 3244 | 3977 | 6673* |

*No production records were taken during the first four seasons, although the McIntosh/M.9/MM.106 trees had considerable production.

During the early years of the life of an orchard, high density plantings produce much more per acre than do low density plantings (Table 3, 4). Throughout the life of the orchard, production costs per bushel are substantially lower for small trees because pruning, harvesting, and pest control costs are lower. Gross profits during the first 10 years are directly related to orchard density (Table 5).

Table 5.—Profits during first 10 years of orchard life with four orchard densities.

| Density Category | Trees/Acre | Cumulative Profit through 10th year |
|---|---|---|
| Low | 121 | $1805 |
| Medium | 218 | 2325 |
| High | 454 | 3664 |
| Ultra-high | 792 | 7291 |

### Pollination

In the old-fashioned square-planted orchards of seedling trees, bees tended to fly from tree to tree on a more or less random pattern. In orchards with definite row patterns and one-directional travel, the bees tend more to fly down the row, rather than across the orchard. With "hedgerow" plantings of small trees, this tendency seems to be even more pronounced. Unless there are pollinator trees located within the row, the chances of a bee encountering a pollinator tree are definitely diminished and pollination efficiency will be decreased. There is twice as much crossing from one row to another with a 10-foot alley as with a 15-foot alley, so it is advisable to avoid excessive spacing between rows.

#### Spring Frost Hazards

Crop loss from spring frost has been a major problem in many orchards, regardless of tree size or planting system. However, crop loss in high density and ultra-high density orchards may be much more significant than in low density orchard of large trees. A high percentage of the total bearing surface of a slender spindle tree on M.9 is near ground level; the

Table 4.—Yields per acre in third and fourth seasons of some high density and ultra-high density plantings on M.9.

| Fruiting Variety | Spacing (ft) | Trees/Acre | Bushels/Acre 3rd year | 4th year | 5th year | Sum |
|---|---|---|---|---|---|---|
| Empire | 5 x 11 | 792 | 639 | 622 | 426 | 1687 |
| Empire | 4 x (11 + 6)* | 1281 | 717 | 936 | 810 | 2463 |
| Golden Delicious | 4 x 11 | 990 | 405 | 542 | 665 | 1612 |
| Golden Delicious | 4 x (11 + 5) | 1361 | 476 | 745 | 932 | 2153 |
| McIntosh | 8 x 11 | 495 | 79 | 289 | 173 | 541 |
| McIntosh | 5 x (11 + 6) | 1025 | 164 | 598 | 362 | 1124 |

*Staggered offset double row system. Four feet between trees in a row, second row offset and 6-foot distant, 11-foot alley.

top of the tree is only 61/2 to 7 feet high. The typical mature tree on seedling roots has very few flowers within 5 feet of ground level. Usually frost hazard decreases as height above ground level increases.

The higher density systems are profitably maintained on a very delicate balance between fruiting and vegetative growth. This balance depends not only on a very dwarfing rootstock, such as M.9, but also to a great extent on the dwarfing effects of heavy fruit production. Early production is necessary to prevent excessive initial tree size; loss of a crop in the third or fourth growing season makes tree size control much more difficult throughout the life of the planting, and loss of two crops in succession virtually guarantees a permanent overcrowding problem. Overcrowding, in turn, leads inevitably to a depression in yield and a reduction in fruit quality.

If, for compelling reasons, a grower should elect to plant on a site on which spring frosts do occur, then the income potential of the high density planting fully justifies the additional investment in a frost protection system.

**The "Umbrella Effect"**

Trees on MM.106, M.7, M.26, and M.9 stocks usually set fruit on the central leader before it has enough girth to support the crop. This results in the leader being carried over to the side, with the branches assuming almost a weeping form (Fig. 19). Care should be exercised to limit the amount of fruit carried by the developing leader. A petalfall spray of napthaleneacetic acid + carbaryl applied at low pressure with a light hand gun is very effective and will not remove the crop from the rest of the tree. Training the leader to a post is also effective.

## ROOTSTOCKS FOR THE FUTURE

It may be said that we are now in the third generation of rootstocks. The first was the traditional seedling. The second generation, the East Mailing stocks, were selected from chance seedlings that were clonalized by commercial nurserymen; M.2, M.7, and M.9 are examples. The third generation; e.g., M.26, MM. 106, and MM.Ill, were selected from large families of controlled crosses made especially for developing new rootstock clones.

New rootstocks are becoming available. The fourth generation could be considered the existing candidates for replacing the best of the present commercial repertoire. From the USSR, Budagovsky 118 appears a worthy competitor for M.7, especially where winter hardiness is a major factor. Ottawa 3 may be superior to M.26 for resistance to collar rot, to fire blight, and possibly to winter cold. The most promising candidate to replace M.9 appears to be the hardy Budagovsky 9, which is, unfortunately, infected with a considerable number of viruses and will not be commercially available until the clone is suitably sanitized (5). From England, the very dwarfing M.27 should be in

*Figure 19.—Early-bearing varieties on precocity-inducing stocks tend to lose the central leader. This "umbrella effect" is shown by Empire/M.9a/MM. 104 (left) and Mutsu/CG.10 (right).*

commercial channels within 5 years. Compared with M.9, M.27 is much more dwarfing, nonsuckering, somewhat more easily propagated, perhaps less susceptible to fire blight, but otherwise quite similar.

Rootstock breeding programs are receiving major emphasis at our station in Geneva, at the East Mailing Station, in the USSR, and in Poland. Although there are some differences in our objectives, dictated by local requirements, we share the same general goals-resistance to the critical diseases, hardiness in the prevailing climate, tree-size control, good nursery behavior, and induction of early and heavy production. At Geneva, our major resistance objectives are fire blight, collar rot, and WAA, with mildew resistance at lower priority. We are especially interested in tree-size control in the M.9-M.7 range.

## ORCHARD MANAGEMENT USING SIZE-CONTROLLING ROOTSTOCKS

As the apple industry moves towards the intensive planting systems, good management is going to become more critically important, compared to management using seedling-rooted trees at wide spacings. As orchard densities increase, greater consideration must be given to all the items that affect ultimate tree growth. Soil, rootstock, variety, and cultural practices, if not arranged in correct balance with the higher density systems, can cause the demise of the planting. Excessive growth, encouraged by a strong soil, or too long a non-fruiting period caused by poor cultural practices or late spring frosts, can throw such a planting system out of harmony. The seedling-rooted orchard could tolerate mistakes, yet only one such error might spell disaster to the high density system employing size-controlling rootstocks. The high density orchard on M.9 demands intensive management; paradoxically, fewer man-hours per bushel and per acre are required.

### Mechanization vs. Tree Size

The large tree on seedling rootstock is the main reason the industry has looked toward mechanization to improve production efficiencies and lessen labor requirements. Mechanical pruning and mechanical harvesting of large trees employing vigorous root-stocks leaves much to be desired. Pomologists and engineers agree that some day mechanical pruning and harvesting are likely to be sound, efficient, and less costly practices compared to hand pruning and hand harvesting once the tree size is reduced.

When a semi-dwarf tree is being shaken with an inertial trunk shaker, the observer gains the impression that the tree has little chance of surviving. To examine whether trees on clonal rootstocks could survive trunk-shaking, in 1968 we initiated a trial with 16-year-old Mclntosh/M.7. Alternate trees were subjected to three 6-second bursts of 900-cycle trunk shaking in 1968, 1969, and 1970. Although during the shaking, it appeared that the trees would jump out of the soil, there was no later evidence of damage of any kind. There was no indication of yield reduction in the 1969, 1970, or 1971 crops, and there was no indication of structural damage caused by the shaking.

Commercial growers have gained experience in shaking semi-dwarf trees. We have had no reports of damage to tree structure. At this time, it appears that after the tenth to twelfth year, trees on M.7, MM. 106, and MM.lll stocks can safely be shaken with the equipment now on the market.

### Wildlife Problems

Although it may appear strange that this is a rootstock problem, experience has illustrated that the problem is a serious one.

Mice find the thick bark of M.9, as contrasted to the seedling rootstock or other vigorous growing rootstocks, a real "delicacy." Furthermore, since M.9 must be used for a high density system to be practical, the mouse has only to move 5 to 6 feet to the next "feast." Trees on M.9 should be protected with mouse guards and extra care given to other control procedures.

Pheasants were never a problem in the apple orchard until M.9 was introduced. Now a significant part of the crop may be destroyed by the birds feeding on low-hanging fruit.

Deer feeding on M.9-rooted trees retard their growth even more severely than other trees are affected. In addition, in the 1972 fire blight epiphytotic, deer browsing was an important means of spreading the disease in a high density planting at Geneva.

## SUMMARY AND CONCLUSIONS

The clonal rootstocks have made it possible to control tree size within predictable limits and to induce early, heavy production. This has opened up a completely new concept of fruit growing—the high density orchard (6,8,10,12). Although research aimed at maximizing profits and minimizing expenses has not yet led to the ideal orchard design, a steady increase in intensification is the obvious trend.

Our long-time preoccupation with bushels per acre has distracted us from the economic implications of production cost per bushel. In reducing costs per bushel of top-quality fruit through savings on pruning, pest control, and harvesting lies the real economic value of any system. We believe the present rapid shift to higher density plantings has come about because it is being shown that the smaller tree:

1. Reduces pruning costs per bushel;
2. Requires less spray material per bushel;

3. Permits use of smaller, and much less expensive, orchard equipment;
4. Extends the spectrum of labor available;
5. Tends to produce more top-quality fruit per acre, especially during the first decade of the planting.

Our present clonal rootstocks are not problem-free, but their superior production potential demands their extended use to replace seedling stocks. Some revisions in our orchard management will be required. The necessary technologies are available to utilize the potentials offered by the available rootstocks; such utilization will substantially improve both the economic and social aspects of apple orcharding.

## LITERATURE CITED

1. Cain, J. C. 1969. Tree spacing in relation to orchard production efficiency. N. Y. State Agr. Exp. Sta., Geneva. Res. Cir. 15. 10 p.
2. Cummins, J. N. 1971. Rootstock notes 1970. N. Y. State Agr. Exp. Sta., Geneva. Spec. Rep. 2.
3. Cummins, J. N. 1972. Tree-raising on the fruit farm. N. Y. State Agr. Exp. Sta., Geneva. N. Y. Food and Life Sci. Bull. 19.
4. Cummins, J. N. and H. S. Aldwinckle. 1973. Fire blight susceptibility of fruiting trees of some apple rootstock clones. HortScience 8: 176-178.
5. Cummins, J. N. and H. S. Aldwinckle. 1974. Apple rootstocks for colder climates. Fruit Vars. J. 28: 9-11.
6. Fisher, D. V. 1969. High density plantings for high profits. Proc. N. Y. State Hort. Soc. 114: 185-195.
7. Heinicke, D. R. 1970. Follow this training program. Amer. Fruit Grower 90(12): 7-11.
8. Norton, R. L. 1971. What you must know about high density plantings. Amer. Fruit Grower 91(5): 14,15,34; 91(6): 20-22; 91(7): 10-11.
9. Norton, R. L. 1973. Apple planting systems. Coop. Ext. Office, Rochester, N. Y.
10. Roosje, G. S. 1970. Experience with high density fruit plantings in Holland. Proc. N. Y. State Hort. Soc. 115: 21-36.
11. Swales, J. E. 1971. Commercial apple growing in British Columbia. B. C. Dept. of Agr. Pub. 71-5.
12. Wertheim, S. J. 1970. The training of the slender spindle of four apple varieties. Proefstation voor de Fruitteelt, Wilhelminadorp, Nds.

## ACKNOWLEDGMENTS

Much of the experimental work which furnished observations on which this publication is based was done on cooperators' farms. For this invaluable help, we thank Frances Kirby, Joe Wilmes, Jack Pearson, Sodoma Bros., Merrit Thomas, Sodus Fruit Farm, Ab McKee, Earl Robb, and Jim Austin.

We thank Dr. Walter Render, Dr. Gene Oberly, and Dr. Phil Arneson, who critically read the manuscript and made helpful suggestions. We particularly appreciate the advice of Dr. Stephen Beer, who suggested major improvements in the fire blight paragraphs.