As an example, assuming you want to maintain your trees at 10 feet within the row and no more than 10 feet tall, the above formulas can be used to help estimate row spacings.

a. 10 / 2 = 5 feet, 5 feet + 10 = 15 feet between rows
b. (2 x 10) - 6 = 14 feet between rows
c. 10 / 0.75 = 13 feet between rows

Therefore, the optimum distance between rows is 13 to 15 feet apart.

Finally, one way to evaluate older plantings to see if they are spaced properly is to observe them late in the afternoon on a sunny day. Looking at the base of the trees in a row, if the shadow cast from the adjacent row is covering less than 10-20 percent of the lower canopy then the trees are spaced properly. If the shadow from the adjacent tree is covering more than 20 percent of the canopy of the adjacent row, then the trees are too close together. If no shadow strikes the adjacent row, then the trees are spaced too far apart. (Portions adapted from T. Robinson, Dept. of Horticultural Sciences, NYAES, Cornell University)

Using Beds to Attain Higher-Density Orchards

Most orchards in Pennsylvania have uniform row spacings. The term "bed" in fruit production originated in the Netherlands, where growers have researched and tested three- to eight-row beds. No equipment traveled between the rows in a bed, and the beds were kept weed free. In Pennsylvania, wide weed-free beds are not advisable because of the likelihood of excessive erosion, so Dutch-style bed production probably is not workable.

In a broader sense, however, "beds" for tree fruit production can simply be thought of as plantings with unequal row spacings. Beds in this sense have been around a long time. Some Pennsylvania growers have alternated narrower rows, where no bin handling occurs, with wider spacings where bin handling does occur. Thus, for example, where a row spacing of 25 feet might be standard in an orchard with uniform row spacing, this 25-foot spacing can be alternated with 20-foot row middles, resulting in an average row spacing of 22.5 feet.

Since most Pennsylvania growers prefer to use relatively wide row middles for spraying and especially for bin handling, row spacing becomes a limiting factor in designing moderately high-density orchards. Thus, growers desiring 6 to 8 feet for operating large equipment cannot obtain significantly higher tree densities. However, growers could design "Pennsylvania bed orchards," in which single, wide row middles are used for spraying and for hauling bins. Figure 1-4 presents examples of the traditional arrangement, a two-row bed, and a three-row bed. Note that within the bed, trees might be staggered to allow spray to penetrate. With the smaller trees being planted today, spray deposition is likely to be more than adequate.

Table 1-8 gives an expanded example of trees at different spacings. The example shows that the increase in trees per acre could range from a low of 10.6 percent to as much as 28.5 percent. The bed itself can be designed with row spacings so that mowing can be done with a small tractor, but spraying would not normally be done within the bed. Alternatively, small compact sprayers can be used. Six-row beds of this design have been used by some South Carolina peach producers. This arrangement would result in significantly higher tree densities and may be a workable plan that would enable Pennsylvania growers to obtain higher tree densities while keeping wide row middles for large equipment.

Determining the Number of Trees Per Acre (TPA) in Bed Plantings

As discussed above, bed systems can be used in many forms in commercial orchards. Beds in the Dutch system have very closely spaced trees with a vegetation-free area. The concept proposed above allows for herbicide strips directly underneath the tree rows within the bed and grassed drive rows between the bed tree rows and the wider drive rows. In either case, it is necessary to alter the traditional method of determining the TPA for bed systems. The following can be used to determine the TPA in a bed planting:

1. Measure the distance from the trunk of the edge tree in one bed to the trunk of the tree in a similar position in the adjacent bed.
2. Divide this distance by the number of rows in the bed to get the average row spacing.
3. Multiply the average row spacing by the distance between trees in a row to get the square feet occupied by one tree.
4. Divide 43,560 square feet (1 acre) by the square feet occupied by one tree (from Step 3). This gives the TPA in the bed system you have designed.

   Example: From the diagrams in Figure 1-4, the TPA is determined as follows:

Two-row bed	*Three-row bed*
1 .30 feet (12 + 18)	42 feet (12 + 12 + 18)
2 . 30 ÷ 2 rows = 15 feet	42 ÷ 3 rows = 14 feet
3. 15 feet x 10 feet = 150 feet	14 feet x 10 feet = 140 feet
4. 43,560 ÷ 150 = 290.4	43,560 ÷ 140 = 311.1
5. or 290 trees per acre	or 311 trees per acre

Apple Rootstocks

History

Rootstocks to control tree size have been used in apple production for over 2,000 years. The clonal apple rootstocks that we use in the United States have traditionally originated in Europe.

In the mid-1800s horticulturists began referring to rootstocks by name. They were called Paradise (or French Paradise) or Doucin (or English Paradise), the former being more dwarfing than the latter. These plants, however, showed much variation in size control. In addition, many new stocks had been introduced inaccurately under these names; undoubtedly viruses and genetic mutations had occurred in the plant material. In the late 1800s one author described 14 different kinds of Paradise rootstocks. This diversity led researchers at England's East Malling Research Station to gather the selections to determine their trueness to name. The researchers concluded that indeed there were numerous misnamed and mixed collections of plant material.

Dr. R. Hatton decided that because of the confusion he would drop the proper names and assign each stock a number. He assigned a Roman numeral to each of 24 selections but did not number them in any order with respect to tree size. Hence, M.9 with a larger number is a smaller tree than M.2. Most of these, with the exception of M.9, M.7, M.2, M.8, and M.13, were never commercially important in the United States. In succeeding years some rootstocks were developed from controlled crosses, M.26 and M.27 being the most famous.

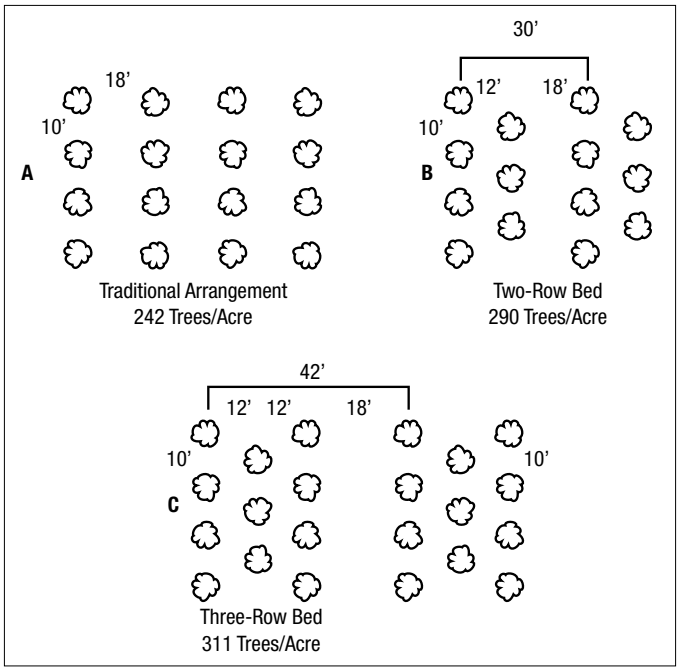

Figure 1-4. Traditional arrangement and possible arrangements of two- and three-row beds.

In 1917 a second research station, the John Innes Institute of Merton, England, joined with the East Malling station to begin a breeding program. Their efforts, oriented mainly toward developing rootstocks resistant to woolly apple aphids, produced the Malling-Merton series of rootstocks, of which MM.106 and MM.111 are still used widely today.

In the late 1960s, researchers began work to remove many of the viruses naturally present in the rootstocks in order to reduce incompatibility problems caused by the viruses. The first rootstock to be partially cleaned up was M.7; it was designated M.7a. Later still, more viruses were removed from all of the Malling and Malling-Merton series of rootstocks. These were then designated EMLA for the East Malling and Long Ashton research stations in England. While the viruses have been removed, some of the rootstocks' size control has been lost. Therefore, the old "dirty" M.9 will produce a smaller tree than the "clean" M.9EMLA. Currently in the industry nearly all apple rootstocks are virus free.

The next few years will bring several new rootstocks, many developed in Europe. Those likely to be available first are the Budagovsky series. Designated as either Bud or B, they were developed in the central plains of the Soviet Union for their coldhardiness. The next rootstocks to be released will probably be from Poland and are called the "P-series." Like the Russian series they are expected to have some coldhardiness. The P-series was developed from crosses between M.9 and common Antonovka. Reportedly, these stocks have good resistance to collar rot.

The newest rootstocks, however, are being developed here in the United States. One group comes from Cornell University's breeding program, which has bred rootstocks for resistance to fire blight. Some of these rootstocks are also resistant to other problems such as apple scab, collar rot, and woolly apple aphids, and exhibit a reduction in burrknot formation.

A large multistate research program known as the NC-140 Research Project is primarily responsible for conducting most evaluations of these new rootstocks. Penn State has been a member of this project since its inception.

Growers should be aware of each rootstock's known capabilities and limitations. Many of the newer rootstocks will probably be available to the commercial industry before they have been thoroughly evaluated with different cultivars.

Specific rootstocks

Following are brief descriptions of and comments on apple rootstocks. Rootstocks are listed in order from smallest to largest. (Much of the information was gleaned from research reports of the NC-140 committee from around the country.)

Poland 22 (P.22): P.22 produces trees that are smaller than those grown on M.9. It is reported to be resistant to collar rot, apple scab, powdery mildew, and crown gall. P.22 is susceptible to fire blight and woolly apple aphids. Its major benefit may be as an interstem piece. In one trial planting with Gala, it has produced a tree slightly smaller than P.16. However, in a younger planting with Ginger Gold, it is slightly larger.

Malling 27 (M.27): A very dwarfing rootstock. Unless the central leader is supported, the tree will be very small. Little is known about disease or insect susceptibility. To date, most commercial nurseries are using this rootstock only as an intermediate stem piece on MM.106 or MM.111. If handled and spaced properly, it can be a very productive stock for a vertical axe system.

Table 1-8. Increase in tree density made possible using beds.

Conventional planting			Bed planting specifications					
In-row tree spacing	*Row spacing*	*Trees/A*	*In-row tree spacing*	*Wide row spacing*	*In-bed row spacing*	*Rows/ bed*	*Trees/A*	*Percent increase trees/A*
10	18	242	10	18	14	2	272	12.4
			10	18	14	3	284	17.4
			10	18	12	2	290	19.8
			10	18	12	3	311	28.5
14	22	141	14	22	18	2	156	10.6
			14	22	18	3	161	14.2
			14	22	16	2	164	16.3
			14	22	16	3	173	22.7

Budagovsky 469 (B.469) induces dwarfing similar to that of M.27 and is very winter hardy. Its only use would be for an interstem. Test plantings of Ginger Gold with this rootstock at University Park have not been viable. In New York State trials B.469 has shown very good compatibility between the scion, without the typical overgrowth.

Poland 16 (P.16) is from the same cross as the other Poland rootstocks and is reported to produce a tree about the size of M.27, although this has not proven to be the case in research trials in Pennsylvania. Test plantings of this rootstock at University Park with 'Gala' and 'Ginger Gold' show that trees are about 40 percent of the size of the same cultivar on M.9 rootstock. At this time this rootstock is suggested for trial only. P.16 is reported to be resistant to apple scab, powdery mildew, collar rot, and crown gall. It is susceptible to fire blight.

Geneva 65 (G.65) was developed by Dr. Jim Cummins at Cornell University. Due to errors in tissue culture buildup of this rootstock, the U.S. distribution of this rootstock has been hindered. Tree size once thought to be about that of M.9 is now considered to be closer to M.27. The rootstock is difficult to propagate in nursery stool beds. It is susceptible to tomato ring spot virus and apple stem grooving virus.

Budagovsky 9 (B.9 or Bud9) is a new dwarfing rootstock bred in the Soviet Union from the cross of M.8 x Red Standard (Krasnij Standart). Like the other stocks in this series, the leaves are a distinctive red. Trees on this stock are 25 to 35 percent smaller than M.9EMLA depending upon the cultivar. In a 10-year trial at University Park, York Imperial, Rome Beauty, and Empire on B.9 were approximately 25 percent smaller than the same cultivar on M.9EMLA; while Jonagold, Golden Delicious, and McIntosh were approximately 35 percent smaller. B.9 appears to be resistant to collar rot and is very cold-hardy. In limited trials, it has performed very well across a wide range of conditions. Trees will need to be supported.

Poland 2 (P.2) was developed from a cross between M.9 and Common Antonovka. Trees grown on P.2 are 15 to 25 percent smaller than M.9. The rootstock is resistant to collar rot and slightly susceptible to apple scab and powdery mildew. Young test plantings in Pennsylvania with Gala and Ginger Gold show that P.2 is nearly as precocious as M.9. Smoothee Golden Delicious on this rootstock produces a very smooth and straight union. However, Delicious grown on P.2 is reportedly as susceptible to apple union necrosis as the same cultivar grown on MM.106.

Malling 9 (M.9): The traditional and best-known dwarfing rootstock. It should be planted on a well-drained site. Trees on this rootstock always require leader support. The rootstock is very susceptible to fire blight and can develop burr knots. Numerous clones of M.9 are now being sold by nurseries, including M.9 NAKB 337, the current dominant strain used. It is a virus-free clone from Holland and appears to be 5–10 percent less vigorous than M.9EMLA. M.9EMLA is a virus-free clone from the East Malling/Long Ashton research stations. It is approximately 25–30 percent more vigorous than M.9. Pajam 1 (Lancep) and Pajam 2 (Cepiland) are French selections that are relatively new. They are 35 to 40 percent more vigorous than M.9 NAKB 337. One other clone is M.9 RN 29, selected by Rene Nicolai in Belgium. In plantings at University Park with Gala, it is approximately 30 percent larger than M.9 NAKB 337.

Geneva 41 (G.41) was released in 2005 as a rootstock that produces trees the size of M.9. The rootstock was developed from a cross between M.27 and Robusta 5 made in 1975. It was selected for resistance to Phytopthora and fire blight. Oldest planting with this rootstock is located at FREC in Biglerville and started in 1998 with Jonagold. Three-year-old trees at Rock Springs with Golden Delicious are 12 percent smaller than trees on M.9T337 and about 30 percent smaller than M.26. Finished trees should be readily available.

MARK: Formerly named MAC 9, developed in Michigan. It is an open-pollinated seedling of M.9. Trials in Pennsylvania indicate that this rootstock is not freestanding and is slightly larger than M.9. The central leader tends to lean. In recent years this rootstock has fallen into disfavor due to an abnormal growth proliferation at the soil line. Trees with this growth proliferation cease to grow and become spur bound; therefore, it is not recommended to be planted unless supplemental irrigation is provided. Very drought sensitive.

Geneva 16 (G.16): This is a recent rootstock released from Cornell University's breeding program. Like others in the series, it is resistant to fire blight. It is tolerant of collar rot and immune to apple scab. It is susceptible to woolly apple aphid and powdery mildew. Size is reported to be between that of M.9 and M.26. In a trial at Rock Springs at the end of the fourth growing season it is approximately 14 percent larger than M.9T337 and 8 percent smaller than M.26. It does appear, however, to induce wider branch angles in the scion cultivar. Geneva 16 is very sensitive to latent viruses in apple and should only be propagated with virus free scion wood on top. At this time, G.16 is recommended for trial only because of this problem.

Ottawa 3 (O.3): This relatively new rootstock was bred in Canada for its coldhardiness, with one parent being M.9. Trees on O.3 are about the size of M.9EMLA but smaller than M.26. Induces early bearing. Resistant to collar rot, but susceptible to fire blight and wooly apple aphids. Ottawa 3, although being available for many years, has not been popular with the nursery industry. Young stool beds of O.3 produce few saleable liners, although with age the stool beds become more productive. Ottawa 3 is very susceptible to apple mosaic virus, so only material known to be virus free should be planted on this rootstock.

Vineland 1 (V.1): This is the newest rootstock to come from the breeding program at the Vineland station in Ontario, Canada. Tree size is comparable or slightly larger than M.26. Yield efficiency and fruit size are equal to or greater than M.26. However, unlike M.26, it appears to be highly resistant to fire blight. It should be in limited supply for the 2003 growing season.

Malling 26 (M.26): A more vigorous rootstock than M.9. It can be used to produce either a dwarf or a semidwarf tree, depending on scion variety, production system, and soil type. It is susceptible to collar rot and fire blight and should not be

planted in a wet site. Certain varieties, such as Rome, Stayman, Golden Delicious, and many triploids, when grafted onto this rootstock may exhibit signs of graft union incompatibility. When incompatibility occurs, the trees may break off at the union in high winds. Because exposed portions of the rootstock have a strong tendency to produce burr knots, the union between the scion variety and the rootstock should be set no more than 1 to 2 inches above the final soil level.

Geneva 935 (G.935) is a 1976 cross of Ottawa 3 and Robusta 5. Size is reported to be slightly larger than M.26, but the rootstock has resistance to fire blight and crown rot. It is not resistant to wooly apple aphid. Production efficiency is rated equal to M.9. In the Golden Delicious trial at Rock Springs in 2006, tree size was about 9 percent larger than M.9 and 12 percent smaller than M.26. Production efficiency was not significantly different although slightly higher than M.9 in 2005. The rootstock seems to induce wider angled branching in the scion. Finished trees should be readily available in 2008.

Geneva 11 (G.11): The second release of the Cornell breeding program; only limited plantings exist in Pennsylvania. Reported to be similar in size to M.26 but more productive. Has the advantage of being resistant to fire blight and crown rot as well as only rarely producing suckers or burrknots. Availability limited. Tissue-cultured trees are larger than trees propagated by stool beds.

Geneva 202 (G.202) is a semi-dwarfing rootstock that produces a tree slightly larger than M.26. It was developed from a cross of M.27 and Robusta 5. It is fire blight and Phytopthora resistant as well as having resistance to wooly apple aphids. The rootstock has been mainly tested in New York and New Zealand. In New Zealand they are looking at this rootstock as a possible replacement for M.26 since it is more productive than M.26. In a 9-year study with the scion cultivar of Liberty, G.202 was about 50 percent smaller than M.7 but had much greater production efficiency.

Pillnitzer Supporter 4 (Pi.80), a cross between M.9 and M.4, has recently been introduced from Germany. It is reported similar in size and in anchorage to M.26. Yield capacity is reported to be better than that of M.26. A planting with McIntosh as the cultivar was established in 1999 at Rock Springs. To date, Supporter 4 is about 15 percent larger than M.7 EMLA. Yield in 2001 was nearly double that of McIntosh/M.7EMLA and 50 percent greater than McIntosh/M.26EMLA.

Interstems are becoming increasingly popular in Pennsylvania orchards. This stock is composed of an understock such as seedling MM.111 or MM.106, onto which an intermediate stem piece of M.9 or M.27 is grafted. The variety is budded or grafted onto M.9 or M.27. Size control is directly related to the length of the intermediate stem piece. Interstem apple trees offer a strong root system while reducing the size of the overall tree. Interstem trees should be planted so that a portion of the interstem is buried. Test plantings in Pennsylvania indicate that interstems on either MM.106 or MM.111 sucker, and very vigorous varieties and Stayman have not performed well on interstems.

Geneva 30 (G.30) is currently available from commercial nurseries. The advantages of this M.7-size rootstock are early production, fewer burr knots, and less suckering. Tests at Rock Springs do indicate that trees on this rootstock come into bearing earlier and produce more fruit than M.7. Unfortunately, in the last two years questions have arisen about the graft compatibility of this rootstock with Gala. In tests around the country in the NC-140 trials, there have been occasions where Gala/G.30 have snapped off at the bud union during high winds. Therefore, it is recommended that if Gala is propagated on G.30, the trees be supported by two wires, one at approximately 36–40 inches above the ground and a second wire at 8–9 feet. Individual stakes or poles have not been sufficient because they allow excessive twisting of the trees in the wind.

Malling 7 (M.7): This rootstock produces a semidwarf tree that is freestanding in deep well drained soils. In rocky, steep, or shallow soils, it tends to lean. High budding and deeper planting may help remedy this problem. The rootstock may sucker profusely and is susceptible to collar rot. M.7a is a clone of the original M.7. but which has had some of the inherent viruses removed.

Poland 1 (P.1): This rootstock appears to be about the size of M.7. It may, however, require some tree support.

Budagovsky 490 (B.490): This rootstock produces a tree the size of MM.106 and has the same favorable characteristic of inducing early bearing. Burr knots rarely occur. The rootstock has some resistance to collar rot and is reportedly moderately resistant to fire blight. Nurseries find this stock easy to propagate by hardwood cuttings and are grooming it to replace MM.106.

Malling-Merton 106 (MM.106): A rootstock, slightly larger than M.7, that produces freestanding, early-bearing trees. Trees on MM.106 are susceptible to collar rot when planted in wet soils and are not recommended for poorly drained sites. Delicious on MM.106 is susceptible to apple union necrosis.

Malling 2 (M.2): An older rootstock that is reappearing in nurseries and orchards. It produces a semidwarf to semistandard freestanding tree, depending on scion variety. Trees are strong, crop well, and do not have collar rot problems.

Poland 18 (P.18): This stock holds the most promise for those wanting a larger tree about the size of MM.111. Its other advantages are tolerance to fire blight and resistance to collar rot. It will probably perform better in wet or heavier soils.

Malling-Merton 111 (MM.111): A well-anchored rootstock, resistant to woolly apple aphids, and tolerant of drier soil conditions. It is the most cold-hardy rootstock readily available. Trees on MM.111 are semistandard to standard in size. Planting depth of this rootstock is critical. The union should be no higher than 1 to 2 inches above the final soil line.

Budagovsky 118 (B.118) is a more vigorous clone out of the Minsk breeding program. It is more vigorous than the other rootstocks in the series but still imparts the high degree of winter-hardiness. It propagates easily in stool beds and does not sucker. It has moderate resistance to fire blight but is susceptible to *Phytopthora*. Because of the vigor of the rootstock it is only recommended for spur strains of apple or in weak soil or replant situations.