reduce bitter pit and enhance color in apples. Flesh firmness of Loring peaches was increased by summer topping. Summer desuckering of peaches has been shown to be beneficial in improving fruit color without the side effects on fruit size. Desuckering consists of removing only the large vigorous upright shoots in the center of the tree.

Economic effects

Dormant-type pruning of apples even done in the summer may not lower overall pruning costs, but it does allow a better distribution of the labor force. Summer pruning offers the grower the option of maintaining a constant number of employees by shifting some of the winter workload to the summer. In mature peach trees, summer topping can save a grower 20 to 25 percent in pruning costs, although there may be a loss in yield after topping.

Summer pruning is a useful tool in fruit production, with certain limitations. It should never be viewed as the sole method of pruning. The best practice is to combine selective summer pruning with yearly dormant pruning. Summer pruning can help improve fruit color, alter fruit quality, train trees, and allow a better distribution of labor.

Before embarking on a program of summer pruning, growers must know what effect they wish to achieve. The earlier in the season summer pruning is completed, the greater the flowering and vegetative regrowth. Conversely, the later in the season summer pruning is done, the less it will affect flowering and the less regrowth there will be. Late-season pruning enhances fruit color but can reduce soluble solids and final fruit size.

Deciding on a Production System

Cost

Generally, cost of trees in the long run is a small part of production costs. The big expense is in the labor required for early training and pruning. This expense should decrease over time, but the higher the density, the greater the labor requirements. A good rule of thumb is: "The more intensive, the more expensive."

Spacing

For optimal production, it is necessary to make best use of the surface area of available land. Spacing that is too wide makes for inefficient planting, while spacing that is too narrow means that excessive labor will be needed to contain trees in their allotted spaces. Once a production system is worked out, spacing is determined by cultivar to be planted, rootstock, soil vigor, and slope.

"Plantsmanship"

Any given production system will be only as good as the grower's ability to manipulate the trees. The more intensive the system, the more growers or their workers must be familiar with how trees grow. There is less room for error in high-density production.

Labor requirements

A high-density orchard requires greater management skills; it also requires that labor be spread over a longer time period. Pruning must be done in both winter and summer. Because tree size is smaller, production becomes more efficient. Brains and nimbleness replace the need for brute strength, allowing greater flexibility in the labor you can hire. High-density orchards also make it easier for fewer people to take care of more trees, but in a smaller area.

Common misconceptions clarified

- There is no perfect production system. You need to develop your own style and a production system that suits your abilities, growing conditions, and chosen cultivars.
- High density does not necessarily mean greater yields. It is very possible to achieve 1,000 bushels per acre on well-managed, standard trees. However, it takes more years to reach full production capacity with standard trees than with dwarf trees.
- Yields and dollar returns do not always occur more quickly in high-density production. Mismanaging a high-density system in the early years can delay fruiting and production. Since the purpose of high-density plantings is to have early production, anything that delays early production will delay returns.

Finally, do not pass judgment on a particular system without adjusting all the factors.

Too often, growers give up on a system because they have tried to handle it the way they handle all their other systems. Make allowances for different row spacings to accommodate smaller equipment.

Production Systems for Apples

As the Pennsylvania industry moves from conventional medium-density, freestanding orchards to high-density, supported orchards, many pruning and training modifications must be made. In the medium-density central leader system, portions of trees are cut back severely for several years to stimulate growth. Emphasis is placed on building a large, strong framework to support future crops.

Conversely, in high-density systems excessive growth is discouraged; and instead of a large, strong framework, a weak-framed tree is desirable. To achieve these ends in a system such as slender spindle, very little pruning is done in early years. The goal is to promote early fruiting, which itself will inhibit future growth. All high-density systems require a greater knowledge and understanding of plant growth and of how the tree will respond to cuts. In early years, more attention is paid to training and positioning limbs than to pruning them. As trees mature, most high-density systems will be more productive if trees are pruned in both winter and summer.

High-density systems also demand greater precision in spacing trees. Since trees are not meant to be vigorous, too wide a spacing is an uneconomical use of the land. Conversely, too narrow a spacing will necessitate more pruning, increasing vigor and reducing light and fruit quality.

Central leader system

This is the most widely planted system in Pennsylvania. Trees are usually, but not always, freestanding. With the range of rootstocks available (see Apple Tree Spacing), trees can vary from 7 to 20 feet tall. Trees can be kept smaller by periodically heading back the central leader into 2-year-old wood to stiffen the central axis. Size and vigor can also be controlled by selecting less-vigorous branches as the central leaders.

Trees are trained into a Christmas tree shape with the tops always narrower than the lower branches. Annual pruning is required for maximum sunlight penetration into the tree's interior and for greater production. In some instances, summer pruning is also beneficial.

The cost of establishing this system is relatively low because no tree supports are used and there are fewer trees per acre. In early years, efforts are focused on trying to invigorate trees to fill their allotted spaces. Early production years are then spent in slowing the trees down and getting them into an annual bearing habit. Later, as the planting grows older, it is necessary to maintain fruit spur quality by pruning annually and keeping tree tops from overshadowing lower branches.

The following is a "cookbook" method of how to prune and train trees to a central leader system.

At planting

- Remove all scaffolds below 18 inches flush to the trunk. Trees with fewer than three scaffold branches should be headed at 30 inches and all feathers removed with a bevel or Dutch cut. Trees with three or more branches offer three options depending upon the vigor of the scion and rootstock. Always remove any scaffolds that are more than half the diameter of the central trunk. The options in order of low vigor to high vigor are as follows:
- Option 1: Head leader 10 to 12 inches above the uppermost branch and all branches by a third.
- Option 2: Head leader 10 to 12 inches above the uppermost branch and do not head the side branches.
- Option 3: Do not head leader or side branches.

First growing season

- May: Install stakes and tie the leader to the stake. Remove two or three competing buds that broke and began to grow below the chosen leader if you headed the tree back at planting. Spread the scaffolds horizontally if you had left them on at planting.
- June: Clothespin new shoots when they are as long as, or just longer than, the clothespin.

Second leaf

- Dormant: If additional scaffolds are needed, score above desired buds in the late dormant season (4 to 6 weeks before bud break) or apply Promalin mixed with latex paint.

  Do not head the central leader. Select three to five first-tier scaffold branches of moderate vigor with wide crotch angles and remove the rest. Care should be taken to attain good spacing of branches around the trunk, both radially and vertically. Scaffold branches that are evenly distributed around the tree will assure even light distribution and scaffolds that are spaced out vertically will assure that leader dominance is maintained.
- June: Position permanent scaffolds at a 50- to 75-degree angle from vertical using spreaders, weights, elastics, or string.

Third leaf

- Head the central leader, removing half to a third of previous year's growth. Thin out overly vigorous limbs that are of no use.
- June: Position permanent scaffolds at a 50- to 75-degree angle from vertical using spreaders, weights, elastics, or string. When 3 to 6 inches of new growth has developed in the top third of last year's central trunk growth, select shoots to be the second-tier scaffolds. Pinch out the most and least vigorous shoots, leaving three to four of moderate vigor. Clothespin these second tier scaffolds to obtain wide crotch angles.

Fourth leaf

- *Do not head the leader.* Prune out only overly vigorous limbs that are of no use.
- June/July: Position first-tier scaffolds at a 50- to 75-degree angle, and position second-tier scaffolds horizontally using spreaders, weights, elastics, or string. Position overly vigorous limbs below horizontal.

Fifth and succeeding years

- Do not head the leader until it has bent over with a crop. Maintain good light distribution by making a minimal number of thinning cuts. Continue to position scaffold limbs with spreaders until this function is replaced by the weight of a crop. Shorten bottom tier of scaffolds by pruning back to side branch. Shorten pendulant branches back to a more horizontal position. Summer prune as needed in August to maintain light penetration.

Final leader height

- The ideal situation is that the leader will bend with a crop to restrict the tree height. This is termed the "crop and flop" method. However, in some cultivars the leader does not bend and the tree continues to grow upward. If this occurs you can cut the leader back to a lower, more horizontal branch, but only do so after the upper portion of the tree has fruited.

Slender spindle

This system is suited for densities of 400 trees or more per acre. It requires a very dwarfing rootstock, some form of support, and early fruiting to restrict tree size. Since all pruning can delay the onset of fruit production, little or no pruning is done in the first few years. The overall shape of trees resembles that of the Christmas tree central leader. However, secondary and tertiary branches off the scaffolds are not created or maintained unless they are very weak-growing.

The ideal is to start with a well-branched, 1-year-old tree. At planting, remove only those branches lower than 18 inches. Heading should not be performed on any of the scaffolds. If the new tree is an unbranched or poorly branched whip, head the tree at 28 to 30 inches. Side shoots, however, should not be headed. Any vigorous branches that arise from the severe heading are then tied or weighed down during the early growing season to reduce their growth and encourage flowering. Failure to restrict the growth of these vigorous shoots in the first year will delay fruiting.

To control tree height and reduce growth, a strong, upward-growing branch should not be chosen as the central leader, but rather a less vigorous shoot tilted at an angle of 20 to 60 degrees above the horizontal. The effect is to create a zig-zag central axis. This weaker lateral is tied to the support pole so that it becomes the new leader for that growing season. It is always important to keep the top of the tree subservient to the lower part. If the top becomes too vigorous, it will shade out the lower portions. All overly vigorous and vertical-growing shoots should be removed. When a branch becomes too long, a heading cut is made to a weak-growing branch or spur.

The following is a "cookbook" method on how to train and prune trees to a spindle system.

At planting

- Remove all scaffolds below 18 inches, flush to the trunk. Trees with fewer than 3 branches should be headed at 30 inches and all feathers removed with a bevel or Dutch cut. Trees with 3 or more branches should be headed 12 inches above the top-most scaffold limb. Remove any feathers that are one-half or more the diameter of the central trunk. Attach trees to the support post or conduit as soon as possible.

First growing season

- May/June: Select the most vigorous upright growing shoot that develops below the headed leader. Remove the two or three competing buds below the chosen leader. Clothespin new shoots that will become future scaffolds or tie down existing shoots to a more horizontal position using string, elastics or weights.

Second leaf

- Dormant: Head the central leader on a weak growing tree by removing one-half to one-third of previous year's growth. On very vigorous trees remove the leader and tie up a weaker leader from a branch below. Alternatively, vigorous leaders can be bent to a 90-degree angle or greater.
- June/July: Remove two to three competing buds below the leader if the tree was headed in the dormant season. Tie developing leader to the support post. Position overly vigorous limbs and shoots horizontally with weights. Tie up scaffolds that may bend under weight of fruit. Remove any branch that is more than one-half the diameter of the central leader utilizing a Dutch cut.

Third leaf

- Dormant: Head the central leader on weak growing trees by removing one-half to one-third of the previous year's growth. On vigorous trees remove the shoot and tie up a weaker leader from a branch below, or bend the leader over to 90-degree angle.
- June/July: Remove two to three competing shoots that broke below the leader if the tree was headed in the dormant season. Install clothespins to spread new developing side shoots. Remove any vigorous vertical growing shoots. Position overly vigorous limbs and shoots horizontally with weights. Tie up scaffolds that may bend under weight of fruit.

Fourth leaf

- Dormant: Remove overly vigorous leaders, and replace each with a suitable side scaffold. Reduce the length of scaffold branches that do not appear capable of supporting a fruit crop by cutting back to a side branch.
- August: Summer prune if necessary to maintain pyramidal shape and to encourage light interception. Remove vigorous upright growing shoots.

Fifth and succeeding years

- Minimize winter pruning to renew vigorous scaffold limbs in the top half of the tree. Maintain tree height at 6 to 8 feet by cutting the leader to a weak side scaffold as needed to prevent excessive growth in the top of the tree. Remove pendulant branches and spur complexes by cutting to a more horizontal shoot or spur system. Shorten bottom tier scaffolds as needed to maintain fruit quality by pruning back to a side branch.

Trellis systems

A trellis system relies on the use of three to four wires to serve as support and training aids. Several ultimate tree forms or training patterns may be chosen in developing a trellis. Certain components critical to this system must be understood and avoided regardless of the tree form chosen:

1. Branches to be trained to the wires should always originate on the main trunk below the wire. Bending branches from the main trunk or axis down to the wire will encourage upright water sprouts at the point of the bend. Water sprouts are unproductive and lead to an overabundance of growth.
2. Do not keep every branch on the tree. Branches growing vigorously into the drive row should be removed. Do not try to bend every branch back into the wire.
3. As trees get older do not allow the upper portions of the trellis to become overly vigorous and shade out the lower branches. Maintain a pyramidal shape as is done with the central leader system.
4. It is not necessary to stop branches from extending into adjoining trees. The ideal is to create an interwoven wall of bearing surface.

The following is a "cookbook" method for training trees to a Penn State low hedgerow four-wire trellis system.

- Oblique Palmette is a central-axis tree with four pairs of oblique scaffolds spaced approximately 18 inches apart in a narrow vertical plane. Scaffolds from adjacent trees cross each other, forming a lattice framework on which bearing wood is developed and managed as the fruiting mantle of the trellis hedgerow.

At planting

- Nonfeathered Trees: A one-year whip is planted vertically and headed at 18 inches, the height of the bottom wire. Usually, three shoots appear as a "crow's foot." The center one is selected to be the leader of the tree, and is tied to the bottom wire. At the same time, or a little later, two lateral shoots about 3 to 4 inches below the wire, one on each side of the tree, are selected to become a pair of scaffold limbs. When about a foot in length, these are inclined at a slope of approximately 60 degrees and secured to the bottom wire. When 2 to 3 feet in length, they are reset at a 45-degree slope. The leader is allowed to elongate and secured to the second wire when its wood has matured sufficiently for tying. Other lateral growth usually is removed. In the fall, the tree's central axis, leader, and scaffolds are secured to the trellis wires for overwintering.

Second year

- The tree's leader and scaffolds are allowed to elongate. Lateral growth normally is retained unless too vigorous, showing dominance on a scaffold or on the central axis. Lowest scaffolds are allowed to elongate at a 30- to 45-degree slope. When the two low scaffolds from adjacent trees pass the second wire, they are crossed and tied together at the middle of the second wire. Some repositioning of the tie on the first wire may be necessary to develop an even slope in the scaffold. Any strong lateral growth from these scaffolds showing dominance is headed at approximately 6 inches to either a downward or lateral growing shoot. One-year wood over 12 inches in length is usually pruned in half. If a terminal in a scaffold sets fruit, the fruit is removed and the leader renewed.
- Lateral shoots usually develop naturally on the central leader. At each trellis wire, a pair of suitable laterals is selected to become scaffolds. These should arise approximately 3 to 4 inches below the wire. Laterals are inclined and attached to give about a 45-degree slope. Later in the season, these are repositioned at approximately 30 degrees. If a young scaffold is not sufficiently long to be positioned, it may be marked for later identification, which is easily done with a spring clothespin. Growth may be enhanced by tying to about 60 degrees. Any strong lateral growth below and/or immediately above a pair of selected shoots is removed.
- This procedure for developing scaffolds is followed at each wire or level in the trellis. However, if suitable laterals fail to develop naturally, a heading cut may be made similar to that done at planting. The cut should be at or near a trellis wire for laterals to arise about 3 to 4 inches below the wire.

Third and subsequent years

- Training follows that outlined for the second leaf. If lateral shoots do not arise naturally at or near the desired location for scaffolds, the tree is headed at the wire to stimulate branching.
- When the central leader of the tree extends a foot or more above the top wire, it is bent to one side along the fourth wire to form half of the top tier. It is tied in a horizontal position. A suitable lateral, originating below the arch on the opposite side of the tree, is trained to form the other half of the fourth pair. However, it is usually inclined to the top wire before being trained horizontally. In future years, as scaffolds from the third tier (below) reach the top wire, top scaffolds are headed back periodically to reduce their shading on those immediately below. Eventually, fourth-tier scaffolds may be no longer than 12 inches in length. All vertical shoots and wood are removed from the top of the trellis (fourth-scaffold tier). This is usually done in early August just prior to summer grooming of the bearing mantle.
- Scaffolds are arrested in further elongation when they reach the middle of an adjacent tree. This is usually accomplished by not tying up the terminal. Occasionally, tipping or cutting back to a downward-growing lateral may be needed.
- Annual pruning is both summer and dormant pruning. Summer pruning is in August, about three months after bloom, and is considered mainly a grooming operation. All vertical vigorous growth from the top of the trellis is removed, which reduces shading, aids in suppression of the vigor in the top scaffolds, and maintains a hedgerow height of 6 feet. In addition, all vertical growth within the hedgerow itself is removed, but this may be done at any time during the summer. Further, all lateral shoots 12 inches or longer are stubbed by heading back to three basal shoot leaves, or to about 1⁄2 or 3⁄4 inches. This August stubbing of shoots is the most important pruning of the year and is what distinguishes the Penn State system. Besides increasing the exposure of bearing wood and maturing fruits to sunlight, stubbing enhances the development of bearing wood by manipulating vigorous growth into short shoots and spurs. Dormant pruning is largely heading back of older bearing wood, making corrective cuts, thinning out spurs, and, where necessary, re-stubbing to continue the control of vigorous wood.
- Feathered trees: A tree is planted vertically and oriented so that two feathers on opposite or nearly opposite sides of the tree occur approximately 14 to 15 inches from the ground (3 to 4 inches below the lowest trellis wire at 18 inches). These are inclined at a 45- to 60-degree slope, depending on length (vigor), and secured to the lowest trellis wire.
- If a suitable pair of feathers is located only above the bottom wire, training is possible for developing them into suitable scaffolds, provided they are located within 4 to 5 inches from the bottom wire. Training is a two-step operation. First, the basal part of a feather is bent horizontally or arched down to the wire. After tying, the remainder of the lateral is brought upward and fixed by dropping either a string or several ties attached together from the second wire. If of sufficient length, it is positioned at 45 to 60 degrees. Otherwise, it is just raised so that the terminal bud becomes the highest point. In a raised position, continued elongation of the young scaffold is assured. After sufficient growth, repositioning may be done. Thus, a high originating lateral may be made into a suitable scaffold. Its appearance would resemble that of a scaffold originating 3 to 4 inches below the bottom wire.

Vertical or French axe

Developed in France, this system has generated interest among Pennsylvania growers. It differs from the trellis or slender spindle mainly in ultimate tree height. Trees in the French axe system are allowed to grow 10 to 14 feet tall, depending on the cultivar. The simplest way to picture this system is to consider a pole with short fruiting spurs.

Trees are planted closer together than in other systems. A critical point in establishing the French axe system is to immediately stake or tie the tree's central axis the first year. Trees can be headed at planting to a height of 28 to 30 inches, but thereafter they are never headed. To achieve the narrowest tree, only a single upright-growing branch is left to grow during the first year. Variations to produce a wider tree permit weak-growing horizontal branches to remain on the tree. Vigorous branches should be removed or tied down early in the season.

The easiest way to control vigorous branches at the top is to allow the leader to bend over with fruit. Later, the drooping portion of the central leader is completely removed. Dormant pruning each year consists of removing vigorous, upright-growing shoots. Vigorous top branches can also be controlled with timely summer pruning. If performed properly, summer pruning can encourage a greater fruiting surface. If a branch has fruited and needs to be replaced, make an angled stub cut. A new branch will emerge from adventitious buds.

The following is a "cookbook" method of how to train and prune trees to a vertical axe system.

At planting

- Remove all scaffolds below 18 inches, flush to the trunk. Trees with fewer than three branches should be headed at 30 inches. Attach trees to the support system as soon as possible. Trees with three or more branches offer two options depending on the vigor of the scion and rootstock. Always remove any scaffolds that are more than one-half the diameter of the central trunk. The alternatives in order of low vigor to high vigor are:
  - Option 1: Head leader 10 to 12 inches above the uppermost branch and do not head the side branches. Bend the side branches to horizontal by using weight string or elastics.
  - Option 2: Do not head leader or side branches. This last option is best used when there are three to five good feathers (branches).

First growing season

- May: Remove the two or three buds that began to grow below the chosen leader if you headed the tree back at planting. Bend the side branches to horizontal by using weight string or elastics.
- June: Clothespin new shoots when they are as long as, or just longer than, the clothespin.

Second leaf

- If additional scaffolds are needed, score above desired buds in the late dormant season (4 to 6 weeks before bud break) or apply Promalin mixed with latex paint.
- *Do not head the leader.* If additional scaffolds are needed, notch above desired buds in the late dormant season (4 to 6 weeks before bud break) or apply Promalin mixed with latex paint.
- June: When 3 to 6 inches of new growth develops on shoots in the top half of the leader, pinch the new growth back by one-third their length. Position permanent scaffolds horizontally by using weights, elastics, or string. Position vigorous shoots below horizontal by means of weights, elastics, or string.
- July: Re-pinch all laterals as outlined above, as needed. If tree is vigorous, pinching the shoots a third time in August may be necessary.

Third leaf

- *Do not head the leader.* Tie down vigorous upright limbs below horizontal. Remove any side branches above the main scaffolds that are more than one-half the diameter of the central axis with a Dutch cut.
- June: When 3 to 6 inches of new growth has developed on shoots in the top third of last year's central leader, pinch them back by one-third to one-half their length.

Fourth leaf

- *Do not head the leader.* Prune out overly vigorous limbs that are of no use.
- June/July: Position excessively vigorous limbs slightly below horizontal.

  ~OR~
- August: Summer prune, removing vigorous limbs, to maintain pyramid shape and improve light interception.

Fifth and succeeding years

- *Do not head the leader.* Shorten bottom tier scaffolds by pruning back to a side branch. If desired begin removing/renewing scaffolds by thinning out the one most vigorous limb in the bottom middle and top of the tree. Remove any side branches above the main scaffolds that are more than 1one-half the diameter of the central axis with a Dutch cut. Leave all weak fruiting wood. Shorten pendulant branches back to a more horizontal position. Summer prune as needed in August to maintain light interception.

Final leader height

- The ideal situation is that the leader will bend with a crop to restrict the tree height. This is termed the "crop and flop" method. However, in some cultivars the leader does not bend, and the tree continues to grow upward. If this occurs, you can cut the leader back to a lower more horizontal branch, but only do so after the upper portion of the tree has fruited.

Tree Support Systems

As apple growers move to higher-density production systems using more dwarfing rootstocks, tree support becomes more of a concern. Most of the very dwarfing rootstocks require support, but there are somewhat more vigorous rootstocks that can perform well without support under certain conditions. However, depending on cultivar, soil type, slope, vigor, and cropping conditions, support may be necessary for semidwarf stocks.

Support systems should be installed soon after planting. In some situations they can be removed later after a strong framework of branches has been established. Some trees, those which have been supported for a few years, may stand on their own because they were initially supported and therefore developed a large, intact root system.

The cost of tree support systems varies widely. One system being used with Fuji in Pacific Northwest orchards of extremely high densities is the V system with a minimum system of posts having two wires with a small bamboo stake at each tree. Some of these systems are extremely expensive. Several systems of tree support and their associated costs are presented to illustrate costs. Below are some comparisons between various tree densities and types of possible support systems. The support systems are: a 6-foot, four-wire trellis system, a 10-foot wooden post without any wires, a 10-foot small diameter conduit (0.706 inch diameter) with a support wire at 6 feet, and a 10-foot large diameter conduit (0.922 diameter) also supported by one wire at 6 feet. One example is given of this larger conduit without a supplemental support system.

The costs of the components used in the above systems are as follows. For end posts a 3- to 4-inch diameter by 8-foot-long wooden post ($4.85) is used in conjunction with a locally procured anchor ($4.00) for a total cost of $8.85. Line posts are pressure-treated wooden posts, 2.5 to 3 inches by 8 feet, at a cost of $3.35. Wire used for all systems is 12.5-gauge, high-tensile-strength wire with a class 3 galvanized coating at a cost of $0.018 per foot. Individual tree support systems include the following types: 10-foot small diameter conduit at $1.35, the 10-foot large diameter conduit at $1.75, and 2-inch-by-10-foot wooden post at $2.95. All systems illustrated were designed for 300-feet rows with line posts spaced at 40 feet. Shown in the following table on a per acre basis are the cost of wire, the cost of end posts, the cost of line posts, the cost of tree stakes, and the total cost of the support system.

Examples of the cost per acre of support system components based on different tree densities.

	Wire	End posts	Line posts	Tree stakes	Total cost
2178 trees per acre = 2 foot x 10 foot spacing					
6 foot 4-wire trellis	$314	$257	$340	0	$911
Staked with small conduit	78	257	340	2,940	3,616
871 trees per acre = 5 foot x 10 spacing					
6 foot 4-wire trellis	314	257	340	0	911
Staked with small conduit	78	257	340	1,176	1,852
622 trees per acre = 5 foot x 14 foot spacing					
6 foot 4-wire trellis	224	184	243	0	650
Staked with small conduit	56	184	243	840	1,323
544 trees per acre = 8 foot x 10 foot spacing					
6 foot 4-wire trellis	314	257	340	0	911
6 foot 5-wire trellis	392	257	340	0	989
6 foot 6-wire trellis	470	257	340	0	1,067
Staked with small conduit	78	257	340	735	1,410
340 trees per acre = 8 foot x 16 foot spacing					
Staked with big conduit	49	161	213	596	1,018
Staked with big conduit w/o wire	0	0	0	596	596
Staked with wooden post	0	0	0	1,004	1,004
272 trees per acre = 10 foot x 16 foot spacing					
6 foot 4-wire trellis	$196	$161	$213	0	$569
6 foot 5-wire trellis	245	161	213	0	618
Staked with big conduit	49	161	213	476	899
Staked with small conduit	49	161	213	368	790
Staked with wooden post	0	0	0	803	803
227 trees per acre = 12 foot x 16 foot spacing					
Staked with big conduit	49	161	213	397	819
Staked with wooden post	0	0	0	669	669
218 trees per acre = 10 foot x 20 foot spacing					
6 foot 4-wire trellis	157	129	170	0	455
Staked with small conduit	39	129	170	294	632
202 trees per acre = 12 foot x 18 foot spacing					
6 foot 4-wire trellis	174	143	189	0	506
Staked with small conduit	44	143	189	272	647
Staked with wooden post	0	0	0	595	595

Apple Tree Spacing

Apple orchards are a long-term investment, so it is essential to choose a tree spacing and a production system that will make best use of land and capital to produce fruit. Potential acre yields depend on the volume of bearing wood maintained in an orchard. Increasing the number of trees per acre is one way to increase the volume of bearing wood and thus yield. Yield can also be increased through proper pruning, training, and management. Growers must consider their ability or inability to manage a particular production system.

To determine in-row tree spacing, consider the following factors.

1. Variety

Table 1-6 lists common Pennsylvania-grown varieties and their characteristics, including vegetative vigor. (For example, Northern Spy is among the most vigorous and spur Delicious is among the least.)

2. Type of production systems

Low-trellis hedgerow

This system requires that the grower have a thorough understanding of tree growth and a large commitment of time and money. In a trellis hedgerow, trees are trained to a four-wire trellis to develop a solid hedge about 6 feet tall and 3 to 4 feet across. Branches originate from a main trunk below the wire and are trained up and across the wires. Trellising has the potential for high yields and early bearing and is a desirable system for growers limited by land or equipment. Suitable rootstocks and suggested in-row spacings are EMLA 9 (6 to 7 ft) and EMLA 26 (7 to 9 ft). M.27 (5 ft) can be used but is still experimental.

Slender spindle, hoop skirt, spindle bush

These systems also require a thorough understanding of tree growth. They differ from trellising in the way in which the scaffold branches are trained. In slender spindle, the scaffolds are bent and tied down to reduce shoot growth and to enhance cropping. In hoop skirt, scaffolds are trained nearly horizontal, with low limbs retained for a period of time. In spindle bush, scaffolds are developed by a combination of pruning and spreading. If posts or wires are used for support, these systems will be the most expensive to establish. Training and pruning require more effort than trellising. Yields may be slightly lower than in the trellis system, depending on the grower's commitment to pruning and training trees. These systems on EMLA 26 may not need individual tree support. Rootstocks suited for these systems and suggested in-row spacings are EMLA 27 (4 to 5 ft), EMLA 9 (5 to 7 ft), and EMLA 26 (7 to 10 ft).

Freestanding central leader tree on semidwarf rootstocks

This system uses a more vigorous rootstock to provide tree support. The tree is kept small by periodically heading back the central leader into 2-year-old wood to stiffen the tree's central axis. Trees are trained to a central leader system and pruned annually to keep them within their allotted spaces. The cost of establishing this system is relatively low because no tree supports are used and there are fewer trees per acre. Suggested rootstocks and in-row spacings are EMLA 26 (8 to 10 ft), MARK (8 to 10 ft), EMLA 7 (9 to 12 ft), M.9/MM.106 and M.9/MM.111 (10 to 13 ft), EMLA 106 (11 to 14 ft), M2 (12 to 15 ft), and EMLA 111 (15 to 18 ft).

Freestanding central leader tree on semistandard and standard rootstocks

In this system tree height is not as severely controlled. Grower knowledge, time, and expense may be the lowest of any other system. Potential yields and returns are also the lowest, especially in the early years. The age of bearing and early production will be inversely related to the ultimate size of the tree. The system still requires early pruning and spreading of branches. Suggested rootstocks and in-row spacings are EMLA 106 (16 to 20 ft), EMLA 111 (17 to 20 ft), seedling (18 to 24 ft).

3. Rootstock effect

The effect of the rootstock on ultimate size, precocity, cultural practice, and spacing is another factor to consider. Penn State has been a leader in testing and evaluating rootstocks for tree fruit. Test plantings of all the new rootstocks for apples are located at either University Park or Biglerville. The more common rootstocks are classified immediately below. Certain rootstocks in each size category may overlap into the next largest tree size owing to scion variety, production system, or soil type.

In the future there will be numerous rootstocks from which to choose. Growers are advised that many of these rootstocks have had only limited testing in Pennsylvania. We recommend proceeding with caution when trying new rootstocks, but urge you to try small test plantings with the cultivars that you grow. (see Table 1-7). In the section titled "Apple Rootstocks," we provide brief descriptions of apple rootstocks that you might see in nursery catalogs.

4. Soil vitality

Soil type, fertility, depth, water-holding capacity, and replant conditions all affect tree spacing. Pennsylvania soils have been divided into five classes according to potential productive capacity. A listing of these classes is available at county extension offices. Soils in Classes II and III are best suited for orchards. Soils in Class I are the most fertile and can lead to overly vigorous plantings.

In-row spacings should be adjusted according to soil strength. For Class I soils the widest in-row spacing is recommended, for Class II the middle range, and for Class III the narrowest spacing. Orchard soil should be a minimum of 2 to 3 feet deep. For shallower soils, in-row spacing can be reduced. Soils with a high water-holding capacity usually encourage more vigorous growth, while droughty soils slow growth.

Old orchard sites require special attention. Continually replanting the same sites can lead to poor tree growth and production. Before being replanted, soil should lie fallow or be put into field crops for 2 or more years. Every effort should be made to replenish soil nutrients before replanting. Before removing the old trees, take a soil test and nematode analysis. After removing trees, apply the recommended amounts of lime and fertilizer. Then subsoil the site and work in the fertilizer. Organic matter additions are also suggested.

5. Cultural practices

Mulching, weed control, irrigation, and other cultural practices all affect orchard spacing. Mulching helps conserve moisture in the soil and reduces the number of competing weeds, but it can also attract meadow and pine voles. Eliminating weeds from under the tree helps reduce competition and produces a larger

Table 1-7. Comparisons of apple rootstock characteristics.

Rootstock	Size class	Support	Suckering	Burrknots	Fire blight	Collar rot	Availability
Budagovsky 146	VD	Yes	No	No	Very susc.	Mod. susc.	Limited
Malling 27	VD	Yes	No	No	Susc.	Resis.	Some
Poland 22	VD	Yes	No	No	Susc.	Resis.	Limited
Geneva 65	D	Yes	Some	No	Resis.	Resis.	Limited
Budagovsky 491	VD	Yes	No	Some	Very susc.	Mod. resis.	Limited
Poland 16	VD	Yes	No	No	Susc.	Mod. resis.	Limited
Poland 2	D	Yes	No	No	Susc.	Resis.	Limited
Budagovsky 9	D	Yes	No	No	Susc.	Resis.	Widely
Geneva 16	D	Yes	No	No	Resis.	Resis	Some
Geneva 41	D	Yes	Some	No	Resis.	Resis.	Some
Malling 9*	D	Yes	Some	Some	Very susc.	Resis.	Widely
Geneva 11	D	Yes	No	No	Mod. resis.	Resis.	Some
Mark	D	Yes	No	Yes	Susc.	Mod. resis.	Some
Ottawa 3	D	Yes	No	No	Susc.	Resis	Limited
Geneva 935	D	Yes	No	?	Resis.	Resis.	Some
Vineland 1	SD	Sometimes	No	No	Resis.	Unknown	Not yet
Malling 26	SD	Sometimes	No	Yes	Very susc.	Susc.	Widely
Supporter 4 (Pi.80)	SD	Sometimes	No	No	Susc.	Unknown	Some
Geneva 30	SD	Sometimes	No	No	Resis.	Resis.	Widely
Malling 7	SD	Sometimes	Yes	Some	Mod. resis.	Mod. resis.	Widely
Malling Merton 106	SV	No	No	No	Susc.	Very susc.	Widely
Malling Merton 111	SV	No	No	Yes	Resis.	Resis.	Widely
Malling 2	SV	No	No	Some	Resis.	Resis.	Limited
Budagovsky 490	SV	No	No	Some	Unknown	Unknown	Limited
Budagovsky 118	V	No	No	?	Unknown	Resis	Some
Poland 18	V	No	No	No	Mod. resis.	Resis	Some
Seedling	V	No	Some	Some	Variable	Variable	Widely

**Refers to NAKB 337 clone of M9*
Size class: VD = very dwarf; D = dwarf; SD = semidwarf; SV = semivigorous; V = vigorous
Some of the material in this table came from information supplied by J. N. Cummins, personal communication, R. L. Perry, Proc. Mich. Hort. Soc., and B. H. Barritt, Intensive Orchard Management.

tree. Although Pennsylvania has a humid climate, frequent dry spells can affect tree growth and performance. Irrigation has been shown to be beneficial.

6. Equipment

The size of equipment to be used in the orchard depends largely on the between-row spacing. Maximum width between rows of trees should be the sum of in-row spacing plus 8 feet. For example, if trees are to be planted 7 feet apart in the row, then between-row spacing should be 15 feet (7 ft + 8 ft). Adjustments downward can be made when narrower tractors and sprayers are used. When a new, more efficient planting is being established, between-row spacing should not be based solely on the width of old equipment. Until the trees fill their allotted space, larger equipment can be used. Smaller tractors can be substituted as the planting ages.

7. Between-row spacing

Research has shown that the most critical factor in determining early production and high yields in an orchard is the rapidity with which the canopy of the trees develops and fills its allotted space. In designing an orchard, growers are often more concerned about planting trees too close. Spacing trees too far apart, however, can be just as detrimental.

The overriding factor in determining optimum row spacing is to choose a spacing that will capture the most sunlight while not shading the adjacent rows. Orchards whose rows are spaced too far apart capture less than the optimum amount of sunlight. The old rule of thumb in determining row spacing is to take the in-row spacing and add 8 feet to it to equal the distance between rows. However, growers switching to small trees should avoid the mistake of keeping wide drive rows to accommodate old equipment.

As mentioned previously, in-row spacing depends upon rootstock, cultivar, training system, and other factors. Between-row spacing is determined by all of the previously mentioned factors plus the ultimate tree height. Many growers in their quest for small trees do not realize that to achieve optimal yields they must also move the rows closer together. Failure to do this will result in significantly lower yields than old standard or semidwarf plantings. The following are three methods that can be used to arrive at possible between-row spacings.

a. (desired tree height/2) + in-row spacing = between-row spacing
b. (2 x desired tree height) – 6 = between-row spacing
c. desired tree height / 0.75 = between-row spacing

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.