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Training and Pruning Apple Trees in Intensive Orchards

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Since the mid 1970s in the U. S., the number of apple trees per acre in new orchards has gradually been increasing. Orchard intensification is motivated by the desire to produce fruit early in the life of the orchard to rapidly recover establishment costs. Intensification is possible by using dwarfing rootstocks that control tree size, induce early cropping, and produce large quantities of fruit relative to the amount of wood produced.

Orchardists and researchers have attempted to grow apple trees on dwarfing rootstocks in Virginia during the past 80 years. Results were usually disappointing because trees on dwarfing rootstocks have shallow or brittle roots systems and trees grew poorly and often leaned or fell over. Researchers recently have learned how to manage dwarf trees and the yield potentials of new training systems using dwarfing rootstocks have been impressive. Thus orchardists are re-evaluating the economic feasibility of growing intensive apple orchards on dwarfing rootstocks. Recent results from research conducted in Virginia indicate that intensive orchard systems are more profitable than traditional low-density orchards on semi-dwarfing rootstocks. However, because the establishment costs for intensive orchards are high, trees must be trained and pruned properly to induce and maintain high yields.

The purpose of this publication is to describe the management of the most commonly used intensive orchard training systems. A general discussion of apple tree pruning, including a description of pruning cuts, how pruning influences growth and fruiting, and a description of training and pruning "central leader" trees can be found in VCE Publication 422-021.

Motivation for orchard intensification. The primary reasons for orchard intensification include: 1.) early fruit production, and 2.) reduced pruning and harvest costs of mature orchards. Yield is positively related to the amount of sunlight intercepted per acre. Profit, which is influenced by yield as well as fruit size and quality, is probably at an optimum when an orchard intercepts about 70% of the available light. Traditional orchards, using vigorous rootstocks, were typically planted at a spacing of about 22 feet x 16 feet with 132 trees per acre. For the first five or six years after planting, fruiting was discouraged to promote vegetative growth so trees would fill their space as rapidly as possible. The first crop was usually harvested four or five years after planting, but high yields were not obtained until trees finally occupied their allotted space. Maximum yields did not occur until about 12 to 14 years after planting.

Intensive orchards are typically planted at a spacing of 16 feet x 8 feet (332 trees/acre) or 15 feet x 7 feet (405 trees/acre). A small crop is often harvested the year after planting and, because trees have so little space to fill, peak production is usually achieved during the 6th or 7th year after planting. Once trees fill their allotted space, maximum yields are similar for all types of orchard systems. Because the primary advantage of intensive orchards is early fruit production, these orchards should be planted only on excellent sites with a low probability of crop loss due to frost or hail.

Intensive orchard training systems. The three basic types of training systems used for intensive orchards are "trellis," "slender spindle," and "vertical axe." There are many modifications of each system, and orchardists will need to adapt a system to suit their own particular situation. The basic systems will be discussed below.

Trellis. Various trellis systems have been developed. These systems involve tying branches to wires and tree

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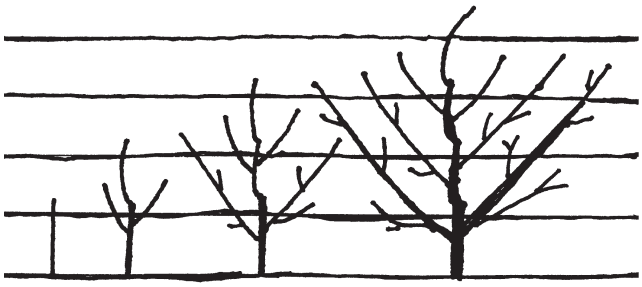

Figure 1. Developing the 5-wire trellis. A vertical central leader is maintained and limbs are fastened to the wire and oriented at 30 o to 45 o from vertical. The mature trees form a hedge about 6′ or 7′ tall and about 4′ or 5′ wide.

height is usually maintained at 6 feet to 10 feet. Trellis systems are not widely planted because pruning and training costs are high and short canopy height is not conducive to high yields unless rows are spaced closely. The number of wires used for a trellis depends on the desired height but 3 to 5 wires are common. The most commonly used trellis is probably the Penn State 5-wire trellis, promoted by Dr. Loren Tukey, at The Pennsylvania State University. Wires are placed 2 feet, 3 feet, 4 feet, 5 feet and 6 feet above ground, to produce a hedge 6 feet tall and about 5 feet wide (Figure 1).

After planting, head the trees 4 to 6 inches below the lowest wire and fasten the tree to the wire. If trees are feathered, two limbs can be retained per tree. Remove all growth below 18 inches. During the first season, several vigorous shoots will develop from buds just below the heading cut. When new growth is 2 to 4 inches long, ensure leader dominance by pinching out strongly competing shoots. Select several candidates for the first pair of scaffolds, and improve their crotch angles by attaching spring clothespins to the leader just above the branches. Tie the leader when it grows to the height of the second wire. The first winter fasten one shoot to wires on each side of the trunk. Limbs should not be oriented horizontally because vigorous water sprouts (upright shoots) will develop from buds on the upper surface of the limb.

First winter. Head the leader 4 inches to 6 inches and remove competing upright growth. Select two scaffolds (below the lowest wire and on opposite sides of the leader) and remove all other shoots. Spread the scaffold branches and tie them to the first wire. The angle of spreading varies with the particular version of the trellis system. In some cases, the branches are trained to a horizontal position, much like some grape training systems. Branches that are tied to the horizontal tend to produce many upright vigorous shoots that are unfruitful and shade the lower branches. Training the scaffolds to 30˚ to 45˚ will maintain a balance between vegetative and reproductive growth.

Second, third and forth winters. Head the leader about 4 inches to 6 inches above a wire. Eliminate competing shoots, select and spread two scaffold branches, one on each side of the tree. Tie the leader and the selected scaffolds once they have reached the height of the next wire. Tie the scaffolds so as to maintain the proper limb orientation. When the leader reaches the top wire, there are two training options: 1.) Bend the leader to one side and develop it as a horizontally oriented scaffold branch, then train a lateral shoot to the opposite side to complete the last pair of scaffold branches. 2.) Retain the leader after the last pair of scaffolds is selected and head it back regularly to a weak lateral.

Pruning mature trees. The objectives of pruning mature trees are to control crowding, provide optimum light exposure, and maintain uniform vigor. Regularly remove vigorous, upright growth arising from the upper surface of the scaffold branches. Regulate vigor in the top of the tree to prevent shading the bottom branches. Remove the most vigorous growth and retain less vigorous, more fruitful growth. If the leader is maintained, rather than headed, at the uppermost scaffold, it can act as a "safety valve" for diversion of excessive vigor. Allow the ends of branches of adjacent trees to overlap to fill the row space. However, in time, some judicious heading-back and/or branch renewal may be required to control crowding.

Vigor, especially in the tops of trees, is often excessive in mature trellis plantings. Therefore, heavy dormant pruning is required to prevent tree crowding. Summer pruning may be required to improve light penetration to the lower portion of the tree and improve red color development of the fruit surface. Summer pruning involves removing upright non-fruiting shoots throughout the tree. Do not head shoots, but rather totally eliminate unwanted growth. Pay particular attention to the top half of the tree. To encourage good light penetration, the width of a mature trellis should be no more than 5 feet at the bottom and 3 feet at the top.

Sometimes limb vigor can be managed by manipulating the orientation of the limb. In general limbs should be oriented about 60 o from vertical (30 o from horizontal) to encourage a balance between vegetative growth and fruiting. If a branch is overly vigorous, reorienting it towards the horizontal will suppress its vigor. Limbs

lacking vigor can be oriented more vertically to encourage vegetative growth. This detailed pruning and limb manipulation may result in high yields of good quality fruit, but it is labor-intensive and may not be practical on a commercial scale.

Trellis systems have not been widely adopted in the Western Hemisphere. Reasons for the non-popularity include: 1.) High establishment costs for posts, wire, and trees, 2.) High labor costs for pruning and tree training throughout the life of the orchard, 3.) Lack of high yields when trellises are less than 10 feet tall, and 4.) Poor fruit color when inadequate attention is paid to detailed pruning of the tree tops.

Slender spindle. The slender spindle system was developed in Northern Europe (Fig. 2). This system requires that each tree be supported with a wooden stake 8 feet long and 3 inches in diameter. Alternatively, smaller diameter stakes, bamboo, conduit, or angle iron can be placed next to each tree if they are supported by a high-tinsel wire at 8 feet to 9 feet above ground. The wire is fastened to 5- to 6-inch diameter posts 8 to 9 feet above ground. The tree is pruned to develop a narrow conical shape and excess vigor in the treetop is controlled by annual cutting into 2-year-old wood, on the leader, to a weak side limb. This system has not performed well in Virginia because treetops grow too vigorously and the lower regions of the canopy are shaded.

In Virginia, trees are typically spaced 14 feet by 6 feet (518 trees/acre) to 13 feet by 5 feet (670 trees/acre). Closer tree spacing is possible in more northern climates

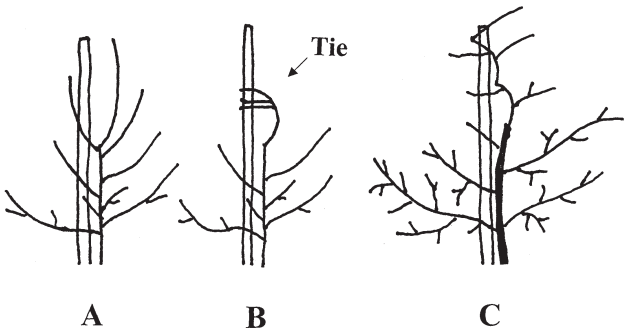

Figure 2. Developing the slender spindle tree. Vigor in the top of the tree is suppressed by annually cutting into 2-year old wood to remove the top-most 2 or 3 limbs, which are usually too vigorous, to a weaker side limb. The side limb is tied to the post, resulting in a zigzag shape. The mature tree is conical in shape and about 8′ tall. There are 4 or 5 permanent limbs in the lower part of the tree and young temporary limbs in the top half of the tree.

where tree growth is less vigorous. Large (4 to 5 feet tall and 5/8 inch di ameter) feathered trees are preferred for planting. At planting, remove all limbs lower than 26 feet above ground. If these low limbs are retained, they will droop to the ground under the weight of a crop during the second and third seasons and they will interfere with orchard operations. Fruit on these drooping branches will also be on the ground or hang in the grass and will not color well and will be prone to rot infection. Retain all branches, with wide crotches, originating at least 26 inches above ground. Feathers longer than 2 feet should be headed by about one-third. Head the leader to 8 to 12 inches above the highest retained feather. If non-branched whips are planted, the trees should be headed at 32 to 36 inches above ground to induce branching. During the first winter, these trees can be pruned as a feathered tree at planting.

The winter after planting. Retain 4 or 5 limbs with wide crotches on each tree to develop a permanent layer of fruiting branches in the lower part of the tree. This layer of branches should be 26 to 40 inches above ground and should be arranged around the tree so that no branch is directly above another branch. Some branches may require spreading to maintain an orientation of about 30o to 45o above the horizontal. Branches may be spread by using wooden spreaders, by placing weights on the branches, or by tying branches down. Several vigorous shoots should have developed from buds on the leader below the heading cut. Make a thinning cut into 2-year-old wood just above one of the weaker-growing lateral branches. This branch will become the new leader. The thinning cut will remove the top-most several lateral shoots. Bend the top-most remaining lateral shoot into a loop by fastening the tip to the support stake. Buds along the top surface of the horizontally oriented section of the shoot (the section at the bend) will develop into upright shoots during the next growing season. When this process of heading into two-year wood and looping the new leader is repeated each year, the central leader zigzags, which restricts growth slightly. This severe pruning of the tree top will slow the vertical development of the tree and allow the bottom of the tree to develop first.

The second, third, and fourth years. The dwarfing rootstock will induce flower bud formation on trees during the first growing season. Trees with adequate size may be allowed to produce a small crop the year after planting.

The crop on most trees should be thinned to retain a maximum of 8 to 15 fruit per tree. Only the lower branches

should be allowed to fruit and fruit should be removed from all 1-year-old wood. Fruit produced on 1-year-old wood tends to be small, matures late, and will pull the ends of the branches to the ground. Excessive cropping of young trees devitalizes the trees. Once the trees are allowed to become reproductive, it is difficult to maintain enough vegetative vigor for the trees to fill their allotted space. Trees that have been allowed to fruit too early never fill their space and never achieve maximum production. It is much easier to maintain vegetative vigor of young trees by limiting cropping than it is to revitalize low-vigor trees.

During summer, some limbs with fruit may need to be tied up to maintain an orientation above the horizontal and to keep fruit off the ground. Shoots that are too upright or too vigorous can be pruned out during July or August, or the shoots can be re-oriented to more horizontal positions with spreaders or weights. Summer pruning will not suppress tree vigor more than pruning in the winter, but it will improve light penetration into the tree and may improve fruit coloration.

Each winter a new leader is selected by cutting to a weak lateral on 2-year-old wood. Zigzag the leader by looping it. Remove upright vigorous shoots and excessive branches.

Mature trees. By the fifth or sixth year, the trees should be at the top of the support stake and should have filled the space between trees. Maintain the final height by replacing the leader with a side limb each winter. Cut the leader at a weaker side limb, and tie that limb into position on the support post as a replacement. Do not head the replacement leader shoot. If excessive tree vigor is a problem, the leader can be substituted in June, which will help to reduce regrowth. All limbs above the bottom layer of branches should be considered as "temporary limbs." When the diameter of a limb is half the diameter of the trunk at the point of attachment, the limb should be removed using a "Dutch cut." A Dutch cut is a slanted or beveled cut that leaves a larger stub at the base of the cut than at the top of the cut. Buds on the underside of the stub will develop into limbs with wide crotches and will replace the vigorous limb that was removed. Removal of the largest branches in the tree top each year is referred to as "replacement pruning" and ensures that the tree top remains narrow to allow good light distribution throughout the tree.

After fruiting for 2 or 3 years, the ends of the lower branches will droop with the weight of a crop. Shorten these branches with thinning cuts by cutting to a slightly upright side-branch. During the summer, other branches may require tying up to keep fruit off the ground.

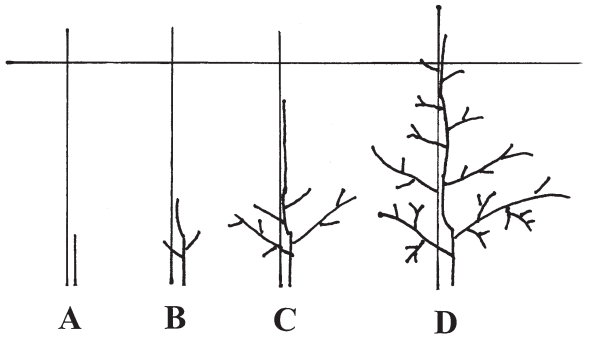

Figure 3. Developing the vertical axis. Each tree is supported by a small pole, which is supported by a wire at 7′ to 9′ above ground. The central leader is headed at planting, but thereafter the non-headed leader is tied to the pole. All limbs with wide crotch angles are retained for about 4 years and are allowed to fruit before being removed. The mature tree is conical in shape and 9′ to 12′ tall. There is a layer of 4 or 5 permanent limbs in the bottom of the tree and young temporary limbs in the top half of the tree.

The slender spindle training system is very popular in Northern Europe. However, the system has not performed very well in Virginia. Tree vigor is difficult to control with our longer growing season. High labor inputs are required for winter pruning and summer pruning to allow adequate light penetration for high quality fruit. The high yield potential of this system does not outweigh the combination of very high establishment costs, along with high pruning costs.

Vertical Axis. The vertical axis, sometimes called the French axe or the central axis, was developed by J. M. Lespinesse in France, and has performed extremely well throughout North America (Table 1). This system requires leader support to a height of 8 feet to 10 feet above ground and minimal pruning is used to develop a tall conical shape (Fig. 3).

Typical tree spacing for the vertical axis is 14 feet x 6 feet (518 trees/acre). The support system consists of stakes next to each tree. There are several choices of stakes, including wooden posts, metal conduit, angle iron, or bamboo. Experiences with bamboo indicate that some stakes will twist, split, or break after about seven years. Conduit (5/8 inch diameter) and angle iron (1/2 inch) have performed well in Virginia. Angle iron is very resistant to bending, but as it rusts the rough surface

may injure bark on tree trunks. No adverse effects have been observed from the bark injury, but the injured areas may be sites for disease infection or insect entry. Some commercial apple growers are also experimenting with a 3-wire system, with no individual tree support, where the central leader is tied to each wire. Preliminary results from an experiment to compare support systems at the Virginia Tech research orchard indicate that three wires may not provide adequate support as the trees start to fruit heavily. By the fourth season some trees have started to lean. The individual tree stakes are then fastened to high tinsel wire at about 7 feet to 9 feet above ground. A second wire at about 3 feet to 4 feet above ground may be desirable to prevent tree leaning and trunk breakage. Lower branches can be tied to the lower wire and aid in limb orientation. Tying limbs to the wire may also reduce tree twisting, and reduce the number of trees that break at the bud union during wind events. Large wooden posts (5 to 6 inch diameter and 10 feet tall) support the wire. Experience indicates that end posts should be well anchored and interior posts (4 to 5 inch diameter) should be spaced no farther than 50 feet apart in the row. In the long run, it is less expensive to initially build a strong support system, than to try to save money with a less expensive, but inadequate support system that must be repaired after the trees are blown over in a hurricane.

When possible, plant large feathered trees. After planting, remove limbs lower than 26 inches. Retain all limbs with wide crotches and head the leader 10 inches above the highest retained limb. Shorten limbs longer than 2 feet by about 1/3. This heading cut will stiffen the limb and reduce the severity of limb drooping as limbs produce heavy crops. Some limbs may need spreading to maintain a 30o to 45o orientation from horizontal. When non-feathered whips are planted, head the tree 36 inches above ground. Once or twice during the first summer tie the longest most vertical shoot, originating below the heading cut, to the support.

Young trees. When tree vigor is moderate, all pruning can be performed during the winter. Limb spreading can be done any time of year. During the first growing season, as the leader grows, tie the longest shoot, originating below the heading cut to the support. This is the tree leader and should never again be headed. Remove low limbs and limbs with narrow crotches. Retain and, if necessary, spread all limbs with wide crotches.

With some cultivars, such as 'Gala', two or three shoots with narrow crotches will develop behind the heading cut on low branches. This condition is sometimes referred to as "crow's feet." Retain the longest shoot and remove all shoots with narrow crotches.

Depending on the scion cultivar and tree vigor, the leader may not branch very well during the second season. If one is patient, adequate branching will usually occur along the leader during the third and fourth seasons. Alternatively, "notching" can be used to promote branching along the leader. Notching involves cutting, with a knife or hacksaw blade, through the bark to hardwood just above a bud. The cut should extend about 1/3 around the circumference of the leader. This cut blocks the downward flow of hormones from the terminal bud that normally inhibits buds from developing into shoots. Approximately 60% to 70% of the notched buds develop into shoots, so about 10 to 12 buds should be notched starting about 6 inches above the highest limb.

Trees should increase in height rapidly and they should be about 9 feet tall by the end of the third or fourth season. During the growing season, continue to tie the leader to the support. The leader should be fastened to the support at 18- to 30-inch intervals.

When necessary, spread branches to the desired orientation. As the lowest four or five branches droop with the weight of a crop, shorten the branches to more upright shoots. All branches above the lower four or five branches should be considered temporary. Such branches should be removed with "Dutch cuts" when the diameter of the branch is equal to half the diameter of the leader at the point where the branch originates from the leader. Therefore, the top 2/3 of the tree is narrow and contains only limbs with low to moderate vigor.

Some pomologists recommend summer pruning in intensive plantings. When trees of a given combination of scion variety/rootstock are planted at spacings appropriate for the soil type, summer pruning is not needed. Summer pruning will not help suppress tree vigor. When the canopy is too dense, summer pruning improves light penetration into the canopy and often improves fruit color. Summer pruning should be done about three to six weeks before harvest and should consist of removing upright non-fruiting shoots, especially in the top half of the tree.

Avoid over-cropping. Because trees are on dwarfing rootstocks and are pruned minimally, trees trained to the vertical axis tend to become reproductive early in the life of the tree. To encourage vegetative growth, so trees fill their space within five years, cropping must be

limited. Trees that grow well the first season can support 8 to 15 apples the second season. Remove all fruit from the leader and all 1-year-old limb sections. Retain fruit on only the older portions of the lower limbs. Adjust the crop load on 3-year-old trees to about 30 to 40 fruit per tree. Depending on the variety, this will provide a yield of about 200 to 300 boxes/acre. Four-year-old trees can support about 100 fruit per tree (400 to 600 boxes/acre), and 5-year-old trees can support about 160 fruit per tree (800 to 1,000 boxes/acre). Depending on the scion cultivar, mature orchards should produce annual yields of about 800 to 1,200 boxes/acre.

Mature trees. An ideal tree in the central axis system is conical in shape and has a lower layer of about four to six limbs 2 to 3.5 feet above ground. Above that layer is a gap with only small fruiting limbs, so light penetrates to the lower part of the tree. Above the gap are non-permanent fruiting limbs. The fruiting limbs are renewed close to the central axis after they have fruited and drooped. Very little pruning is usually needed before the fifth year. Don't remove branches with wide crotches in the lower part of the tree until they have cropped.

When trees have filled their space, pruning mostly involves removing the larger limbs in the top half of the tree to maintain a conic form. In most cases limb renewal will begin in the fifth or sixth year. Sometimes, especially with vigorous scion cultivars on the more vigorous dwarfing rootstocks on fertile soils, trees grow taller than desired. Trees 9 to 10 feet tall are often desirable, but trees can sometimes attain a height of 14 to 16 feet. Avoid the temptation of shortening tall trees until the tops have fruited for two years. Shortening the trees requires large cuts into 2- or 3-year-old wood. Trees that have not settled into a fruiting pattern will respond to heavy pruning with vigorous upright growth in the tree top. This type of wood is non-fruitful and reduces light penetration to the lower parts of the tree. Removing vigorous shoots will become an annual and expensive chore. If tree tops are allowed to fruit, the branches will sometimes flop over or break under the weight of the crop and will cease to be a vigor problem. Even when growth in the tree top is quite vigorous, large pruning cuts to lower the tree induce only moderate vigor if tree tops have been allowed to crop for two years. Lower the tree by cutting to a low vigor limb arising from 2- or 3-year old wood.

To keep the tree top narrow, limbs can sometimes be shortened by cutting into 2- or 3-year old wood to low-vigor side shoots. Usually it is more desirable to remove the entire limb with a Dutch cut to produce a new replacement limb. Although the bottom of the tree should be wider than the tree top, the lower limbs sometimes droop to the ground or extend into the row middle and interfere with orchard operations such as mowing, application of herbicides and pesticides, and harvest. In these cases, the lower limbs must be shortened. The best way to shorten a limb is to cut the limb back into 2- or 4-year old wood to a weak side branch that is oriented slightly above horizontal. Never head shoots into 1-year-old wood because this will reduce future yields and cause shading problems by inducing shoot proliferation on the tree periphery.

Table 1. Influence of training system and rootstock on cumulative yields for 'Empire' and 'Delicious' apple trees in Blacksburg, Virginia, after 10 years. Although slender spindle trees had high yields, crop value was low because trees were too dense and required heavy pruning and produced fruit with inadequate red color.

			Cumu lativeYield (tons/Acre)	
Training System	Rootstock	Trees/Acre	Empire	Delicious
Slender Spindle	M.9	996	210	135
Slender Spindle	Mark	996	179	171
Central Leader	M.26	450	152	122
Central Leader	Mark	450	112	114
Vertical Axis	M.9	608	188	156
Vertical Axis	Mark	608	160	145