The Penn State Low Trellis Hedgerow System of Apple Production

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Trellising is a form of espalier where plants are trained as a hedge but supported on posts and wire rather than on a wall. Although originating several hundred years ago, trellising is being used successfully today as a system for commercial apple and pear production in various parts of France and Belgium. Conversely, the potentials of a trellised system for the commercial apple production in the U.S. have been realized only recently. Current feasibility is related to the greater availability of the more dwarfing size-controlling rootstocks, the introduction of growth regulating chemicals, the ability to utilize various training methods more effectively with smaller sized trees, and certain economic advantages of the system. Further, the form of the system has certain potentials for improved mechanization and labor use, especially in relation to mechanical harvesting. Trellising has been under study at the University for over a decade, and has led to the development of the Penn State low trellis hedgerow system for the commercial production of apples. This system is suitable also for the small or amateur fruit grower. To meet current needs and conditions, the art of trellising has been simplified. The philosophy behind this system is the complete control of growth and the regulation of cropping.

The Penn State low trellis hedgerow system consists of trees on dwarf rootstock trained on a 4-wire trellis to develop a row of trees as a solid hedge about 6 ft tall and 3 to 4 ft broad. Four to 5 pairs of scaffold limbs are formed on each tree in the row plane, and trained at an angle. Limbs from adjacent trees overlap in a formal way to build a framework for the development of a continuous fruiting mantle for each row. A planting becomes a series of closely spaced parallel hedgerows. Once developed, cultural operations are largely devoted to managing the mantle for continued annual production of premium-value fruit.

Regulation of Growth

An apple tree consists of two main parts: that above ground or the vegetative and fruiting part, and that below the ground-line or the root part. The top and bottom of a tree constitute the living unit with each part influencing the growth of the other. Each apple variety has a certain inherent growth potential or vigor, and a characteristic pattern of vegetative growth and fruiting. Certain apple varieties when used as a root system (rootstock) for a second variety grown for its fruit, can limit (dwarf) the size of the tree. This effect of growing one variety on another is the basis for the low trellis hedgerow system. Without dwarfing rootstocks, maintaining tree size and the management of tree growth and fruiting would be difficult.

In trellising, the support system is used largely for training purposes, although it also has support functions. Vegetative shoots or wood when in a vertical position are stimulated to elongate, while when in a horizontal position are stimulated to bear fruit. By varying the angle of the main scaffold limbs and branches their growth and bearing can be modified. The wires serve as tying points in positioning the trees' main scaffold limbs.

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Since fruiting has a dwarfing influence on vegetative growth, wood may have to be raised or positioned at a greater angle from the horizontal to maintain a good balance between growth and fruiting. Spur variety types should be positioned near 45° while non-spurs near an angle of 20° to 30°. When scaffold limbs are positioned horizontally (tied along the wires), an important potential is lost in using wood positioning as a technique for the regulation of growth and fruiting. Further, the overall expression of growth is suppressed laterally but encouraged vertically, resulting in taller trees. For a low trellis hedgerow, a lateral growth habit is preferred over a vertical habit.

Pruning also has an effect on the regulation of growth, especially the time of the year when it is done and how it is done. Pruning in April up through petal fall is less stimulating vegetatively than when done earlier during the dormant period. Rather than the complete renewal of branches as in dormant pruning, branches are stubbed to encourage growth renewal. However, this should be performed only in late spring when buds are expanding and new growth is commencing. Cuts made into older wood should be done only at this time of the year.

Where the terminal region of a main scaffold limb has lost some of its vigor during formative years and further extension is needed (renewed vigor), a cut can be made to stimulate new growth by the removal of the apical fruit bud, or by heading back the scaffold limb to a vigorous lateral (1-year wood). The lateral is then bent and tied to form a new leader for the scaffold limb. Where lateral branching needs to be encouraged, as on the tree's leader for the formation of suitable scaffold limbs (too much vigor), the leader can be headed back and a new leader established. Where a pair of scaffolds need to be formed (not occurring naturally), the cut should be made about 3 to 4 inches above the desired location of a pair of scaffolds. This pruning forms what is called a "crow's foot" type of growth. The middle shoot is trained to become the new leader, and the 2 lateral shoots, the scaffolds. Such cuts are usually made in late spring, but can be made during the early summer, if shoots are still growing rapidly.

Growth regulation by selective bud and wood removal can be done also during the summer months, but it should be thought of more as grooming rather than as a pruning operation. Summer tipping is done to encourage lateral bud activity for branching, but generally this is not a standard practice in trellising. Any summer pruning is stimulative, but the degree of stimulation depends upon when and how it is done. In trellising, summer training is the removal of undesirable vigorous shoots and the suppression of vigorous shoots to enhance spur formation in the bearing hedge. This can be accomplished most effectively when performed during August, preferably in mid to late August. The operation includes the removal of all vertical vigorous growth arising from the top tier of scaffolds, and stubbing to 3 leaves (about 1 inch) of all shoots longer than about 12 inches. This action is to remove the shading effect of growth above the trellis, and of vigorous growth along the sides of the trellis to allow more sunlight penetration into the fruiting mantle. It is done also to encourage spur development and formation of short shoots on vigorous wood, by the dilution of vigor through more growing points. If this operation were done earlier in the summer, regrowth would be more vigorous. By stubbing, seats for regrowth are retained, in contrast to the complete removal of wood.

Fruiting has a natural regulating effect on growth. Every apple variety has its characteristic vegetative growth limit before bearing begins to arrest further rapid extension. This limit can be extended by methods delaying the onset of fruit bearing (e.g., use of size controlling rootstocks, limb bending, limited pruning, and growth inhibitors). Cropping has a regulating effect by competing with vegetative growth for carbohydrates and other plant materials. Many of the intensive orchard systems rely or depend upon fruiting as an aid in growth regulation. Thus, a crop failure can be disastrous. Further, removing fruit from the tree, removes some of the regulating effect of cropping. However, fruit should be removed from the terminal of main scaffold limbs if further extension of these limbs is desired. Otherwise, fruits are retained to reduce further elongation.

Chemical growth inhibitors are useful on non-spur apple varieties as a training aid in conjunction with pruning in regulating and maintaining tree size and cropping. Their effects are not only through a reduction in the amount of shoot extension but also by encouraging axillary bud development and fruiting. To be most effective on bearing trees, these chemicals should be applied annually during the rapid shoot growth period following bloom. For this purpose, Alar and NAA have been the most effective. Alar (½ to ¾ lb./100 gal., or 500 to 700 ppm) should be timed at the 6-8 inch shoot growth stage, about 30 days after full bloom under eastern conditions. NAA should be used at the regular rate for chemical fruit thinning, but applied later than that for chemical thinning, when fruits are at least 15mm in diameter, if the fruit thinning action of the chemical is not required. A third chemical, but not considered a growth inhibitor, is Promalin. In Pennsylvania repeated annual applications have caused an increase in spurring and flowering on non-spur varieties. Where fruit lengthening is not desired, it should be applied after calyx closing at the recommended rate.

In forming a tree on a trellis, the basal portion of the tree should be developed before the upper parts. Each scaffold level is allowed to develop before the next tier. That is, growth is regulated from the ground up so that an upper level does not have dominance over a lower level. Growth of the terminal at the top wire is arrested by bending and training it horizontally to one side along the top wire. Vigorous lateral growth from scaffolds is suppressed by stubbing and not bent back to the trellis, especially if arising on the lowest scaffold level. In forming the tree's basic framework, the objective is to fill space (form the lattice work) between adjacent trees before developing the breadth or width of the trellis hedgerow. Once scaffolds have elongated sufficiently to possess a dominance in the tree growth in breadth can be allowed to develop.

In forming lateral bearing wood on scaffolds, some bending of lateral growth may be necessary. This growth can be arched by tying down (by various means) to lower wood. Lateral growth should never be tied up or allowed to develop vertically because of vigor stimulation and dominance reasons. Once bearing wood has been formed in the hedgerow, further growth regulation is primarily with bearing wood, or within the fruiting mantle. A scaffold limb is arrested in further development by allowing it to fruit out. Usually this occurs when the limb reaches the middle of the next tree (central axis).

Stubbing and bending shoots are normal practices which should go hand-in-hand in developing and maintaining the fruiting mantle. At one point in time, or in certain locations on the trellis, one practice may dominate the other depending upon the need for growth regulation and control. These practices are methods used in training, and not training itself.

Growth regulating chemicals are tools which also can be used, and should be used, in training. Their usefulness generally begins once the framework of the tree and trellis has been formed, and the mantle is being developed and maintained. Their use should go hand-in-hand with pruning to reduce shoot lengthening, and enhance spurring and cropping. Annual applications at a low concentration in the spring are suggested to help maintain a favorable balance of growth and cropping.

Rootstocks

The successfulness of a trellis planting is largely dependent upon the effect from using the more dwarfing rootstocks, such as M.9 and M.26. Trees on very dwarfing rootstocks have less vigorous vegetative growth and fruit earlier and heavier than when on more vigorous rootstocks, such as M.7, M.106 and M.111. However, the proper choice of a suitable rootstock will depend upon the vigor of the scion (top variety), and the vigor of the soil, such as nutrients, available moisture, and soil type. Vigorous top varieties, such as Golden Delicious, N. Spy, Summer Rambo, and Jonathan, need the most dwarfing rootstock variety available (M.9). Moderately vigorous top varieties, such as Delicious and McIntosh, do well on a slightly more vigorous rootstock (M.26). Top varieties with less vigor, such as the spur sorts of Delicious, should be on M.26, and in some situations even on M.7. The general usage is: non-spur top varieties on M.9, and spur sorts on M.26. However, on fertile soils, even spur sorts do well on M.9. Generally, M.9 is better suited to the heavier soils (not sandy dry soils) and M.26 to the lighter soils (not wet soils). M.9 should be used on the more fertile soils, and M.26 on the less fertile soils or in replant situations. M.7, especially with spur sorts, should do well in replant situations.

Rootstocks are available as the regular type (not virus tested) and virus tested (free from the more harmful viruses). Generally virus tested or virus free material is more vigorous than the regular. This difference in vigor puts M.9 virus tested more in the class with M.26 regular. For example, in replant situations on heavier soils where M.9 was suitable, M.9 virus tested should be used in preference to M.9 regular.

In the future, a more dwarfing rootstock than M.9 will become available. This variety is M.27, and will be available only as virus tested. Thus, in those situations where more dwarfing is needed than M.9 virus tested, M.27 may be useful.

Apple Varieties

Some apple varieties, because of their tree growth and bearing habits, are more suitable and easier to handle on a trellis than others. Spur sorts and varieties with spur habit of bearing are ideally suited. Conversely, terminal bearers such as Rome Beauty, Tydeman's Red, and to some extent Jonathan have long shoots and branches with little if any lateral development (extended blind areas). This makes the filling of the bearing mantle (hedgerow) difficult, requiring greater attention to summer pruning. Growth regulators are needed to inhibit shoot growth and to encourage spurring and branching. Growth regulators, which encourage spurring and enhance mantle formation and retention, are Alar, NAA, and Promalin. Excessive terminal growth should not be encouraged (e.g., heavy applications of nitrogen). Nevertheless, trellising can be done with almost every apple variety, and in fact, trellising has often made management of vigorous varieties easier than with other training systems (e.g., slender spindle for Mutsu). With vigorous varieties and on fertile soils, M.9 should be used rather than M.26.

In a mature trellised apple planting, the bearing mantle is developed on the scaffold system (basic framewood) rather than being the scaffold system itself. To maintain the narrow hedgerow-trellis form, bearing wood is constantly being renewed (brought in). Thus, the growth and fruiting habit of the tree is being regulated.

Pollinizers

A suitable pollinizer would be one which has viable pollen and blooms in the spring at the same time as the variety to be pollinated. These may be as a second commercial variety, or as a specific apple and crabapple variety used solely as a pollinizer. Most nursery catalogs contain a list of apple varieties which are cross compatable, according to early blooming, midseason blooming, and late blooming. Suitable crabapple varieties are Manchurian (early), Rosedale, and Pioneer Scarlet, plus Golden Hornet and Hillieri. Common apple varieties unsuitable for cross-pollination purposes are Mutsu, Stayman, and Winesap.

Where another variety is being grown and at the same time being used as a pollen source, it should be located in an adjacent row (every other row). Where pollinizers are being placed in a solid planting of a variety, they should be located in each row to give coverage for every 50 to 60 ft of adjacent trellis rows (e.g., 3 in one row and 2 in the next, or 4 and 3). Bees move up and down adjacent rows rather than across the planting. Pollinizers should be grown on M.9 or M.26 rootstocks. Spur Winter Banana works especially well on M.9 for this purpose, but can be on M.26. Nonspur varieties, including crabapples, should be on M.9 or even M.27. Pollinizer trees can be trained on the trellis in the same manner as the main variety, or handled as an independent tree with only its central leader attached to the trellis. These trees should be handled only as a pollen source (not for fruit production). For example, Golden Hornet tends to be biennial, if fruit is not removed.

Planting Material; Methods of Planting

Suitable trees for trellising may be obtained in one of several ways: purchase of 1-year whips and bench grafted material, or propagation of trees by the grower. Preferred are 1-year whips, 3 to 4 ft in length and with a good root system. Larger caliper or more vigorous trees may be used, but are apt to require extra training. When headed at 18 inches, suitable bud break for the formation of the lowest or first tier of scaffold limbs is difficult to obtain on vigorous nursery trees, since original bud breaks in the region of needed scaffolds have been removed in the nursery.

Trees may also be obtained by planting bench grafted material, or by planting the rootstock and budding in place. However, an extra year or two will be required to obtain a tree size comparable to that of a 1-year tree when planted in the orchard. If bench grafted material is used, or if rootstocks are obtained and budding is done, these materials should be handled as in a nursery until the trees are of suitable size for moving to the orchard. Young trees can be cared for more easily in a nursery type of planting than if spread over an acre or more of land.

Where a large number of trees is to be planted, the use of a tree planter is suggested. But hand planting with a shovel can be used, especially where a small number of trees is involved. Planting trees with an auger is not suggested because of the time involved. An effective method of hand planting with a shovel has been to make a trench with a "V" plow. Tree locations are staked in the trench and trees planted to just cover the roots. Then the whole row is back filled. Regardless of the planting method, the soil should be adequately prepared, including subsoiling down the middle of the row and finishing off by rotatilling the row.

At planting, the graft union must be located above the soil line with the rootstock trunk exposed 4 to 6 inches. Where trees have been planted in deep loose soil (e.g., by auger, mechanical planters, or sub-soiling) and both the tree and soil is expected to settle, the union should be placed even at 8 inches above the soil line or orchard floor. After planting, the tree would be mounded to cover the exposed trunk of the rootstock. Throughout the life of the tree, it is much easier to mound around the tree to bring the soil line up to the union than to raise the entire tree to keep the union above ground.

Scion rooting can be a problem in orchards using tree size controlling rootstocks, especially in humid areas and in heavier soils. For the size controlling influence from a rootstock to be expressed fully, there can never be any scion rooting for the life of the tree. The failure of dwarf planting in later years is frequently due to a loss in tree size control because of scion rooting. This can occur either because the graft union was not planted sufficiently high enough to allow for natural tree settling, and/or because soil, grass clippings, mulch, and other materials are allowed to build up around the union. A build up of materials around the tree trunk, or natural mounding over time is not uncommon in orchards.

Burr knots can occur on the trunk of certain rootstocks, and under certain environmental conditons. These appear on some, but not all, M.9, M.26 and M.7 rootstocks as circular masses of small fibrous aerial roots. They can restrict the vascular system of a tree acting as a girdle weakening the tree. However, if covered with soil or mulch (mounding to the union) a vigorous root usually develops from each knot, retaining or returning tree vigor.

Tree Spacing

Tree spacing is always a factor related to stion (rootstock and scion) vigor, fertility of the soil, and how much spacing is being used to control plant size. Close spacings reduce tree size through root competition. For example, trees at 4 ft in the row are less vigorous vegetatively than those at 8 ft. With slower tree growth, fruiting occurs earlier, which in itself aids in controlling the length of new shoots or growth. Since fruiting has a dwarfing effect on vegetative growth, annual cropping is very important in maintaining a balance between fruiting wood and vegetative growth. In-row spacing should be thought of more in terms of the amount of cropping per linear foot of row rather than the time (number of years) required to fill the space between trees in the row (age of commercial cropping vs. vegetative development).

Normally, trees on M.9 should be at 6 ft and on M.26 at 7 ft in the row. The actual spread of each tree in the row will be greater than the tree distance because scaffolds are allowed to extend into adjacent trees. Tree spacings of 8 to 10 feet have been used by some growers, but these distances generally do not permit the development of an adequate bearing surface per row for maximum production, especially in the early years. For example, there is a 17% greater production potential with trees on M.9 at a spacing of 6 ft than at 7 ft, if trees are allowed to overlap. This greater potential at 6 ft is obtained through a greater number of trees per acre, assuming production per tree would be the same. In trellising, one wants to fill the tree row space as early as possible to form a continuous hedgerow and mantle.

Rows should be 11 ft apart (10 to 12 ft). Any distance greater than 12 ft lessens some of the advantages and characteristics of an intensive orchard. This means that small width equipment should be used. When row width is increased from 10 to 11 ft, or from 11 to 12 ft, the potential for productivity would be reduced theoretically 9 to 10% because of a smaller volume of acre bearing wood. Ideally, equipment should be between 36 and 42 inches wide for 11 ft rows. At this close a row spacing, shading of trees would not be a problem for 6 ft high trees.

A general north to northeast and south to southwest orientation of rows is suggested for sunlight reasons, and to provide protection from strong westerly winds. A windbreak should be used to reduce wind pressure on the outside row, and to help reduce windy conditions in a trellis planting. However, the close spacing of trellis rows in itself helps to reduce wind velocity by forcing the wind to pass over the planting rather than through it. Conversely, in locations where drifting snow can create problems, a row orientation in the direction of the wind may be necessary to remove the snowfence effect of the trellis. But an adequate and properly placed windbreak would greatly reduce this problem.

Topography also can be a factor in row orientation to provide for air damage in spring frost protection. On slight to moderate slopes, rows should be oriented with the slope rather than across it. Tired equipment will operate on a 10% slope, but crawler equipment would be needed on a 16% or greater slope. On steep slopes where adequate air drainage would not be a problem, rows should be terraced across the slope. Normally, straight rows are suggested, but a slightly curved row can be handled in a modified contained planting. Where rows are oriented with the slope, washing of soil down the tree row may occur under heavy rains, if no provision has been made to reduce erosion.

Training Systems

There are several tree forms which can be used in forming the Penn State low trellis hedgerow: Marchand or French Flag, Lepage, Belgium Fence, Delbard Tri-crossarm, and Palmette or fan. The Palmette has been the easiest to form and manage, and follows 1 of 3 types: Oblique Palmette, Delayed Oblique Palmette, or Horizontal Palmette (Figure 1). Of the 3 types, the oblique types have been the most versatile from a training and productivity standpoint.

In the Oblique Palmette, a 1-year tree usually is planted in a vertical position (Figure 1, upper right). Lateral growth is encouraged and selected as in the horizontal form. Scaffolds are developed at a 30° to a 40° angle from the horizontal, and trained across the wires rather than along them; these should originate several inches below the wire, especially the lowest pair of scaffolds. For each tree there would be from 8 to 10 scaffolds (4 to 5 pairs) located from 12 to 14 inches apart. When fully developed, these would extend into adjacent trees as much as 25 to 50%, forming a latticework on which the bearing wood is developed.

In the Delayed Oblique-Palmette, the 1-year tree is planted at a 45° angle, or planted vertically and then bent (Figure 1, lower left). The leader becomes the first scaffold on one side of the tree. Then a vigorous lateral, originating below the first wire, is selected to become the first scaffold on the opposite side (#1). A second vigorous lateral, about 6 to 8 inches above, is used to form the new leader of the tree. The remainder of the scaffolds are secured from this new leader. This method encourages production in the lower part of the tree, and reduces the potential developmnt of a

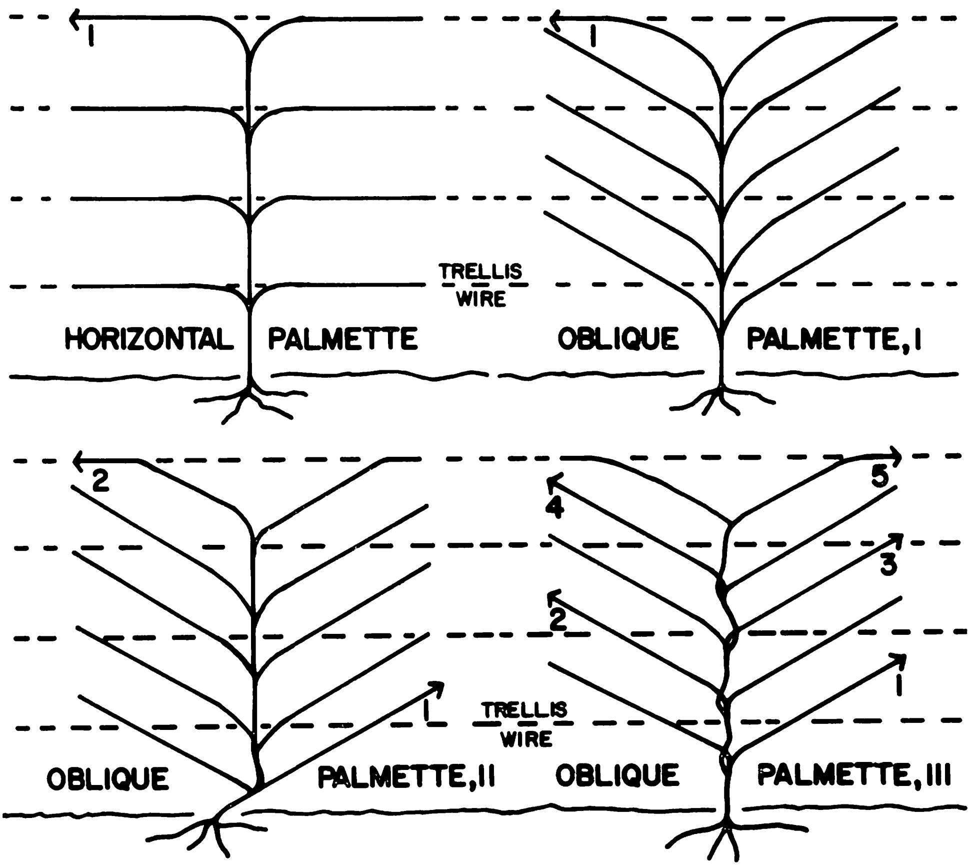

Fig. 1. Diagrams of tree forms for low-trellis hedgerow apples trees on dwarfing rootstocks. UPPER LEFT: horizontal palmette with leader (1) carried to the top wire, and scaffolds trained along the wires. UPPER RIGHT: an oblique palmette with leader (1) carried to the top wire, and scaffolds trained across the wires. MIDDLE LEFT: an oblique palmette (delayed type) with tree planted at an angle (1), and a new leader formed (2). MIDDLE RIGHT: an oblique palmette with leader (1) bent to form a scaffold. A new leader selected (2) and then bent to become a scaffold. System repeated.

vigorous top by delaying the formation of the central leader. In other respects, this system resembles the oblique-palmette. By bending the tree (Figure 1, lower right), this form can be used also on vertically planted palmettes where it is necessary to encourage branching in the lower portion of the tree.

The Horizontal Palmette is started by planting a 1-year tree in a vertical position (Figure 1, upper left). Scaffold limbs are trained to follow the wire in a horizontal position. Usually, a limb should originate a few inches below the wire so that it can be easily bent to the wire. In bending, the terminal of the branch should be kept at the same level, or slightly higher than the bend. If it is positioned with the apical region below the arch of the bend, vigorous undesirable shoot growth usually occurs in the area of the arch. If the wood is too young to be bent satisfactorily (very flexible), it is better to leave it until the next year, or bend it by using a small spreader. On a 4-wire trellis, there would be a total of 8 scaffolds, 4 on each side of the tree. The leader should be bent to form one of the scaffolds rather than being cut off at the level of the top wire (#1).

Training and Pruning the Oblique Palmette

Training the oblique palmette begins in the year of planting for 1-year trees. Often, growth has started following planting; whips should be headed at 17 to 18 inches to encourage initiation of the two lowest scaffolds. In a 4-wire trellis, this is just below or at the bottom wire height. A "crow's foot" usually develops. The highest shoot is trained as the central leader, and 2 laterals from 3 to 4 inches below the cut are trained to become the lowest scaffolds in the oblique palmette.

Research at Penn State has shown the advantages of this procedure. Higher heading has usually resulted in scaffolds being located higher on the tree, a problem situation which needs special handling. Serious problems may result when trees are topped at heading heights for conventionally formed trees. When trees were headed at 18 inches, acceptable feathering (branching) has occurred on spur Rome for 100% of the trees; on York Imperial, 95%; on spur McIntosh, 92%; on Mutsu, 72%; and on Delicious, 59%. Lower percentages were obtained for all varieties when headed at 24 inches. With Delicious, some reheading in midsummer (or the following year) may be necessary to adequately develop scaffolds in problem situations. Similar treatment to Mutsu appears feasible during the summer, because this variety is vigorous on M.9.

As soon after planting as possible, preferably the first year, trellis posts should be set and the bottom wire strung. This wire is needed to secure the central leader and the low scaffolds to encourage their growth and proper development. The new leader of the tree should be attached to the bottom wire as soon as possible. The 2 laterals, which will become the lowest scaffolds in the oblique palmette, should be slightly inclined and secured to the wire. Later on, these should be repositioned, first at a 45° angle and then at 30° angle as the scaffolds become longer. On spur trees, a slightly greater angle should be used to enable shoot extension of the scaffold.

The 30° positioning may be done in the fall, but most generally it is done in the late spring of the following year. The terminal region of a young scaffold should be kept always in a raised position when in active elongation to encourage further extension. The shoot should not be allowed to curve upward in its growth, but rather to elongate at the desired angle. The leader of the tree, however, is allowed to grow vertically, being secured as it passes a wire.

Further feathering may occur naturally, but if shoots fail to arise at the proper location for the subsequent scaffolds, the leader should be headed back the following year at a point approximately 3 to 4 inches above the desired location for a pair of scaffolds. When the leader reaches the top wire in a year or so, it is trained along the top wire; it is not headed at the top wire. An oblique palmette should have 4 to 5 scaffolds along each side of the tree. These will usually arise in pairs at each level.

The objective in training during the first 3 years is to form the framework, and to develop future fruit bearing wood. Thereafter, training is mainly one of controlling shoot vigor and regulating cropping. In training, the lower parts of the tree should be developed and encouraged to bear fruit before the upper part of the tree.

Fruiting, in itself, is a dwarfing process which encourages further development of fruit buds and spurs. A mature tree should bear fruit uniformly over its entire surface. If not handled properly, especially with Golden Delicious, the bearing wood will develop largely in the upper part of the tree. Corrective pruning will be necessary then to re-establish a uniform bearing mantle.

Lateral growth from scaffolds should be encouraged to set fruit buds and fruiting spurs either by stubbing to lower shoot vigor, by training horizontally through bending, by the brutting of shoots, by re-setting the terminal of a shoot to a downward growing lateral, or by selection of more horizontally growing shoots. All vigorous growth over 12 inches in length in mid-to-late August should be stubbed at that time of the year back to 3 leaves, or to about an inch. These vigorous shoots also can be brutted by physically cracking the shoot near its base in several spots to bend it to the horizontal or downward position. They also may be bent or arched by tying or stapling. Bending can be done at any time during the summer when shoot length is sufficient to enable them to be bent. Brutting is best done after the wood in the lower region of the shoot has matured somewhat. However, stubbing is the preferred method.

Development of lateral buds usually occurs in August stubbing. If shoot growth from them is vigorous, the stub should be recut in the spring after new growth has started back to about ⅛ of an inch. Stipule bud development usually arises from these short stubs, and commonly produces spurs.

Once the framework of the trees in the trellis row has been developed, tree training is limited largely to handle the bearing mantle. Ideally, the bearing mantle should consist of both fruiting spurs and 3-year wood reformed by growth renewal, maintained within an area about 1½ to 2 ft in depth on each side of the tree framework. Bending, brutting, stubbing, and the use of growth inhibitors are useful techniques to control this bearing mantle.

The trellis itself serves an important role in tree training by enabling the controlled bending and positioning of limbs to regulate vegetative vigor and fruiting. Tying a young scaffold in a more upright position stimulates vegetative extension, while positioning in a horizontal or downward position stimulates flowering and fruiting. Pruning becomes grooming in the selective removal of wood to maintain the bearing mantle, and to control the height and width of the tree. Tree form is usually completed during the first 3 years. Annual pruning can be done during the dormant period. But at Penn State, it has been done between the time of bud break and petal fall. Some summer pruning has been effective, in addition to the mid to late-August stubbing of vigorous shoots.

The amount of training and pruning necessary is related to the growth characteristics of a variety, and especially to the vigor of the tree as influenced by the rootstock and fertility of the soil. For example, Golden Delicious on M.111 has taken twice as long to summer prune as when on M.9. Those on M.26 have taken a little longer than on M.9. Acre yields with these rootstocks have been comparable in general. Thus, the choice of rootstock has an influence on the ease of maintaining a bearing trellis. Similarly, trees that are forced to grow by fertilizer additions require more time in training than those not fertilized as heavily.

Corrective Training of Oblique Palmette

Normally, an apple tree trained as an oblique palmette is positioned vertically with scaffold limbs oriented in the tree-row plane. These are formed from lateral branches developing in this plane, and arising from the central leader. However, not all trees develop as desired, and problems arise as to how best certain situations should be handled. The following are a few suggestions:

1. *Branches fail to occur in the plane of the row:*

   A branch growing into the clear alley area can be bent into the row plane to become a scaffold (Figure 2, upper). A few extra ties may be necessary to accomplish this. Such bending should be done with great care; work the hand along the branch as it is bent. This is best done in warm weather when the branch can be flexed easily without breaking. If handled correctly, a branch can even be brought from one side of the tree around to the opposite side to form a scaffold, a 180° turn.

2. *Branches fail to develop at a desired location:*

   The central leader can be cut about 4 inches above the desired location of a pair of scaffolds (Figure 2, lower). Usually, buds will break within 3 to 4 inches below the cut, and 3 shoots develop as a "crow's foot." Two are selected to become scaffolds, with the third as the new leader. This can be repeated at the next location if necessary.

3. *Absence of branches in the lower part of the tree:*

   Usually, this problem is noticeable in the second year after the tree has become established, and can be corrected in one of two ways. One technique is to bend the tree at a 30° angle so that the leader now becomes a scaffold limb on one side of the tree (Figure 2, upper). A suitable branch developing in the area of the bend

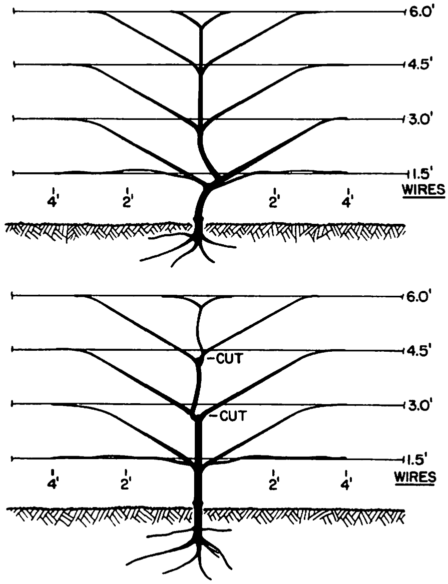

Fig. 2. Two methods to stimulate lateral shoot growth in the lower part of the tree for the formation of scaffolds. UPPER: the vertical tree is bent, and shoots are selected to form the second scaffold and the new leader of the tree. LOWER: the top of an established tree is removed about 4 inches above the location for a pair of scaffolds. Shoots developing in the area of the cut are used to form the 2 scaffolds and the new leader. This method can be repeated at the next level, if necessary.

is trained as a scaffold in the opposite direction. About 6 to 8 inches above, a second lateral shoot is used for the new leader. Such a tree is handled then as a delayed-oblique palmette. However, if satisfactory shoots develop, the central leader can be repositioned vertically.

The second technique should be used only on trees which have become established for at least one year in the orchard. In early April, the tree is cut off about 10 inches above the ground. One or more vigorous shoots usually arise on the trunk above the union. The best one is retained as the new leader

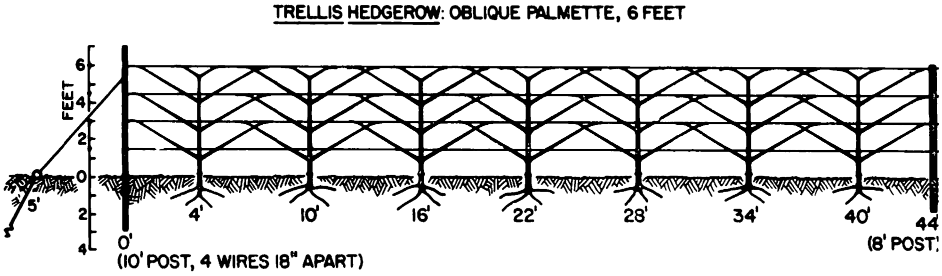

Fig. 3. Design of an end section of a trellis row showing the location of posts and trees in a 4-wire system of oblique palmettes at a 6 ft spacing. Trees actually overlap as much as 50%.

of the tree, and the others removed. Scaffold limbs are then selected in the usual manner. In some respects, this method is preferred to the previous one, since a more "healthy" tree results. The tree can be trained as a regular oblique palmette.

4. *Narrow angle crotches and limb positioning:*

   In selecting laterals for scaffolds, one may be found with a narrow-angled crotch which splits when the limb is bent. No serious damage has occurred. In fact, controlled splitting of crotches may be preferred on stiff limbs with narrow angles to eliminate arching in its basal region when it is bent — a poor scaffold limb form. When split, the limb should be positioned at the desired angle and tied in several locations to prevent further splitting. The exposed areas of the crotch are covered with grafting wax or a tree coating material. In practice, such limbs have developed into productive cordons. None have been lost even when mechanically harvested.

5. *Reestablishing scaffolds and the tree's leader:*

   At times it may be necessary to reconstruct a scaffold limb because of damage or injury (e.g., fire blight). Resetting the terminal of a scaffold can be done by bringing around (bending) a suitable lateral on the scaffold, originating below the damaged or injured area. A new leader can be reset by bending up a scaffold limb.

Correcting problem situations is not difficult once the objectives in tree training are clearly understood. In fact trellising enables corrective measures to be followed quite easily and with success. Through trial and error, experimentation, and cultivation of a "green thumb," one can develop the technique of successful trellising. However, the use of too vigorous a rootstock on fertile soils increases both the likelihood of problem situations, and the difficulty of maintaining a tree in the desired form with a productive bearing surface.

Trellis Design

The trellis consists of a series of wires supported by posts (Figure 3). On this "wire fence," limbs and branches are positioned in various ways in tree training to facilitate the development, regulation and control of the fruit-bearing mantle. Further, a row of trees can be trained into a fixed unified form to facilitate various labor and machine operations. The trellis also serves as a method of support for fruiting limbs. However, the training aspects of trellising apple trees have far more significance than the support aspects. In this regard, a trellis is not a true trellis unless it is being used in training the tree.

In designing a trellis row, it is best to determine the location of each tree and each post in the row. A suggested plan is given in Table 1 and Figure 3. In this plan, the distance between a post and tree is less than that between adjacent trees. This has been done to reduce the problem of post interference in the overlapping of branches from adjacent trees in limb positioning and training. From a planning and construction standpoint, however, trees can be planted at the desired distance, and posts set between trees, or in place of a tree. A post and tree can also be placed together by planting the tree in its proper location and offsetting the post slightly down the row at the edge of the tree hole.

Posts are set approximately every 35 to 42 ft depending upon tree spacing and orchard floor topography. If possible, a post should be placed at or near low and high points in the row where land changes in slope. This is done to keep the wires as parallel as possible with the orchard floor, especially the bottom wire. Suitable are 8 ft treated wood posts, 2½-inch top diameter, set 2 ft in the ground with 6 ft out of ground. End posts should be 10 ft (3-inch top diameter) set 3 ft below ground and anchored with a deadman of some type. Screw-auger type anchors, as used in grape vineyards or with telephone poles, have been convenient. These should be placed 5 ft from the end post and fastened by twisting #9 soft-iron wire. However, 8 ft row-type posts can be used, but set only 2 ft in the ground, where longer posts are difficult to obtain. The deadman usually provides sufficient anchorage for the smaller end post.

Wooden posts can be obtained from various sources, or fabricated locally. All treated posts should be weathered before use, especially freshly creosoted posts. Salt-treated pine posts as commonly used in vineyards are suggested. Metal posts can be used, but are usually more expensive. Fabricated black locust posts are also satisfactory.

Ideally, a 6 ft high apple trellis should have 4 wires, each 18 inches apart. Three wires can be used, each 24 inches apart, but the relatively low cost of an added 4th wire is more than offset by its advantage in tree training. Various types of wire can be used. HTS steel wire is superior to soft iron wire, and heavy galvanized wire to black wire. Heavily rusted wire can act like a saw severely cutting limbs, especially when the orchard is located on a windy site. Crimped HTS wire affords better tying conditions than smooth wire, and has good expansion and contraction characteristics.

The gauge of the wire satisfactory for an apple trellis will depend upon its strength and resistance to rusting. In these regards, #11 gauge HTS crimped galvanized steel wire has been most satisfactory. A similar type wire of #12.5 or #13 gauge, crimped on location, appears adequate. However, crimping does not have to be done. If soft wire is used, it should be heavy galvanized #9 gauge. Recently, plastic wire has appeared on the market for use in grape and apple trellises. The 4.00 mm size appears better than the 3.00 mm, but any smaller size is not recommended. Generally, steel wire has been better than plastic wire. Other types of wire can be used such as old telephone wire, surplus wire, or Alumoweld wire.

The wire can be fastened to the posts in one of several ways. Commonly, fence staples are used. Another method is to drill a ¼ inch hole in the post and pass the wire through it. With an electric drill and a long steel bit, this is quite rapid. Besides giving good support to the wire, wires are located in the midle of the post which facilitates the positioning of overlapping tree limbs around the post. The top wire at 6 ft is stapled to the top of the post, or can be passed through holes drilled about an inch below the top of the post. Where 8 ft end posts are used, the top wire at the end post should be 6 inches below the top to facilitate the use of a tightener.

Relatively inexpensive wire tighteners can be made from ½ inch round steel rod formed in the shape of an "L." The short leg is about 6 inches long and the long leg is 10 inches. On the short leg, a hole, located about 2½ inches from the end of the short leg (off center) is drilled for the wire. The edges of the hole or countersunk slightly. In turning the crank, the wire is tightened. The wire should be coiled around the crank working from the hole towards the long leg, and not coiled in the reverse direction. The crank is located by catching the long leg across the post. However, a ratchet type tightener has worked well also.

Where #10 or #11 gauge HTS wire is tightened by coiling around a small diameter shaft (e.g., "L" crank), the wire should be spliced to a 4 to 5 ft piece of soft #9 wire. This HTS wire is too stiff to coil around a small diameter shaft. Usually tightening devices are located at one end of a 200 to 250 ft trellis row or section. The opposite end of the wire is secured by wrapping it around the post in the usual manner, or by passing through a hole in the post, and looped back and clamped to form a plug.

Designing the Planting

Because of the intensity of planting, use of posts, and need for cross-over

Table 1. A spacing schedule for posts and trees in a trellis hedgerow for trees at different spacing in the row.

Tree spacing at—	Left anchor	End post	Trees										Row post	Trees				End post	Right anchor
			Location in row, cumulative distance in feet																
			1#	#2	#3	#4	#5	#6	#7	#8	#9	#10		#11	#12	Note y	T_n		
4 ft	−5′	0′	+3′[z]	7′	11′	15′	19′	23′	27′	31′	35′	39′	42′	45′	49′	etc.	X′	X′ + 3′	X′ + 8′
5 ft	−5	0	+3[z]	8	13	18	23	28	33	38	—	—	41	44	48	etc.	X	X + 3	X + 8
6 ft	−5	0	+4[z]	10	16	22	28	34	40	—	—	—	44	48	54	etc.	X	X + 4	X + 9
7 ft	−5	0	+4[z]	11	18	25	32	39	—	—	—	—	43	47	54	etc.	X	X + 4	X + 9
8 ft	−5	0	+5[z]	13	21	29	37	—	—	—	—	—	42	47	55	etc.	X	X + 5	X + 10

[z]Also the distance in the row between a tree and post, and a post and tree. Note this spacing is different from that of trees in the row.
[y]Basic unit from End Post to first Row Post repeated in the row.

points in a trellis hedgerow system, a blueprint of the entire planting should be developed. This would include location of trees, posts, augers, pollinizers, cross-over points, and main access avenues. The design of a row section has been discussed earlier. The general feeling is that rows should be no longer than about 500 ft before a cross-over point is located to facilitate walking and moving from row to row. The cross-over point need be only 3 to 4 ft in width. Thus, a person would have to walk no more than 250 ft to get to the next row. Cross-over points in the trellis row can be constructed easily by using 2 tall posts anchored at the tops with wire rather than by using ground augers which would interfere with passage. Trellis wires would have to terminate and start again at this location, with wire tighteners added for the second section. Cross-over points could be made wider to allow for bin handling.

Trellis Tree Maintenance

Certain basic procedures should be followed to maintain tree vigor and an acceptable bearing mantle. However, it is difficult to outline all the procedures in handling mature trees. Each situation and year is a little different. The general nutritional status of the tree should be matched closely, preferably through leaf analysis, and the tree maintained towards the lower side of the acceptable range for leaf nitrogen. On good soils, occasional foliar feeding may be all that is necessary to maintain trees in satisfactory nutritional status and vigor.

The pruning procedure generally followed on established trellises has been to cut all vigorous growth over 12 inches in length back to 3 leaves in mid-to-late August. This also opens the tree, exposing the maturing fruit to the sunlight. Terminals of main scaffolds are left unpruned. Vigorous growth at the top-wire level should be pruned back to ⅛ inch. If not pruned, it is stubbed or completely removed the following spring in late March. Retying and placement of scaffolds is also done at this time. Main pruning begins at pink, or a little earlier, and can continue through petal fall. Vigorous 3-leaf August stubs are cut back to ⅛ inch. Other wood is pruned away, corrected or bent. Vertical wood is removed or bent, as outlined previously.

During the growing season, vertical growth should be stubbed to ⅛ inch, or if allowed to grow longer, should be bent. Growth as doubles and triples near the terminal of last year's wood should be reduced to a single shoot and preferably to a downward growing shoot. Those arising near the base of older laterals should be retained for future bending. These shoots are important in renewing growth on the bearing mantle.

The extent to which shoots are allowed to develop laterally, to give width to the tree, is a matter of choice. If a thin-wall trellis is desired, more stubbing should be followed. If thicker, up to a tree width of 4 ft, or more bending or placing of growth near the horizontal should be followed. Scaffolds are handled in all cases at the 20° to 30° angle.

When the oblique palmette has become completely formed, top scaffolds will have to be headed back sufficiently to prevent the shading of the next level of scaffolds immediately below. The growth of all scaffolds is stopped by allowing their terminal region to flow freely, or by training horizontally or downward. Fruiting in the terminal region of a mature scaffold usually will control its further lengthening. On mature scaffolds, some thinning out of small growth and spurs may need to be done to balance growth and fruiting in the bearing mantle, and to provide space for the fruit. Shaded and weak wood should be removed. Older lateral wood is pruned away from time to time to maintain the bearing mantle as a hedge, rather than as a bush. The top of the hedge should be narrower than its base to allow fruiting to occur uniformly over the entire mantle volume.

Spring Frosts

Loss of blossoms and young fruits by spring frosts usually occurs because of a faulty site, poor row orientation and air drainage, and low plant vigor. Dwarf trees are not necessarily more subject to frost damage. In fact, trees on M.9 show a greater resistance to spring frosts than those on more vigorous rootstocks. In general, non-spur apple sorts are often more resistant to spring frosts than spur sorts (e.g., Delicious). As with any fruit planting, proper site is the greatest deterrent to the occurrence of a frost during bloom. (See Rootstocks and Tree Spacing, row orientation). In frost protection, the trellis provides an ideal support system for overhead sprinklers.

General Culture

Trellis hedgerow trees should be managed in the same way as in any tree planting. However, problems can arise from applying too much nitrogen and insufficient water. Since the root system of dwarfing-type rootstocks is much shallower than standard or seedling rootstocks, special attention should be paid to cultivation, herbicides, mice, soil erosion, poor soils, and winter freezing. The root system is mainly in the top 12 to 18 inches of the soil. The concern is that most growers will be working with a new type of tree with different characteristics, and with different performances expected from it than has been customary in the past. Further, trellised trees need attention beginning with the day of planting. They cannot be left alone to fend for themselves, as is often done with standard trees and in conventional plantings.

Table 2. Extrapolated yields for various apple varieties in the Penn State low trellis hedgerow at the Rock Springs Agricultural Research Center, 4th through 8th leaf.

Stion, Year Planted, and Orchard System	Boxes/Acre by Years (42 lb. units)					
	1976[z]	1977	1978	1979	1980	cum. (yrs)
1. Golden Delicious/M.9, 1973 trellis (726/acre).						
(leaf)	(04)	(05)	(06)	(07)	(08)	(4-8)
Total	602	654	619	725	858	3457 (5)
2¾ & >[y]	457	637	536	664	789	3083 (5)
	76%	97%	86%	92%	92%	89%
2. Red Prince Delicious/M.9, 1973 trellis (726/acre).						
(leaf)	(04)	(05)	(06)	(07)	(08)	(4-8)
Total	129	375	318	623	964	2410 (5)
2¾ & >[y]	127	375	292	591	916	2302 (5)
	98%	100%	92%	95%	95%	96%
3. Stayman/M.9, 1973 trellis (726/acre).						
(leaf)	(04)	(05)	(06)	(07)	(08)	(4-8)
Total	561	469	634	893	1206	3763 (5)
2¾ & >[y]	536	455	614	701	827	3132 (5)
	96%	97%	97%	78%	69%	83%

[z]Years of severe fire blight infection.
[y]Number of boxes of fruit 2¾ inches in diameter and larger. Percent value (%) is the percentage of yield in this size group and larger.

Table 3. Extrapolated yields for various apple varieties in the Penn State low trellis hedgerow research planting at the Rock Springs Agricultural Research Center, 6th through 13th leaf.

Stion, Year Planted, and Trees/Acre	Boxes/Acre by Years (42 lb. units)							
	1974	1975[z]	1976[z]	1977	1978	1979	1980	cum. (yrs)
1. Golden Delicious/M.26, 1969 trellis (622/acre).								
(leaf)	(06)	(07)	(08)	(09)	(10)	(11)	(12)	(6-12)
Total	796	1202	830	1391	1134	718	1921	7994 (7)
2¾ & >[y]	710	891	626	1229	610	605	1454	6125 (7)
	89%	74%	75%	88%	54%	84%	76%	77%
2a. Golden Delicious/M.9, 1968 trellis (726/acre).								
(leaf)	(07)	(08)	(09)	(10)	(11)	(12)	(13)	(7-13)
Total	1509	379	1373	624	1321	986	1691	7884 (7)
2¾ & >[y]	624	373	1212	605	974	839	1341	5968 (7)
	41%	98%	88%	97%	74%	85%	79%	76%
2b. Golden Delicious/M.9, 1968 trellis (726/acre).								
(leaf)	(07)	(08)	(09)	(10)	(11)	(12)	(13)	(7-13)
Total	967	562	1119	430	1281	1047	1444	6850 (7)
2¾ & >[y]	590	548	950	415	971	912	1189	5575 (7)
	61%	97%	85%	96%	76%	87%	82%	81%
3. Red Prince Delicious/M.9, 1968 trellis (726/acre).								
(leaf)	(07)	(08)	(09)	(10)	(11)	(12)	(13)	(7-13)
Total	738	291	911	1215	1159	883	1436	6633 (7)
2¾ & >[y]	591	286	756	1193	912	564	1058	5360 (7)
	80%	98%	83%	98%	79%	64%	74%	81%
4. Royal Red Delicious/M.26, 1968 trellis (726/acre).								
(leaf)	(07)	(08)	(09)	(10)	(11)	(12)	(13)	(7-13)
Total	499	102	727	1118	1674	1068	1813	7001 (7)
2¾ & >[y]	450	102	675	1094	1595	959	1644	6519 (7)
	90%	100%	93%	98%	95%	90%	91%	93%
5. Bisbee Red Delicious/M.111, 1968 trellis (622/acre).								
(leaf)	(07)	(08)	(09)	(10)	(11)	(12)	(13)	(7-13)
Total	720	348	678	964	909	943	1073	5634 (7)
2¾ & >[y]	350	340	483	862	572	100	583	3290 (7)
	48%	98%	71%	89%	63%	11%	54%	58%

[z]Years of severe fire blight infection.
[y]Number of boxes of fruit 2¾ inches in diameter and larger. Percent value (%) is the percentage of yield in this size group and larger.

Trellised trees should not be forced vegetatively by the use of fertilizer. In the formative years, trees on fertile soils often have more than an adequate supply of nitrogen, especially if irrigated. Because young trees on M.9 and even M.26 are shallow rooted, a uniform moisture supply in the top 12 to 18 inches of the soil during formative years can greatly affect tree growth and performance in future years. The lack of adequate soil moisture in the root zone is probably the most serious problem contributing to poor success with these rootstocks.

In trellis plantings, fruit thinning is done easily by hand. Since the fruit is readily displayed, selective thinning can be practiced efectively to remove all potential culls — misshapen, injured, russeted and small fruits. These otherwise might remain on the tree until harvest. Only potentially high quality fruit would be retained in fruit thinning, and be allowed to develop to maturity.

The productivity of Penn State low trellis hedgerow has been highly favorable, giving early high yields beginning in the 4th leaf (Table 2). In later years, yields have been at the 1000 box level or greater (Table 3). Further the size of fruits, expressed as percentage of fruits 2¾ inches in diameter and greater, has been very satisfactory in most years. Returns would be expected to be more than sufficient to offset both the cost of the trellis itself, and the cost of a large number of trees per acre required for this system of apple production.

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