# 13 Pruning, Training, Growth, and Plant Size

## Pruning versus Training

It is important to distinguish between pruning and training. Pruning is the removal of tissue from a plant by cutting or pinching. Training is the establishment of a desirable size and shape of a plant to achieve specific goals, such as aesthetics in the landscape or fruiting in an orchard. Well-trained plants are developed through proper pruning. Training also includes directing growth into a desired direction using metal or wooden spreaders, string or rope, weights hung from branches, poles, and trellises.

Pruning is most often performed during the winter while training usually includes dormant and summer pruning as well as growth placement during the growing season. A major goal of training is to direct plant growth to minimize the amount of pruning needed for the desired effect.

## Pruning

Pruning is performed for a variety of reasons. It is often a source of great angst for inexperienced horticulturists, but it shouldn't be. Pruning is performed for very specific reasons in an organized and logical manner to achieve some very specific goals. Pruning should be viewed as a planned series of operations rather than a one-time event. If the pruning process is well thought out and planned, great results can be easily achieved.

Many perennials are pruned regularly. Heavy pruning for training in the early years is followed by lighter maintenance pruning later on. Many annual flowers are pruned by pinching to encourage a nicely branched plant and promote bushiness. Senesced flowers are also pruned or deadheaded to encourage continued flowering and prevent seed and fruit set. Some annual vegetable crops, most notably tomatoes (*Solanum lycopersicum*) and trellised cucumbers (*Cucumis sativus*) require pruning to maximize yield and facilitate easy management. Biennial ornamentals such as roses (*Rosa* spp.) must be regularly pruned to promote flowering and reduce disease and insect pressure. Biennial fruit crops such as floricane fruiting raspberries and blackberries (*Rubus* spp.) are also pruned. Most perennials which include both ornamental and fruit crops, require some amount of pruning.

It is far beyond the scope of this text to cover pruning and training of specific horticultural crops. There are many excellent references covering specific pruning recommendations. This chapter will focus on the physiological ramifications of pruning. Understanding what the different cuts of pruning and different positioning effects of training are doing to the plant will make decisions about whether or not to make them much easier.

### Reasons for pruning

There are many different reasons for pruning and knowing why you are pruning makes decisions during the process easier to make. Pruning should always consider safety first, especially in ornamental situations. For example, a large dead limb should be removed from a tree before it falls and hits someone on the head. After safety, plant health is considered. All dead or injured branches should be removed with an appropriate-type cut. Branches or limbs that rub together should also be removed.

Pruning is often performed to establish, maintain and adjust the plant for its intended purpose. In the landscape, this often includes creating and maintaining a particular size and shape. Keep in mind that the best approach is to try and follow a plant's natural size and shape when pruning. Most plants usually have either one central dominant shoot with laterals that don't really compete with the main stem (many evergreens) or several co-dominant shoots that are competing with each other (many deciduous species). Don't try to prune a plant into a size and shape it would not naturally assume since in the end it is a losing battle. When pruning is

appropriate for a specific landscape plant it is often difficult to tell that it has even been pruned.

In the orchard or vineyard, pruning is performed for size and shape control as well as to create and maintain a productive fruiting canopy. Fruit crops are often trained and pruned more severely than landscape plants and are often forced to conform to 'unnatural' configurations to facilitate management. Pruning fruit crops often increases fruit quality by improving overall light exposure. Pruning to improve light penetration into the canopy also helps maintain fruitfulness by encouraging flower bud formation well into the canopy rather than just on the periphery. Opening up the canopy also improves the penetration of pest control sprays making them more effective. Pruning is often performed to either stimulate vegetative growth of trees that are particularly low in vigor or to remove excessively vigorous shoots that cause shading. Pruning can also be used to renew fruitfulness of trees that have declined in productivity over time.

Careful pruning of both ornamental and fruit species produces a strong framework. Well-angled branches can be selected early in the plant's life to produce strong main scaffold limbs. Well-selected scaffolds lead to better light penetration into the canopy and increases plant vigor and productivity.

## Pruning equipment

Effective pruning requires the right tool. For smaller jobs or fine-detailed pruning, hand tools are used (Fig. 13.1). For larger jobs or those not requiring detailed work, mechanical equipment may be required.

**Fig. 13.1.** Bypass (left) and anvil (right) pruning shears used for hand pruning.

### *Shears*

Shears are capable of making cuts up to about 2 cm. There are two kinds of hand shears: (i) bypass (also called cross-cutting, scissor, or draw-cut); and (ii) anvil (also called snap-cut). Bypass shears cut by gliding one sharp blade against another thicker blade much like a pair of scissors. Anvil shears make cuts by pressing a sharp blade against a broad flattened anvil. Bypass shears are more desirable because anvil shears tend to crush the stem while cutting.

### *Loppers*

Loppers or lopping shears are like regular shears with larger blades and much longer handles to provide more leverage for making bigger cuts, up to 4 cm. Look for loppers with rubber shock-absorbing bumpers between the blades. Again, use only cross-cutting loppers. Cut with one smooth motion to avoid tearing and injuring the plant. Both shears and loppers are available with ratchet action to provide more leverage for those with arthritis or poor hand strength.

### *Hedge shears*

Hedge shears have long, cross-cutting blades designed for trimming hedges. Blades are normally around 30 cm long with similar length handles. They are used exclusively to prune the small, succulent growth of hedges. Electric and gas-powered hedge trimmers are also available. They normally utilize two blades that oppose each other and slide back and forth over each other to achieve the cutting action desired.

### *Saws*

Pruning saws are often needed for cuts larger than those that can be easily made with loppers or shears. Saws are available in many configurations but typically are either bow saws or blade saws. Bow saws consist of a blade with large, sharp teeth mounted on a metal frame shaped like a slightly misshaped upper case letter 'D'. They come in a variety of sizes, can make large cuts but may be awkward for reaching into tight spaces. Blade saws may be rigid or folding and consist of a narrow blade with coarse teeth attached to a wooden handle that is either D-shaped or crescent-shaped.

Teeth on a blade saw are often finer than those of a bow saw blade. Pruning saw blades are often curved and usually cut on the draw stroke (pulling the blade towards you).

### *Pole pruners*

Pole pruners are used for cutting branches high up in a canopy without using a ladder or other means of height extension. They consist of a saw blade and a lopper attached to a long pole of wood, fibreglass, or aluminum. The lopper is operated by a long rope that is pulled downwards. Be careful when using an aluminium-handled pole pruner around power lines.

Electrical or gas-powered chain saws are used to remove large branches. They should be used with care and never above the shoulders or when the operator is on a ladder.

### *Tractor-mounted equipment*

Loppers attached to tractor-mounted air compressors are often used in orchard settings. These units are loppers with a trigger-activated cutting mechanism. Compressed air provides the cutting power thereby reducing human effort required for large jobs.

There are two types of tractor mounted mechanical hedgers and toppers. One operates as a series of circular saws mounted on to a windmill mechanism, with three or four rotating arms, while the other is a rigid arm with three or four overlapping saw blades. Both work well, but the windmill type can remove some of the cut brush as it rotates.

### *Disinfecting pruning equipment*

It is a good idea to disinfect pruning equipment before and after each day's use. More frequent disinfecting should occur if you are pruning specimens that may be infected with certain disease organisms. Diseases caused by organisms carried in the vascular tissue may be easily spread via contaminated pruning equipment. Thus when dealing with these types of diseases, frequent disinfecting with a household cleaner such as Lysol® or a bleach solution (one part commercial bleach to nine parts water) is recommended. Lysol® is least corrosive to pruning tools while bleach is extremely corrosive (Teviotdale *et al*., 1991). Oil tools regularly to prevent corrosion.

### *Safety goggles*

Safety goggles or glasses should always be worn when pruning, and especially when using pole pruners.

## Types of cuts

Effective pruning and training requires a number of different types of cuts, each used when a specific result is desired from the cut.

### *Pinching*

Pinching is the process of manually removing the terminal portion of a succulent shoot in order to promote bushiness (Fig. 13.2). It is most often accomplished without tools and is usually performed on ornamental annuals to create nicely shaped plants.

### *Heading back cut*

A heading back cut involves removing the terminal portion of a shoot or stem back to a bud (Fig. 13.3). The bud should be positioned to provide new growth in the desired direction. If there are two vegetative or mixed buds at a node, remove one of them to induce growth in only one direction. Leaving both of them will result in weak, forked growth. If the pruning

**Fig. 13.2.** Pinching removes the terminal portion of a succulent shoot in order to promote bushiness.

**Fig. 13.3.** A heading back cut involves removing the terminal portion of a shoot or stem back to a bud.

**Fig. 13.4.** A bench cut is a modified heading back cut. Rather than a cut back to a bud, the shoot, stem or branch is cut back to a lateral branch.

objective is to increase the canopy size the bud should be pointing outwards. If pruning is done to induce new growth to fill in a section of the canopy, choose a bud that is pointed in the appropriate direction. The direct effect of this type of cut is vigorous growth of the buds immediately below the cut.

By removing the terminal portion of a shoot or stem, the terminal bud is removed. This is accomplished in both pinching and heading back. The terminal bud is a source of auxin which suppresses lateral bud growth as it is transported basipetally down the shoot or stem. By removing the source of auxin, apical dominance is reduced and buds 15–20 cm below the pruning cut are invigorated. If the shoot or stem is at a 45–60° angle, buds further down the shoot or stem will be invigorated.

The cut should be made at a slight angle about 0.6 cm above the selected bud. The angled cut allows water to run off the cut, facilitating quicker healing. Make sure the angle is not too great, since this creates a larger wound. Wounds take longer to heal if more than 0.6 cm is left above the bud.

### *Bench cut*

A bench cut is a modified heading back cut (Fig. 13.4). Rather than a cut back to a bud, the shoot, stem or branch is cut back to a lateral branch. Bench cuts do not induce vigorous bud growth. When young trees are pruned using a bench cut, the stem below the cut often stiffens creating a stronger branch. Bench cuts are often used to encourage outward-growing limbs. However, spreading young limbs is a better alternative to a bench cut, since bench cuts often lead to watersprout production. Watersprouts are vigorous, upright-growing shoots that develop in response to pruning or wounding. In addition, the lateral just below the bench cut is often weak and breaks under any stress. Bench cuts should only be used if there is no other solution to a problem.

### *Thinning-out cut*

A thinning-out cut removes an entire shoot, stem or limb at its point of origin (Fig. 13.5). It is not invigorating. Thinning-out cuts are used to reduce interior canopy shading and remove excessive growth without stimulating new shoot production. When large limbs are removed using a thinning cut, the three saw cut approach is used to minimize injury to the tree. In a three saw cut, the first cut is made on the lower side of the limb about half way through the limb several centimeters out from the point of origin. The second cut is made on the top of the limb all the way through the limb, several centimeters out on the limb from where the first cut was made. The limb will usually break off due to its own weight during the second cut. The third cut removes the stub at the point of origin to achieve the desired thinning cut.

### *Hedging and topping*

Hedging and topping are non-selective mechanically made pruning cuts to the tops (topping) or sides (hedging) of a tree or shrub canopy. Both are

**Fig. 13.5.** A thinning-out cut removes an entire shoot, stem or limb at its point of origin.

used extensively in landscape maintenance, citrus (*Citrus* spp.), avocado (*Persea americana*), and to a lesser degree in other fruit crops such as peach (*Prunus persica*), apple (*Malus domestica*), grape (*Vitis* spp.), and blueberry (*Vaccinium* spp.), as well as others. The main drawbacks to topping and hedging are the indiscriminate cuts that are made during the process and the potential for spread of disease inocula.

Hedging consists of cutting back the sides of canopies to reduce canopy width and enlarge the space between rows. When hedging is used, it should be performed regularly so that only small branches are cut during trimming. Don't wait until crowding becomes a problem in the orchard, hedge to prevent overcrowding. If too much growth is removed, excessive vigor may be induced, exacerbating the crowding problem and reducing yield.

Hedging is most often done on an angle of 10–15° such that the top of the canopy is narrower than the bottom giving it a triangular appearance. Yield in fruit crops is often reduced the year following hedging, but recovers after that. The frequency of hedging depends on the crop, tree vigor, and grower preference, but is normally on a yearly or every-other-year schedule.

Topping consists of removing vegetation from the top of the tree canopy at a predetermined desired height. Yield reduction following topping depends on the distribution of fruiting wood prior to topping. If much of the fruiting wood has migrated to the upper portions of the canopy due to shade-induced reductions in the lower portion, significant yield reductions will occur the year following topping. If most of the fruiting wood is located in the lower canopy, little if any yield reduction will occur following topping. The canopy height should be no more than twice the row middle width to ensure adequate light distribution.

Another major reason for hedging and topping is for canopy size management. Without hedging and topping, canopies may quickly become too large for maintenance operations making orchard or landscape management very difficult.

### Wound treatment

Pruning wounds should almost always be left without the application of any wound dressing. Allowing the wound to heal naturally is the best approach. The only benefit to using a wound dressing is to prevent the introduction of pathogens causing Dutch elm disease (*Ophiostoma* spp.) and oak wilt (*Ceratocystis fagacearum*) (Zins and Brown, 2009).

### When to prune

Effective pruning begins at planting. When young trees, shrubs, and vines are properly pruned at planting, pruning and training in later years is much easier. Proper pruning at planting leads to a well-structured mature plant. Any broken or injured branches or roots should be pruned at planting. Consult a good reference for specific recommendations regarding pruning at planting for the species being planted. For example, it is important to know whether or not you should cut back the leader at planting, how many buds should be left, how many shoots should be allowed to grow that first growing season, etc.

Pruning is often categorized as either dormant or summer pruning. Most pruning should be done late in the dormant season just before new spring growth begins. Branch selection is easy when there are no leaves to obstruct the view. Dormant pruning is an invigorating process while summer pruning reduces vigor by removing photosynthetic area and energy available for growth. Excessively vigorous growth is removed with thinning-out cuts while other growth is reduced in length via heading back cuts. The severity of pruning varies with each specimen. The goal is to establish a regular modest pruning program to avoid excessive pruning in any 1 year. Excessive dormant pruning leads to overly vegetatively vigorous trees that are not very productive, especially in the case of fruit trees.

Pruning too early in the dormant season may induce growth which is particularly susceptible to freezing injury. All fruit trees should be pruned as late in the dormant season as possible to avoid winter injury induced by pruning. Older trees should be dormant pruned first followed by younger trees as younger trees are more susceptible to winter injury caused by early pruning. Pruning induces flower bud growth (Durner, 1995) and a concomitant loss in bud hardiness. Thus later blooming trees should be pruned first followed by earlier blooming trees.

Some landscape shrubs are grown for flowers that originate in buds formed the previous growing season (e.g. redbud (*Cercis canadensis*), *Forsythia*, honeysuckle (*Lonicera* spp.), azaleas and rhododendrons (*Rhododendron* spp.), and others) thus pruning is usually delayed in these species until after flowering. Other species bloom on the current season's growth (e.g. butterfly bush (*Buddleia* spp.), crape myrtle (*Lagerstroemia indica*), and hills of snow (*Hydrangea arborescens*) to name a few) and should therefore be pruned to encourage vigorous spring shoot growth.

Summer pruning may be performed as soon as buds begin to grow in the spring; however, it is normally done after several inches of new growth have occurred. Summer pruning reduces vigor by removing photosynthetic area and energy available for growth. Summer pruning should only use thinning-out cuts to remove vigorous and upright growth in the canopy. It should be completed early in the summer to avoid a reduction in winter hardiness which can occur with late-season summer pruning. In many cases, summer pruning is limited to removal of tissue damaged by wind or injured by a pest, or to hedging and topping of certain landscape species and specific fruit crops. Local recommendations should be consulted for timing and severity of summer pruning and whether or not it is recommended for the species in question.

## Physiology of pruning

With an understanding of the interconnected effects pruning has on plant physiology, horticulturists can make much better decisions regarding when and where pruning cuts should be made. Pruning ornamentals is almost always for aesthetic or plant health concerns. Pruning fruit crops is done to: (i) enhance fruit quality; (ii) promote a balance between vegetative and reproductive (fruiting) growth; and (iii) make crop management easier. Much of the work surrounding physiological responses to pruning has been with fruit crops, thus they will be emphasized here. It doesn't matter whether the species is ornamental or one used in fruit production, the responses to pruning are generally the same.

### *Pruning: a dwarfing process*

Pruning removes wood, buds, and cambial tissue. The wood that is removed represents a store of carbohydrates and nitrogen that could have served as reserves for next year's potential growth. The buds removed during pruning are a loss of potential leaf area and fruit while the cambial tissue removed would have been a source for secondary growth. While shoot growth the year after pruning is often significantly increased in pruned versus non-pruned trees, trunk and root growth are both greatly decreased (Forshey *et al*., 1992). Thus, overall, pruning is a dwarfing process (Faust, 1989).

Shoot growth is stimulated by pruning, particularly with heading cuts, for several physiological reasons. Heading cuts lead to an altered hormone balance among the buds remaining on the shoot after pruning since the terminal bud and one or more subtending lateral buds are removed. Thinning cuts do not lead to alterations since the entire shoot is removed. Pruning with either heading or thinning cuts removes terminal meristems which are a rich source of auxin. Initially following pruning, the overall canopy level of auxin is reduced in pruned versus non-pruned trees. Root tissues continue to produce cytokinins which are transported to the shoots, thus the balance of auxin:cytokinin is shifted in favor of cytokinin, which stimulates shoot growth via increased cell division. As shoots develop, they produce significant amounts of auxin and gibberellins in their rapidly growing apices, especially early in the season, which further enhances shoot growth.

Pruning, particularly with heading back cuts, removes terminal meristems and the associated apical dominance. Thus heading back cuts lead to a proliferation of lateral shoots with a concomitant reduction in shoot growth from elongating terminal meristems. Too many heading back cuts can lead to an extremely bushy canopy which can cause excessive shading.

Heading a shoot near the apex induces five to seven of the uppermost buds below the cut into

growth while heading a shoot close to its base often only invigorates the bud immediately below the cut (Faust, 1989). The response to a pruning cut may be attributed to the growth potential of buds as affected by the position on the shoot. Distal buds on a shoot have a much greater growth potential than basal buds (Faust, 1989) thus when a cut is made above distal buds, they grow significantly because they have more potential to grow than basal buds. Similarly, buds higher in the canopy have a greater growth potential than those lower down. Thus the response to pruning is more prominent for pruned shoots higher in the canopy compared with those closer to the ground. Moving a shoot or branch to a more horizontal position reduces the rate of bud growth regardless of position in the tree or on the shoot (Faust, 1989). By manipulating branch angle and adjusting the intensity or position of cutting on the shoot, the growth of stimulated buds can be controlled.

### *Pruning reduces yield*

When a fruiting plant is pruned, flower buds (potential fruit) are removed which usually leads to reduced yield. Additionally, shoot and fruit growth compete for the products of photosynthesis and the enhanced shoot growth stimulated by pruning reduces the photosynthates available for transport to developing fruit.

### *Pruning improves fruit quality*

Pruning in general increases the relative amount of leaf area per individual fruit thus increasing the supply of photosynthates to each fruit which leads to larger, sweeter fruit. Even though the percentage of blossoms which set fruit may be greater on pruned compared with non-pruned trees, the total number of blossoms per tree is greatly reduced on pruned trees. Thus even though a greater percentage of blossoms on pruned trees set fruit, the total number of fruit is much less than on non-pruned trees. The increased light penetration into the canopy afforded by pruning improves fruit color and thereby improves fruit quality.

### *Pruning delays fruiting in young trees*

Pruning stimulates vegetative growth, particularly in young trees, thereby delaying the onset of flowering and fruiting (Faust, 1989). While this may seem undesirable from an economic standpoint, it is imperative to prune for training regularly and intensively early in the life of an orchard. A strong framework is important for production. Additionally, younger trees do not have the limb strength or the photosynthetic capacity to support a large crop.

### *Physiological effects of summer pruning*

Summer pruning is a very selective process performed on a limited number of horticultural crops. Pruning of annual crops during the growing season is not usually considered summer pruning. Summer pruning is selective removal of actively growing shoots of perennial crops such as peaches (*Prunus persica*) and citrus (*Citrus* spp.). When summer pruning utilizes hedging equipment, it is not very selective, but is still considered summer pruning. Specific responses to summer pruning vary with: (i) species; (ii) time of pruning; (iii) severity of pruning; (iv) tree vigor; and (v) geographical location.

Summer pruning should only be practiced with a thorough understanding of its consequences. Summer pruning reduces photosynthetic leaf area thus reducing the photosynthates available on a whole plant basis for both vegetative and fruit growth (Forshey *et al*., 1992). While it is true that summer pruning often stimulates vegetative regrowth, much of the photosynthate produced in new tissue is used for growth of the new tissue and is not exported for fruit growth. Overall, summer pruning leads to smaller trees compared with non-pruned or dormant-pruned trees.

Summer pruning is often used to improve fruit color by increasing light penetration into the fruiting canopy. Fruit color quality is improved, but taste quality may be compromised by reduced sugar levels in fruit from summer-pruned trees (Marini and Barden, 1987).

Summer pruning is often used to reduce crowding in dense plantings. This should only be done as a temporary solution to excessive vigor, as summer pruning may induce vigorous regrowth thereby exacerbating the problem or it may induce fruit or wood sunburn. Plant density should be managed via other horticultural practices such as rootstock selection, fertility management, etc. Root suckers and watersprouts should be removed as they appear as they serve no purpose in the field and may promote and harbor pest problems such as fireblight (*Erwinia amylovora*) or woolly apple aphid (*Eriosoma lanigerum*).

### Pruning and photosynthesis

Dormant pruning reduces the potential leaf surface area of a plant. Thus one might think that pruning reduces the overall photosynthesis of a plant compared with a non-pruned specimen. Initially, the total plant photosynthesis may be lower on pruned versus non-pruned trees, however, new shoot growth that is stimulated by pruning more than makes up for the lost leaf area induced by pruning so that by midsummer, total plant photosynthesis of pruned and non-pruned trees is similar (Forshey *et al*., 1992). Dormant pruning may lead to larger leaves with larger mesophyll cells, and increased chlorophyll content on a leaf area basis when compared with non-pruned trees (Faust, 1989). Stomata may also stay open longer during the day in leaves on dormant-pruned versus non-pruned trees (Aldrich, 1935).

Summer pruning before terminal bud set may exhibit a photosynthetic response similar to that with dormant pruning, since shoot regrowth may occur after pruning. If summer pruning is performed after terminal bud set, overall photosynthesis is reduced in pruned compared with non-pruned trees since the actual leaf area removed is not replaced by regrowth. This is significant because carbohydrate production later in the season is reduced with summer pruning and may have negative impacts on winter hardiness and/or shoot growth the following spring.

Better light penetration into the canopy due to either dormant or summer pruning may lead to increased photosynthesis, particularly in leaves that are more interior in the canopy. This may help compensate for the reduced photosynthesis caused by pruning-induced reduction in leaf area.

## Training

Training begins at planting whether the crop is annual or perennial. Training is initiated to ensure a well-structured plant that is capable of maximum productivity of high quality product. This might be apples (*M. domestica*), or it might be the display of flowers in an ornamental setting. Delayed training often results in less-than-desired results, poor structure, and weak specimens.

While training often focuses on perennial species, some annuals and biennials are also trained. This includes annuals such as tomatoes (*S. lycopersicum*) and cucumbers (*C. sativus*) and biennials such as raspberries and blackberries (*Rubus* spp.). The reasons for training are the same for all life cycles.

The main reason for training is to develop a strong plant framework from which a large crop can be efficiently produced with minimal limb breakage and maximum light interception. Limb breakage often reduces the productive life of a planting. High light penetration into the interior of a canopy leads to good flower bud formation and the production of high quality flowers and fruit, depending on the commodity. Open canopies also allow for good air circulation which helps reduce disease problems and allows maximum penetration of any pesticide sprays.

Another reason for training is for aesthetics. This is true for both ornamental and non-ornamental situations. A nice looking production system provides a certain level of satisfaction that is hard to describe. Poorly trained and disheveled plantings are undesirable.

### Training systems

#### *Ornamentals*

Ornamentals are trained primarily for aesthetics based on the desired final form. Selection of appropriately sized species for the landscape under consideration can minimize the amount of pruning and training required, especially in later years. Generally ornamentals are trained as a bush (multiple co-dominant trunks) or a tree (one central dominant trunk or several co-dominant trunks). Once a final form is selected, limb distribution along the trunk(s) is considered. Windbreaks or screening plantings will maintain many limbs lower on the main trunk(s) while specimen trees will gradually shift the bulk of scaffold limbs higher and higher on the main trunk(s). Removal of limbs on specimen trees should not occur until the limb is 2.5 cm in diameter. Leaving lower limbs on the main trunk(s) until they are this size will result in a larger diameter trunk. If lower limbs are removed too soon, a thinner, weaker main trunk will develop. A mistake many people make with a newly planted ornamental specimen is to remove all the lower branches at planting resulting in a long slender trunk with a bushy apex. Leave the lower branches until they are 2.5 cm in diameter.

Ornamental trees should be trained to one dominant trunk or central leader unless the species is normally grown with several co-dominant trunks.

Selection of the central leader and subsequent scaffolds should ideally begin in the nursery. Branches selected to become the permanent structures on a tree should be at an angle of 60–70° from the trunk. This leads to a strong point of attachment and much less chance of breakage. Branches with smaller angles are much more likely to break. Major scaffold limbs should be spaced at least 20 cm but preferably 60 cm apart vertically along the trunk. Five to seven branches should be spaced radially around the trunk to form the final canopy. This radial and vertical spacing sets the stage for a well-structured mature canopy. Trees should be trained and pruned every year or two until the desired final form is attained. Waiting to prune every 4 or 5 years often leads to excessively vigorous regrowth which must then also be pruned.

Smaller trees and bushes may be trained to their natural form or as topiaries or espalier. If a topiary or espalier is desired, make sure an appropriate species is selected. Smaller leaved species such as boxwood (*Buxus* spp.), yaupon holly (*Ilex vomitoria*), or natal plum (*Carissa macrocarpa*) often produce nice topiaries. *Pyracantha, Fatshedra, Magnolia*, yaupon holly (*I. vomitoria*) and others are well suited to espalier training. Sometimes species that most consider as large shrubs can be trained into small trees if desired, by removing lower branches from the trunk(s) over several years. The longer lower branches remain on the trunk, the sturdier the main trunk will be at maturity. Species well suited to this type of training include *Photinia*, wax myrtle (*Morella cerifera*), and *Pittosporum* (Gilman and Black, 2005).

### *Fruit trees*

Fruit tree training normally considers two major types of training based on selection and placement of scaffold limbs. These two major categories include: (i) central leader training; and (ii) open vase or open center training (Fig. 13.6). While they are two very different approaches to tree training, they are both seeking the same outcome: a well-structured tree capable of consistently supporting and producing a large, high quality crop of fruit.

**LEADER SYSTEMS** The most popular type of leader training system is called the central leader system. A tree trained via a central leader is characterized by one main, vertical trunk called the leader and several whorls of scaffold limbs starting at about 60–90 cm above the ground that are increasingly shorter as height increases which allows maximum light penetration into the canopy. Each layer of scaffold limbs is 45–60 cm above the one below it. Each scaffold whorl consists of three or four well-spaced branches that are not directly opposite any other scaffold limb on that level and does not align with scaffolds of any other level. This ensures minimal shading and maximum light penetration. The number of scaffold layers is determined by the final desired tree height. A well-developed central leader tree looks very much like a Christmas tree. Crops that are often trained to a central leader include apple (*M. domestica*), cherry (*Prunus* spp.), pear (*Pyrus* spp.), plum (*Prunus* spp.), and pecans (*Carya illinoinensis*).

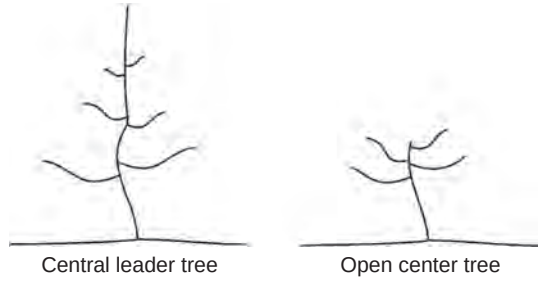


**Fig. 13.6.** Central leader training versus open center training of fruit trees.

Most fruit trees are purchased as whips, slender, unbranched dormant trees 1–2 cm in diameter, 120–180 cm long. Each tree consists of a rootstock and a scion. Trees are planted either in the fall or late in the dormant season depending on location. Regardless of planting season, the bud union must remain approximately 5 cm above ground at planting. Just before growth begins in the spring, head back the tree (i.e. cut the young tree using a heading back cut) to 75–85 cm above the soil surface. The lowest whorl of scaffolds will develop from buds that grow 10–30 cm below the heading cut, thus the height at which the whip is headed can be adjusted to suit the grower. Thus the lowest level of scaffolds is normally around 45–75 cm above the soil surface.

During the first growing season, vigorous shoots will develop from lateral buds located immediately below the heading cut down the trunk for about 30–45 cm. From these shoots, one vigorous shoot at the trunk apex will be selected to be the leader. All shoots in the first 10 cm of the trunk immediately below the selected leader must be removed.

Four shoots equally spaced around the trunk in the region 10–30 cm below the apex will be selected to form the first and lowest layer of scaffold branches. These four branches should not originate at the same level on the trunk, but rather be at different levels within the mentioned 10–30 cm region below the apex. These shoots are normally spread to form an angle with the trunk of approximately 60°. Spreading is accomplished using toothpicks or spring-type clothes pins positioned at the junction of the shoot and the trunk. Once shoots have elongated sufficiently, clothes pins can be moved to the ends of the shoots to weigh them down and provide the needed spreading to maintain a 60° crotch angle. Any remaining shoots should be removed from the trunk. For the remainder of the first growing season, summer pruning should only consist of removing any new shoots on the main trunk that are not the leader or scaffolds and any directly upward- or downward-oriented growth on the developing scaffold limbs. Failure to effectively train trees during the first growing season will result in extremely difficult, if not impossible, training and pruning during subsequent years.

After the first dormant season, both dormant and summer pruning will be needed. Dormant pruning involves heading the central leader back to 60–75 cm above the highest branch of the layer of scaffolds developed during the first growing season. Any diseased or broken wood should also be removed. Each lateral branch that was selected as a scaffold limb during the first growing season should be headed back by about one-quarter of its length. This will encourage branching of the scaffold branches. Summer pruning that second growing season will consist of selecting a new central leader from a vigorous shoot at the apex along with three or four shoots to become the second scaffold layer starting at about 45–60 cm above the topmost limb of the first scaffold layer. Shoots between the first and second scaffold layers and between the second layer and the central leader should be removed.

Branches of the second level should be spread with toothpicks or clothes pins. Scaffolds in the first level probably still need spreading with larger spreaders made of 2.5 cm square wood with headless nails embedded in each end to act as a spike. Wood pieces are cut to various lengths, say 15, 30, and 45 cm, to provide different-sized spreaders for different-aged scaffolds. Scaffolds are normally spread for about 5 years.

In addition to spreading, any shoots directly competing with the central leader, or with the leader of each scaffold where the heading back cut was made, should be removed. The best way to think of each scaffold limb is that you are developing a horizontal central leader at each scaffold position. Thus the first level of scaffolds consists of four horizontal central leader branches on which side shoots nicely spaced along the length of each branch will be selected. Once the scaffold limbs have reached their desired length, yearly maintenance pruning replaces training pruning.

Dormant pruning in each successive year follows the same general procedure where a new scaffold level is selected each year until the desired tree height is obtained. Mature trees that were properly trained and pruned during their early years will require minimal pruning. Once the desired number of scaffold layers is established, a vigorous central leader is maintained each year via a heading back cut. Scaffold length is maintained as desired with a bench cut to a lateral about the same diameter as the scaffold itself. Summer pruning in subsequent years is aimed at maintaining good tree structure and promoting light penetration through very selective pruning, spreading and removal of all vigorous upright growth. For more details and an in-depth discussion of central leader training see Forshey *et al.* (1992).

Pears (*Pyrus* spp.) are often trained to a multi-leader system since they are extremely susceptible to fireblight (*E. amylovora*), a devastating disease encouraged by cool, wet conditions. A multi-leader tree is one in which several shoots are developed as central leaders so that if one becomes infected with fireblight, it can be removed. Each individual leader is developed as an independent central leader tree with respect to scaffolds and leaders.

Some apple orchards are considered high density orchards with 1000 or more trees/acre. With such close spacing, trees are kept small using size-controlling rootstocks and modified central leader training such as the slender spindle or vertical axe. Both systems are central leader systems with branches along the entire 1.8–3.6 m length of the trunk. Their canopies are generally around 1 m out from the leader.

**OPEN CENTER OR VASE TRAINING** Peach, nectarine, and plum trees (*Prunus* spp.) are often trained to open center architecture. In open center trees, the central leader is removed early in the tree's life

producing a tree with an open center rather than a central leader. Three to five scaffolds provide a donut-shaped canopy surrounding the open center.

Open center trees are planted as whips or branched trees. Whips are headed back to about 75–85 cm above the soil surface. Remember to keep the bud union about 5 cm above ground when planting. Shoots will develop from buds 15–22 cm below the heading back cut. Three to five shoots uniformly spaced around the main trunk are selected to become scaffolds. Shoots should be at varying heights along the trunk, not at the same height.

Trees planted with branches are treated a bit differently. Any branch below 60–80 cm on the trunk should be removed. Select three or four branches that are well spaced around the trunk to become scaffolds and head the main trunk to just above the topmost scaffold. If fewer than three branches are available for scaffolds, remove all branches and treat the tree as a whip.

During the first growing season scaffolds should be spread to 45–60° to encourage strong branch angles. All upright growth should be removed. New trees should be checked for spreading and upright growth once a month during the first growing season.

Dormant pruning during the first 3 years should encourage lateral growth on scaffolds. Summer pruning can also be utilized to remove unwanted growth and to direct the scaffold growth rather than waiting for dormant pruning. Pruning of mature trees should remove dead or diseased wood while maintaining tree shape and encouraging moderate vegetative growth. Excessive growth will lead to shading while insufficient growth will limit production by limiting flower bud formation on new growth. Fruiting wood should be maintained as close to the trunk as possible to minimize scaffold breakage caused by excessive fruit around the canopy periphery.

### *Biennials*

Biennial species flower and fruit on second year wood. The first year of growth is strictly vegetative. Pruning and training systems for biennial crops such as raspberries and blackberries (*Rubus* spp.) must produce new first year shoots (primocanes) while at the same time managing the second year wood (floricanes) for fruit production. Once fruit is harvested, floricanes die and are removed from the field at the end of the growing season or the beginning of the following one. Most brambles require some form of supporting trellis for production, making training and pruning a bit more difficult.

New cultivars of primocane fruiting brambles make crop management much easier. In the simplest system, all canes are mowed to the ground in the early spring. Fruit is harvested in the late summer or early fall from primocanes that may or may not be supported by a trellis. Canes are mowed to the ground the following spring and the cycle repeated.

### *Annual vegetables*

Two vegetable crops that are most often trained and pruned are tomatoes (*S. lycopersicum*) and cucumbers (*C. sativus*). Both are produced around the world and are most often grown in a greenhouse or a high tunnel (Hochmuth and Hochmuth, 2012a, b).

**TOMATOES** Greenhouse/high tunnel tomatoes are normally either beefsteak or cluster (on-the-vine) type, however, cherry and grape tomatoes have found a niche market (Fig. 13.7). Most cultivars

**Fig. 13.7.** Greenhouse tomatoes (*Solanum lycopersicum*) trained to a single leader.

have an indeterminate growth habit and will flower and fruit along the main stem for 10 months or more on a vine that may reach 12 m long. The vine must be regularly pruned and trained to a trellis system. The usual trellis consists of a single overhead wire (0.24 cm diameter) at about 2.5–3 m above the greenhouse floor suspended from two strong endposts. Posts are often located every 9 m or so to help support the fruit and vine load on the wire. Plants are trained up a string that is attached to the overhead wire. Within the row, plant spacing is governed by cultivar vigor, but is generally 45–60 cm. Since vines may grow to 12 m, strings must be long enough to accommodate this growth, with the extra string temporarily attached to the support wire. There are different ways to manage the extra string at the top of the vine at the support wire, but the main objective is to keep it from getting tangled and make it so that it is easy to loosen and tighten as the vine requires.

Each string is loosely attached to the base of the tomato plant stem when the plant has six to eight leaves. Plants are attached to the string with clips, vinyl tape looped around the string and stem fastened with a staple, or by gently wrapping the string around the stem being careful not to cause scraping or crushing of the stem. All lateral shoots (suckers) are removed every 3 or 4 days by pinching or snapping them from the leaf axil from which they originate. Vines also require leaf pruning and it is normally done when vines are lowered as the season progresses. Once the vine has reached the trellis wire, it must be lowered, string and all, so that the indeterminate vine can continue to grow and flower. Generally before lowering, four to six of the oldest leaves are carefully removed from the base of the vine and any old clusters from which fruit has been harvested removed. Plants are then lowered about 45–60 cm and the vine gently coiled or serpentined on the greenhouse floor. There should be 20–25 cm of air space between the greenhouse floor and the lowest set of leaves. The string is then reattached to the support wire. Leaf pruning and vine lowering is performed once every 2 weeks.

Most tomatoes set from one to ten flowers per cluster and should be thinned after fruit set to three to five fruit per cluster, depending on cultivar. Some cultivars may not require thinning.

**CUCUMBERS** Greenhouse cucumbers are normally standard European seedless, parthenocarpic, gynoecious cultivars producing fruit that is around 35 cm long, slender, seedless and thin skinned (Hochmuth and Hochmuth, 2012b).

Greenhouse cucumber seed is usually expensive at $0.75 each. Germination is high and cultivars are productive. Seedlings with three or four leaves are transplanted and spaced according to training system adopted. Generally a cucumber plant requires 0.46–0.65 $m^2$ of space to be productive.

A widely used trellising system used for greenhouse cucumbers is a vertical cordon that converts into an umbrella (Fig. 13.8). The main stem of the plant is trained vertically up to an overhead wire positioned about 3 m above the greenhouse floor. Plants are arranged in either: (i) single rows spaced 1.5 m apart; or (ii) double rows (with a space of 0.6 m between the two rows of a pair) and a distance of 1.8 m from the center of one pair of rows to the center of the next pair of rows. Plants are spaced about 45 cm apart within the rows. Double rows will require two support wires.

Plants are trained up strings attached to the support wire and all lateral branches are removed until

**Fig. 13.8.** Greenhouse cucumbers (*Cucumis sativus*) in the initial stages of training to a vertical cordon system.

the plant reaches the support wire. When one or two leaves have developed on the main stem above the support wire, the growing point of the main stem is removed. Two laterals are allowed to develop and drape over the support wire and grow downwards creating the umbrella modification. The growing point of each lateral is removed when the lateral reaches the greenhouse floor. Fruits develop at the node of each leaf. Fruit developing on the basal 75 cm of the vine are removed. This allows the vine to develop the appropriate vegetative growth to support a full crop. Productivity of the draped laterals is usually less than that of the main stem. Cucumbers are usually harvested about 14 days after fruit set.

Another popular trellising system is the V cordon. Single rows of plants are spaced 1.5 m apart with plants spaced 30 cm apart within the row. Two overhead support wires are fastened above the row, with each wire 38 cm away from the row center. Vines are then alternately trained to the two wires, growing away from the row center. Fruit then hangs nicely making harvesting easier and preventing fruit from rubbing on the main stem or lateral. Vines are pruned similarly to the vertical cordon/umbrella system.