VEGETATIVE GROWTH RESTRICTION IN POME AND STONE FRUITS
- A REVIEW

Sanjeev Sharma, A.S. Rehalia and S.D. Sharma
Dr. Y. S. Parmar University of Horticulture and Forestry,
Nauni, Solan-173230 (H.P), India

ABSTRACT

The balance between vegetative and reproductive growth in temperate fruits is associated with improved production efficiency and fruit quality. Horticultural approaches have great potential to regulate the tree size. Among these approaches, rootstocks have provided apple growers with trees of reduced stature suited to a wide range of planting densities, but poor anchorage and disease susceptibility of dwarfing rootstocks are major concern for their exploitation to control growth in temperate fruits. The lack of suitable dwarfing rootstocks compatible with peach, pear, plum, apricot, and cherry have further added to the problem. Pruning has proved efficient method of growth control. Judicious pruning coupled with branch orientation offers a much better approach to growth control in many temperate fruit trees. It is possible that significant control of fruit tree growth could be obtained by improved management of fertilizers in orchards, including timing of fertilizer application. Use of plant growth regulators continue to offer the most efficient and cost effective technique for regulating shoot growth and controlling tree size.

Modern system of fruit culture is concerned with methods of controlling vegetative growth in bearing trees. In temperate fruits, the vegetative growth must be balanced with flowering (Hugard, 1980; Walker, 1980). The maintenance of delicate balance between the vegetative and reproductive processes is a major challenge in tree fruit production (Bukovac, 1981). Horticultural practices that reduce shoot growth and tree size such as rootstocks, pruning, scoring, etc. have long been used to regulate growth and tree size. Pruning is universally adopted to reduce tree size. Management of edaphic resource inputs with irrigation and/or fertilization or resource removal (such as deficit irrigation) with regulated competition is techniques to control tree size. These techniques are most expedient, economical, and practical means available to the fruit grower to control vegetative growth under high density planting. Most techniques alter the tree physiology and hormonal production, resulting in growth suppression or inhibition and possibly changes in tree architecture. Horticulturally imposed growth control techniques and genetic dwarfing have usually additive effects (Faust, 1989).

IMPORTANCE OF VEGETATIVE GROWTH REGULATION

The need to regulate growth is based on several factors, of significance is the relationship between growth and fruiting. Excessive vegetative growth reduces flowering and ultimately fruiting (Forshey and Elfving, 1989; Luckwill, 1970). A certain amount of growth is necessary to maintain vigour and healthy bearing canopy with an adequate leaf surface. The desire to obtain early cropping and to reduce labour inputs have also necessitated the maintenance of dwarf trees planted in high density systems. Modern high density orchards are designed to move quickly from the juvenile vegetative phase to reproductive or fruiting phase (Luckwill, 1970). Moreover, excessive growth in bearing orchard often leads
to overcrowding and reduced light penetration into the canopy, poorer fruit quality and increased pest problems. In addition, there is often a greater need for vegetative growth control as trees age.

WAYS OF VEGETATIVE GROWTH REGULATION

Rootstocks

Rootstocks control tree size through a direct effect on growth and indirectly through enhanced crop load (Avery, 1970; Layne et al., 1976, Faust, 1989). Size controlling rootstocks are more common in apple than in other temperate fruits. Clonal apple rootstocks produce a range of tree sizes from larger than seedling (M 25) to 15 to 20 per cent of the size of trees on seedling root (M 27 and P 22) (1997; Ferree and Carlson, 1987). The McIntosh on M 26 can be expected to produce a smaller tree than McIntosh on M 7 over a wide range of planting sites (Autio et al., 1990). The effect of rootstocks on tree size is generally discernible in the early life of the tree, but not always (Fallahi and Mohan, 2000). However, the dwarfing effect on shoot extension growth may be less evident, particularly in the first two or three growing seasons (Tukey and Brase, 1941). As the tree ages, the effect of the more dwarfing rootstock can be seen as reduced shoot (Hirst and Ferree, 1996) and trunk (Fallahi and Mohan, 2000) growth compared to the same cultivar on a more vigorous rootstock.

A wide range of size controlling rootstocks are also available for pear and stone fruits (peach, cherry, plum, etc.) but dwarfing rootstocks for these species have proven less successful than for apple (Rom and Carlson, 1987). The most common dwarfing rootstocks for pear are Old Home x Farmingdale (OH x F) and quince (Cydonia oblonga L.) selections that result in trees about 50 to 70 per cent of a standard size pear tree (Lombard and Westwood, 1987). Rootstocks, as a means of growth and size reduction in peach, have been inconsistent and, for the most part, unsuccessful (Reighard, 1997). However, certain reports in the literature suggest size control up to 50 per cent (Layne, 1987) with Prunus tomentosa and P. besseyi rootstocks in peach (Rom, 1983). Clonal rootstocks have recently been developed for cherries that showed considerable promise for controlling tree size in commercial orchard plantings (Choi and Andersen, 2001; Perry et al., 1996). Rootstocks derived from interspecific hybrids of Prunus in Gembloux, Belgium (the GM series) and Giessen, Germany (the GI series) have produced cherry trees 20 per cent or less than the size of trees on the standard Mahaleb or Mazzard rootstocks (Perry et al., 1996). The most promising dwarfing cherry rootstocks produce trees between 20 and 50 per cent of a standard size tree.

Pruning

It is well established that removal of a portion of the fruit tree by pruning results in a smaller tree. Pruning is a dwarfing process, but growth is stimulated in the vicinity of the pruning cut (Forshey et al., 1992; Geisler and Ferree, 1984; Mika, 1986; Myers, 1990.) Pruning can be used as dormant, summer, or root pruning.

Dormant pruning

Dormant pruning reduces trunk size (Elfving, 1990;) and canopy volume (Mika et al., 1983) as compared to the same tree that is not pruned. Generally more severe the pruning the greater is the dwarfing effect on trunk, branch and/or canopy size (Barden et al., 1989; Miller and Byers, 2000). Miller and Byers (2000) reported 21 per cent reduction in canopy volume when peach trees were severely pruned in comparison to unpruned trees or lightly pruned trees. Dormant hedging or shearing has shown success in controlling tree size, but often results in a proliferation of shoots over the periphery of the tree resulting in very dense tree canopies (Ferree and Lakso, 1979; Forshey et al., 1992). The effect of dormant pruning may seem to have stimulated growth, but the total dry matter produced by the pruned tree is less than the nonpruned tree (Myers and Saville, 1996). Therefore, to avoid localized and invigorating effects, it is recommended that pruning consist primarily of thinning cuts and few heading cuts be used (Forshey et al., 1992; Marini et al., 1993; Myers, 1990). Thinning cuts that remove an entire shoot or branch back to the point of origin accomplish the dwarfing effect without stimulating invigoration of adjacent buds.
Summer pruning

Summer pruning is more dwarfing than dormant pruning (Hayden and Emerson, 1976; Mika, 1986; Utermark, 1977) however, certain reports in the literature indicate that much of the evidence to support this claim are inconclusive (Marini and Barden, 1987; Saure, 1987). Many factors influence the growth response to summer pruning (Forshey et al., 1992; Mika, 1986; Saure, 1987;) principally the type of cut used, the timing, and severity of pruning (Miller, 1982.). Studies with apple (Ferree and Rhodus, 1993; Myers and Ferree, 1983; Taylor and Ferree, 1984), peach (Leuty and Pree, 1980), cherry (Flore, 1992; Kappel et al., 1997; Mika and Piatkowski, 1989), and plum (Mika and Piatkowski, 1989) report that summer pruned trees are smaller than dormant pruned trees. Marini (1985) reported that the effect on tree size in peach varied with cultivar. Miller (1982) reported that regrowth following summer pruning of vigorous Topred Delicious apple trees depended on time of pruning after full bloom (FB). When pruning was delayed until 16 weeks after full bloom (FB), regrowth was significantly reduced compared to 8 weeks after full bloom (FB). Several studies have reported reduced shoot growth following summer pruning (Elfving and Cline, 1990; Mika et al., 1983; Rom and Ferree, 1984; Taylor and Ferree, 1984), while others have reported no effect (Ferree and Rhodus, 1993; Reischel, 1997) or increased shoot growth (Greene and Lord, 1983; Taylor and Ferree, 1984). Marini and Barden (1982) summer pruned Red Delicious apple trees and reported reduction in trunk growth, shoot growth and root growth of trees. However, in the following year, the growth of summer pruned trees was similar to dormant pruned trees. Later, Barden et al. (1989) reported the growth response to summer pruning in August was very similar to dormant pruning in February in apple. Elfving and Cline (1990) reported that summer pruning reduced shoot length in vigorous Northern Spy apples and reduced dormant pruning time but did not replace the need for dormant pruning. The fruit yield was not affected and therefore, concluded that summer pruning was ineffective for controlling vegetative growth. The general conclusion drawn by various workers (Gardner et al., 1952; Marini and Barden, 1987; Saure, 1987; Elfving and Cline, 1990; Reischel, 1997; Guimond et al., 1998; Kappel and Bouthillier, 1995; Kikuchi et al., 1989) is that summer pruning is no more dwarfing or devitalizing than dormant pruning.

Root pruning

Limiting the uptake of water and nutrients can be achieved through manipulating root systems of fruit trees. Root pruning can decrease resource uptake or create a plant hormone imbalance which can adversely affect shoot growth. Pruning of root systems has been successful in some fruits but less efficacious with others. Pruning roots of young and mature apple trees reduced shoot growth and thus controlled tree size (Ferree, 1989, Schupp and Ferree, 1988). Root pruning reduced the number of apple tree roots in the top 30 cm of soil (Ferree, 1994). In 15-years-old apple trees, this method of root pruning reduced trunk cross sectional area (TCSA) and shoot length without reducing fruit yield (Schupp and Ferree, 1988). A later study indicated that yield, as well as trunk cross sectional area (TCSA) of Golden Delicious was reduced by root pruning that were grown on different rootstocks (Ferree and Knee, 1997). Root pruning reduced shoot growth and fruit load in Empire and McIntosh apple trees (Elfving et al., 1996). The timing of root pruning is an important factor and root pruning in the dormant season or at June drop was more effective in reducing shoot elongation than at June (Schupp and Ferree, 1987). Similar results were obtained with peach where root pruning in April was more effective for reducing shoot elongation than root pruning in June (Santos et al., 1991). In apple trees, root pruning was more effective in reducing shoot growth in bearing trees (Schupp et al., 1992). However, root pruning has not proven consistent for shoot growth control in high vigour trees (Miller, 1995). Reduced fruit size and yield associated with root pruning may limit its use as a remedy where shoot growth requires extreme corrective control (Ferree and Knee, 1997). Root pruning may not be economical to manage tree size for high density plantings as an alternative to planting apple trees.
at an appropriate spacing (Ferree and Rhodus, 1993). The abundant rainfall can also negate the potentially inhibitory effects of root pruning (Ferree, 1992).

**Branch orientation**

Vertically oriented branches on fruit trees are usually more vigorous (Elfving and Forshey, 1976; Myers and Ferree, 1983) and less productive than branches oriented in a more horizontal position (Tromp, 1970). Bending and/or spreading branches to a more horizontal position is an old practice (Tukey, 1964) that has several benefits including reduced terminal growth, enhanced lateral growth, spur formation and increased flowering and fruiting (Forshey et al., 1992). Wareing and Nasr (1961) provided the first detailed investigations on branch orientation in apple, cherry and plum and demonstrated the effect on the growth of the apical and lateral buds along the shoot when vertical shoots are reorienting to the horizontal. Later studies by Mullins (1965) and Mullins and Rogers (1971) provided additional evidence and support to the finding of Wareing and Nasr (1961) while studies by Kato and Ito (1962) provided evidence for the role of auxins and gibberellins. Ethylene is also involved in the growth response to limb bending (Rom, 1989). Elfving and Forshey (1976) reported that bending shoots on vigorous ‘Delicious’ apple trees to a horizontal position reduced shoot growth by about 80 per cent compared to vertical shoots. Elfving and Forshey (1976) did not report the effect of bending on flowering or fruiting. Hamzakheyl et al. (1976) oriented shoots at 30°, 60° and 90° on newly planted Oregon Spur Delicious trees and found that shoot growth was reduced proportional to the degree of bending toward the horizontal. Trees with shoots trained to 90° had the fewest number of spurs and the greatest number of vigorous watersprouts. Production of vigorous shoots near the base of limbs bent to 90° from vertical has also been reported by Dann et al. (1990) and Kaini et al. (1984). Shoots trained at an angle of 30° in the first season and 60° in the second season had the greatest reduction in shoot growth in the second season and the highest number of flower clusters among all treatments. In another study, Myers and Ferree (1983) reported that vertical limbs had more flowers than horizontal limbs, but fruit set did not differ based on limb orientation. According to Greene and Lord (1978) spreading of limbs on vigorous nonspur Delicious trees in two years resulted in reduced terminal shoot growth and increased blossom clusters without affecting fruit number. The bending on young Smoothee Golden Delicious and Lawspur Rome Beauty apple trees reduced shoot growth slightly in the second season of bending but had no significant effect on tree size or yield over four seasons (Ferree, 1994). The response of branch spreading depends on a number of factors including cultivar and growth habit, timing, tree age, rootstock, and degree of spreading (Myers and Savelle, 1996; Rom, 1989). Spur-type apple cultivars with a basitonic (Starkrimson Delicious) growth habit produce the best balance between growth and fruiting when limbs are spread to 45° while natural spreading cultivars (Golden Delicious) respond best to spreading to 60° or more from vertical (Forshey et al., 1992). Stebbins (1980) recommends spreading in Comice and Bosc pear, but not Bartlett and Anjou. Spreading is also recommended for high density sweet cherry systems to reduce growth (Long, 1999). Spreading or bending in peach has focused on inclined canopy systems (Dann et al., 1990; DeJong et al., 1992) rather than spreading of individual branches to achieve growth control.

**Scoring, girdling and bark inversion**

Several reports in the literature suggest that scoring and girdling can reduce growth in different fruit trees. Scoring is an ancient technique used primarily to enhance fruiting and to reduce shoot growth (Greene and Lord, 1986; Tukey, 1964). Scoring and girdling affect assimilate partitioning and the flow of nutrients and growth hormones that leads to growth and fruiting responses (Cutting and Lyne, 1993; Forshey and Elfving, 1989; Kato and Ito, 1962). Scoring or girdling may produce responses in the year following treatment, but Hennerty and Forshey (1971) indicate the effects are not related to carbohydrate reserves. A number of studies have reported reduced shoot (Batjer and
Westwood, 1963; Cutting and Lyne, 1993; Greene and Lord, 1978, 1983; Miller, 1995; Veinbrants, 1972; Wilton, 1999) and trunk (Autio and Greene, 1994; Batjer and Westwood, 1963; Greene and Lord, 1983; Miller, 1995) growth when fruit trees are scored or girdled. The technique is considered most effective for controlling shoot growth in the year of the treatment (Batjer and Westwood, 1963; Greene and Lord, 1978), but it may also affect growth for one or more years after the treatment (Greene and Lord, 1978, 1983; Hoying and Robinson, 1992). Veinbrants (1972) reduced shoot length by 25 per cent when scored Granny Smith apple trees soon after bloom but the reduction was 12 per cent only, if scoring was delayed by 2 weeks. Wilton (1999) demonstrated a progressive loss in shoot growth control on Pacific Rose apple trees as scoring timing progressed from petal fall (PF) to 6.5 weeks after petal fall (PF). Girdling of mature Macspur McIntosh trees resulted in reduction of average shoot length by 18 per cent and shoot numbers by 20 per cent (Hoying and Robinson, 1992). Ringing or scoring vigorous 15-year old Gardiner Delicious and 16-year old Rogers Red McIntosh apple trees resulted in slight increase in trunk cross sectional area compared to control trees, but shoot length was not affected. Miller (1995) found no effect on terminal shoot growth after scoring 3-year old Gala, Empire and Jonagold apple trees on M 7A rootstock planted at 1.8 m in row spacing. Miller (1995) suggested that trees growing on deep fertile soils supplied with irrigation may be too vigorous to respond to scoring. Stang et al. (1976) observed 14 to 25 per cent reduction in shoot growth in scored trees of Red Prince or Melrose apple.

**Fertilization**

Fertilization disproportionately increased root and shoot growth as a result the root to shoot ratio decreased in apple trees (Robinson et al., 1992). Tree growth control with selective application of fertilizer is further made difficult by the potential reservoir of minerals stored in the different portions of the tree. Niederholzer et al. (2001) found that peach tree growth in spring drew strongly from stored nitrogen, independent of nitrogen supplied in the fall. Root uptake of nitrogen by apple trees was negligible in early spring because trees used more of the stored nitrogen (Neilsen and Neilsen, 2002). Greater nitrogen use efficiency resulted when nitrogen was applied to the soil after reserve nitrogen was remobilized from storage tissue in apple in early spring. Fertilizers are often targeted for application below a fruit tree canopy dripline. In young apple trees grown in herbicide treated strips with grass alleys between the strips, most root growth and nutrient uptake occurs in the herbicide strip (Atkinson, 1974). Withholding fertilizer to maintain a desired tree size is obviously difficult because of spatial and temporal variation in nutrient availability and uptake in young and mature trees but carefully managed fertilization should help reduce undesirable vegetative growth.

**Deficit irrigation**

Irrigation at selected times during the growing season has been shown to reduce vegetative growth without adversely affecting yield in peach and pear (Chalmers et al., 1981; Mitchell et al., 1989). This form of irrigation, which is restrictive to shoot growth, is termed deficit irrigation. Dormant pruning of peach can be reduced by one third if postharvest irrigation is withheld in areas with little or no summer rainfall (Larson et al., 1988). Withholding irrigation during the dry summer thus can help to reduce vegetative growth of peach (Ghrab et al., 1998; Johnson et al., 1992). Deficit irrigation may lead to tree adaptation to dry conditions. Apple trees also respond to deficit irrigation but responses are not identical to peach. Growth response of apple to soil water availability varies with type of rootstock used. Fernandez et al. (1997) demonstrated that apple trees on dwarfing rootstock (M 9 EMLA) were less affected by drought than the apple trees on more vigorous rootstock (MARK). Combinations of deficit irrigation and managed competition or
reduced tree root volume have been used to control tree growth. Rooting volumes can also interact with available soil water to affect vegetative growth of peach trees. Reduced root volume had little effect on shoot growth when deficit irrigation was applied with 30 per cent replacement of water that had been used (Proebsting et al., 1989). Regulated deficit irrigation may be most effective to control shoot growth mainly in dry regions, where stress can be applied early and quickly, particularly in shallow soils (Johnson and Handley, 2000).

**Plant growth regulators**

Plant growth regulators have been extensively tested as a vegetative growth control on deciduous fruit trees. The subject of plant growth regulators as vegetative growth retardants in various fruit crops has been reviewed by various workers (Davis and Curry, 1991; Looney, 1983; Miller, 1988; Williams, 1984). Growth retardants are compounds which reduce plant size without obvious phytotoxicity to plants (Davis and Curry, 1991). Daminozide [Butanedioic acid mono-(2,2 dimethylhyrazide)], a GA biosynthesis inhibitor (Rademacher, 2000), was the first synthetic plant growth regulator to exhibit strong vegetative growth retarding properties in fruit trees (Batjer et al., 1963). The ability of daminozide to reduce growth in apple and pear at rates between 1000 and 10,000 ppm is well documented (Miller, 1988). Daminozide is also effective in reducing shoot growth in cherry (Proebsting and Mills, 1976; Unrath et al., 1969), but has shown minimal effect on peach shoot growth (Byers and Emerson, 1969). Use of daminozide on tree fruit crops was discontinued in the year 1989 due to suspected toxicological risks. Chlormequat (2, chloro-N,N,N-trimethylethanaminium chloride) is another GA biosynthesis inhibitor to exhibit growth retarding effects in fruit trees (Davis and Curry, 1991). Chlormequat has limited activity in apple (Miller, 1988) but is an effective shoot growth retardant in pear (Embree et al., 1987). Edgerton and Blanpied (1968) first recognized the growth controlling properties of ethephon (2-chloroethylphosphonic acid) on apple. Ethephon at 2000 ppm applied to growing apple shoots was as effective as the daminozide in reducing shoot growth. A combined spray of ethephon and daminozide was more effective for growth suppression than either material applied alone (Byers and Barden, 1976). However, the early post-bloom sprays, which affect maximum growth control, reduce fruit set, thus, ethephon has not received widespread use as a growth retardant (Davis and Curry, 1991; Miller, 1988). Byers (1993) demonstrated that multiple low dose (100 to 200 ppm) sprays applied at weekly intervals during the first 45 days after full bloom (FB) reduced shoot growth without excessive fruit abscission in Starkrimson Delicious apple trees. Single low dose (50 to 250 ppm) applications have not proven effective in controlling shoot growth in Empire apple trees (Elfving and Cline, 1993). Success in vegetative growth control with daminozide, ethephon and chlormequat sparked interest in the search for new plant growth regulator with growth controlling activity. In the late 1970s and early 1980s research was begun on several triazole compounds, the most promising of which was paclobutrazol (2RS, 3RS-1-{2, 2-dichlorophenyl-4, 4-dimethyl-2-(1H, 1, 2-triazol-1yl) pentan-3-ol} (Williams and Edgerton, 1983). The triazoles compounds inhibit gibberellin biosynthesis (Rademacher, 2000) by inhibiting the oxidation of ent-kaurene to ent-kaurenoic acid (Dialziel and Lawrence, 1984). Triazoles have several unique properties that distinguish them from other GA biosynthesis inhibiting growth retardants (Miller, 1988) most notably are strong residual effect and systemic activity on both pome and stone fruits (Avidan and Erez, 1995; Blanco, 1988; Edgerton, 1986; Facteau and Chestnut, 1991; Tukey, 1983; Williams and Edgerton, 1983; Williams et al., 1986). The foliar absorption and translocation of triazoles is minimal (Williams et al., 1986), although it does occur (Craighton et al., 1990) and will result in growth suppression when properly timed (ElKhoreibi et al., 1990) and directed (Lehman et al., 1990). The triazoles are absorbed primarily through stem, bark, and root tissue (Davis and Curry, 1991; Tukey, 1983). The foliar sprays of paclobutrazol at 3000 to 8000 ppm resulted in growth suppression on apple lasting 2 to 4 years after treatment (Greene, 1986; Tukey,
Soil applied paclobutrazol produced residual activity, but generally of less duration than foliar sprays (Williams and Edgerton, 1983). Response to soil applications on peach and cherry occurred in the year of treatment, but on apple response was not evident until the year following treatment (Curry and Williams, 1986; Edgerton, 1986; Tukey, 1983). The strong residual and systemic effects provided a degree of unpredictability in the use of triazoles. The multiple low rates of foliar sprays were sufficiently effective and more consistent in suppressing vegetative growth (Estabrooks, 1993; Greene, 1991) compared to high rate foliar sprays. At the present time, paclobutrazol is labeled in several countries for growth control in apple and stone fruits. A class of growth retardants, the acylcyclohexanediones, with the common name prohexadionecalcium (3-oxido-4-propionyl-5-oxo-3-cyclohexenecarboxylate) was reported from rice in 1990. The mode of action of prohexadionecalcium is to block the conversion of GA₂₀ (inactive) to GA₁ (active), thereby reducing shoot elongation (Rademacher, 1993; Evans et al., 1999). Prohexadionecalcium is absorbed by the foliage and moves acropetally to the growing points of shoots (Evans et al., 1999). Prohexadionecalcium has shown no carry over effects on apple (Miller, 2002) and GA₄⁺₇ sprays reversed the growth suppressing effect of prohexadionecalcium (Guak et al., 2001). The studies showed that a foliar spray of prohexadionecalcium was an effective growth inhibitor over a range of concentrations from 125 to 375 ppm when applied to several apple cultivars. Greene (1996, 1999) observed a linear increase in fruit set with increasing concentration and at the highest rate (375 ppm) fruit set was nearly doubled on McIntosh apple trees. Unrath (1999) confirmed the growth retarding effect of prohexadionecalcium on Delicious apple trees over a similar concentration range and found equal response when applied between petal fall and 20 days after petal fall (DAPF). Additional reports have suggested that multiple applications provide better growth control than a single application (Byers and Yoder, 1999; Unrath, 1999). Byers (2000) reported an additive effect on growth suppression when prohexadionecalcium was combined with ethephon. Timing of the initial spray is more important than rate in achieving early growth suppression, but rate is also important for maximum growth control (Miller, 2002).

**Summary and Future Needs in Vegetative Growth restriction**

The need to manage excess vigor in temperate fruit trees is associated with improved production efficiency and fruit quality. There are many approaches in regulating growth, but to date none have proven to be universally successful or complete. Great benefit would result from improved knowledge of the plant growth substances involved in rootstock/scion fruit tree interactions with different climatic and edaphic conditions. Advances in molecular biology and genetic engineering offer the potential for improving our understanding of plants and the ability to manipulate plant growth. It is not unrealistic to consider a dwarfing gene that could be inserted into the DNA of a desired peach cultivar producing a tree that would match a specific planting density. Recent advances by fruit tree breeders in developing growth habits adapted to high density planting systems illustrate a promising approach. Rootstocks have provided apple growers with trees of reduced stature suited to a wide range of planting densities (Faust, 1989) but are partially successful in controlling excess growth. Poor anchorage and disease susceptibility are major disadvantages with most of the available dwarfing apple rootstocks. There is still a pressing need for dwarfing rootstocks compatible with peach, pear, plum, apricot, and cherry, although the recent introductions for sweet cherry represent a significant advancement. Pruning will continue to be used as a quickfix method of growth control (Mayers, 1990) because it can easily be applied, but pruning alone cannot be relied upon to effectively contain growth while maintaining annual production. Judicious pruning coupled with branch orientation offers a much better approach to growth control in many deciduous tree fruits (Tukey, 1964). The benefits of summer pruning are associated more with fruit quality than growth.
control. Root pruning is not economical (Ferree and Knee, 1997) and difficult to apply under many soil conditions, and often has adverse effects on fruit size. Root restriction, however, has shown good response and additional work is needed to better understand the effect on growth and tree physiology. A practical and economical solution in applying root restriction techniques to fruit trees should be developed. More research is needed to provide fundamental information on the quantitative removal or restriction of roots relative to the entire root and shoot. It is possible that significant control of fruit tree growth could be obtained by improved management of fertilizers in orchards, including timing of fertilizer application (Elfving, 1988). Beside rootstocks, plant growth regulators continue to offer the most efficient and cost effective technique for regulating shoot growth and controlling tree size (Elfving, 1988). The recent development and registration of prohexadionecalcium represents a major advancement in the search for effective growth controlling materials. There is still a great need for an effective growth retardant for stone fruits, particularly peach. Unfortunately the development of new plant growth regulators faces many risks and challenges (Rademacher and Bucci, 2002). A fundamental knowledge of the factors that regulate growth may lead to the development of natural plant hormones for growth suppression. In addition, more information is needed on the economics of plant growth regulators use for growth control compared to other methods. The pome and stone fruit trees will continue to be planted at higher densities in a wide variety of edaphic and climatic environments, there will be a continuing need for shoot growth control and means to achieve that control.

REFERENCES


