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Reevaluating Summer Hedging and Root Pruning for Intensive Apple Orchard Systems: A Review

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Abstract

Some commercial apple orchards have recently been adopting hedging as an alternative, or supplement, to hand pruning. With rising labor costs across the United States, alternatives to hand pruning and current training systems require consideration. Root pruning has also been used to suppress tree vigor. Most of the research on these two practices was performed on central leader trees on semi-vigorous or semi-dwarfing rootstocks. Since the terms referring to pruning and hedging are used inconsistently in the literature, the aim of this review is to define different types of pruning and also to summarize information pertaining the feasibility of using hedging and root pruning in modern orchard systems.

Summer pruning in the 20th century. Fruit trees are pruned to maintain tree size and shape, to help manage crop load, and to enhance light penetration and distribution throughout the canopy (Forshey et al., 1992). Trees can be pruned during the summer when leaves are on the trees or during the dormant season. During the first two decades of the 20th century, pomologists recognized that there were few data to support the commonly held belief that summer pruning suppressed tree vigor and encouraged fruiting more than dormant pruning as reported by Saunders (1863). Vincent (1917) stated that “The concept of pruning apple trees in winter to encourage wood growth and in summer to induce fruitfulness are principles that have long been recognized by horticulturists. It is surprising to learn in reviewing the literature that these principles [summer pruning] are based on very meager experimental evidence; moreover, the experimental evidence from different sources in many ways is contradictory.” The realization that opinions concerning summer pruning had little experimental basis led some pomologists to study summer pruning and several summer pruning experiments were initiated during the first two decades of the 20th century to methodically evaluate summer pruning. Blake (1917) was probably the first to extensively review summer pruning results in America. Results for those summer pruning experiments varied depending on many factors, such as cultivar, tree age and vigor, soil moisture, method of pruning, the type of pruning used as a control, and the types of data collected (Alderman and Auchter, 1916; Batchelor and Goodspeed, 1915). Vincent (1917) and Dickens (1906) reported that summer pruned trees had improved yield and fruit red color for some cultivars. Batchelor and Goodspeed (1915) found that summer pruning reduced yield and Howe (1923) reported no effect on yield. Drinkard (1915) reported that summer pruning suppressed vegetative growth and stimulated flower buds. In general, summer pruning in these early studies was like dormant pruning and involved removing water sprouts, and excess

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branches with thinning cuts, but results were so inconsistent that few pomologists recommended the practice.

In the 1970s and 1980s summer pruning was again evaluated with central leader trees on semi-vigorous rootstocks. Interest in summer pruning was probably stimulated by a presentation by Utermark (1977) at the annual meeting of the International Dwarf Fruit Trees Association, where he claimed that heading all one-year-old shoots to about 3 leaves in summer resulting in a suppression of vegetative growth and the subsequent improved light environment in the canopy was conducive for improved fruit quality, flower bud formation and fruit set. This severe summer heading may have been based on the system described by Lorette (1914). In general, summer pruning that involved thinning cuts and water sprout removal improved fruit red color (Autio and Greene, 1990). Heading all shoots in the summer suppressed trunk enlargement and root growth, and often improved red fruit color, but it also suppressed fruit growth and had little influence on flower bud formation, shoot elongation, or fruit set (Preston & Perrin, 1974; Marini and Barden, 1982a; Marini and Barden, 1982b; Ferree, 1984; Saure, 1987). This work was previously reviewed in detail (Marini and Barden, 1987; Saure, 1987).

During the past 25 years, North American apple orchards have transitioned to intensive systems on dwarfing rootstocks. Despite the smaller tree size, excessive tree vigor, resulting in shade within the canopy, and increasing pruning costs continue to be of concern. Summer pruning or summer hedging, combined with root pruning and new growth retardants may help alleviate these problems. In this review, we focus on summer hedging and root pruning for intensive orchard systems.

Pruning terminology. The terms 'pruning', 'hedging' and 'mechanical pruning' are often used interchangeably which leads to confusion in the literature. For this paper the terms are defined as follows. 'Pruning' is the *selective* removal of limbs, shoots, water sprouts, and spurs to balance vegetative and reproductive growth and maintain tree size and shape. Proper pruning enhances air movement and light penetration throughout the canopy for production of high-quality fruit. 'Dormant pruning' is the style of pruning that is typically performed while trees are dormant. 'Summer pruning' is defined as dormant-type pruning to remove branches and upright water sprouts while leaves are on the tree (Autio and Greene, 1990).

'Hedging' involves nonselective heading of mostly one-year shoots with a cutting bar/mower. 'Heading' involves manually removing the terminal portion of a shoot (Childers, 1969; Marini, 2020) along with terminal buds that would normally inhibit development of axillary buds below the terminal. 'Summer heading' involves heading all one-year-old shoots during the summer (Marini and Barden, 1982a; Tukey, 1964; Utermark, 1977). 'Summer hedging' is hedging performed while leaves are on the tree and is usually less severe than summer heading. Considering rows of trees, the goal of hedging is often to develop a canopy with a certain height and shape, usually an angled wall. The terms "hedging" and "mechanical pruning" are often used interchangeably, but this can lead to confusion. Since pruning refers to selective removal of shoots and limbs, hedging is the term that will be used in this paper when referring to nonselective pruning of trees with a cutter bar. While systems of all sizes and tree densities require some amount of pruning, high-density systems often require more severe and detailed pruning to prevent overcrowding and excessively large trees. Apple growers are interested in cost-reducing practices and hedging has been proposed as an inexpensive tool to manage vegetative growth and shape the canopy for enhanced light penetration and distribution.

Importance of light for fruit production. Light is required for photosynthesis (Heinicke, 1963), fruit bud initiation and development, fruit set (Miller et al., 2015), and fruit quality (Jackson and Palmer, 1977). 'Light interception' is a major factor limiting total orchard productivity and is the only manageable process for affecting potential productivity when evaluating orchard/tree design and canopy display (Wünsche et al., 1996). Modern orchards are designed and pruned to capture a high proportion of available light for fruit production. Fruit developing in the interior of large canopies are exposed to less sunlight than those on the outer canopy and have less red color, starch, and sugar (Robinson et al., 1991). Removal of branches and/or foliage with pruning is essential to obtain light levels that are adequate for high quality fruit throughout the canopy.

Summer hedging is currently recommended when terminal shoots have 12-14 expanded leaves (Lewis, 2018). The goal of these recommendations is to push buds on blank wood on older branch sections, but supporting data are lacking. This timing of summer hedging after terminal bud set theoretically should not stimulate proleptic shoots because trees have already ceased producing new shoots for the season. In intensive orchards regrowth is more often short and terminal buds are more often flower buds, as opposed to summer headed trees on vigorous rootstocks (T. Robinson, personal communication). Additional work is needed to determine if summer hedging increases flower bud formation and fruit set and suppresses shoot growth the following season in intensive orchards. Detailed evaluation of branch sections is necessary to evaluate the influence of summer hedging on vegetative and reproductive characteristics of branches and to determine if flower bud formation and fruit set can be improved. The quantity and quality of light within the canopy should also be considered when trying to increase fruit production in the interior canopy where red fruit color for some cultivars is difficult to obtain.

Summer pruning and vegetative growth. In the late 1970s it was suggested that summer pruning suppressed vegetative vigor and increased light penetration to enhance fruit color and quality and improve flower bud initiation and fruit set (Utermark, 1977). The method of summer pruning described by Utermark (1977) involved heading current season shoots to three or four leaves about four weeks before harvest. This type of summer pruning was like the Lorette system explained by Tukey (1964), except the Lorette method involved pruning three times during the growing season. In the Lorette pruning system, shoots were cut back above the first two leaves for the first pruning, from end of June to early July. The second pruning, from late July to early August, removed any shoots that reached the appropriate thickness in an identical fashion. The third pruning, from late August to early September, pruned any shoots that were thick enough and left smaller branches for pruning in the following spring. Regrowth from heading cuts in the current season is reduced or eliminated if summer pruning is performed 1-2 months before harvest but after terminal buds have formed (Ferree and Warrington, 2003). Results from other experiments found that summer pruning increased shoot length that same year, and in certain cases, shoot number (Forshey & Marmo, 1985; Watanabe et al., 2006).

Summer pruning theoretically suppresses vegetative growth by reducing whole-tree photosynthesis and carbohydrate reserves used for growth the following year (Li et al., 2003). However, this is not necessarily supported by the literature. Li et al. (2003) found that whole-canopy carbon fixation and transpiration was reduced in proportion to the amount of leaf area that was reduced by summer pruning. Marini & Barden (1982a) investigated the vegetative growth response by measuring shoot growth on summer- and dormant-headed vigorous mature trees and one-year-old container-grown trees. Although summer heading reduced whole-tree photosynthesis enough to suppress fruit growth and fruit soluble solids, when all one-year-old shoots were headed to three leaves in the summer or three buds in the winter, the shoot growth response was similar. Heading cuts induced the same shoot growth whether the heading cuts were made in the summer or dormant season, but the response was delayed until the following year for summer-pruned trees. The season following summer pruning light levels were similar for dormant- and summer-headed trees until tress were again summer headed the second year. Following summer heading, light distribution was enhanced throughout the canopy and leaves from the tree interior had higher specific leaf weight and higher photosynthetic rates, but fruit red color, flower bud formation and fruit set were not consistently affected by time of heading.

Saure (1987) cited delayed apple fruit development and later induction of dormancy as some of the main drawbacks associated with summer pruning in apples. Marini (1986) also found that summer hedging delayed leaf abscission and cold acclimation in peach. In areas with a short season, summer pruning could delay or prevent the onset of dormancy, and adversely affect winter hardiness. The positive influence of summer pruning was improved fruit color through better light penetration into the canopy (Saure 1987). Cultivars such as ‘McIntosh’ that are considered difficult to color had a dramatic improvement in red fruit color when trees were summer pruned with thinning cuts to remove limbs that caused shading rather than by heading shoots (Autio and Greene, 1990). Summer pruning with thinning cuts is an effective method of reducing leaf/stem area without risking current-season regrowth.

Transitioning from manual to mechanized pruning. The tree fruit industry is interested in mechanizing orchard practices to reduce labor costs, but orchards with varying tree size/shape within and between rows create challenges. Trees can be pruned to produce trees with the sizes and shapes that are conducive to mechanization or robots. To mechanize pruning, a system is needed that is repeatable and based on whole-tree quantitative metrics. Such an approach was tested by Schupp et al. (2017) where a pruning severity index was calculated from the sum of the cross-sectional area of all branches on a tree divided by the cross-sectional area of its trunk. Trees were then pruned to provide a range of limb-to-trunk ratios by successively removing the largest branches. As pruning severity increased, the fruit number per tree, yield, and yield efficiency decreased, resulting in increased fruit set, fruit weight, soluble solids concentration and titratable acids. Most modern tree training systems rely on detailed manual pruning. While these systems may vary in overall shape and structure, the general trend over the last 20 years has been toward high-density, intensive systems with closely spaced trees with a pyramid shape for greater light interception (Robinson and Sazo, 2013a). Canopies that are two-dimensional, such as V-trellis and fruiting wall systems are more automation-friendly than three-dimensional tree forms, such as the vertical axe and tall spindle. The “fruiting wall”, one of the systems being implemented in new plantings, is a modification of the tall spindle, where the trees are encouraged to quickly fill their space horizontally within the row and vertically, forming a narrow wall of vegetation that facilitates tree management and fruit harvest. Fruiting walls may facilitate robotic harvesting and pruning as appropriate hardware and software become commercially available (Adhikar and Karkee, 2011; Zahid et al., 2021).

Hedging to manage intensive orchards. According to Ferree (1976), pruning was responsible for more than 30% of production costs with large central leader trees. Marini and Barden (2004) reported similar results for trees trained to the vertical axe system and pruning accounts for about 20% of the total labor cost in Pennsylvania orchards (Crassweller et al., 2020).

Tall spindle training systems are

considered easier to prune: the simple, step-by-step pruning formula/instructions and smaller, fewer cuts required remove some of the intricate, detailed cuts often associated with pruning larger central leader and vertical axe trees, but fruiting walls further facilitate mechanization of orchard operations. Hedging has been recommended as a method of creating and maintaining fruiting walls (Lewis, 2018; Robinson, 2013b; Robinson et al., 2014). Hedgers make non-selective heading cuts as the blades run alongside the tree row and can be used to form what is commonly called a "narrow tree wall". During the 1960s and 70s, dormant hedging of central leader trees was evaluated. Hansen et al. (1968) implemented dormant hedging with little experimental evaluation and developed a dense shell of shoot growth on the canopy periphery that shaded the interior canopy and reduced fruit quality. Ferree (1976) emphasized the need for supplemental manual pruning following dormant slotting-saw hedging of trees to reduce shading in the interior fruiting areas. Dormant hedging was not recommended for commercial central leader trees because it was not economical.

As previously explained, results from summer heading experiments in the 1970s and 80s, did not verify the expected results and summer heading, which removes more foliage than summer hedging, was not commercially recommended (Marini and Barden,1987; Saure, 1987). Although results from dormant hedging and summer heading experiments with central leader trees on semi-vigorous rootstocks were disappointing, some growers and researchers have been re-evaluating hedging as an alternative to manual pruning in high-density orchards on dwarfing rootstocks to control tree vigor and enhance yield and fruit quality (Milkovich, 2020). Through non-selective removal of the ends of branches a certain distance from the trunk, hedging can potentially create a dense canopy shell preventing light penetration that may negatively affect fruit quality (Mika et al., 2016; Sazo, 2018). After three years, trees hedged at pink bud or about three weeks after bloom had higher yields than manually pruned trees, but fruit size and red color were reduced due to lower light levels. To alleviate shading and the subsequent negative effects induced by hedging, Mika et al. (2016) suggested that hedging must be supplemented with hand pruning and additional attention must be given to fruit thinning. Others have suggested that summer hedging should be performed more than once a season, or it should be combined with dormant hedging (Tukey, 1964; Courtney & Mullinax, 2016; Lewis, 2018).

Combining summer hedging with other horticultural practices. Since manual pruning is expensive and requires skilled labor, and hedging often has negative consequences, it may be feasible to combine hedging with new cultural practices to minimize the negative effects of hedging. One such practice may be the use of Prohexadione calcium (PCa), a naturally occurring gibberellin inhibitor that was registered in 1997. When applied to apple trees it reduced terminal shoot growth an average of 59% compared to controls (Glenn and Miller, 2005; Uselis et al., 2020). PCa also reduced the weight of prunings removed annually from the tree (Uselis et al., 2020). Three to five applications of PCa are commonly used in commercial orchards to suppress June drop, shoot growth, and fire blight infection (Crassweller et al., 2020). Early-season PCa applications may reduce the negative effects of hedging by suppressing shoot growth induced by heading cuts.

*An Overview of Root Pruning***.** Root pruning is another vegetative growth control method that may be combined with summer hedging, in which roots are severed from either side of the tree to reduce tree vegetative growth. This pruning method, studied in detail by Schupp and Ferree, among others (Ferree and Rhodus, 1993; Rom, 1982; Schupp and Ferree, 1987; 1988; 1990; Schupp et al., 1992), was never adopted as a major commercial practice by growers. Recent applications of high-density plantings with semi-dwarfing rootstocks indicate it may be combined with hedging to further improve growth control/efficacy of hedging in commercial orchards. Root pruning is not a novel concept and was previously studied, although adoption is limited. Schumacher (1975) found root pruning to be effective only when the correct number of roots were cut; cutting too few roots (60 cm from the trunk) led to excessive root development and shoot growth, while excessive root cutting (40 cm from the trunk) could lead to tree death, especially in dry years.

The response to root pruning is different for trees of different ages. Established bearing fruit trees growing in northern regions have a single shoot growth flush (Head, 1967) of much shorter duration than newly transplanted trees, where root and shoot growth occur concurrently (Atkinson, 1980), explaining the stronger response to root pruning for established trees. Results from root pruning vary based on the severity of pruning treatment. Schupp & Ferree (1990) suppressed shoot diameter with all root pruning treatments, but Rom (1982) reported no effect on shoot diameter. Root pruning 3-year-old container-grown 'Fuji' apple trees suppressed coarse root length while simultaneously increasing leaf chlorophyll content and transpiration rate (Fang et al., 2017), indicating that roots are often produced in excess, and apple trees can compensate for localized disruption to the root system. This raises the question of how closely spaced trees in high-density systems might respond to root pruning treatments.

Root pruning can affect trees that are suffering water stress/drought conditions. McArtney & Belton (1992) found root pruning apples during the dormant season and at petal fall "resulted in a significant reduction in mean leaf area of shoot leaves". At petal fall, spur leaves are fully expanded and water demands are high to fuel fruit development and shoot growth. Root regeneration after root pruning is more prone to branching, increasing absorbing surface, suggesting that nutrient uptake will be like non-root pruned trees (Geisler and Ferree, 1984). Water absorption will obviously be reduced with root pruning and could potentially cause water stress in the plant, as reported for holly (Randolph and Wiest, 1981) and maize (Brevedan and Hodges, 1978). Andrews and Newman (1968) compared the growth of root pruned vs. non-root pruned wheat plants with and without drought stress. Root pruning reduced growth of watered plants, but there was some indication that root pruning increased growth in the dry treatment. While root pruning suppresses shoot growth, careful consideration should be used in regions where water stress is a major concern.

Schupp and Ferree (1988) found no reduction in yield following root pruning, and the positive impacts included controlling tree size, and increased yield efficiency and fruit quality in vigorous cultivars. However, in drier years, fruit size was reduced following root pruning (Schupp and Ferree, 1988). Root pruning at full bloom increased fruit total soluble solids (TSS) concentration and slightly increased fruit firmness, corresponding to decreased fruit size (Schupp and Ferree, 1988). In addition, starch hydrolysis was decreased at harvest, resulting in fruit that had inferior postharvest shelf life and decreased TSS (Schupp et al., 1992). Schupp et al. (1992) also found no impact of root pruning on return bloom, fruit set, or yield. Khan et al. (1998) found root pruning decreased tree height, shoot growth, total yield, and average fruit size, although flowering spurs increased.

Root pruning results often varied with crop load. At higher crop densities, mean fruit weight was lower on root pruned apple trees (McArtney & Belton, 1992). As crop density decreased, the mean fruit weight of root pruned treatments approached those of controls. Root pruning can reduce mean fruit weight and affect the marketability of the fruit. While root pruning reduced shoot length and average shoot growth in apple trees (Miller, 1995; Mitre et al., 2012; Uselis et al., 2020), results were often inconsistent regarding yield and other fruit and tree characteristics.

Summer hedging/heading in intensive plantings. Hayden and Emerson (1976) suggested hedging high density peach plantings twice (July and August) as a method of tree containment, while stressing that dormant hedging resulted in "excessive shoot proliferation in the outer canopy and required considerable detailed corrective pruning, while trees summer hedged twice each year did not have this problem" (Ferree 1984; Hayden and Emerson 1976). Ferree and Lasko (1979) found dormant hedging apples reduced canopy spread and was an acceptable practice when combined with biennial hand pruning. In the past decade, summer hedging has been proposed for high density apple orchards to control vegetative growth, improve light penetration within the canopy, and improve red fruit color in intensive orchards (Gandev & Dzhuvinov, 2014; Lewis, 2018; Robinson, 2013b; Rosecrance et al., 2021). Although several articles appearing in trade journals mention summer hedging is essential for commercial operations, there are few data or evidence to support these claims.

Future work investigating summer hedging for intensive systems. Hedging is being adopted in some commercial orchards with little data to support the practice. Intensive orchards on dwarfing rootstocks may react differently to hedging than those on vigorous rootstocks (Robinson et al., 2014). Hedging combined with PCa and/or root pruning may suppress tree vigor, increase light penetration, and improve flower bud formation and fruit set more than hedging alone. Research is needed to evaluate the use of dormant and/or summer hedging, combined with cultural practices such as PCa and root pruning to convert tall spindle orchards to narrow walls and to maintain the tree walls. One approach would be to compare dormant-, summer-, and dormant- plus summer-hedging to nonhedged trees to determine the most effective timing for hedging. After identifying the best timing of hedging, a factorial follow-up experiment might consist of non-root pruned non-hedged tees, root pruned non-hedged trees, non-root pruned hedged trees and root-pruned hedged trees. Another approach to identify the individual and combined effects of hedging and root pruning might involve a factorial experiment where treatments include no hedging, dormant hedging, summer hedging, and dormant + summer hedging with and without root pruning. In addition, comparison of early vs. late-maturing cultivars ('Gala' vs. 'Cripps Pink') might yield different responses based on time of fruit maturity. Lobos and Yuri (2006) found flower induction timing differed by cultivar. Flower buds of 'Fuji', 'Red Chief', and 'Braeburn' were initiated 100 days after full bloom and buds of 'Royal Gala' were initiated 114 days after full bloom. Different flower induction timings could be impacted by hedging and root pruning treatments.

A few additional factors related to current recommendations that have not been discussed in this review should also be considered before adopting hedging. One recommendation is to hedge trees in the summer at about 60cm from the trunk followed by hedging in the dormant season at about 50cm from the trunk (Courtney and Mullinax, 2016). If a goal of summer hedging is to induce terminal flower buds, then the dormant hedging would likely remove most of these flower buds. A potential problem with hedging is the creation of many stubs on the periphery of the canopy that interfere with manual pruning and harvest operations. Laborers in our research orchard complained about being poked while working in trees that were hedged.

Many pomological experiments lack data to determine the economic impact of the treatments being studied. The variables most often reported that are associated with fruit quality include average yield (kg/tree), average fruit weight (g/fruit) and average percent red surface color. Although averages can be informative, they can be misleading when considering the potential economic impact of a treatment. A treatment that increases average fruit red color from 25% to 55% red blush, may be statistically significant, but neither of these treatments have adequate color to be considered fancy grade and will be sold for processing, and the extra red blush would not affect crop value. Although more expensive to obtain, fruit size distributions (Hanrahan et al., 2020) and fruit color distributions are much more informative and are necessary to estimate commercial pack-out that is needed to evaluate the economic impact of a treatment such as hedging (De Silva et al., 2000; Marini et al., 2019; Zhang et al., 1995). To perform an economic analysis, yield, fruit size distribution and fruit color distribution should be recorded in addition to time required for manual pruning, hand fruit thinning, root pruning, hedging, and harvest, plus the cost for the equipment and equipment operator.

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