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Summer pruning of apple: impacts on disease management

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Abstract: Pruning, including summer pruning, of apples can have a positive impact on disease management in two basic ways: through removal of dead tissue and inoculum, and through alteration of the canopy microclimate. Summer pruning can also increase diseases if it is done when disease risk is high. However summer pruning is used almost exclusively as a horticultural tool to improve fruit quantity and quality. As orchard planting and training systems have moved from semi-dwarf trees to high-density, fully-dwarf trees, very few summer pruning studies have looked at impacts related to disease, yet summer pruning in high-density systems may have important disease management effects. Growers should avoid summer pruning practices which will increase disease risks, and use those that offer both horticultural and disease management benefits. More research in this area is needed, as cultural components of apple disease management will become increasingly important in sustainable production systems. This review looks at important apple diseases, including apple scab, fire blight, sooty blotch and flyspeck, black rot, white rot, Nectria canker and powdery mildew, and uses dormant pruning studies plus knowledge of the epidemiology of the diseases to suggest ways that summer pruning would be expected to impact disease management.

1. Introduction

Summer pruning of apples (*Malus* x *domestica*) is a practice used primarily to enhance fruit quality through the manipulation of tree physiology and alteration of the canopy environment, particularly light. The majority of studies of summer pruning in apple have focused on physiological impacts such as photosynthate partitioning, winter hardiness, return bloom, fruit coloring and post-harvest quality. However, summer pruning can have impacts on apple diseases, because it alters canopy microclimate, can remove diseased tissue, improves deposition of fungicides and other chemicals, and in altering tree physiology may change resistance to disease. Summer pruning may enhance disease management, but in some cases may increase the risk of disease. Of the few studies that have investigated interactions between summer pruning and apple diseases, most were done on semi-dwarf trees, and very few have looked at high-density systems.

In semi-dwarf trees, summer pruning offered both horticultural and disease management benefits. This is illustrated by an example from the mid-1980's in the northeastern US, where summer pruning was used to compensate for the loss of daminozide in commercial apple production (Autio and Greene, 1990). The predominant cultivar produced in the region at that time was 'McIntosh', which frequently drops fruit to the ground before they are sufficiently colored for harvest. Daminozide (Alar®) prevented this premature fruit drop, allowing development of full fruit color. When the manufacturers of daminozide removed the registration for apple use, it created potentially devastating crop loss through premature drop in 'McIntosh'. As a response, growers were encouraged to summer prune, primarily to accelerate development of fruit color through increased light penetration in the canopy. The practice was successful, to a large extent compensating for daminozide treatments. It also had a side-benefit, in that incidence of the summer disease complex sooty blotch and flyspeck (SBFS) decreased in summer-pruned trees, primarily as the result of reduced humidity and improved fungicide penetration in the canopy (Cooley *et al*., 1997).

At this time, the most recent major review of summer pruning was written 25 years before this review, focusing exclusively on effects on tree growth, yield, flowering, and fruit development (Saure, 1987). Since then, commercial apple production has seen wide-spread adoption of high-density planting systems in which the methods and impacts of summer pruning would be expected to differ substantially from those used in semi-dwarf (e.g. M.7, ca. 5 m tall) trees, but few studies have examined the impacts of summer pruning on apple diseases in high-density trees. In larger, semi-dwarf trees, summer pruning does not have an impact on the tree scaffold, but focuses on small branches and is largely intended to increase light penetration and

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air circulation, beneficial to both fruit quality and disease management. However, in modern high-density production systems a primary goal is light penetration, and overall tree training maintains a relatively small, open canopy. In such trees, summer pruning may not significantly increase air circulation, improve drying in the canopy, or improve pesticide deposition, and it is unclear whether it has benefits in terms of disease management. Instead, pruning cuts during the growing season may increase the risk of infection. Alternatively, pruning and removing diseased tissue, sanitation, may reduce disease impacts and future risks, but such cuts may conflict with desired tree architecture in a high-density system. Yet as restrictions on chemical use in plant disease management increase, cultural controls such as sanitation and inoculum destruction become more important. Much of this review must extrapolate from studies on semi-dwarf trees, dormant pruning, and the epidemiology of apple diseases to identify potential benefits and risks of summer pruning related to disease. It outlines types of summer pruning used in high-density systems, and then looks at important apple diseases that may be impacted by summer pruning and how pruning for sanitation may be useful.

2. Impacts on tree growth, yield, flowering and fruit development

Summer pruning can take on various forms from simple watersprout removal only to significant reductions in canopy density. Much study of summer pruning came from an interest in enhanced light penetration into the summer canopy, thus improving fruit color development. Vincent (1917), Preston and Perring (1974), Stiles (1980), Lord and Greene (1982), Marini and Barden (1982), Morgan *et al.* (1984), Autio and Greene (1990), Schupp (1992), and Ystaas (1992) all showed increased fruit redness as a result of summer pruning. Decreases in fruit size, however, have also been reported in some studies (Stiles, 1981; Marini and Barden, 1982; Greene and Lord, 1983; Myers and Ferree, 1983) but not all and not consistently. Li *et al.* (2003) modeled tree physiology as a result of summer pruning and found reductions in carbohydrates, potentially leading to a carbohydrate shortage after summer pruning. The potential for shortage was greater as the intensity of summer pruning increased. Fruit size impacts of that shortage can be mediated by improved water status resulting from reduced transpiration. Additionally, varying responses may be partially explained by the location of the summer-pruning treatment. Greene and Lord (1983) suggested that, as the severity of pruning increased or as the distance between the cut and the fruit decreased, the potential for a size reduction is enhanced.

Timing of summer pruning also is an important consideration. In general, regrowth during the period following summer pruning is greater the earlier the summer pruning is performed. Autio and Greene (1990) showed a linear decrease in the amount of regrowth as the pruning was performed from early (~45 days after full bloom) to late summer (~105 days after full bloom). Zamani *et al.* (2006) described a similar response from summer pruning from 30 to 90 days after full bloom.

Such data indicate that summer pruning acts as a stress on apples. If a stress is severe enough it can predispose woody plants to disease particularly from canker pathogens, but plants will recover from light to moderate stress (Schoeneweiss, 1981). At the same time, abiotic stresses can induce disease resistance in plants, including apples, though the physiological mechanisms behind induced resistance are not well understood (Hammerschmidt, 1999; Poupard *et al.*, 2003). Developing a better understanding of the detrimental and positive impacts of pruning stress at the physiological level is an area in need of more research.

3. Impacts on disease

Pruning apple trees, including summer pruning, can impact disease in several ways: by altering microclimate and architecture of the canopy, by removing inoculum and infected tissue, and by creating wounds that pathogens can invade. In their experiment in an organic orchard, Simon *et al.* (2006) observed that centrifugal training decreased apple scab and key insect pests in an organic orchard, and listed five explanatory hypotheses: 1) removal of inoculum and arthropods with the removal of fruiting spurs; 2) change in canopy microclimate, particularly better aeration; 3) decreased shoot density and increased distance between growing shoots slowing transmission; 4) changes in tree physiology inducing resistance or otherwise changing tissue susceptibility; 5) decreased canopy density improving pesticide penetration and deposition.

Pruning for sanitation is specifically designed to remove inoculum, thereby delaying or slowing epidemics and decreasing disease incidence and severity. For example, pruning removes primary inoculum of apple powdery mildew and fire blight, and is routinely recommended as part of the management programs for these diseases (Covey and Fischer, 1990; Xu, 1999; Steiner, 2000; Holb, 2005). However, pruning for sanitation often requires pruning cuts that do not conform to horticultural goals, and in most cases is performed in winter or early spring rather than summer. Summer pruning may remove inoculum, though it is not the primary purpose of the practice.

Changing the canopy density alters microclimate thereby impacting infection and disease development. Microclimate factors, particularly those related to moisture, have a major effect on plant diseases (Huber and Gillespie, 1992), and altering canopy density, as summer pruning does, influences canopy drying and disease (Gubler *et al.*, 1987; Cooley *et al.*, 1997; Sentelhas *et al.*, 2005; Batzer *et al.*, 2008). Leaf wetness duration (LWD) is a particularly important factor in plant disease epidemics and is often used in disease forecast models (Gleason *et al.*, 2008). For example, LWD has a major impact on whether or not apple scab (*Venturia inaequalis*) infections occur (Mills, 1944;

MacHardy and Gadoury, 1989; Stensvand *et al*., 2005; Xu and Robinson, 2005). High humidity and LWD also increase disease incidence and severity of SBFS (Cooley *et al*., 2011), cedar-apple rust (*Gymnosporangium juniperi-virginianae*) (Aldwinckle *et al*., 1980), black rot (*Botryosphaeria obtuse*) (Arauz and Sutton, 1989), white rot or Bot rot (*Botryosphaeria dothidea*) (Sutton and Arauz, 1991), Nectria canker (*Nectria galigena*) (Krahmer, 1981; Xu *et al*., 1998), and fire blight (*Erwinia amylovora*) (Steiner, 2000). Of these diseases, apple scab, SBFS, black rot, white rot and bitter rot drive most of the fungicide applications made in the eastern US, and account for substantial fungicide use in many apple production areas around the world (Cooley, 2009). By maintaining an apple canopy that dries relatively quickly, LWD periods are shortened, which may allow decreases in fungicide use.

The relationship between plant growth and the rate of an epidemic is complex, depending on tissue susceptibility, existing infections and the density of susceptible tissue, among other factors (Ferrandino, 2008). For apple scab, the relative risk of infection is affected by the amount of leaf tissue available for infection interacting with increasing ontogenic resistance and inoculum availability, which all change over time (Ficke *et al*., 2002). Summer pruning removes target tissue as well as sources of inoculum, and hence should slow development of apple scab epidemics. The timing of tissue removal should affect disease, and in general removal early in the growing season should reduce disease more than mid- or late-season removal. Still the interaction between pruning and the different epidemiological factors is complex. In the scab example, if early pruning stimulates vegetative growth, the rapid development of relatively large amounts of young, susceptible tissue may erase any early-season disease suppression. Holb *et al*. (2004) observed that heavy winter pruning suppressed foliar scab, but the impact on fruit at harvest was not significant.

For fire blight, it is recommended that flower clusters be removed from non-bearing trees before bloom, because the flowers are an important infection court for *E. amylovora* (Steiner, 2000). Pruning relatively non-productive flower clusters, as in centrifugal training, may reduce risk of fire blight.

Pruning also usually improves penetration of fungicides and other disease controlling chemicals (Sutton and Unrath, 1984; Travis *et al*., 1987; Cooley *et al*., 1997; Cross *et al*., 2003). Both summer (Cooley *et al*., 1997) and winter pruning (Ocamb-Basu *et al*., 1988; Holb, 2005) have been shown to improve spray penetration relative to non-pruned trees, though a comparison between two high density pruning methods in which centrifugal training reduced scab relative to original solaxe pruning did not show a difference in spray deposition (Simon *et al*., 2006).

Apple scab

Scab is probably the most important diseases threatening apples in humid production regions, but only one published study has been done on the impacts of summer pruning on the disease. Disease incidence in apple scab is strongly related to the duration of wetting periods and the amount of inoculum available in an orchard, with longer wetting periods and more inoculum increasing disease incidence and severity (MacHardy, 1996). Simon *et al*. (2006) showed a decrease in scab in high-density plantings pruned using centrifugal pruning relative to original solaxe pruning. They suggested that centrifugal pruning shortened wetting periods in the canopy thereby reducing the number and/or intensity of infection periods, though they do not present data on canopy microclimate.

A study by Holb (2005) looked at different levels of winter pruning on scab in high-density organic orchards, and concluded that heavy pruning significantly reduced the area under the disease progress curve for foliar and fruit scab on susceptible cultivars. They hypothesized that suppression of scab epidemics were caused by a reduction of inoculum overwintering in apple buds, improved fungicide deposition in pruned trees, and modification of the in-canopy microclimate, though microclimate factors did not consistently vary among pruning regimens.

Fire blight

Fire blight is an increasingly serious disease of apples worldwide. The disease affects all apple tissues, but is most damaging when it migrates from primary infections, commonly in blossoms and young shoots, to limbs and trunks. Scaffold limb and trunk infections are particularly damaging, cutting production over several seasons and often killing trees (Van der Zwet and Beer, 1995; Steiner, 2000; Thomson, 2000). Primary infections may also occur when trees are damaged mechanically by hailstones or other means, allowing the bacterial pathogen to enter the plant.

In the case of fire blight, pruning for horticulture purposes also may provide entry points for the pathogen. An early study of effects of summer pruning on fire blight in apple showed that it markedly increased infections (Lake *et al*., 1975). Hence pruning when fire blight models (e.g. (Steiner and Lightner, 1996; Smith, 1999) indicate risk of infection is high should be avoided if possible, or a treatment of streptomycin or other chemical prior to pruning be made if it is not. For example, mechanical hedging as practiced in fruiting walls would be expected to open multiple sites to fire blight infection for several days, and would be analogous to a hailstorm in terms of generating risk of infection from fire blight.

Fire blight epidemics often force growers to prune in an attempt to stop the progress of infections and remove inoculum. Recommendations for such pruning generally suggest cutting back to a healthy branch union approximately 25 cm below visible infections; disinfection of pruning tools with alcohol or bleach between cuts may also be recommended (Van der Zwet and Beer, 1995; Steiner, 2000; Toussaint and Philion, 2008). In apples it has generally been recommended diseased tissue be pruned out as soon as symptoms are observed, and pruning continued at frequent intervals thereafter in order to slow and stop epidemics (Covey and Fischer, 1990; Steiner, 2000; Toussaint and Philion, 2008). Shtienberg *et al*. (2003) found that factors related to the host, pathogen and environment should all be taken into account when determining whether and how to prune fire blight in pears, and elements of this approach may be useful in apples.

Sooty blotch and flyspeck

Summer pruning has been shown to decrease SBFS in apples, primarily because it reduces relative humidity and improves fungicide penetration and coverage in the canopy (Cooley *et al*., 1997). This study was conducted on free-standing semi-dwarf apple trees approximately 5 m tall by 3 m diameter. It is not known whether similar results would be obtained in systems using fully dwarf trees in dense plantings. However a trial in the US showed that it took over 450 hours LWD for SBFS symptoms to develop in fully-dwarf, well-maintained trees while large trees with dense canopies developed signs at 225 hours LWD (Ellis *et al*., 1999). The extent to which fully-dwarf trees in high-density systems may benefit from summer pruning has not be studied. Mummified fruit have been shown to harbor inoculum for SBFS pathogens, and removing these mummies can reduce disease incidence (Gleason *et al*., 2011).

Black rot and white rot

Black rot and white rot are fungal diseases that can attack fruit, foliage and woody tissue of apples. Sutton (1981) showed that much of the inoculum for these diseases comes from prunings in or near production blocks, and it is recommended that prunings be removed or chopped so that they rapidly disintegrate so as to remove inoculum from the orchard. Removing mummified fruit is also recommended as a cultural control. In that rates of these diseases on fruit is related to wetness duration and can be controlled with fungicides, pruning that reduces canopy humidity and improves fungicide coverage would be expected to enhance their management (Sutton, 1981; Arauz and Sutton, 1989; Arauz and Sutton, 1990; Sutton and Arauz, 1991; Parker and Sutton, 1993).

Nectria canker

Nectria can cause infections on fruit and woody tissue in apple. Pruning wounds are susceptible to the disease, and hence summer pruning can have an impact on canker incidence (Krahmer, 1981; Xu *et al*., 1998). Studies have consistently shown that new wounds, including pruning cuts, are readily colonized by *N. galigena*. While this is another example of a disease that can be exacerbated by summer pruning, unlike fire blight, there are no forecast models to predict when summer pruning is less risky. There are fungicidal chemicals that can be very effective in reducing canker incidence if applied right after pruning, including the organically accepted slaked lime (Heijne *et al*., 2005).

Powdery mildew

Since the early 20th century, dormant pruning has been recommended as a control measure against powdery mildew (Fisher, 1920). More recent studies from eastern Europe suggest that summer pruning that targets infected shoots can significantly reduce the disease, and even eliminate the disease (e.g. Berbekov *et al*., 2006; Holb and Abonyl, 2007). Disease reduction is probably primarily the result of inoculum removal, though reduction in canopy humidity may play some role as well (Xu, 1999).

4. Conclusions

While the role of summer pruning in modern high-density apple orchards is not disease management, the practice does alter the canopy architecture in ways that may reduce moisture levels and wetting period duration. For some diseases, notably fire blight and Nectria canker, summer pruning can increase the risk of infection by causing wounds. While some recent studies show that summer pruning can reduce risk for major apple diseases, such as scab and powdery mildew, virtually no studies have been done outside Europe. There is a need to assess the horticultural and disease management benefits and costs of summer pruning across a broader range of climates and high-density production systems, in order to determine whether summer pruning can be an element in economically and environmentally sustainable apple production.

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