Factors Contributing to the Death and Decline of Young Apple Trees

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Keywords: Sudden apple decline, rapid apple decline, apple cold injury, apple viruses, herbicides, fire blight

All across North America, apple growers have been noting occasional but increasing problems with decline and death of young apple trees that cannot be easily explained by attribution to common insect, pathogen, or environmental problems. This phenomenon usually involves trees from the time of planting until they are about eight years old and has become known as rapid apple decline (RAD) or sudden apple decline (SAD), the latter being the term that will be used in this article.

> **"Based on available evidence at this time, I suspect that our current tree decline problems result from a complex of interacting factors that will be very difficult to disentangle and which may differ from one orchard to the next. Cold injury, perhaps exacerbated by viruses or other pathogens, may be more common than is usually recognized."**

The problem began receiving attention sometime around 2014 (Peter, 2017). A variety of potential causes or contributing factors have been suggested, but no single factor can so far explain all of the apple decline problems that have been observed in commercial orchards. This article summarizes our current understanding of the problem, including potential causes and diagnostic characteristics for some specific factors that are known to contribute to the decline and death of young apple trees. For purposes of this article, I will apply the term "SAD" only to sudden tree death that cannot be easily attributed to previously identified biotic or abiotic causes.

Recognized Problems that Predate SAD

Winter injury, fire blight, root rots, canker fungi, trunk boring insects (e.g., dogwood borers, leopard moths), and some viruses have long been recognized for their abilities to cause the decline and death of young apple trees. These factors can usually be identified either via common symptoms, via testing for viruses, or by recovering and identifying the pathogens or insect larvae found in declining trees. However, identifying the role of these factors becomes more difficult when they appear in unusual ways or when interactions with other factors may allow them to become more lethal than would otherwise be expected.

Winter injury damage to trunks can appear on the southwest sides of trees if the injury results from heating-cooling cycles that occur when the sun, sometimes abetted by reflection from snow cover, heats trunks on the southwest sides of trees during the day and that tissue then cools rapidly to subfreezing temperatures at night. Southwest injury can be minimized by painting trunks white so that they reflect sunlight in winter.

Winter injury of the lower trunk can also occur if trees grow late into the season and then encounter extreme temperature drops in late November or December before trees have become fully acclimated to cold temperatures or during mid-winter as the result of fluctuating temperatures. The last part of the tree that acclimates to cold temperatures is the lower trunk from the lower scaffold limbs to the soil line. Young trees that are "pushed" with too much nitrogen fertilizer may continue growing late into the season, thereby making trees more susceptible to winter damage. Even recommended levels of fertilization can cause problems if drought conditions during spring and early summer prevent nitrogen uptake and the applied fertilizer then becomes available to trees following rains in late summer or fall.

Figure 1: Gala apple on M.9 rootstock showing bacterial ooze below the graft union, evidence that fire blight bacteria are killing the rootstock.

Symptoms of winter injury include browning of the bark and cambium layer (i) that stops abruptly at or slightly below the soil line, (ii) that usually extends, at least in a patchy pattern, for a foot or more above the soil line, and (iii) that occurs on all sides of the trunk unless the damage is attributable to southwest injury. Trees affected by winter injury, if they survive, usually develop brown or black discoloration of the older xylem that can easily be seen in cross-sections through the trunks, and this damaged wood is subject to invasion by various weak pathogens than can eventually appear as cankers on trunks and limbs via processes that have been described elsewhere (Rosenberger, 2007).

Fire blight in the rootstock is known as rootstock blight and has been described in numerous extension publications. Rootstock blight should be the first suspect as a cause of tree decline if the orchard had ANY visible fire blight either during the current or previous season AND if the rootstock is either M.26 or M.9 (including all M.9 clones). Rootstock blight is unlikely to occur on trees propagated on M.7, MM.111, Bud.9, or any of the Geneva series of rootstocks. Rootstocks with fire blight often show bark darkened by bacterial oozing (Figure 1) and the necrosis of the root tissue extends well below the soil line. The fire blight bacteria can get into rootstocks either by traveling down through symptomless trunk tissue from infections in the scion cultivar, via direct invasion from infection of shoot tips on root suckers, or perhaps via burr knots or borer damage (although I suspect these are low probability entry points). Trees with rootstock blight often develop reddish foliage just prior to leaf fall in autumn (Figure 2).

Trees with rootstock blight sometimes exhibit unusual symptoms. In Vermont, abundant bacterial ooze from infected rootstocks was noted when trees were at green tip in spring (Rosenberger, 2015). More recently, Dr. Srdjan Acimovic and I identified fire blight as the cause of tree losses in a newly planted block of trees on M.9 'Pajam' rootstocks where trees appeared to have been infected at the base of the tap roots during or shortly after the nursery digging operations. Tree losses totaled 8% of 16,000 trees from a single nursery. These trees grew very well for the first few months after they were planted in spring of 2017, but then gradually succumbed as the pathogen slowly moved upward through the root system, killing roots until no live roots were left. No oozing or necrosis was evident in the rootstock above the soil line because the fire blight pathogen has not evolved to move upward within infected tissue and therefore moves upward very slowly as compared to the downward invasion that occurs when blossoms are infected. Dr. Acimovic confirmed the presence of the pathogen in affected trees using PCR. No additional trees were lost in 2018. This case study illustrates that some tree losses attributed to SAD may actually be caused by known pathogens appearing in unexpected patterns.

Figure 2: Apple trees with rootstock blight showing red foliage in October as compared to unaffected trees with yellow-green foliage. (Photo courtesy of Dr. Srdjan Acimovic)

Figure 3: Warty cankers caused by *Botryosphaeria dothidea* that developed on an apple trunk following drought stress (left) and similar cankers with some of the bark removed to show that small patches of the phloem and cambium are sometimes killed beneath these cankers (right).

Drought stress is an increasing concern in new plantings because the restricted root systems of dwarfing rootstocks used in high density systems (1,000 to 2,000 trees/A) cannot access enough water during dry spells that are increasingly common in the eastern half of North America. Trees under drought stress are frequently attacked by *Botryosphaeria dothidea,* an opportunistic fungus that is resident in older bark and that can damage and even kill the bark and cambium on trees that are water stressed. When periods of water stress are limited, *B. dothidea* may kill only the outer bark, which then peels off in large flakes to reveal healthy, relatively green bark beneath the flakes. Bark infected by B. dothidea may develop a warty appearance (Figure 3). To avoid drought stress, new high-density plantings should be established only where water is available for irrigation during dry spells.

Boring insects of most concern are dogwood borers and black stem borers, both of which have been described in other publications. While borers can contribute to tree decline problems, their presence can be detected easily enough by careful scouting and they therefore fall outside of our narrow working definition for trees affected by SAD.

Root rots caused by *Phytophthora* species can cause decline and death of trees on M.26 and MM.106 rootstocks, but *Phytophthora* root rot has virtually disappeared as the industry has switched to newer rootstocks because M.9, B.9, and the Geneva series are resistant to the most common species of *Phytophthora*. Even when isolations or PCR tests show that *Phytophthora* species are present in declining trees, there is reason to question whether these fungi are primary invaders or only opportunistic pathogens of trees dying from other causes. The one situation where *Phytophthora* species may still be killing trees involves the cultivar "Topaz" and its associated sports where the cultivar, not the rootstock, may die if *Phytophthora* spores are splashed onto the trunk. In these cases, the rootstocks usually remain alive but the trunks die starting at the graft union with necrosis extending upward (Rosenberger 2015). Oak root rot caused by *Armillaria* species is relatively rare in apple orchards in the northeastern and northcentral regions of North America, although it can still cause losses in stone fruit orchards. Other root-invading pathogens, such as *Xylaria* species, which forms "dead man's fingers" around the base of dying trees (Figure 4), is occasionally found in older trees but has not been reported in trees showing SAD. Other relatively rare root pathogens have occasionally been recovered from declining trees but do not seem to be common in blocks showing SAD.

Herbicide injury from glyphosate (Roundup and generics) was identified as the cause of trunk damage on apple trees beginning in 2004, and other symptoms associated with herbicide damage have also been described by Rosenberger (2016, 2019). No one has been able to establish a direct association between SAD and herbicide injury, although indirect effects of herbicides cannot yet be excluded as contributing factors.

Figure 4: Fruiting structures of *Xylaria* species form "dead man's fingers" around the stump of a dead tree. *Xylaria* is occasionally found as a root pathogen in older orchards.

Apple latent viruses are transmitted only via propagation or by root grafting from adjacent trees. The common latent viruses are apple stem pitting, apple stem grooving, and apple chlorotic leaf spot (Fuchs, 2016; Fuchs et al., 2018). Apple mosaic virus is sometimes included in the list of latent viruses, although it occasionally produces visible symptoms on leaves. These latent viruses generally do not cause any visible symptoms or direct tree decline, although they have been documented to reduce tree growth by up to 43% and yields by up to 46% in some cultivars (Cembali et al., 2003; Maxim et al., 2004). Clean nursery stock programs initiated during the 1950s and 1960s pretty much eliminated these virus problems, but those programs gradually were abandoned due to lack of interest and funding (i.e., they were too successful).

Now tree decline from latent viruses is re-emerging as a commercial problem, especially if virus contaminated budwood is used to propagate trees on G.935 rootstocks. Although more research is needed, it seems likely that if healthy trees on G.935 (i.e., trees propagated with virus free budwood) are later top-worked using grafting wood that carries latent viruses, then those trees will decline following top-working. It behooves growers to request and insist upon trees that are propagated using virus free scion material so as to avoid tree losses and growth/yield reductions that can be associated with latent viruses.

New Factors That May Contribute to SAD

New pathogens: New molecular tools have vastly increased the ability of scientists to discover and identify pathogens that have either been recently introduced or that were previously overlooked. In some cases, damage from new pathogens may have been lumped together with similar damage from older, known pathogens.

Within the past few years, scientists working on tree decline in Pennsylvania identified a luteovirus, a class of virus never before reported in apples (Lui et al., 2018.) Virologists in Washington State have also identified several additional new viruses in Honeycrisp apple trees (Wright et al., 2018), and a new viroid has been described in Pacific Gala in British Columbia (Messmer et al., 2016). Also in British Columbia, Úrbez-Torres et al. (2016) reported new species of aggressive wood-invading fungi in apple trees. In Japan, Fujikawa et al. (2019) recently reported that a soft-rot bacterium, *Dickeya dadantii* (formerly *Erwinia chrysanthemi*, a cause of potato soft rot), can cause a quick decline of apple trees. This pathogen was found primarily in water-logged, saturated soils and caused trunk lesions somewhat similar to those caused by the fire blight pathogen but with mushy bark as occurs following infection by *Phytophthora*. It is not yet known if this pathogen is present in apples in North America, but the fact that it is associated with poorly drained soils suggests that it probably is not a major factor in the SAD problem in North America.

At this point, scientists employing new tools to detect pathogens are a bit like a three-year-old at Christmas who, having unwrapped a new toy, excitedly exclaims "Look what I got!" But then, after a moment's consideration, the child asks "What does it do?" It may take a number of years to sort out exactly what the newly reported pathogens of apples actually do to the trees because in most cases the ability of these new pathogens to cause disease is still in question and their effects on different cultivars and rootstocks remain totally unexplored. If the new pathogens only weaken trees, perhaps by making them more susceptible to winter injury, then it will take even longer to sort out exactly how important they are because pathogenicity tests in the absence of interacting stresses may fail to show their importance.

Interaction effects: Several seasoned observers have suggested that most of the SAD problem can be explained by winter injury. In fact a very detailed study of one orchard in Wayne County resulted in the conclusion that there were no pathogens or soil microflora problems that could explain the tree decline, and the authors suggested that winter injury might have been the underlying cause of the problem (Singh et al., 2019). The authors of that study noted that most of the visible damage in declining trees occurred below the graft union, something that might be expected from winter injury on trees where a very cold-resistant cultivar (in this case Honeycrisp) is grafted onto a less winter-hardy rootstock, such as M.9. Other observers have noted that symptoms on declining trees sometimes appear primarily above the graft union, something that might also result from winter injury if the rootstock is more cold hardy than the scion cultivar.

Nevertheless, other factors suggest that winter injury alone cannot account for the SAD phenomenon in many orchards. The patterns of tree loss often are too random, not limited to the coldest parts of the orchard, and in some cases the area encompassing declining trees enlarges every year in patterns that would suggest spread of an active pathogen. Dan Donahue of the Eastern NY Commercial Horticulture Program has documented the spread of tree decline in a Zestar block in Columbia County for the past four years, but he and his colleagues have not been able to determine the cause of the decline and have so far found no direct correlation with virus infections.

Based on available evidence at this time, I suspect that our current tree decline problems result from a complex of interacting factors that will be very difficult to disentangle and which may differ from one orchard to the next. It may be that some viruses (either newly discovered or older) may decrease winter hardiness. I noted over many years in the Hudson Valley that peach trees that developed stem pitting from infection by tomato ringspot virus, while they may have appeared slightly unthrifty to growers, almost always were killed during harsh winters and their loss was often attributed to winter injury. An extensive review of the literature revealed no controlled trials looking for interactions between viruses and winter hardiness in apples.

Glyphosate exposure is known to reduce by several degrees the winter hardiness of trees exposed to glyphosate drift (Rosenberger et al., 2013), but impacts of other herbicides on winter-hardiness have not been evaluated. The observation that SAD problems seem more common in orchards with very clean strips beneath trees as compared to orchards with more weeds raises questions about possible linkages between ground cover management and SAD (Rosenberger, 2019). Jentsch (2019) also discussed other potential but unproven interactions that might contribute to tree decline and subsequent borer infestations.

It is worth noting that decline problems in young apple trees are not really new. In his annual report for the Geneva Experiment Station for the year ending June 30, 1924, Dean A.R. Mann noted that the station was addressing a problem with death of young trees, especially via scientists who were first appointed to work in the Hudson Valley in 1923: "Frequently fruit trees die without apparent cause. In some cases their condition is first noticed when they fail to put out leaves in the spring. In other cases they put out leaves but die quite suddenly soon afterwards. This trouble is not confined to the Hudson Valley or even to New York State. It is of wide occurrence and plant pathologists, as well as fruit growers, have been long puzzled by it. Last year when a special appropriation was made for horticultural investigations in the Hudson Valley it was decided to make an attempt to find out the cause or causes of such dying of fruit trees in the Hudson Valley, where complaints of the trouble have been rather numerous of late. It is planned to make detailed observations of a large number of the dead and dying trees. ..."

Four years later in May 1928, the plant pathologist in charge of those investigations, E.V. Shear, entered the following in his annual progress report for that project: There have been no practical results under this project. It is expected that, in time, some of this work may yield something of practical value to fruit growers. Some of the work is not expected to furnish any conclusions for some year in the future.

Hopefully, our current problems with tree decline will be resolved more efficiently and effectively, but my guess is that it will still take considerable time to sort out the contributions and importance of the various factors involved in causing the decline and death of young apple trees in our modern orchards.

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