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# Organically acceptable practices to improve replant success of temperate tree-fruit crops

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ABSTRACT

For most temperate perennial fruit crops, replanting into soil that was used previously to grow the same or a related crop species usually results in poor early growth, preventing new plantings from reaching potential levels of productivity and economic returns to growers. Increases in population densities of root pathogens along with deleterious changes in soil quality under the preceding crops are largely responsible for these replant disease complexes. Driven by the rise in organic fruit production and new restrictions on fumigants and fumigation practices in the conventional sector, considerable research has been aimed, over the past two decades, to the development of non-chemical and organically-acceptable means of managing replant disease complexes. As apple is the most widely grown temperate perennial fruit crop, the majority of this research has been directed at the apple replant disease complex. This review summarizes knowledge of the causes of replant disease complexes of temperate orchard crops, and recent applied research on organically-acceptable practices to reduce the impacts of these disease complexes. *Brassica* seed meal amendments and composts show considerable promise as pre-plant soil amendments to improve replanted tree establishment. Composts have the added benefit of contributing to improvements in overall soil health that may enhance productivity in the long-term. Additional research to understand better the mechanisms by which compost amendments enhance replanted tree establishment would lead to improvements in the effectiveness and reliability of their utilization to alleviate replant disease.



## 1. Introduction

For most temperate perennial fruit crops, replanting into soil that was used previously to grow the same or a related crop species usually results in poor early growth, preventing new plantings from reaching their full potential for production and economic returns to growers. Increases in population densities of root pathogens along with deleterious changes in soil quality under the preceding crops are largely responsible for these replant disease complexes. Conventional producers often use pre-plant fumigation to reduce the impacts of replant disease complexes. Driven by the rise in organic fruit production as well as new restrictions on fumigants and fumigation practices in the conventional fruit sector, considerable research has been aimed, over the past two decades, at the development of non-chemical and thus organically-acceptable means of managing replant disease complexes. This review first summarizes knowledge of the causes of replant disease complexes of temperate orchard crops and then examines recent applied research on organically-acceptable practices to reduce the impacts of these disease complexes. As apple is the most widely grown temperate perennial fruit crop, the majority of the research has been directed at the apple replant disease complex. The more limited research that has been conducted on stone fruit trees (Browne et al., 2013), as well as *Rubus* spp. caneberry crops (Forge et al., 2015a; Trudgill, 1984) indicates that the disease complexes afflicting those crops are remarkably similar to apple. Pre-plant soil management practices that will be covered in this review include pre-plant incorporation of organic amendments, microbial inoculants, nematode-suppressive cover crops, green-manure/bio-fumigant cover crops and bio-fumigant seed meals. The differential genetic tolerance of new rootstocks to the replant disease complex will also be considered.

Nutrient and water management practices implemented after planting also have strong influences on root growth and tree establishment during the first few years after planting, but will not be considered in this review. For additional information on beneficial post-plant practices, the reader is referred to recent research addressing the influences of organic mulches on plant-parasitic

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nematodes and other aspects of orchard soil health (e.g., Forge et al., 2003, 2008, 2013, 2015b; Leinfelder and Merwin, 2006; Neilsen et al., 2014a; Peck et al., 2011; Rumberger et al., 2004, 2007), as well as the benefits of high frequency pulsed irrigation and annual bloom-time phosphorus fertigation (Neilsen et al., 1993, 2008, 2010, 2014b).

## 2. Causes of poor orchard replant establishment

### 2.1. Nematodes and soil microorganisms

The poor growth of young fruit trees replanted into old orchard soil, a syndrome which has been referred-to as "soil sickness", "soil exhaustion", "replant disorder" and "replant disease", has been recognized for decades (Ark and Thomas, 1936; Colbran, 1953; Hoestra and Oostenbrink, 1962). Plant-parasitic nematodes, particularly root-lesion nematodes (genus *Pratylenchus*) have been associated with this syndrome since it was first identified (Ark and Thomas, 1936; Colbran, 1953, 1979; Hoestra and Oostenbrink, 1962; Mai, 1960; Parker and Mai, 1956; Pitcher et al., 1960). Early studies using controlled inoculation (Ark and Thomas, 1936; Colbran, 1953, 1979; Jaffee and Mai, 1978; Mai, 1960; Pitcher et al., 1960) established that root-lesion nematodes are damaging to apple and other temperate fruit trees. These controlled inoculation studies were complemented by field observations that replant disease could in many cases be alleviated by application of specific fumigant nematicides such as 1,3-dichloropropene (Telone®, Dow AgroSciences, Indianopolis, IL, USA), dichloropropene-dichloropropane (DD) or ethylene dibromide (EDB) (Colbran, 1953, 1979; Hoestra and Oostenbrink, 1962; Mai and Abawi, 1978, 1981; Parker and Mai, 1956, 1974) as well as the non-fumigant nematicide, fenamiphos (Dullahide et al., 1994; Santo and Wilson, 1990). The species of *Pratylenchus* most often associated with orchard replant problems is *Pratylenchus penetrans* although other species of *Pratylenchus* are also pathogenic to temperate fruit trees and have been linked to poor replant growth (e.g., Dullahide et al., 1994; Nyczepir and Halbrendt, 1993; Stirling et al., 1995). Due to the wide host range of *P. penetrans* and most other *Pratylenchus* species, and early observations that growth of other crops was inhibited in nematode-infested apple orchard soil, the term "general soil sickness" or "general replant disease" came to refer to the version of replant disease associated primarily with root-lesion nematodes (Hoestra and Oostenbrink, 1962; Traquair, 1984). While most of the research on root-lesion nematode impacts has focused on tree establishment in replanted orchards, data indicate that they also have ongoing effects on productivity of mature trees (Santo and Wilson, 1990).

Early researchers recognized that poor replant growth could also occur in soil without nematodes or soil in which the nematode population was reduced by treatment with a specific nematicide. This form of replant disease was initially thought to be more host specific, primarily affecting plant species planted into soil previously used to grow the same tree species, and it was therefore referred-to as "specific soil sickness" (Hoestra and Oostenbrink, 1962) or "specific replant disease" (Pitcher et al., 1966; Traquair, 1984). In recent decades considerable research effort has been aimed at elucidating these non-nematode causes of replant disease. Soil microbes that have most often been associated with replant disease are the fungal genera *Cylindrocarpon*/*Ilyonectria*, *Rhizoctonia* and *Pythium* (Braun, 1991; Manici et al., 2013; Mazzola, 1998; Mazzola and Manici, 2012; Traquair, 1984). No particular species of any of these genera have been definitively identified as a universal primary cause of replant disease, and multiple genera are usually present infecting roots at any given site presenting replant disease symptoms. Koch's postulates have been performed on some of the fungi isolated from diseased tree roots, demonstrating that they are capable of causing disease under a given set of conditions. No studies have also reported the natural frequency of occurrence of these fungi in soils that do not cause replant disease. Changes in bacterial community structure have been correlated with replant disease, but no particular bacterial species have been identified conclusively as apple root pathogens (Caputo et al., 2015; Franke-Whittle et al., 2015; Manici et al., 2015).

Because replant disease has been observed in the absence of root-lesion nematodes or where their population densities are apparently low (Manici et al., 2013), some researchers have generalized that root-lesion nematodes do not contribute to replant disease, but there is no doubt that root-lesion nematodes are key components of the complex where they are present. On other crops root-lesion nematodes are known to act synergistically with fungal pathogens. For example, *Rhizoctonia* infection of strawberry is increased in the presence of root-lesion nematodes, causing black root rot (LaMondia and Martin, 1989). Although such specific synergistic interactions have not been conclusively demonstrated for temperate fruit trees, the frequent co-occurrence of root-lesion nematodes with *Cylindrocarpon*/*Ilyonectria* and *Rhizoctonia* species in orchard replant soils suggests that such synergistic interactions are likely. Root-lesion nematodes are easier to isolate, identify and quantify than the array of fungal pathogens that may be associated with poor replant growth. Consequently, root-lesion nematodes can be viewed as indicator organisms for the replant complex where they are present, and research describing the effects of soil management practices on replant disease has more often included analyses of root-lesion populations, in addition to tree growth responses, than any of the fungal pathogens.

### 2.2. Chemical residues

A considerable number of early studies explored the possibility that compounds toxic to juvenile trees build up in the root zone of mature orchard trees (reviewed by Traquair, 1984). One proposed mechanism was that decomposition of old apple roots liberated the toxic phenolic compound phloridzin into soil. In the case of *Prunus* spp., wounding of roots by nematodes or other organisms was proposed to lead to the hydrolysis of amygdalin, a cyanogenic glycoside in root bark, releasing toxic by-products. The buildup of pesticide residues, e.g., arsenic residues from historical use of lead arsenate insecticides, have also been implicated in poor replant establishment. Research has shown that even where soil arsenic concentrations are elevated, biological factors still have a dominant influence on replant growth (Benson et al., 1978). While it seems evident that neither biogenic nor anthropogenic chemical residues are important direct causes of poor replant growth, they could nonetheless be important factors shaping soil biological communities in old orchard soil and thereby contribute indirectly to the development of the pathogen complex that causes poor replant growth.

### 2.3. Inadequate phosphorus availability and the mycorrhizal connection

The non-pathogen factor that has most often been implicated in poor replant establishment is phosphorus (P) nutrition. Slykhuis and Li (1985) demonstrated that P fertilization, particularly with mono-ammonium phosphate (11-55-0) (MAP) generally improves apple seedling growth in both pasteurized and non-pasteurized replant soils. Indeed, they found that in some replant soils P fertilization improved growth as well as pasteurization. A number of subsequent studies have demonstrated the benefits of P fertilization for apple replant establishment under field conditions in a wide range of soils (Dullahide et al., 1994; Moran and Schupp, 2003, 2005; Neilsen et al., 1990, 1991, 1994, 2008; Neilsen and Yorston, 1991; Wilson et al., 2004). Phosphorus fertilization appears to