A review of the current knowledge of apple replant disease

A study funded by The AHDB

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1. Background and introduction

With the recent rise in establishing apple fruit wall production systems on old orchard ground, there has been a corresponding increase in apple replant disease which has significantly reduced the financial returns in the early years after establishment. In response to growers concerns about the problem, AHDB commissioned the production of this review of current knowledge of the disease, its management and possible control measures.

Apple replant disease is a debilitating soil problem affecting trees when they are replanted on the same site. Due to the inconspicuous nature of the reduced tree growth, it can be easily attributed to poor establishment of young trees due to poor soil conditions and/or poor quality nursery trees. This type of reduced tree growth in young orchards has been called various names, including soil sickness, soil exhaustion, replant disorder, replant problem and replant disease. The current consensus is that the primary causal agents of this phenomenon are of the microbiological nature, and hence it has now been commonly called replant 'disease'. Apple replant disease affects plant propagation in nurseries as well as apple production worldwide. Replant disease was a significant problem in UK apple production in the 1970s and 80s, but then declined in importance. However, recently the problem has increased in prevalence mainly due to the domination of the nursery industry by a few large nurseries and the lack of virgin land for new planting. In addition, the life expectancy of modern commercial orchards is shorter, resulting in more frequent replanting.

2. Replant disease symptoms

Apple replant disease has no definite symptoms other than poor growth within the first few years after replanting on old orchard sites. Uneven growth across the orchard, stunting, and shortened internodes on shoots are typical symptoms of replant disease (Figure 1). Leaves on affected trees are often smaller and lighter green than leaves on vigorous trees. When the roots are examined,

Figure 1. Symptoms of apple replant diseases: uneven growth, reduced tree vigour and reduced fruit production potential. Trees in the photo were replanted into a previous apple orchard.

root tip necrosis and reduced root biomass can be seen; existing roots become discoloured and deteriorate. In severely affected cases, young trees may die within the first few years. Although many will survive, overall fruit production and quality can be significantly reduced (Figure 1). The severity of replant effects can vary from site to site.

Replant disease has also been reported in other plants; members of the Rosaceae, such as cherry, peach, plum, strawberry, rowan and rose, are especially prone to the problem. Previous studies have categorised replant disease as having two forms: specific and non-specific. It is assumed that specific apple replant disease only affects apples when they are planted after apples, while non-specific replant disease affects apples that are replacing other fruit crops, such as stone fruit or vice versa.

3. Causal agents

Poor tree growth may result from a plethora of abiotic and biotic factors. Abiotic factors may include diminished soil fertility, degraded soil structure, extreme pH values, phytotoxic compounds produced from crop residues in soils and residual herbicide activity. However, in newly planted orchards, such abiotic factors are not usually an issue, as they are identified and corrected by the grower in routine site preparations prior to planting. Therefore, in newly planted orchards, the biological factors that include nematodes, various fungal pathogens and oomycete[1] pathogens, are usually considered to be the cause of poor tree growth. The identity and consistency of individual biotic factors that give rise to replant disease are often debated for two principal reasons:

1. Not every biotic factor needs to be present to cause replant disease – the relative importance of each factor may vary greatly from site to site.
2. Investigations to confirm the biotic factors responsible have been hampered by a lack of precise methodologies to profile microbiota and isolate candidate organisms.

The view that biotic factors are the main cause of replant problems is supported by some strong evidence. Replant disease issues occur globally in all major apple producing areas indicating that specific soil characteristics are unlikely to be a primary causal factor of the replant problem. Fumigating soils with broad-spectrum biocides, such as methyl bromide, leads to significant increases in growth of young trees in comparison with non-fumigated plots. The high efficacy of methyl bromide in preventing replant problems suggests that the causal agents are of biological rather than physical origin. Dilution of pasteurised soil with as little as 10% of the original field soil can still cause reduced tree growth, which is a further indication

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[1]The Oomycetes, also known as water molds, are a large group of terrestrial and aquatic eukaryotic organisms. They superficially resemble fungi in mycelial growth and mode of nutrition (hence previously referred to as "lower fungi" and classified in the kingdom Fungi), recent studies place them in the kingdom Chromalveolata with brown and golden algae and diatoms. The terrestrial Oomycetes are primarily parasites of vascular plants, include several important crop pathogens: downy mildew pathogens, and several species from *Pythium* and *Phytophthora*.

that biological factors are the primary cause of apple replant disease. Finally, more direct evidence for biological factors is the frequent isolation of commonly known plant root pathogens both from replant soil and roots of trees with replant syndrome. Direct inoculation of apple trees with these pathogenic strains leads to typical apple replant syndrome. It is therefore now generally accepted that apple replant disease is a disease-complex primarily caused by microbial pathogens but its severity can be influenced by many other factors including the soil characteristics and environmental conditions of individual sites.

Although various approaches have been employed in an effort to characterise the etiology of replant disease, differences continue to exist in terms of quantifying the relative importance of individual pathogens. Convergence has evolved around a group of fungal, oomycete and nematode agents that appear to contribute to the disease worldwide. These include the oomycetes *Pythium* and *Phytophthora* and the fungi *Cylindrocarpon*, *Rhizoctonia* and *Fusarium*. The presence of parasitic nematodes can exacerbate replant disease severity probably because nematodes damage the roots, facilitating infections by pathogens. More recently, numerous studies on microbial community analyses of replant soils confirmed large differences in the microbial community structure between replant and non-replant soils. These studies indicated an association of high fungal abundance and low bacterial abundance with rhizosphere soils of trees with replant symptoms. Nevertheless, on their own these molecular-based microbial population studies will not be able to identify specific casual organisms. They are a powerful tool to identify both pathogenic and beneficial microbial organisms associated with tree health, helping the development of management strategies.

4. Management and control strategies

When implementing replant disease management measures, it should be borne in mind that the relative importance of replant causal agents can vary greatly between orchards. Consequently, a single disease control measure is unlikely to manage apple replant disease consistently and effectively across regions. It is now generally accepted that managing apple replant disease will rely on implementation of several measures, especially at those sites where more than one replant pathogen is likely to be present. Table 1 in the Appendix lists possible measures to minimise potential losses due to apple replant disease.

4.1 Testing soils

Progress toward achieving sustainable management of apple replant disease continues to be hindered by a lack of understanding of the effect of interactions between biotic and abiotic factors on replant disease development. As replant disease can be caused by several pathogens and further exacerbated by other factors, it is important to gather some information on the presence and the level of specific pathogens and general soil characteristics such as pH, soil fertility and microbial communities. This information helps to guide what measures should be implemented. Soil testing for pH and nutrients is part of the routine for preparation of the site prior to planting. There are currently no commercial tests available to check for replant disease.

4.2 Pre-planting control – cultural

Old plant material (particularly roots) should be thoroughly removed as soon as possible once the existing orchard is grubbed. This will not only minimise phytotoxicity due to plant residues but is also likely to reduce the level of pathogen inoculum.

4.3 Pre-planting control - chemical

Previously, replant disease was effectively managed by soil fumigation using broad-spectrum products, such as methyl bromide and chloropicrin. However, these broad-spectrum fumigants are now banned because of their harmful effects on the general environment. Other fumigants, such as dazomet, may not be as effective as methyl bromide. Because of the lack of a single effective soil fumigant, the complex nature of agents causing replant disease, the environmental concerns and the incurred cost, chemical fumigation of soils is no longer considered as a viable measure in commercial apple production in the UK.

4.4 Pre-planting control – non-chemical

4.4.1 Anaerobic soil disinfestation (ASD)

ASD offers a pre-plant (non-chemical) soil disinfestation technique and is often proposed as an alternative to chemical soil fumigation to control soil-borne diseases, plant-parasitic nematodes and weeds in different vegetables and fruit crops. The method consists of the introduction of plant-based products (granular or liquid) into the soil, followed by covering the soil for a certain period of time to increase soil temperature and contain the chemical by-products released. The general mechanism of this technique is believed to be related to the increase in bacterial abundance in treated soils. In a recent Dutch trial, Herbie (a specific ASD product) treatment led to reduced apple replant disease development. Molecular profiling of rhizosphere soils showed that the Herbie treatment led to greater bacterial abundance in the rhizosphere, including several well-known bacteria such as the genus *Pseudomonas* and the genus *Bacillus*. However, the use of such ASD products may need approval from CRD before they can be used commercially.

4.4.2 Soil biofumigation

Incorporating Brassica plants/green materials into soils has been shown to be effective in controlling several soilborne pathogens such as *Verticillium*. Research at the Washington State University indicated that *Brassica juncea* seedmeal can provide effective management of apple replant disease through generation of biologically active glucosinolate hydrolysis products and/or transformation and activity of resident soil biology. However, brassica seed meal appears to be able only to control fungal pathogens in apple replant disease complex and is not effective against oomycete pathogens. However, the use of the seed meal together with a post-planting application of metalaxyl M + mancozeb (Fubol gold) can completely control apple replant disease. Using 7 tonnes of brassica seed meal per treated hectare as a pre-plant soil amendment in the autumn prior to planting is recommended in the USA.

4.4.3 Beneficial microbial products

If fungal pathogens are the main cause of apple replant disease at a given site, the use of specific biocontrol products and beneficial microbial products should give some control. Beneficial products may include arbuscular mycorrhizal fungi (AMF) and plant growth promoting rhizobacteria (PGPR). However, if oomycete pathogens are the main cause, use of these products may not be effective. There are currently no known alternative products that can control oomycetes effectively.

4.5 Planting - Cultural practices

4.5.1 Planting position

Replanting in the rows that made up the alleyways of the previous orchard offers an alternative approach which may reduce the replant problem. Recent studies have shown that the soil microbial community (including potential replant pathogens) differs greatly between tree stations and the grass aisle although they are only a couple of metres apart. However, it must be stressed that intensive competition from weeds at the early tree establishment stage will likely cause more problems than replant disease. Therefore, if trees are to be planted in the previous grass alleyways, extra care is needed to control weeds fully before planting. For the same reason - different plant species are associated with different rhizosphere microbiota and may considerably affect microbial community in bulk soils - a ‘break crop’ may be grown before replanting. Following the same reasoning, it has been suggested that if specific plant species are grown in the alleyways in the last few years of an orchard’s life, replanting in the alleyways may avoid replant disease problems.

4.5.2 Rootstock choice

Whenever possible, avoid replanting trees with genetically similar rootstock genotypes. It is known that rootstock genotypes differ in their susceptibility to apple replant disease. However, recent knowledge indicates that the response of rootstocks to replant disease is influenced by soil conditions (e.g. pH, soil type). Currently there is insufficient knowledge to make an informed decision on choice of rootstock. Thus, only general recommendations can be made. Firstly, avoid replanting trees with the same or genetically very closely related rootstock genotypes as the previous one, particularly dwarf ones. Secondly, more vigorous variety/rootstock combinations are much less likely to be affected by replant problems and offer an alternative if the site is known to suffer from replant disease.

4.6 Treatments at planting time

Trials have shown that placing peat compost in the planting hole and/or using trickle irrigation and soil mulches can partly or wholly suppress the effects replant disease. However, the limited knowledge over the effect of compost on microbial dynamics in soils makes predicting its efficacy difficult. Including beneficial microbial products such as AMF and PGPR in the planting hole may also reduce replant disease.

Appendix 1

Table 1 Possible management and control strategies to combat apple replant disease problems

Timing	Method	Comments
Pre-planting	Soil preparation	Removal of old tree roots as much as possible to eliminate inoculum. Correct soil preparation for new orchard site to provide conditions for optimum tree growth.
	Chemical soil disinfestation	Effective products no longer approved. Dazomet unlikely to be effective.
	Anaerobic soil disinfestation	Possible alternative. Boosts bacteria in the soil. May need CRD approval.
	Biofumigation	Brassica plants/green materials incorporated into the soils. May only be active against fungal pathogens not oomycetes.
	Beneficial microbial products	Use of beneficial products such as arbuscular mycorrhizal fungi (AMF) and plant growth promoting rhizobacteria (PGPR) may give some control but not effective against oomycetes.
Planting	Planting position	Replanting in the area that were alleyways in the previous orchard can reduce replant problems. Extra care is needed to control weeds fully before planting.
	Rootstock choice	Avoid planting trees with closely related rootstock genotypes. More vigorous variety / rootstock combinations are likely to be less affected by replant disease and offer an alternative provided the site is known to have a replant problem.
	Treatments at planting time	Placing peat compost in the planting hole and / or using trickle irrigation and soil mulches can partly or wholly suppress the effects replant disease. Use of beneficial products such as AMF and PGPR in the planting hole at this time may give some control.