Ecology and control of grapevine root diseases in New Zealand: a review

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Abstract Grapevine root diseases can result in economic loss during vineyard establishment. Symptoms may not be noticed in vineyards until vines die. The death of young vines as a result of root rots can be a point of contention between the grower and the nursery supplying the plants. In New Zealand root diseases include black foot rot (caused by *Cylindrocarpon* spp.), verticillium wilt (caused by *Verticillium dahlia*), phytophthora root rot (caused by various *Phytophthora* spp.) and armillaria root rot (caused in New Zealand by *Armillaria novaezelandiae* and *A. limonea*). Of these diseases, black foot rot is the most commonly observed in the field in New Zealand and has received the most study. This review provides information on symptoms, causal organisms, disease cycles and, where available, control of grapevine root rots under New Zealand conditions.

Keywords root diseases, grapevines, management.

INTRODUCTION

Grapevine root diseases can cause whole plant losses in vineyards, resulting in additional costs of replacement vines and the management of mixed-age plantings. Grapevine root rots observed in New Zealand include black foot rot (caused by *Cylindrocarpon* spp.), verticillium wilt (caused by *Verticillium dahlia*), phytophthora root rot (caused by various *Phytophthora* spp.) and armillaria root rot (caused in New Zealand by *Armillaria novaezelandiae* and *A. limonea*). Root diseases are often a problem in nurseries (Graham 2007; Jaspers 2013b) and during vine establishment in the vineyard (Gubler et al. 2004). Anecdotally, the replanting of vines at sites with a history of grape growing results in higher losses of vines to root rots than in new sites, and most of the management practices for root diseases aim to reduce the inoculum present

in the soil at the time of planting (Graham 2007; Jaspers 2013a,b).

Root diseases can be managed through good vineyard hygiene, especially with regard to infected roots and residues (Jaspers 2013a). Vineyard manipulations can also be used to prevent root disease, with drainage often the most useful cultural control (D.C. Mundy, unpublished data).

As infection sites are below ground, by the time top symptoms are seen it may be too late to save the vine. Disease management options are usually aimed at prevention and removal of infected grapevine tissue. This review summarises the research that has been carried out in New Zealand, the current information from the literature available to vineyard managers, and information gleaned from sources such as PhD theses and popular articles.

BLACK FOOT ROT

This is a commonly identified disease of young vines in New Zealand, and has only been observed in vines in Marlborough since 2000 (D.C. Mundy, unpublished data). Due to the relatively recent reporting of this disease, it is not listed in “Compendium of Grape Diseases” (Pearson & Goheen 1988) or “Grape Pest Management” (Flaherty et al. 1992), which are the common reference texts for other root diseases of grapes in New Zealand. Lincoln University researchers and others have remedied this gap by publishing on the pathogen, and on disease management for New Zealand winegrowers and the associated nursery industry (Graham 2007; Jaspers 2007; Bleach et al. 2008; Shiller 2008; Probst 2011; Brown et al. 2012; Jones et al. 2012; Bleach et al. 2013; Brown et al. 2013; Jaspers 2013a,b).

In California, this disease of young plants has become more widespread and serious since 1995 (Gubler et al. 2004). First reported in France in 1961, black foot disease occurs in all the major viticultural regions throughout the world, including Italy, Portugal, Spain, South Africa, New Zealand, Australia and California (Bleach et al. 2013). Young vines up to 8 years old are primarily affected by the disease. Because diseased plants must be removed, the disease causes substantial economic losses from replanting costs (Gubler 2013).

Within Marlborough black foot rot is the most commonly identified root disease associated with death of young vines. It is commonly observed on vines with waterlogging or other stress factors such as frost damage of young vines under Marlborough conditions (D.C. Mundy, unpublished data). While vines as old as 14 years with black foot rot have been observed in Marlborough, these vines were of low vigour and had very restricted root areas. More often, the disease is observed in vines 6 years old or younger (D.C. Mundy, unpublished data). One case of 50% mortality of vines has been observed in Marlborough in a section of vineyard that was lower lying than the surrounding area and could not be drained (D.C. Mundy, unpublished data). Other cases with up to 20% vine mortality have been observed, but always with other factors such as frost damage or waterlogging present as well as the disease (D.C. Mundy, unpublished data).

Symptoms

The pathogen is soil borne and causes severe losses when grapevines are grown on susceptible rootstocks in heavy, poorly drained soils (Gubler et al. 2004). The pathogen invades the roots of grapevines and quickly moves into the butt of the rootstock, showing dark purplish or reddish brown necrotic streaking (Bleach et al. 2013). The vascular tissue turns black and the xylem becomes occluded with fungal tissue, gums and tyloses (Gubler et al. 2004). When young vines are attacked, they die very quickly, but as the vines age, infection results in a more gradual decline and death may take more than 1 year to occur (Gubler et al. 2004). However, death seems to be inevitable when vines less than 10 years old are infected with *C. destructans* (Gubler et al. 2004) and vines up to 14 years old have been observed to succumb to the disease (D.C. Mundy, unpublished data). Purple discolouration of the root tissue is common, but isolations are required to confirm the pathogen is present.

Causal organisms

In New Zealand, *C. liriodendri*, *C. macrodidymum* and *C. destructans* have all been reported to produce disease when inoculated onto callused and rooted grapevines from rootstock varieties 101-14 and 5C (Bleach et al. 2009). *Cylindrocarpon parvum* has also been shown to be pathogenic to grapes (Jones et al. 2012; Brown et al. 2013). Bleach et al. (2009) found that callused vines had significantly greater disease incidences than rooted vines. Conidia, chlamydospores and mycelia from all of the isolates were capable of infecting grapevines through wounded roots and callused basal ends. In the Bleach et al. (2009) study, *C. liriodendri* was consistently the most pathogenic species. However, the genus *Cylindrocarpon* has since been reclassified and many of the old species groupings are now shown to represent multiple species complexes (Cabral et al. 2011; Chaverri et al. 2011; Cabral et al. 2012; Pathrose et al. 2014). Within these complexes, different isolates have been reported to be more or less pathogenic than isolates from other complexes. Some infections can be achieved with very low

inoculum. Experimentally, concentrations of 10^2 spores/ml and 1 g of mycelium-infested wheat grains were capable of causing an infection on grapevines in potting mix (Probst 2011). Lincoln University researchers have developed a rapid method of screening isolates for pathogenicity using detached grape roots (Pathrose et al. 2010). This method of screening maybe required to determine how pathogenic individual isolates are, as research carried out before the reclassification may be hard to align to the newly-named species.

Disease cycle and epidemiology

Cylindrocarpon species can persist as resting spores (chlamydospores) or mycelium in rotten root fragments in the vineyard soils even after fruit or forestry host trees are removed (Jaspers 2013a). When vine roots come in contact with the fungus, infection can occur if conditions (such as wet soils and root wounding) are conducive. In New Zealand vineyards, grass grub larvae damage may provide wound sites for black foot rot or other rot rots (Mundy et al. 2005). When insect damage to the roots was observed in the field, black foot rot symptoms were also often present. Non-symptomatic infections may also enter the vineyard on nursery plants (Bleach et al. 2013). Once infected plants are present in the vineyard, asexual (conidia) spores allow the disease to spread from plant to plant within drainage water. Carbohydrate reserves of vines may be important during the infection stage as defoliation has been reported to increase susceptibility of rootstocks to *C. destructans* (Brown et al. 2012). These results have implications for over cropping of young vines during establishment.

Control

One of the best ways to control the disease is correct planting site preparation. The use of bio-fumigation of soils with mustard cover crops has been investigated under New Zealand conditions for the control of this disease, with significant reduction in inoculum (Bleach et al. 2009). Recommendations on rates of mustard seed to be applied to replant areas and timing for turning in a cover crop have been made available

to the industry as a factsheet (Jaspers 2013a). Soil preparation for new plantings, using mustard and addressing some drainage issues with deep ripping to remove any compacted areas are all possible methods of control that can be considered at pre-planting. Pre-planting is also the easiest and most cost-effective time to insert field drains to address any areas of poor drainage.

The use of mycorrhizae on roots before planting did not provide consistent protection against *Cylindrocarpon*, but it did increase root and shoot growth (Bleach et al. 2008; Jaspers 2013a). The use of mycorrhizae in conjunction with other management options may be useful to growers as any one method is unlikely to provide total control.

In a number of cases in Marlborough, when replant problems have been observed with continued cases of black foot rot, changes to the soil physical environment have been required to produce successful re-establishment of vines within the vineyard (D.C. Mundy, unpublished data). For example, in the case of a vineyard planted on an old cherry site with a low area in which vines were dying, drainage of that area prevented any further vine deaths at the site (D.C. Mundy, unpublished data). At a hill site with drainage in place, the unblocking of the field drain in the area of vine deaths prevented any more vines succumbing to black foot rot disease (D.C. Mundy, unpublished data).

To prevent the distribution of infection in nursery material, a number of control steps can be taken. The current New Zealand wine industry recommendations to reduce the risk of nursery material contamination with *Cylindrocarpon* species are to grow plants only in well-drained soils; to rotate nursery beds to avoid build up of inoculum; to use good sanitation during grafting, including the use of fungicide solutions; to wax-dip grafted joints on cuttings; and to sterilise callusing media before use (Jaspers 2013b). Hot water treatment of dormant harvested nursery vines at 50°C for 30 min can provide control without significantly reducing growth rate (Jaspers 2013b). In soils with heavy disease pressure, partially resistant rootstocks

(e.g. Riparia Gloire, 3309 and 5C) can be used (Jaspers et al. 2007; Jaspers 2013b).

One of the problems in trying to control black foot rot is detecting the pathogen in young vines that are non-symptomatic. Two molecular tools have been investigated as possible detection methods for nurseries to determine if plants are infected with the fungi responsible for black foot rot and other wood-based diseases (Shiller 2008; Weir & Graham 2008). Their effectiveness as a standard field tool for the detection of non-symptomatic infections in young vines is yet to be determined.

VERTICILLIUM WILT

Symptoms

The external symptoms of verticillium wilt can be similar to those of other diseases or stress, potentially resulting in misdiagnoses (Pearson & Goheen 1988). Shoots and leaves wilt and die in mid-growing season, with characteristic brown-red discolouration of the vascular tissue of the affected areas. Leaves drop prematurely and fruit clusters fail to develop, then shrivel and mummify. Symptoms range from one or two shoots on a vine to whole plant collapse (Balasubramaniam et al. 1993). Symptoms are associated with restricted water movement in the vascular elements, so symptoms develop as the season progresses and water stress within the plant increases (Pearson & Goheen 1988). Vines not killed may recover completely by the following year.

Causal organism

The fungus *V. dahlia* Kleb. is the causal organism and can be grown on potato dextrose agar if it can successfully be isolated from the infected tissues (Pearson & Goheen 1988). Isolation from field samples has been more difficult than for *Cylindrocarpon* species, and repeated isolations may need to be made. If this disease becomes more common in New Zealand, a molecular detection method may need to be considered, but its occurrence currently appears to be infrequent.

Disease cycle and epidemiology

Verticillium wilt disease is often associated with new plantings into green fields with a past

cropping history of alternative hosts for the pathogen (Flaherty et al. 1992). Infection of the vine occurs via the roots from soil inoculum resulting from previous susceptible crops (Pearson & Goheen 1988). Once established in the roots, the pathogen moves in the vascular tissue up the vine, resulting in wilting or water stress symptoms (Flaherty et al. 1992). Symptoms occur from year 2 onwards and may range from a single wilted shoot to total vine collapse up until year 6 (Pearson & Goheen 1988). The delay in symptom expression could allow nursery stock to be shipped without the disease having been detected.

As with many root diseases in vineyards, the main issue other than the cost of replacement plants is the delay in bringing the vineyard to full production. Vineyards with mixed-age plantings during establishment require multiple passes for vine management, which incurs additional costs compared with conventional establishment in New Zealand conditions.

Control

Infected vines that die should be removed. During 1999 to 2015 in the Nelson/Marlborough district, very few confirmed cases of verticillium wilt were observed. At a site in Nelson, vines with poor growth were removed and replacements planted the following year, with compost (to enhance vine establishment) in each of the planting holes; no new disease occurrences were observed the following season (D.C. Mundy, unpublished data). In one site in Marlborough, affected plants were drenched with carbendazim fungicide and returned to production the following season. However, the vines succumbed in the following season and were removed (I.C. Harvey, PLANTwise Services, personal communication). In California specific control of the disease is not practised, as few vines die and the vines that have symptoms but survive produce normally by year 5 or 6 with no further symptoms (Pearson & Goheen 1988). One method of control is the avoidance of high-risk sites where the disease may have been on another host (e.g. lucerne, potatoes, fruit trees, berryfruits or tobacco). However,

Verticillium spp. causing wilt diseases have about 200 hosts worldwide and are very difficult pathogens to control (Balasubramamiam et al. 1993). In other crops such as olives, solarisation and *Trichoderma* additions to soil have been reported to reduce severity of verticillium wilt (Otero et al. 2014) and may be options under New Zealand conditions.

PHYTOPHTHORA ROOT ROT

Phytophthora root rot occurs in many grape-producing areas of the world, but it is often considered a minor disease because of its low incidence and sporadic occurrence (Pearson & Goheen 1988). This disease is often observed in vineyards with standing water, or it can be associated with vines where the drip irrigation is allowed to run down the side of the lower trunk (Flaherty et al. 1992). The disease is most often associated with young vines (Pearson & Goheen 1988). In Marlborough, cases of this disease have been associated with poorly drained clay slopes (D.C. Mundy, unpublished data). The disease has been observed on single vines, or small areas of diseased vines have occurred where water naturally pools during rainfall events.

Symptoms

In poorly drained areas of the vineyard, infected plants are stunted and appear stressed. Foliage often yellows and the vines defoliate prematurely. Necrotic dark brown cankers are present on the vine trunk at the soil line, extending up and/or down into the roots (Balasubramamiam et al. 1993). Unlike *Armillaria* spp., no white mycelium mat is present under the bark of the root crown (Flaherty et al. 1992). Girdling of the trunk at the ground level by the pathogen will cause vine death (Balasubramamiam et al. 1993). Symptoms are most common in seasons following excessive irrigation or high rainfall (Pearson & Goheen 1988). Vines with early leaf discolouration or fall may be suffering from this disease or another root rot, so digging up of the root system is required to determine if the symptoms are a result of phytophthora root rot.

Causal organism

Various *Phytophthora* species have been reported as pathogens on grapes, including *P. cactorum*, *P. parasitica*, *P. cryptogea*, *P. megasperma* and *P. cinnamomi*. Of these *P. cinnamomi* has been reported as the most virulent on grapes (Pearson & Goheen 1988). These fungi are not restricted to grapevines as host plants and may be present in the soil associated with other infected plant material. There are no published data on the virulence of New Zealand *Phytophthora* species against the rootstocks or own-rooted vines varieties used by the wine industry.

Disease cycle and epidemiology

The disease cycle will depend on which of the *Phytophthora* species are present. Both *P. megasperma* and *P. cinnamomi* have been reported as pathogens of grapevines in California, with slightly different optimum temperatures and wetness conditions for infection (Pearson & Goheen 1988). *Phytophthora* spp. survive in soil as oospores. Direct contact with oospores in infected colonised roots is unlikely. The most likely method of infection is by indirect germination and zoospore production, which then allows movement of zoospores in water films, resulting in root or crown infection as has been observed with kiwifruit (I.J. Horner, Plant & Food Research, personal communication).

Control

The disease is unlikely to develop in vines that are not subjected to prolonged periods of excessive soil moisture (Pearson & Goheen 1988). Avoidance of poorly drained soils or improving the drainage of areas where problems exist are recommended, preferably before planting. Irrigation design to minimise saturation at the base of the plant is also desirable (Balasubramamiam et al. 1993). Long-distance spread of these pathogens can be aided by the movement of infested soil on farm equipment (Flaherty et al. 1992). Hence when deep ripping a vineyard to provide drainage, equipment such as bulldozers should be cleaned before the earthworks start to minimise the introduction

to the site of contaminated soil residue from other actives such as horticulture clearance where *Phytophthora* species may be present (I.J. Horner, Plant & Food Research, personal communication). Judicious use of irrigation is also recommended to reduce the spread of the disease in vineyards already infected (Flaherty et al. 1992). In studies conducted in the Nelson region on apple orchards with drainage issues, the suggested methods of overcoming waterlogging and associated disease issues were: ridging planting rows; soil amendments to increase aeration, address element deficiencies and adjust pH as required for individual soils; and removing water stress with irrigation scheduling, which stops the top soil from becoming waterlogged (Griffiths & Horner 1991). Studies in South Africa have indicated that Paulsen 1045, Paulsen 1103 and St George grapevine rootstocks are highly resistant to *P. cinnamomi* (Pearson & Goheen 1988). In the 1990s rootstocks SO4, 5BB, 5C, 420A, 110R 3309 and 101-14 were extensively planted in California for Phylloxera resistance but with little assessment of resistance to soil-borne pathogens (Gubler et al. 2004). No New Zealand studies have been published, possibly due to the low occurrence of this disease. However, rootstock selection may provide some control at sites at high risk of phytophthora root rot or other grape root rots.

ARMILLARIA ROOT ROT

Armillaria root rot can be a problem in vineyards that have previously been planted with fruit trees (Pearson & Goheen 1988; Horner 1991) or shelterbelts (Horner 1987). The fungus has been called the mushroom fungus, the shoestring or bootlace fungus, the honey fungus and the oak root fungus (Pearson & Goheen 1988). Most commonly the disease results in the loss of only a few vines at a time (Flaherty et al. 1992). In Marlborough a single case was positively identified between 1999 and 2015 at a site with a large number of shelter trees and a high water table. In this case, only two vines died of the disease and further spread was stopped by removing the infected vines. In other regions of New Zealand where mixed horticulture is more common, the risk of armillaria root rot may be higher.

Symptoms

Severe foliage wilting leading to rapid vine death may occur, or sometimes death can be much slower, with the vine having stunted dark green leaves, which may then develop sunburn during the season (Pearson & Goheen 1988). Cane growth becomes weaker and a general decline in vigour is observed before collapse (Flaherty et al. 1992). Under the bark are white mats of the fungus (mycelium), which have a mushroom smell (Pearson & Goheen 1988). These plaques of mycelium never appear on the outside of the bark (Flaherty et al. 1992). Black rhizomorphs can develop on diseased roots, and honey-coloured mushrooms develop on some infected vines in the autumn and early winter (Balasubramamiam et al. 1993). The symptoms on the grape trunk are distinctive from those of other hosts. The mycelial pattern in the grapevine occurs as striations in the white mat found between the bark and hardwood, whereas in other hosts the mat is solid.

Causal organism

The fungus *A. mellea* (Vahl:Fr.) is the causal fungus for this disease overseas (Pearson & Goheen 1988). However, this species is not present in New Zealand. In New Zealand horticultural crops, the two main species are *A. novaezelandiae* and *A. limonea*. These can be readily identified by the presence of characteristic rhizomorphs, which no other fungi possess (I.J. Horner, Plant & Food Research, personal communication). In Marlborough the one sample collected was identified only to the genus level (D.C. Mundy, unpublished data).

Disease cycle and epidemiology

Infection of susceptible roots results from contact with infected woody plant material (Pearson & Goheen 1988). As the disease progresses, patches of vines may die in a vineyard (Balasubramamiam et al. 1993). These will often progress down the row as root-to-root contact allows the disease to spread. In older vineyards, spread across rows is also possible where roots make contact (Pearson & Goheen 1988). Deep tilling can also move the infected roots in a vineyard, resulting in disease spread.

Control

In the past in California, the use of methyl bromide reduced the problem in blocks coming out of fruit tree production (Pearson & Goheen 1988). However, in New Zealand and other countries the widespread use of methyl bromide is banned for soil fumigation. Fumigants can have limited success because of the ability of the pathogen to survive on dead roots at depth for prolonged periods of time (Pearson & Goheen 1988) so the removal of root residues is an important step in an intergrated approach to reduce disease risk. If a susceptible host is present at a site of vineyard development then checking the residues during the clearance phase of development may provide an indication if *Armillaria* is present (Pearson & Goheen 1988). Options for control are limited at a site that has the fungus. Hence in New Zealand it has been recommended to remove and dispose of infested vines; avoid planting susceptible areas such as along or near old tree rows; and if planting in risk areas, to use biological drenches (of active saprophytes) to decay residues or soil fumigation with registered products (Balasubramamiam et al. 1993). Two commercial New Zealand *Trichoderma* products that could be trialled as biological drenches are Growchem DRH (Novachem 2015a) and Agrimm Technologies Limited Vinevax™ (Novachem 2015b). However, neither product is currently registered to control armillaria root rot.

CONCLUSION

Black foot rot has been the most commonly observed root disease during the rapid expansion of the Marlborough wine region from 1999 to 2015 (D.C. Mundy, unpublished data). With a slowing of new plantings and a change to maintenance of existing plantings, the other root diseases outlined here may become more common. Alternatively, with new plantings moving into areas that have previously been considered marginal, root rot issues may change in occurrence. However, regardless of which grapevine root rot is to be managed, site selection and good drainage are common themes.

In New Zealand, methyl bromide is banned for soil fumigation, and other methods of soil treatment are required if a vineyard block is deemed to be high risk. The use of Telone C35 and chloropicrin soil fumigants, which are alternatives to methyl bromide, were not successful at reducing vine deaths when investigated at two previously used grapevine nursery sites (Bleach et al. 2008). New fumigants are under investigation for other crops in New Zealand, such as the carrot industry (Horner et al. 2010), and research from these crops maybe useful to the wine industry. Fumigation would need to be cost effective or, as is the case with carrots, many growers may choose not to fumigate, as the cost is greater than the perceived risk from root rots. Use of fumigants in vine propagation with higher densities of vines and the reuse of soils from season to season may be more economically rewarding.

The use of biofumigants that can be grown on site and worked into the soil without the cost of contractors and fumigation chemicals provides another option for the wine industry (Jaspers 2013a). Biofumigants for black foot rot may also be useful for other root diseases, but these studies under New Zealand conditions are yet to be conducted. In the longer term, rootstocks with resistance or tolerance may be an option for sites that have a high risk of root disease during establishment.

In summary, with the aging of many New Zealand vineyards and the replacement of vines in existing vineyards following removal because of trunk disease or virus infection, root rot issues may become more common.

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