Fruit and Vegetables for consumption do not present such a risk as planting material; nevertheless they are usually infested to some extent with insect pests in particular and they are imported in relatively large quantities. New Zealand will not import these commodities from countries where a serious pest risk exists. For example, we are completely free from fruit flies (family *Tephritidae*) and will not import fruit from areas where the more serious species of this family occur unless an effective treatment such as fumigation is available.

SOIL-BORNE DISEASES AND THEIR ROLE IN PLANT PROPAGATION

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Abstract. The effects of four genera of fungal plant pathogens on seedlings and cuttings are reviewed. Current control measures for these diseases are discussed.

Poor seed germination, seedling diseases, and failure of cuttings to grow are common problems. Many fungal disease organisms have been found to be associated with these disorders. All are soil-borne, while some are also carried on seed and may cause disease when seed is sown in moist soil.

Symptoms caused through invasion of plant tissue by these organisms may include seed rot, pre-emergence or post emergence seedling rot and collapse ("damping off"), and a root rot and/or stem dieback of cuttings.

Unfortunately, conditions required for propagation (i.e. misting, high humidity, etc.) often favour growth of disease organisms which are present. The cut base of cuttings and wounding may provide an entry point for disease organisms. In some cases, poor growing conditions may precede fungal invasion (e.g. with *Pythium* spp.).

The following fungal organisms can be important in preventing establishment of seedlings and/or cuttings:

Fusarium spp. A large number of *Fusarium* spp. are present in soil, often occupying a saprophytic role from where susceptible host tissue may be attacked.

Fusarium avenaceum, *F. culmorum*, *F. oxysporum* and *F. solani* are the more important species involved in diseases of seedlings and cuttings. These species are generally not host specific at the seedling stage and have a wide host range. *Fusarium* attack can result in seedling death, (34, and J.W. Ray,

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pers. comm.), failure of cuttings to become established, or it may produce a debilitating effect on older plants or cuttings by means of root and crown rots. Serious losses from *Fusarium* infection in cuttings have been reported (1).

Symptoms. Although some pre-emergence death of seedlings is often attributed to *Fusarium* attack, this is not a characteristic of the disease. Generally *Fusarium* infection result in ill-thrift, stunting and occasionally death of emerged seedlings. Unevenness of growth and associated leaf yellowing of stunted seedlings can be caused by *Fusarium*. Infection by this fungus occurs particularly in young plants (3) on the root tips at the point of attachment to the mother seed, or via wounds, particularly in 'soft' foliaged or 'succulent' plants (41).

Seedling infection is seen as a root discolouration, ranging from light tan to brown in colour. Often an associated orange-red colouration can be seen within cut roots.

Cuttings are frequently invaded by *Fusarium*, resulting in dieback of the stem from the cut base and infection and death of developing roots. Symptoms include dark brown or black external colouration, brown to orange-red staining within the stem of the cutting, and browning of the young emerging rootlets.

Environmental Conditions. A wide range of soil temperatures [i.e. 5 to 35°C (41 to 95°F); optimum: 15 to 30°C (59 to 86°F)] and low-moderate conditions of soil moisture (14) (i.e. soil above permanent wilting point but below field capacity) favour *Fusarium* attack. High temperatures may stress the plant and make it more susceptible to *Fusarium* (38). Very wet soil and poor aeration suppress *Fusarium* growth and attack.

High levels of available soil nitrogen have been shown to increase the severity of attack by *Fusarium*, partly due to increased growth by the pathogen and partly to increased susceptibility of the host because of additional root growth. Nitrate nitrogen produces this effect to a greater degree than does ammonium nitrogen (43).

Fusarium rarely grows on aerial parts of plants, except where the relative humidity is very high (i.e. almost 100%). Under these conditions, mycelia may grow over the plant and groups of conidia may be formed on stems or leaves of young plants.

Spread. Fusarium spp. are generally soil-borne although conidia are often detected on seed. Seedling infection can arise from the seed-borne source.

Saprophytic growth of *Fusarium* spp. occurs in soil on plant debris, from where the organism can grow to attack living tissue. Contaminating fungi grow much more rapidly through

sterilized soil than through soil where other micro-organisms exist which compete with the pathogen. Any movement of soil on boots etc. can also contaminate previously sterilized soil.

Control. Fusarium can be controlled by a number of methods:

1) *Disinfection of soil.* The most effective, and most generally used methods of soil sterilization involve the use of steam, steam-air mixtures and chloropicrin/methyl bromide.

2) *Cultivation and hygiene.* Removal of plant debris and early cultivation to enable breakdown of any remaining plant debris will reduce the incidence of *Fusarium* infection. Good crop rotation practices will also assist in avoiding *Fusarium* infection.

Flooding has been used as a control measure for *Fusarium*, especially in the case of *F. oxysporum* f.sp. *cubense* on banana (banana wilt) where fields are flooded to a depth of 60-150 cm for up to 6 months (35). However, although this is not generally a practical method for curbing *Fusarium* infection in seedling/cutting material it illustrates its susceptibility to poor aeration.

Hygiene in hormone powders with cuttings is also important as infected cuttings can contaminate the hormone powder. Allowing the cut surface of cuttings to dry prior to planting is most important (41) as this results in less infection.

3) *Fungicide Application.* A number of fungicides have been used to control *Fusarium:*

(a) *Benzimidazoles.* The development of systemic benzimidazole fungicides has been important in the control of *Fusarium*. Benomyl (Benlate*), thiabendazole (Thibenzole*) and thiophanate (Topsin*) act as protectants (applied as a soil drench, coated on seed or used as a cutting or root dip), or eradicants (generally applied as a soil drench) to control *Fusarium*. Fuberidazole is used as a seed dressing, often in combination with captan.

Excellent control of *Fusarium* spp. has been achieved with these materials, although some reports of tolerance to the fungicide by *Fusarium* (15,30) may indicate a need for caution in the use of these chemicals. Benomyl appears particularly useful on rhododendron cuttings where it has been shown to increase rooting (20). Stevens *et al* (41) applied benomyl to stock plants prior to taking cuttings but this technique was not effective in preventing decay of the cuttings. Benomyl at concentrations of 5% or more (in talc) can be phytotoxic to cuttings and concentrations should be kept low (e.g. 2.5%) (Hocking and Thomas, unpubl.).

* *Trade Name.*

(b) *Other Fungicides.* Captan, quintozene (or PCNB) and thiram have all been used in the past in control of *Fusarium*. However, they have all been largely superseded by the use of the benzimidazole fungicides. The main advantages of the non-systemic materials lies in their relatively low cost and low toxicity.

4) *Biological Control.* Attention is now focusing on the use of biological control of seedling diseases. Often this may be used in conjunction with chemical control; e.g. soil treatment with trichodermin (extracted from the fungus *Trichoderma viride*) combined with thiram seed treatment produced control of *Fusarium* in pine seedlings (18).

Pythium and Phytophthora species. A number of *Pythium* species are important pathogens in the early stages of seedling growth. *P. debaryanum*, *P. irregulare*, and *P. ultimum*, all of which are well recognized as seedling pathogens, have been isolated in New Zealand (7,31,32). Other *Pythium* species found in soil in New Zealand may be important pathogens on less frequent occasions.

Phytophthora megasperma, *P. cryptogea*, *P. cinnamomi*, *P. dreschleri* appear to be the most important species attacking seedlings/cuttings. Other species may also be important in some areas; e.g. *P. lateralis* on *Chamaecyparis lawsoniana* (25).

Pythium spp. readily attack young root tissue. However, seedlings have been observed to become resistant to attack by *Pythium* after a short period of time as the tissue begins to harden and lignify. *Phytophthora* can infect seedlings through to relatively mature plants, although as the plant ages, it becomes less susceptible to attack. For example, 2 week old lucerne seedlings sown into soil inoculated with *P. megasperma* had a higher incidence of infection than in 4 week old seedlings sown in the same soil, which in turn had a higher mortality than 8 week old seedlings similarly treated (29).

Symptoms. Infection of young seedlings by *Pythium* spp. occurs at two points on seedling plants — at the point of emergence from the seed, in which case the fungus appears to colonize the seed in a saprophytic role, and then move to the healthy seedling tissue of both root and shoot; or at the root tip from where infection moves up the plant.

Pre-emergence damping-off is caused by total infection of the seedling prior to emergence. Post-emergence damping-off is characterized by a later or, perhaps, slower infection which eventually engulfs the stem of the seedling above ground level and produces collapse of the seedling.

Pythium infection normally produces a soft wet rot of the roots and/or stem, which turn tan to mid-brown in colour. If

drier conditions prevail following a late infection of a seedling, the lesion on the stem may appear drier, and collapse of the cell walls give the lower stem a slightly constricted appearance.

In a seed-box or seed bed, *Pythium* infection is usually seen in patches of plants which may develop symptoms, often in a wetter area of the box. Alternatively, individual plants with slight infections may remain stunted.

Phytophthora spp. generally attacks roots, often entering at injury points (10). As with *Pythium*, a soft wet rot may be produced, although in some cases (e.g. with *P. megasperma* on some hosts) very dark dry lesions result from infection. *Phytophthora* infection in a seed bed normally occurs in patches.

Environmental Conditions. Pythium develops more readily under conditions of moderate to high levels of soil moisture (i.e. 30 to 90% moisture holding capacity), (12,33). Lack of drainage and resultant poor aeration favour growth of *Pythium*. Lower temperatures, i.e. less than 20°C (68°F) also favour attack by *Pythium* species recorded in New Zealand, although this effect may be indirectly caused by slowing the growth of the host, which exposes it more readily to pathogenic attack. Some *Pythium* spp. are unaffected by soil temperatures of up to 30°C (86°F), (2) *Pythium* is more readily isolated from soil in winter and early spring than in summer and autumn when soil moisture levels are lower and temperatures are higher (21).

Phytophthora spp. also grow more readily under conditions of moderate to high soil moisture (25,29).

Phytophthora spp. have variable optimum temperature requirements for survival and growth (40). Sporangia and oospores of *P. cactorum* survived freezing temperatures, although the hyphae did not. *Phytophthora cinnamomi*, however, has a minimum temperature range for growth of 5 to 16°C (41 to 61°F), an optimum range of 20 to 32.5°C (68 to 90.5°F), and maximum temperature for growth of 30 to 36°C (86 to 97°F) (48). *P. syringae* attack has been observed to occur more readily in the late autumn to early winter period (36).

Both *Pythium* and *Phytophthora* are affected by varying oxygen (O_2) and carbon dioxide (CO_2) levels. *Pythium irregulare* and *Phytophthora megasperma*, when exposed to an atmosphere containing 1% CO_2, produced less than 20% of their normal growth in air (23). Growth and survival of *Pythium irregulare* and *P. vexans* were favoured by higher levels of CO_2 combined with normal concentration of O_2, rather than lower O_2 and normal CO_2 levels (9).

Varying the pH of the potting mix between 4.0 and 9.0 appears to have little effect on infection by *Pythium acanthicum*,

P. debaryanum, *P. irregulare* and *P. ultimum* (McCully, unpubl.).

In general, any condition which tends to induce poor vigour in seedlings exposes them to a greater risk of *Pythium* or *Phytophthora* infection than where more favourable conditions prevail.

Spread. *Pythium* and *Phytophthora* are soil-borne organisms and can spread in a similar manner to *Fusarium*. Fruiting structures and zoospores of these pathogens may also be carried in water by either splash dispersal, movement through soil, or in irrigation water (42). Both *Pythium* and *Phytophthora* (25) can survive in host debris in soil, from where infection of susceptible host tissue occurs.

Control. *Pythium* and *Phytophthora* may be controlled by a number of methods:

1) *Sterilization of Soil.* As for *Fusarium* spp. (see earlier).

2) *Cultural Practices and Hygiene.* Adequate fertilizer balances, provision of drainage, and guarding against sowing seed too deeply are all factors which can assist in preventing *Pythium* and *Phytophthora* infection. Well aerated free-draining soil or potting soil mixes should also be used.

Removal of plant debris, weeds, etc. is also encouraged. The provision of formalin footbaths at the entrance to glasshouses, potting-sheds, etc. to prevent contaminated soil from entering the area sterilized is also important, particularly where crops are grown in the soil. Seedling boxes, particularly those of wooden construction should be thoroughly cleaned and sterilized (e.g. by formalin dip, well prior to sowing seed).

3) *Fungicides.*

(a) *Etridiazole.* This fungicide is sold as 'Terrazole' either as a wettable powder (35% active ingredient (a.i.) or an emulsifiable concentrate (25% a.i.)). Excellent results have been achieved particularly against *Pythium*, although this is not always the case (F.R. Sanderson, pers. comm.). Etridiazole is most commonly used either within a soil mix or as a soil drench. Reports of phytotoxicity have been published, e.g. in *Chamaecyparis lawsoniana* cuttings (44). Etridiazole is not known to have activity against *Rhizoctonia* or *Fusarium*.

(b) *Captan.* This has been the standard fungicide for *Pythium* control for some years, and is used as a seed dressing, root dip, soil drench or is incorporated in soil. It is relatively inexpensive and has a low toxicity to plants and animals.

(c) *Fenaminosulf.* This fungicides is sold as 'Bayer 5072' (formerly 'Dexon'), a wettable powder which is used as a soil

drench. Applications may need to be repeated at 14 day intervals.

Excellent results have been achieved for *Pythium* and *Phytophthora* control with fenaminosulf (6,47). The chemical is toxic to animals and man and extreme care should be taken when using this material. As a lengthy waiting period must be observed, soil application is normally restricted to the early seedling stage of plant growth.

(d) *Thiram.* Thiram can be applied as a soil drench or a seed dressing. It has the advantages of being a relatively safe chemical to handle and has a short waiting period (maximum 7 days in New Zealand). However it may not eradicate the pathogen (24) and may give inadequate control, particularly with *Pythium* (6).

A number of new fungicides are becoming available for use against *Pythium* and *Phytophthora*. These include "Milcol" (drazoxolon), and a systemic material known as "Nurelle". It is most important that the correct fungicides be chosen for control of *Pythium* and *Phytophthora*.

Our own trials and the work of many others (46) have reported an increase in the incidence of *Pythium* and *Phytophthora* where benomyl use has occurred. This is believed to be due to the suppressive effect of the fungicides on antagonists and competitors, thus allowing *Pythium* and *Phytophthora* to grow more freely. Smith *et al*, (39) observed a similar phenomenon when reporting stimulation of growth of a basidiomycete on turf by benomyl application. Neither the water moulds nor most basidiomycetes are controlled by benomyl.

4) *Biological Control.* Researchers are at present evaluating the use of spores of the fungus *Trichoderma viride* as a seed treatment to reduce *Pythium* infection (Robertson, pers. comm.).

Rhizoctonia solani. *R. solani* is an important disease-causing organism capable of infecting plants at most stages of growth from early germination and seedling stage (where pre- and post-emergence damping-off can result) through to mature plants where root and crown rots may develop through *Rhizoctonia* infection. *R. solani* has a wide host range, and is generally air-borne, although cases of seed-borne infection have been reported (17).

As with *Pythium*, *R. solani* has a wide host range. Dingley (7) records the pathogen on grasses, cereals, fodder crops, vegetables (e.g. cabbage, rhubarb, potato) bedding plants (e.g. carnation and anemone) and trees and shrubs (e.g. *Pinus radiata* and *Citrus sinensis*).

Symptoms. R. solani normally infects the host at ground level, eventually girdling the stem at this point causing constriction of the stem — a symptom often referred to as 'wire-stem'. Close examination of the seedling stem at this point (by means of a hand lens) may reveal brown or black mycelium strands running up and down the stem — a characteristic of *Rhizoctonia* infection.

R. solani lesions are normally much drier in nature and darker in colour than those of *Pythium*. The margins of the lesion tend to be more clearly defined, partly because of the darker colouration of the lesion, than is the case with *Pythium* infection.

Where humid conditions prevail, the coarse grey-brown mycelium of *R. solani* may be observed growing over aerial parts of seedlings. Spread from seedling to seedling can occur in this manner, resulting in patches of infected plants covered with mycelium.

Environmental Conditions. Moderate to high soil temperatures (15 to 30°C; 59 to 86°F) (4,19,22), and only slightly moist soil conditions favour growth and pathogenicity of *R. solani*. Pochanina (28) observed that in potato the most vigorous development of *R. solani* on stems and roots was associated with higher temperatures and a simultaneous reduction in rainfall and soil moisture. Papavizas *et al* (26) and Herr (13) observed a similar effect with low inoculum density in spring which increased to a maximum in mid to late summer.

Where extremely dry conditions prevail, *Rhizoctonia* may form resting structures known as sclerotia, which tolerate dry or low nutrient conditions. When favourable conditions subsequently prevail, the sclerotia germinate by means of mycelial growth which can then infect susceptible host plants. Under conditons of high humidity and warm temperatures, coarse grey *Rhizoctonia* mycelium may be seen growing over groups of dead and dying seedlings. In potatoes, the incidence of *R. solani* is reduced in the presence of sulphur, but increased with lime application (8).

Spread. R. solani is soil-borne, both as hyphae and sclerotia, and can be moved with soil. Plant debris may harbour the pathogen, which tends to lie dormant until susceptible live host tissue is placed near it, which it will grow towards and colonize. As with *Pythium*, wooden seed boxes or trays may harbour infection. *R. solani* has also been found to be seed-borne (17) and can be carried on vegetative material used for propagation (e.g. bulbs, corms, tubers, etc.).

Control.

1. *Sterilization of Soil.*

2. *Cultural Practices and Hygiene.* Removal of weeds and plant residues, sowing seed which is debris-free and not discoloured or shrivelled, and provision of hygiene methods as noted for *Pythium* should be observed.

3. *Fungicides.*

(a) *Benzimidazoles.* The benzimidazole group of fungicides was the first fungicide group to successfully control *Rhizoctonia*. Benomyl was found to provide excellent control of the pathogen. Sharma *et al* (37) found that benomyl was most effective against seedling blight of mung bean caused by *R. solani*. Pergola *et al* (27) found benomyl, carbendazim, thiophanate and benodanil all gave good control of *R. solani* compared to quintozene, a previously used non-systemic standard fungicide for this pathogen.

(b) *Other fungicides. R. solani* has traditionally been difficult to control with fungicides. Quintozene and chloroneb have been used, but neither gave entirely satisfactory control (27,37).

Conclusion. Fungal diseases are very important in plant propagation. Those which we have considered:

(a) Are all soil-borne and attack the plant roots.
(b) Are capable of causing seedling and cutting death and decay.
(c) Can be controlled by soil sterilization and plant hygiene procedures.
(d) Can be controlled by fungicides — it is important, however, to ensure that the problem is correctly identified before fungicides are used; e.g. benomyl should *NOT* be used to control *Pythium*. On occasions two or more pathogens may act together on a host to produce a synergistic effect in terms of decay, e.g. *Rhizoctonia* and *Fusarium* on geranium cuttings (16). In cases where a complex of pathogens is thought to be present the use of combinations of fungicides is advocated, e.g. etridiazole and benomyl; chloroneb and benomyl (45).

The universal incorporation of a single fungicide in propagation and potting media may lead to the promotion of growth of fungi resistant to the fungicide. Such a situation should be carefully watched for, should it occur, so that remedial action can be taken.

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LOSS OF PRODUCTIVITY IN CLONAL APPLE ROOTSTOCKS

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Abstract. The paper outlines the apparent loss of rootability and juvenility in the Ottawa series of apple rootstocks in Canada. The lack of a suitable quick chemical test, as well as the uncertainty of using morphological characteristics associated with juvenility for assessing rootability is briefly discussed. Based on published work, as well as anatomical differences between the easy-to-root and difficult-to-root sources of the Ottawa rootstocks, a quick, easy test using the mid-nodal region of the basal internode of one-year old apple wood and staining cross-sections with phloroglucinol-HCl is suggested. Not only the lesser amount of phloem fibre in the easy-to-root type, but also the existence of large gaps in the ring is important. Suggestions are made for retaining rootability in clonal apple rootstocks and for their distribution.

There is a need to safeguard the existing levels of rooting in clonal apple rootstocks but more important, new clonal or vegetative lines must be kept in the juvenile condition especially for their successful propagation by softwood cuttings. According to Beakbane (2), Gardner first reported the loss of rooting ability over the period of change from juvenility to maturity in 1929, but even for tissue culture, Abbott (1) specified juvenile material. This paper is not intended to review the vast amount that has been published on juvenility, but rather it is an