Soilborne root pathogens in production nurseries

Introduction

The purpose of this paper is to provide information on destructive soilborne fungal pathogens that can occur in production nurseries, how they can be spread and how they can be managed. Practical application of this knowledge will lead to healthier plants, as well as improved plant growth and greater uniformity. It will also help to minimise biosecurity risks. Several serious soilborne pathogens are being spread around the world with nursery plants. As "best practice" is fundamental to the production of healthy plants, short cuts should never be taken.

Root rots are especially detrimental to nursery plants. Many soilborne pathogens thrive in the nursery environment. Free water (from rain, dew and irrigation), high levels of humidity, favourable temperatures, and susceptible plant tissue from rich fertilisation (young, succulent, rapidly growing, unsuberized roots) is always available for infection. Most nursery crops are monocultures with limited genetic diversity and thus they are extremely vulnerable to disease epidemics such as those caused by *Phytophthora* and *Cylindrocladium.*

The Root Environment

Growers need to give heed to the root systems of their plants. As roots cannot be directly observed, they are generally taken for granted. Plant roots are both dependent on and essential for the normal functioning of the aerial parts of the plant. The most important function of roots are anchorage and water and nutrient uptake. They also incorporate absorbed nitrogen into amino acids which are essential for protein and nucleic acid synthesis. Another function is to produce growth hormones and they are the major source of cytokinins and gibberellins. Roots must undergo growth or be continually replaced to perform their absorptive function (Fig. 1).

Fig. 1. *Ixora* with a healthy root system..

Factors affecting root growth are soil temperature and moisture, soil aeration, soil carbon dioxide, pH, mineral elements and salt concentration. Roots need to breathe and can die from a lack of oxygen, i.e. in the soil with low oxygen (hypoxia) or no oxygen (anoxia). Respiration, which supplies the energy necessary for roots to function, relies on soil pores to supply oxygen and remove carbon dioxide. If roots cannot respire, root growth is restricted, root tips are brown to black rather than white, there are

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less root hairs and there is reduced uptake of water and nutrients. The proper amount of pore space in the growing medium is also important to achieve good drainage as well as aeration. If pore space is inadequate there is reduced aeration and longer periods of soil saturation. Oxygen diffuses through air about 10000 times faster than it diffuses through water. To prevent hypoxia and anoxia it has been suggested that a potting mix must be free draining and allow air into 15% of spaces after watering. Plants with healthy root growth at the top of the container and rotting roots below is a good indication that aeration needs to be improved (Fig. 2).

Poor drainage restricts leaching and leads to salt accumulation. Salinity will interfere with the growth of plants. Water becomes unavailable because dissolved salts increase the osmotic pressure of the growing medium. Both low oxygen and salinity predispose plants to infection by soilborne pathogens.

A water-saturated, oxygen-deficient growing medium stresses plants and predisposes them to attack, particularly by water moulds such as *Pythium* and *Phytophthora.* Oxygen-deprived roots leak greater amounts of soluble metabolites and ethanol which attract zoospores. *Phytophthora* is an aerobic organism and in a water-saturated growing medium, zoospores will infect roots near the surface where there is sufficient oxygen.

Symptoms

The major soilborne pathogens causing root disease in nursery plants are *Phytophthora, Pythium* and *Cylindrocladium* and less commonly *Rhizoctonia, Chalara, Fusarium* and *Aphanomyces. Sclerotinia* and *Sclerotium rolfsii* sometimes infect roots near the soil surface.

Some root rot pathogens are also well adapted to attack the aerial parts of plants. For example *Cylindrocladium* and *Rhizoctonia* will also cause leaf spots, shoot and seedling blight and stem cankers as well as root rot and damping off.

The symptoms caused by these soilborne root pathogens are remarkably similar. Initially plants may appear stunted and slow growing. This is followed by yellowing of leaves, wilting and leaf necrosis. Affected root tissue is soft and watersoaked, becoming discoloured to dark brown or black. There may be decay of root tips and later an absence of secondary and tertiary roots. Symptoms will vary depending on the pathogen, host plant and the extent of root rot.

It is difficult to determine which pathogen is causing such non-specific symptoms. These symptoms can also be easily confused with those caused by

Fig. 2. Unhealthy roots can appear similar to healthy ones until cut open. The root on top has vascular discolouration and an unhealthy colouration (see inserts) whereas the root in the middle (from the same Ixora, is very healthy in appearance.. *Pythium* was detected (below). However, note healthy roots growing at the top of the growing media indicating poor aeration of soil and hypoxic or anoxic conditions further down the container.

vascular wilt pathogens (*Verticillium, Fusarium, Ralstonia*) and anoxia. However vascular wilt pathogens also cause a browning of the vascular tissue in the stem (vascular browning). Plants affected by the bacterium *Ralstonia* can be characterised by the presence of bacterial ooze in addition to vascular browning. This ooze may be difficult to detect in some hosts especially in the early stages of infection.

Plants can have root infection but not show symptoms until they are stressed. Stresses include transport from the nursery, planting in the field, repotting or the application of extra water or fertilizer. It is not unusual for plants with root rot to regenerate new roots to replace those killed by the pathogen, but the newly developed root system may only support the plant when adequate moisture is available. Such plants may not show above ground symptoms well enough to be culled in the nursery prior to sale.

As several pathogens can produce the same symptoms, and two or more pathogens may be affecting the nursery crop, nurseries need access to a professional diagnostic laboratory. Accurate identification of pathogens is essential to allow the correct decision to be made regarding disease management.

Root disease pathogens

This section provides information about each of the major soilborne pathogens which may be present in production nurseries.

Phytophthora and *Pythium*

These organisms, which are commonly referred to as 'water moulds', belong to the class Oomycetes within the Kingdom Chromista. They are not true fungi but are fungal–like organisms. *Aphanomyces* is also a water mould but is treated separately below. They can be distinguished from true fungi by their non-septate hyphae and production of motile swimming spores (zoospores) which play a key role in their life cycles (see lifecycle in Fig. 4). It is the zoospores that enable the rapid spread of disease from infected plants in wet growing media or irrigation water.

Fig. 3. Pythium oospores present in the roots of pansy (top - photo by E. Bush, Virginia Polytechnic Institute and State University, bugwood.org) with close up of oospores in insert. Pythium root and stem rot of *Pelargonium* (below).

Phytophthora spp. infect living plant tissue, grow into and between plant cells and leave a necrotic lesion behind (Fig. 4-5). They are hemibiotrophs (i.e. organisms that initially derive energy from living cells and later derives energy from dead cells). *Pythium* spp. can infect either living or dead plant tissue. They can be either hemibiotrophs or necrotrophs (i.e. organisms that kill host cells before invading them).

Pythium can cause seed rots and death of young seedlings (damping-off) (Fig. 3) but in older plants they generally attack undifferentiated feeder roots and disrupt the uptake of water and nutrients. They may cause a minor disruption in growth but rarely cause mortality in older plants. *Phytophthora,* the 'plant destroyer' is one of the most widespread and destructive nursery pathogens. *Phytophthora* epidemics can be explosive when favourable conditions prevail. Infection by *Phytophthora* usually starts at the root tip and rapidly involves all below ground parts of the plant. Unlike *Pythium* it is able to destroy the entire root system of mature plants and also cause trunk cankers near the soil surface. Most *Pythium*

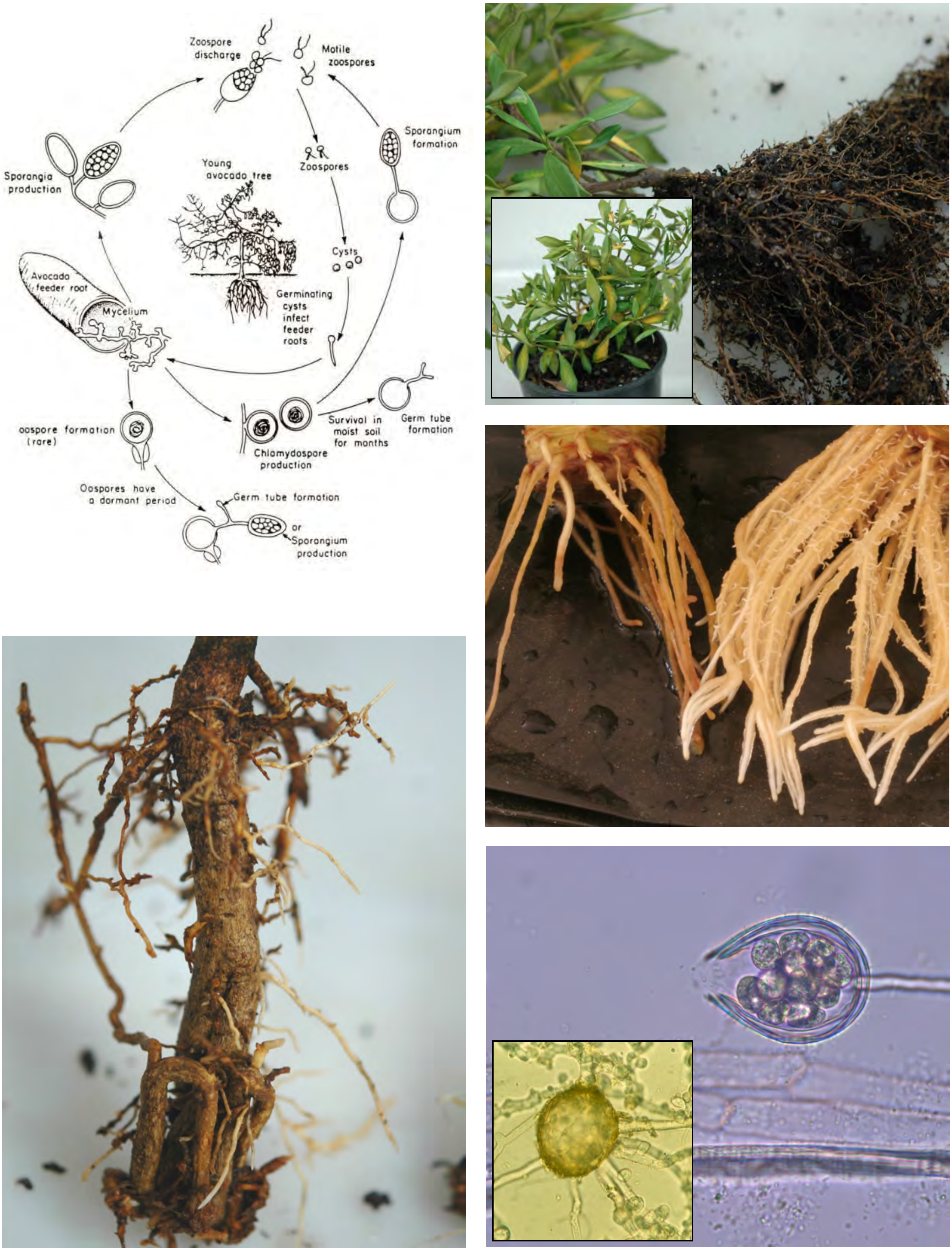

Fig. 4. General lifecycle of *Phytophthora* (top left). Root rot caused by *P. nicotianae* in mandarin Troyer rootstock (bottom left) and gardenia (top right) with whole plant symptoms in insert. Pineapple roots (middle right) infected with *Phytophthora* next to a healthy root system. *Phytophthora cinnamomi* zoosporangia with individual zoospores developing within (bottom right), germinating chlamydospore (insert).

species have a wide host range; the host range of *Phytophthora* depends on the particular species. *Phytophthora cinnamomi* has a very wide host range (>3000 hosts) whereas *Phytophthora infestans* has a narrow host range. The major commonly encountered species of *Phytophthora* in nurseries are *P. cinnamomi, P. nicotianae, P. palmivora, P. cryptogea, P. megasperma* and *P. cactorum.*

The following factors make the 'water moulds' efficient nursery pathogens:

- Growing conditions in nurseries where plants are young, richly fertilised and often over-watered are ideal for water moulds.
- Wet conditions play a critical role in disease development. Sporangia release asexual zoospores (primary inoculum) which use tail-like flagella to swim out of the sporangium into saturated soil pores. They are attracted to root tips by chemical stimulus as well as root generated electric fields. They also infect wounds on roots. They encyst and produce germ tubes which infect healthy root tips.
- Water moulds have the capacity to increase propagule density rapidly. If an infection is successful another generation of sporangia and zoospores (secondary inoculum) are produced on the host surface within 3 to 5 days; this rapid cycling of infection followed by another generation of sporangia and zoospores, will result in an explosive epidemic if environmental conditions are favourable.
- They are spread by contaminated water, infested soil (usually containing small pieces of infected root tissue) and nursery plants. Some species of *Phytophthora* with deciduous sporangia are dispersed by wind.
- 'Water moulds' have the ability to survive adverse conditions without a host plant for long periods.
- *Pythium* survives in the soil as oospores produced through sexual reproduction. *Phytophthora* survives as oospores and/or chlamydospores (asexually produced resting spores) in soil. Pythium is better able to use dead organic matter as an energy source than *Phytophthora.*
- 'Water moulds' may be present in nursery plants long before symptoms appear depending upon host plant susceptibility, environmental conditions and other factors. For more information on Pythium and Phytophthora, refer to the nursery factsheets on each of these pathogens available on the NGIA and NGIQ websites.

Aphanomyces

Aphanomyces is a 'water mould' belonging to the class Oomycetes and the order Saprolegniales.

Fig. 5. *Phytophthora* root rot of daylily (top) and heart rot in *Dracaena* (bottom)

Sexual versus Asexual Stages

Most fungal pathogens have a sexual and asexual stage in their lifecycle. The asexual stage produces conidia or zoospores (depending upon the organism) which are identical to it's 'parent'. Fungi also produce sexual stages which result in the combination of genetic material from more than one 'individual' and result in sexual ascospores or oospores. Both types of fruiting bodies can infect a plant but result from different methods of cell division. In certain cases, particular survival structures can be either asexual or sexual, e.g. chlamydospores and oospores. Thus, there are many different terms associated with different groups of fungi and the structures they produce, however, the overall themes are very similar.

Similar to Phytophthora and Pythium, it is no longer classified as a fungus and is closely related to diatoms and brown algae. The genus contains several destructive root pathogens, the two main ones are *Aphanomyces enteiches* which attacks legume seedlings, and *Aphanomyces cochlioides* which infects beetroot and spinach seedlings (Fig. 6). Affected roots are initially grey and watersoaked, eventually becoming soft and brown to black. Disease is favoured by warm, wet conditions and slow draining potting mixes. When cultured in a laboratory it can be distinguished from *Phytophthora* and *Pythium,* which also have non-septate hyaline hyphae, by its delicate, sparse, wandering growth on media.

The following make *Aphanomyces* an efficient nursery pathogen:

- Large numbers of sporangia and zoospores are produced in slow draining potting media which also predisposes plants to infection. The zoospores travel in water and affect the roots.
- Survives adverse conditions as sexually produced oospores which form in abundance in tissues of diseased plants.
- Infects seedlings when temperatures are between 20 and 28°C, wet conditions are essential.
- Roots affected by *Aphanomyces* are prone to further attack by *Pythium, Rhizoctonia* and *Fusarium.*

Cylindrocladium

The fungus *Cylindrocladium* belongs to the *Hypocreales* (Ascomycetes) and is the anamorph (asexual stage) of *Calonectria* (sexual stage).

Various species of the fungus are destructive pathogens of nursery plants especially in more tropical regions. They are favoured by warm, moist, humid conditions. Besides root rot and damping-off, they also cause leaf spots, shoot and seedling blight, stem cankers and infection of cuttings.

They produce necrotic lesions on both lateral and tap roots. These lesions coalesce to completely destroy the root system. Root infection can spread to the crown. Sometimes the plant may produce new roots as quickly as root rot progresses. Such plants may not show symptoms until water stress occurs. Important species in Australian nurseries are *Cylindrocladium scoparium* and *C. spathiphylli.*

The following factors make *Cylindrocladium* an efficient nursery pathogen:

- Disease develops best in warm, wet, and humid conditions.

Fig. 6. *Aphanomyces* on beetroot seedlings (top), maturing beetroot (middle), and parsnips (bottom - L. Minchindton &D. Auer, DPI Vic).

- Disease is more severe if plants have nutrient stress.
- Infected plants can remain asymptomatic until stress triggers the onset of disease.
- Infections are initiated with germination of conidia, ascospores or microsclerotia. Free water (rain, dew, irrigation water) is required for germination. This shows the importance of irrigation and free draining, well aerated, potting mixes in nurseries.
- Conidia (asexual spores), which are produced in large numbers, are easily splash dispersed to healthy plants or cuttings which underlines the importance of seedling spacing and the need for good nursery hygiene.
- Perithecia (another type of fruiting body) produce sexual spores (ascospores) on the stems of infected plants. These spores are spread by water splash, on air currents or dispersed by insects.
- Microsclerotia (highly resistant fungal structures which consist of chains or clusters of thick walled chlamydospores) allow the pathogen to survive unfavourable environmental conditions for many years.
- Spread is by infected plant material, infested growing mix or soil, or in moving water. For additional information on Cylindrocladium, refer to the nursery paper available on the NGIA website.

Rhizoctonia

Rhizoctonia solani, a common nursery pathogen, is the anamorph (asexual) of the basidiomycete *Thanatephorus cucumeris. Rhizoctonia* does not produce conidia (asexual fungal spores) and only rarely produces basidiospores (sexual spores). Instead, they produce sclerotia, a protective structure which is effectively a ball of mycelium that can survive in soil for many years.

There are different species and strains of the fungus *Rhizoctonia,* which vary in host range and pathogenicity, and cause a variety of diseases in nurseries. These include seed decay, damping-off, cutting and stem rot, web blight, collar rot and death of feeder roots which may progress to kill the major root.

Rhizoctonia persists more or less continuously as vegetative growth of threadlike branching mycelium in warm, moist soil. It promotes the decay and break-down of soil organic matter. When soils dry it survives by producing sclerotia or as hyphae in host plant residues.

The following make *Rhizoctonia* an efficient nursery pathogen:

Fig. 7. Cylindrocladium root rot on avocado (top and middle) and *Spathphyllum* showing healthy and infected roots (bottom. Cylindrocladium spores resemble cobbler's logs (middle insert).

- The fungus has a wide host range; is disseminated by contaminated soil, water-splashed sclerotia, contact with diseased plant parts, with dust and by insects, e.g. fungus gnats.
- Rhizoctonia survives as a competitive saprophyte (aggressively colonises organic debris) and produces sclerotia and hyphae in soil and host plant residues. Both propagules can directly infect host tissue.
- Sclerotes can survive on nursery equipment (pots, labels and stakes).
- In addition to damping-off and cutting decay, Rhizoctonia can attack seedlings to produce reddish brown lesions just below the soil line. When these are transplanted into the field lesions enlarge and plants fall over at the soil line.
- Hyphae from the surface of the potting media can grow up the stem to infect leaves and produce web blight, a serious disease which can spread widely within one week. It is important to set plants with adequate spacing to avoid crowding and formation of high humidity.

For more information, refer to the factsheet on Rhizoctonia available on the NGIA and NGIQ websites.

Fusarium

Fusarium species associated with plants can be pathogens, endophytes or saprophytes. They are widespread and can be a significant threat to production nurseries. They can cause damping-off, root and bulb rots, crown rots, stem and cutting rots, leaf spots and vascular wilts. Arguably the two most important species which impact nursery production are *Fusarium oxysporum* and *Fusarium solani*.

Fusarium oxysporum can cause damping-off of seedlings, root and crown rots as well as vascular wilt diseases. The fungus contains a complex group of strains some of which are pathogenic and others are not. Most pathogenic strains have excellent saprophytic capabilities and can live in alternative hosts as endophytes. Some strains cause a root and crown rot, while others colonise the vascular tissue causing discolouration and a characteristic wilt symptom. The latter are placed in forma speciales based on pathogenicity, and strains often have a very narrow host range.

Fusarium solani comprises a complex group of strains including plant pathogens and saprophytes. Some strains have a *Haemanectria haematococca* sexual stage. Orange to crimson perithecia form on infected stem tissue; this is more frequent in tropical rather than temperate regions. They produce ascospores which are pathogenic. *F. solani* is not a particularly aggressive pathogen and tends to attack

Fig. 8. *Rhizoctonia* diseases including damping off (top) with insert of characteristic hyphal growth, root and stem blight on carnation (middle) and death of mature primula (bottom).

plants where growing conditions are unfavourable. It infects roots and crowns causing a general cortical rot. *F. solani* can often be recovered from asymptomatic plants and such plants can be moved from the nursery as apparently 'healthy' stock.

Factors that make *Fusarium* an efficient nursery pathogen:

- *Fusarium* species can produce up to five types of propagules that can serve as inoculum sources – macroconidia, microconidia, chlamydospores, ascospores and mycelium. Conidia and spores are normally dispersed by water splash although some are dispersed by air currents.
- Species generally possess excellent saprophytic capabilities, and can survive for long periods as chlamydospores in host tissues, and as non-pathogenic parasites on alternative hosts. They can grow in these hosts without causing obvious symptoms of infection.
- *Fusarium* can be introduced into nurseries in a number of ways but most commonly with infected seed, corms or bulbs, cuttings and transplants. Seed coats can be contaminated with spores, or pieces of infected plant tissue, or there may be internal seed infection. Infected cuttings can be taken from apparently healthy plants.
- Irrigation water is also an important source for the introduction of Fusarium.

For more information, refer to the factsheet on *Fusarium* available on the NGIA and NGIQ websites.

Chalara elegans

Chalara is the anamorph of the ascomycete *Thielaviopsis basicola*. It causes black root rot and destroys much of the root system. The roots are dark because distinctive barrel-shaped chlamydospores form in infected tissue. They are readily observed under a dissecting microscope. Symptoms include poor growth, stunting and nutrient deficiency symptoms. Commonly affected hosts include the bedding plants pansies, petunias, daphne, viola, fuschia as well as lettuce. Other hosts include citrus, peach, rose and Poinciana.

The following make *Chalara* an efficient nursery pathogen:

- Chlamydospores enable it to survive adverse conditions.
- It produces endospores which allow rapid spread of the fungus by air-and splash-dispersal.
- It can be present in peat moss.
- Disease is favoured by a wet growing medium and any condition that stresses the host plant.

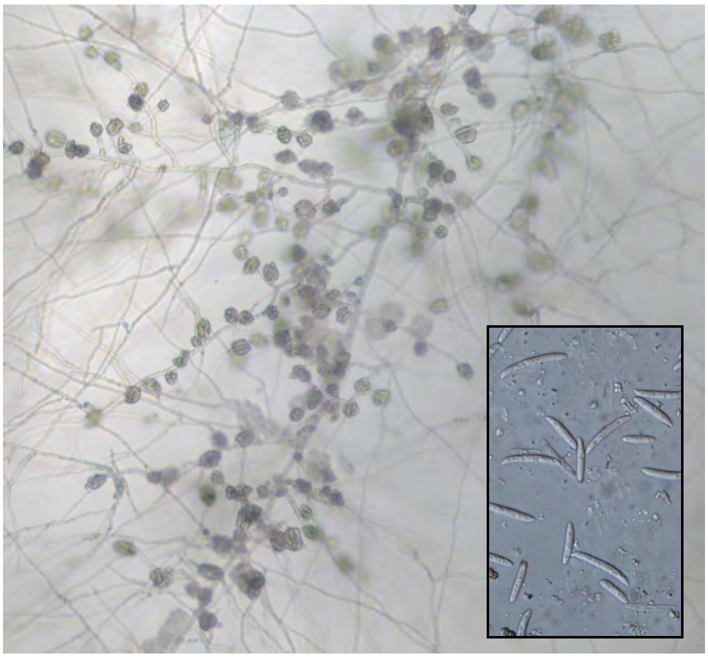

Fig. 9. Typical growth of *F. oxysporum* on fungal growing media (SPDA) showing clumps of microconidia (top). Close up of slightly curved macroconidia and much small microconidia (top insert). *Fusarium* stem and root rot on Brussels sprouts (middle) and capsicum seedlings (bottom).

- The spores are soilborne, airborne within the nursery and waterborne in drainage water. Fungus gnats and shore flies can vector spores around the nursery, particularly in propagation areas.

For more information, refer to the nursery paper on Chalara available on the NGIA website.

Sclerotinia and Sclerotium rolfsii

These two fungi can occasionally infect lateral roots of nursery plants near the soil line and quickly move up into the stem. *Sclerotium rolfsii* produces small, brown, round, sclerotia which germinate to form new mycelia; *Sclerotinia sclerotiorum* forms large black irregular sclerotia which may either form mycelia or give rise to external fruiting structures (apothecia which produce ascospores – sexual stage). Ascospores infect above ground parts of plants usually at leaf axils. Ascospores of *S. sclerotiorum* are wind borne and can be blown into old flower petals and pollen and assist the fungus in the infection process.

Factors making *Sclerotinia* and *Sclerotium* efficient nursery pathogens:

- Both fungi produce resting structures (sclerotes) that allow them to survive in the soil, or as loose contaminants of seed, for long periods.
- *S. sclerotiorum* prefers cool, wet weather. *S.rolfsii* thrives in warm to hot, wet and humid weather.
- Both spread with infested soil, as seed contaminants, in potting mixes and infected plants.
- *Sclerotinia sclerotiorum* has a high reproductive capacity. A single apothecium can produce 30 million ascospores which are forcibly discharged into the air and disseminated by wind.

Disease Management

A fundamental principle for disease control in nurseries is that it is better to avoid disease than to have to apply controls after a disease outbreak. Excluding soilborne pathogens from production nurseries can be difficult at times, but is the most cost -effective disease management strategy. Operations based on strict hygiene guidelines can be used to maintain a nursery free of soilborne pathogens. Growers should have knowledge of what destructive soilborne pathogens exist, and which ones are likely to threaten their particular nursery crop.

While nursery diseases are best excluded, the management of a disease outbreak in a production nursery will depend on early recognition and a

Fig. 10. Black root rot caused by *Chalara elegans* on citrus (top and middle). Black growth is masses of chlamydospores (middle insert). Black root rot on kiwifruit (bottom) with close up of chlamydospores (bottom insert).

detailed knowledge of the pathogen and how disease develops. It is important to ask questions. Where did it come from? How does it spread? What environment and host factors favour disease development? How does it respond to fungicides and biocontrol agents?

As discussed extensively above, soilborne pathogens are most likely to enter the nursery through soil, water, or plant material. The importance of following factors cannot be emphasised strongly enough:

- Good hygiene is a fundamental component of effective pest and disease control.
- Poorly-drained and aerated potting mixes will aggravate soilborne diseases.
- The introduction of plants or cuttings into a production nursery comes with inherent risks. Take actions to only bring clean plants into the growing area.
- Fungicides should not be used to compensate for poor nursery practices and poor plant growth.

There is no 'quick fix' to a disease problem in a nursery. Disease control generally requires an holistic approach which combines host resistance, cultural control measures, sensible application of appropriate fungicides to protect healthy plants and biological control measures.

Cultural Control

It is important that production nurseries produce healthy plants free of soilborne pathogens. This may be difficult and challenging to some nurseries due to the complex disease cycles of the many soil pathogens, with their diverse spore forms, but it is achievable.

Limit nursery access to essential staff. Those entering a nursery should walk through footbaths which are regularly cleaned and replenished. Nursery staff should then wash their hands with soap and water or an approved hand-washing biocide.

Nursery floors should preferably be sealed with concrete or bitumen. Coarse gravel (75 mm deep) can be used where the ground is well drained. Floors should be washed and drenched with disinfectant solutions on a regular basis.

As some soilborne organisms (e.g. *Rhizoctonia, Phytophthora nicotianae*) can survive in dust, dust from adjacent roads must not enter production or propagating areas.

Working surfaces should be cleaned daily. They should be thoroughly washed, then disinfected with quaternary ammonium chloride, chlorine solutions or

Fig. 11. *Sclerotinia* diseases with heavy fungal growth on stems of snapdragon (top) and small dark pellet-like sclerotes inside stems of snapdragon (middle). Sclerotes also may form outside stems, e.g. *Poinsettia* (bottom).

methylated spirits (70%). All tools should also be regularly scrubbed or pressure cleaned with 2000 ppm quaternary ammonium chloride prior to being disinfected.

Ideally plants should be on raised benches (slatted or with mesh) to provide drainage and aeration; otherwise on raised beds of coarse gravel making sure water does not accumulate in ponds.

Use high quality (preferably pasteurised by steam-air), well drained and well aerated, growing media obtained from a NIASA accredited supplier. Store growing media so that it does not become contaminated from run-off water, dust and plant material. It is best stored in closed disinfested containers.

Use irrigation water that is free of soilborne pathogens. Surface supplies (dams, rivers) are nearly always contaminated with soilborne pathogens especially following heavy rainfall and associated surface run-off. Such water must be disinfested using a NIASA approved method.

Regularly monitor nursery crops for symptoms of plant disease. As pathogens responsible for root disease in nurseries tend to cause non-specific symptoms (namely poor growth, yellowing, wilting leaf necrosis and plant death) it is important that an accurate diagnosis of the pathogen be obtained.

It is important to remember that two or more soilborne pathogens may be affecting the plants at the same time. This is another reason for submitting plants with root diseases to a diagnostic laboratory.

The introduction of plant material into a production or propagation nursery comes with inherent risks. For example, a pathogen such as *Phytophthora cinnamomi* may have invaded primary root tissue of a plant, but the plant does not show any symptoms due to the favourable growing conditions in the nursery. Once an environmental stress (e.g. reduced water status) is imposed on the host, symptoms will become evident. *Fusarium solani* can often be recovered from asymptomatic plants and such plants can be moved as 'healthy stock'. The physiological status of the host will have a major influence on the development of the pathogen. For these reasons plants and cuttings entering the nursery must be separated from the rest of the nursery, preferably in a specially designated quarantine facility and carefully monitored for pests and diseases for at least one month. Cuttings should be disinfested with an appropriate chemical (e.g. immerse in a chlorine solution for 3 minutes followed by rinsing in clean water).

Insects such as fungus gnats should be managed using integrated pest management as they are

Fig. 12. Plants grown on benches or on well drained gravel on which an appropriate fungicide is applied (top). Monitor root health on a regular basis (middle). It is recommended to designate a growing area for new stock to ensure that it is free of pest and disease prior to introduction into the rest of the nursery (below).

vectors of soilborne pathogens. Refer to the pest management plan of fungus gnats available on the NGIA and NGIQ websites.

Immediately remove diseased plants and leaf litter from production areas. Try not to carry over old stock. This may allow pathogens to persist or increase.

Chemical Control

Fungicides to control soilborne pathogens in the nursery should be used only as a last resort to help prevent the spread of an existing infestation. They rarely eradicate a pathogen or eliminate disease, and should not be used to compensate for poor nursery hygiene and adverse growing conditions. Inappropriate use of chemicals can lead to serious problems further down the supply chain, as chemicals will generally only mask symptoms and the pathogen will still be present. Temporary suppression of symptoms is not control! Chemicals to control soilborne organisms are best used as protectants to healthy plants at vulnerable times, e.g. when roots are damaged during repotting.

Shoe dips are recommended but must be maintained to a high standard to be effective. The above dip should be cleaned and filled to an appropriate level.

Since water moulds such as *Phytophthora* and *Pythium* do not belong to the true fungi, fungicides used to control soilborne fungi are sometimes ineffective. The chemicals metalaxyl and phosphonate have been very effective in controlling water moulds. Metalaxyl is very water soluble, moves readily in potting mixes and is absorbed by plant roots. It is xylem mobile and rapidly translocated to new tissues. Metalaxyl will kill some but not all water mould inoculum in the growing media. Resistance to metalaxyl has become a major problem.

Phosphonates are xylem and phloem mobile and can be used as both a drench and foliar spray, where registered. Phosphonates persist well in plant tissues but in perennial crops sequential applications are needed to maintain effective concentrations. Phosphonates do not have any effect on the population of water moulds in the potting mix. They act as a fungistat and activate the defence responses of the host plant. Resistance to phosphonates is unlikely but reduced sensitivity to the chemical has been found. This has not affected disease control. They inhibit spore production and chlamydospore germination.

The chemical etradiazole also reduces root rot caused by water moulds in nursery plants. Common fungicides used to control the soilborne fungi in nurseries are thiophanate-methyl and PCNB (quintozene). These active ingredients are less likely to be effective against water moulds than etridiazole, metalaxyl and phosphonates. Always refer to the label or minor use permit to ensure that it is suitable for use.

Biological Control

Biological control does offer an environmentally friendly approach to the management of soilborne pathogens. However the introduction of specific organisms that work against pathogens in potting mixes will fail unless it is combined with cultural and physical controls, a degree of host resistance, and limited chemical control. They do not totally suppress disease but can provide a partial level of control. They do not work as quickly as chemical methods.

The nursery environment, where there is a well- drained and aerated potting mix, and a suitable temperature and humidity for root growth, will favour biocontrol agents. The outcome is more likely to be successful if the biocontrol organism is introduced into a soil or potting mix which has been pasteurised and contains a reduced number of competing microflora and fauna. This means that there will be less chance of interaction with other organisms. There is no doubt that biological control can be an important component of the integrated management of soilborne diseases in nurseries. They will have a supporting role in reducing the activity and spread of the pathogen. There a number of biocontrol agents available. These include *Trichoderma* spp., *Gliocladium virescens, Bacillus* spp., *Streptomyces* spp. and *Pseudomonas* spp.

Biological control can be manipulated by adding unsterilised composted barks, which have high microbial activity, to potting mixes. These suppress soilborne pathogens without affecting plant growth. It has been found that seedlings in a propagating media containing composted pine bark had less damping-off than seedlings in a more inert media such as peat and perlite. The problem is that composts, that have not been pasteurised, will suppress disease but the resting spores of pathogens will remain. The same applies to chemical control; they both disguise infected but asymptomatic plants.

Fig. 13. It is extremely important to ensure growing media is free of all pathogens and it is recommended to pasteurise or otherwise treat media before use. Aerated steam sterilisers (pictured above) should reach 60°C for 30 minutes.

A range of plant endophytes have also been shown to protect against pathogens. The primary mode of action is thought to be direct antagonism.

If disease management in nurseries is to be based heavily on biological control, the research effort in this area will need to be substantially increased, actively testing the growth of plants with an without the biological control agent from time to time. The basic problem is that nurseries should not be spreading pathogens, and therefore disease suppression is unacceptable. Furthermore, any pesticide active against plant pathogens is likely to reduce biological control agents substantially.

Biosecurity

The spread of many soilborne pathogens has been linked to the international nursery trade. For example, *Phytophthora ramorum* has spread from being a minor foliar blight pathogen of ornamentals in nurseries, to cause serious and widespread damage in natural woodland ecosystems in Europe and North America. In contrast to *Phytophthora cinnamomi,* which is a root pathogen transmitted by soil and water, *Phytophthora ramorum* is primarily an aerial pathogen with a soilborne survival phase. If introduced, it would become a major threat to Australian forests and woodlands. Nursery plants have also played a major role in the evolution and spread of other pathogens (e.g. *Phytophthora alni*). Nurseries need to adopt best management practices to minimize biosecuriy threats, and to improve pest and disease management. This will help prevent infested and infected asymptomatic plants from entering the supply chain, and perhaps the international trade in plant products.

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