

Title: Identification Protocol and Management Strategies of Plant Pathogens in the Morris Arboretum Greenhouse

Author: Vincent Galatolo
The Martha J. Wallace Endowed Plant Propagation intern

Date: February, 2019

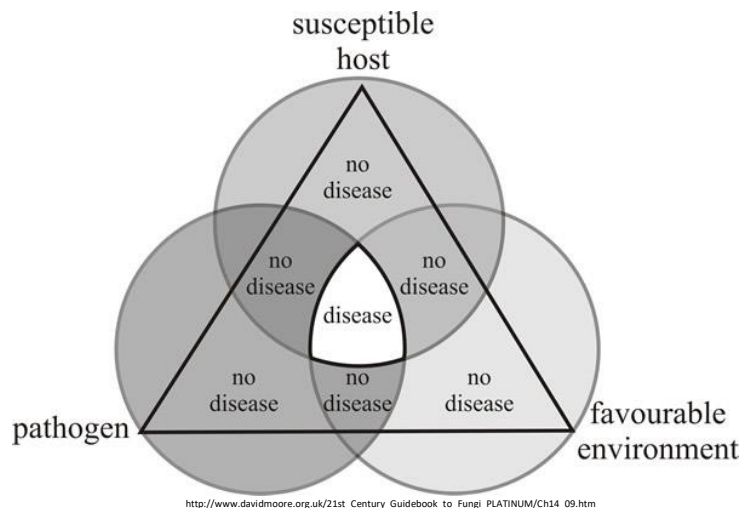
Abstract:

The purpose of my project is to develop a streamlined protocol for staff to identify, track, and diagnose plant pathogen infections in the Morris Arboretum greenhouses. Plant pathogens are one of the greatest challenges greenhouses face. They are extremely detrimental to the viability and continuity of a rare plant collection. Morris Arboretum is no stranger to these negative effects and has sustained losses due to infections.

Plant pathogens are commonly mistaken for abiotic factors or misdiagnosed as symptoms caused by pests. Due to this assumption many infections are never correctly diagnosed and treated. Misidentification can cause just as much damage as the infection itself. The greenhouse staffs' ability to identify and interpret symptoms correctly is essential the healthcare of Morris Arboretum's plant collection. Robust plant disease protocol procedures will facilitate the effective collection of plant material and the expedient transportation to a reputable pathogen testing facility. Successfully identifying an infection enables the disease to be carefully tracked and diagnosed before it spreads to the remaining plant population. Implementation of a strict identification protocol and management strategies will significantly reduce the probability of the reoccurrence of plant diseases within the Morris Arboretum greenhouses.

Introduction

The capability of a plant disease to cause extensive damage to a plant collection is immense. It is imperative that diseases be quickly identified and treated continuously. However, progress can be stifled by misidentification and improper diagnosis. Factors such as these have the potential to pose unforeseen issues in a greenhouse and enable a disease to spread unabated. Proper training and rigorous protocols are paramount to the effective mitigation of a plant disease. Symptoms stemming from an infection should be observed collectively and interpreted as a systemic issue with a central pathogenic antagonist. The pathogens that have the greatest chance of infecting a plant are viruses, bacteria, and fungi. These infectious agents represent themselves through uniquely distinguishable signs and symptoms. Three conditions need to be met for a disease to successfully manifest within a host. These factors are a susceptible host, pathogen, and favorable environment. They form the disease triangle and mark the foundations on which an infection takes hold in a vulnerable host.



Plant disease is described as “a condition of abnormal physiology in a susceptible host plant that is a result of the plant’s constant association with a disease causing agent within a set of favorable environmental conditions” (D’Arcy & Schumann, 2013). The predominance of pathogenic organisms that infect plants are considered parasites. Parasitic relationships provide essential nutrients to the causal agent of the infection at the expense of the host. An organism does not become a pathogen when it enters another living organism. It becomes a pathogen when it begins to inflict physical damage on a host plant. Many diseases are harmless in their natural environments because native plant species are resistant to them. Plant pathogens whose nativity is different than that of its geographical location can lead to catastrophe, like potato blight and the resulting potato famine. The virulence of a disease causing agent determines the infectious and destructive potential it is capable of inflicting. Those with greater virulence factors can cause more devastation within a plant population. The varying life cycles of a pathogen make it exceedingly challenging to treat effectively. The reproductive structures that a pathogen reproduces by dictate how it perpetuates its life cycle. Careful identification of the signs and symptoms of an infection provides the opportunity to interrupt the pathogens life cycle and prevent further infection.

Discussion: Plant Pathogens

Plant pathogens that cause the most extensive damage to greenhouse operations can be divided into three separate categories: viruses, bacteria, and fungi. Each category has its own distinguishing signs and symptoms that inflict damage to plant collections. Viruses are one of the most difficult plant pathogens to identify and treat effectively (D'Arcy & Schumann, 2013). Plant pathologists debated for decades as to whether or not these pathogens were in fact living or dead. Despite the long standing debate, it is well known that viruses are incredibly infectious and intracellular in nature. They are the smallest of the all plant pathogens and are defined as obligate parasites (D'Arcy & Schumann, 2013). Obligate parasitism means viruses need a living host in order to replicate successfully. Their reproductive process, called replication, require amino acids, nucleotides, and enzymes. They need energy produced by a living host cell (D'Arcy & Schumann, 2013). Viruses are predominantly vectored by insects and cause a variety of symptoms. Common symptoms displayed by viral infections are mottling, stunting, or dwarfing, and vein banding (D'Arcy & Schumann, 2013).

Bacteria are much larger organisms than viruses and are categorized as prokaryotic life forms. They do not have membrane-bound organelles or membranes. However, the majority of bacteria have cells walls that determine their shape, which can be coccial, bacilliform, or spiral-shaped (D'Arcy & Schumann, 2013). Other bacteria secrete extracellular polysaccharides that allows them to attach to the exteriors surfaces of host cells. Most bacteria poses a flagella that acts a propeller that enables them to move when in a liquid. Bacteria rely on a unique form of asexual replication called fission (D'Arcy & Schumann, 2013). They create identical copies of themselves by dividing their chromosomal DNA. Bacteria are facultative parasites and have the ability to create progeny outside of a living host. This enables them to function as epiphytic organisms that subsist on the surfaces of plants. These bacteria only have the potential of becoming infectious when the conditions are completely optimal (D'Arcy & Schumann, 2013). They display a variety of signs and symptoms that can aid in diagnosing an infection. Bacteria move intracellularly and cause blockages in leaf tissue that give rise to bacterial leaf spots. Furthermore, they can cause water-soaking in infected tissue or cause a yellow-halo (D'Arcy & Schumann, 2013). The yellow-halo is caused by dying cells at the border of leaf spot on foliar tissue. Bacterial infections also cause soft rot in stem tissue due to the liquefaction and collapse of cells. Bacterial infections cause similar diseases in plants as fungi and can cause inaccurate diagnoses.

Fungal pathogens are one of the biggest threats to greenhouse production areas. D'Arcy and Schumann state that only 10% of known fungi are pathogenic to plants. Although this seems like a small amount, fungi are some of the most virulent pathogens that adversely affect plants. Fungi are eukaryotic organisms and their cells are predominately composed of chitin (D'Arcy & Schumann, 2013). All pathogenic fungi are characterized as heterotrophic, which means they require a food source. Some fungi are considered saprotrophic and break down dead organic material. Conversely, other fungi feed on living organisms. Fungi that feed on living organisms are considered necrotrophs or biotrophs. Necrotrophs kill the living cells and feed on the dead matter while biotrophs establish relationships with living cells and feed on them (D'Arcy & Schumann, 2013). Fungi are separated into individual groups that include: ascomycetes, basidiomycetes, chytridiomycetes, and zygomycetes. One of the most prominent groupings of

pathogenic fungi are ascomycetes. Ascomycete reproduce by sexual spores that are called ascospores and are produced within an ascus (D'Arcy & Schumann, 2013). The asci and ascospore are securely kept within a structure called an ascocarp. Their reproductive biology makes them particularly difficult to effectively treat and are often the cause of the some of the worst greenhouse diseases.

Methods

Several steps are required to successfully scout and identify plant diseases in a greenhouse setting. The first procedure is walking through the greenhouse area and looking for signs and symptoms that indicate a disease. Signs and symptoms displayed by a disease can be a myriad of colors, shapes, and sizes. I carefully inspected for lesions, discolored leaves, and decaying foliage for initial telltale signs of infection. There are over 7,000 plants in the Arboretum's greenhouse collection that needed to be meticulously searched for infection. During this tedious segment of plant scouting I identified several groups of plants that displayed signs and symptoms of disease. After identifying a potential disease I carefully took samples of the suspected culprit to send to the Penn State Disease Clinic. The Clinic provides free diagnostic tests of infected plant material. Visible signs and symptoms displayed by an afflicted plant dictated what tissues samples I collected from my specimen. Samples of both foliage and root tissue yielded the best potential for successful results.

Collected tissue samples were placed in Ziploc bags depending on its size. The date, genus, and species were labeled on the front of the bag. The samples are required to be accompanied by an information form that is provided by the Penn State Disease Clinics web homepage. The form needs to be filled out with as much detail as possible to aid the clinic in the identification process. The collected samples along with the attached forms are shipped to the Penn State Disease Clinic. The package is shipped through Gates Hall and is attached with a two day shipping label to ensure an expedient delivery. The clinic generally takes one to two weeks to send back results via email depending on the number of samples that were sent. Positive results that are sent back cite the genus of the pathogen that are found on the tissue samples. After confirmation was received of suspected plant disease I logged the information into an Excel spreadsheet designed to organize information and track treatment progress. The Excel spreadsheet logged a variety of data including: collection date, number of specimens, pathogen genera, cultural treatments, chemical treatments, results, and comments. The spreadsheet not only enables greenhouse staff to track treatment progress but also to catalog disease infestations over extended periods of time. This is an invaluable tool in the fight against plant pathogens at Morris Arboretum.

Results

The samples that were collected during the identification process yielded interesting results that highlighted a variety of pathogens that are infecting Morris Arboretum's plant collection. The severity of the disease varied between groups of plants depending on the pathogen that was afflicting them. In total 22 samples were sent to the Disease Clinic to be tested for a pathogen infection. Fourteen of the samples came back positive with conclusive evidence that they had a disease. There were six samples that came back negative while the remaining

two were inconclusive and have to be retested. The two species that need to be retested are the *Abies squamata* and the *Picea engelmannii*. Fourteen of the samples that came back positive had several diseases that were caused by ascomycete's pathogens. The samples that were tested were both coniferous and deciduous species. The majority of these species collected were kept in the outdoors area and the tunnel houses. Three of the samples were kept in the glass greenhouses. These samples included the *Davidia involucrata*, *Huperzia carinata*, and *Huperzia nummularifolia*. The positive samples had a broad range of pathogens which included nine different genera.

Plant Specimen:	GH#	Perm Accession #	# Plants	Collection Date	Result	Name of Pathogen
<i>Abies squamata</i>	2011x022	2011-037*#	9	9/12/2018	Resend	Resend
<i>Acer ceriferum</i>	2010x078	2010-156*#	5	9/12/2018	Negative	None
<i>Acer griseum</i>				9/12/2018	Positive	Phyllosticta
<i>Acer pycnanthum</i>	2016x091		5	8/27/2018	Positive	Pestalotia
<i>Acer tsinglingense</i>	2011x085	2011-096*#	8	9/12/2018	Positive	Pestalotia and Colletotrichum
<i>Cornus kousa</i> 'Scarlet Fire'			1	9/12/2018	Negative	None
<i>Davidia involucrata</i>	2017x096	2017-227*#	1	10/1/2018	Positive	Phyllosticta-like Fungus
<i>Huperzia carinata</i>			1	10/23/2018	Negative	None
<i>Huperzia nummularifolia</i>			1	10/23/2018	Positive	Fusarium and Colletotrichum
<i>Ilex colchica</i>	2016x183	2016-284*#	45	9/12/2018	Positive	Phytophthora
<i>Quercus macrocarpa</i>	2011x068	2011-070*#	4	8/27/2018	Positive	Tubakia
<i>Picea engelmannii</i>	2015x141	2015-269*#	5	9/12/2018	Resend	Resend
<i>Pieris floribunda</i>	2015x122	2015-251*#	27	10/23/2018	Positive	Phytophthora
<i>Prunus laurocerasus</i> 'Chestnut Hill'				9/12/2018	Positive	Shothole- Fungus/Bacteria
<i>Prunus X 'Okame'</i>	2015x069		8	9/12/2018	Negative	None
<i>Prunus sargentii</i>	2013x083	2018-034*B		9/12/2018	Negative	None
<i>Prunus x yedoensis</i>	2015x052	None	3	9/12/2018	Positive	Cercospora-like Fungi
<i>Sinocalycanthus chinensis</i>	2018x051	None	8	8/27/2018	Positive	Colletotrichum
<i>Stewartia malacodendron</i>	2017x013	2018-007*#	14	8/27/2018	Negative	None
<i>Styrax hemsleyana</i>	2010x074	2010-149*C		8/27/2018	Positive	Colletotrichum
<i>Thujaopsis dolobrata</i> 'Variegata'		2016-131*#		8/27/2018	Positive	Colletotrichum
<i>Tsuga canadensis</i>		2016-228*A-C	3	9/12/2018	Positive	Phomopsis

Discussion

The results of the research demonstrate that the greenhouse area of Morris Arboretum has several pathogen infections in their collections. The majority of these infections are fungal pathogens. The only pathogen that was not specifically designated as a fungal pathogen was the shot hole infection on the *Prunus laurocerasus* 'Chestnut Hill.' It was not specifically identified as a fungi because it can be caused by either a fungal or bacterial pathogen. Fourteen of the 24 samples that were tested came back as positive. This means that 58.3% of collected samples were positive for a pathogen infection. 33.3% of the samples were negative while the remaining 8.3% of the samples have to be retested. On average 85% of all plant diseases are caused by

fungi. My data has shown that nearly 100% of the 14 samples that tested positive were caused by fungal pathogens. Eleven out of the 14 positive samples were kept in the outside area of the greenhouses on tables or in the hoop houses. 2018 was an exceptional year for rain in the northeast continental United States. In total Philadelphia saw over 61 inches of rain in just a year's time (Kummer, 2018). The deluge of water that fell in 2018 could be one potential factor that explains an increase of fungal pathogens in the outdoor greenhouse area. Furthermore, 2018 was also the fourth hottest year recorded since reliable global temperature data started to be taken in 1880 (Borenstein, 2019). These factors combined create a perfect storm of environmental conditions that can drastically increase the probability of fungal plant pathogen infections.

Conclusion

Plant diseases and the pathogens that cause them are one of the biggest challenges that face the greenhouses at Morris Arboretum. They jeopardize important parts of the plant collection as well as have the potential of spreading to other parts of the property if they are planted out. Fungal plant pathogens are by far the leading culprits that afflict plants in the greenhouse collection. They can cause adverse prolonged symptoms in a host plant that can potentially lead to its death. More importantly, the virulent nature of fungal pathogens are the greatest cause of concern because they have the ability to quickly spread throughout a population of plants. Despite the insidious nature of plant pathogens, steps can be taken to prevent them from spreading and causing damage in the greenhouse area. The easiest way to reduce the potential for spreading disease is adapting cultural practices to reduce pathogen pressure. Cultural practices refer to methods in which plants are cultivated. These methods include application of nutrients, irrigation, and cultivation strategies (D'Arcy & Schumann, 2013). Controlling cultural practices, otherwise known as cultural controls, is achieved by carrying out activities like leaf removal from pots or improved sanitation practices (D'Arcy & Schumann, 2013). Establishing polices like sanitation practices or establishing guidelines that prevent overwatering are at the forefront in the battle against plant disease. Executing correct disease identification protocol and management strategies is paramount in the struggle against plant pathogens at Morris Arboretum greenhouses.

Colletotrichum



Colletotrichum

Species

- *C. gloeosporioides*
- *C. siamense*
- *C. australisinese*
- *C. fruticola*
- *C. acutatum*

Susceptible Plant

Species

- *Hydrangea*
- *Ligstrum*
- *Magnolia*
- *Nandina*
- *Osmanthus*
- *Peperomia*
- *Pinus*
- *Protea*
- *Sanservaria*
- *Syngonium*
- *Tolmeia*
- *Vinca minor*
- *Yucca*
- *Zinnia*
- *Ficus*
- *Camellia*
- *Anthurium*
- *Dionea*

Life Cycle

Colletotrichum is a fungal pathogen that gives rise to anthracnose disease in plants. It is a virulent pathogen by nature and causes severe damage to the foliage of infected plants. *Colletotrichum* is characterized by having two alternating sexual and asexual reproduction stages that makes it particularly hard to treat (Coats, 2019). These two sexual life cycles are distinguished by the different types of fruiting bodies they produce. However, the sexual life cycle is far more important due to its acute proliferation of spores (Coats, 2019). The pathogen is unique in the fact that it has a significant range of host species that can make it particularly detrimental in greenhouse or nursery operations.

Common Signs and Symptoms

The most common symptom that is noticeable on infected plants are leaf spots. Despite leaf spot being the most noticeable indication of anthracnose disease, there are numerous other symptoms that are attributed to an infection (Coats, 2019). The symptoms of the disease are also presented in dieback or canker of stems, cutting rot, and blight on flowers and fruits. Manifested symptoms are highly dependent on the host species that have become infected with *Colletotrichum* (Coats, 2019). Lesions that form on host plants, with a sufficient amount of time, will become enlarged and turn a dark brown to black color. If warm temperatures and adequate humidity are persistent fruiting bodies will form in the center of the lesions. These fruiting bodies are observable without aid from a microscope and demonstrate a sign of an infection (Coats, 2019).

Greenhouse Management Practices

The most effective measures to reduce *Colletotrichum* infections is to implement strict cleaning and sterilization practices in a greenhouse. Infected plants should be immediately quarantined in a separate area to reduce contact with healthy specimens. Due to spores being spread through splashing water, overhead watering should be minimized as much as possible (Brown, 2018). Dead foliage and stems should be immediately removed from infected plants to reduce the accumulation of spores. Plants that are severely infected should be immediately discarded and its container sterilized. Furthermore, high humidity and temperatures should be kept in check to reduce the potential formation of fruiting bodies (Coats, 2019).

Fusarium



Fusarium Species

- *F. avenaceum*
- *F. circinatum*
- *F. culmorum*
- *F. oxysporum*
- *F. sporotrichioides*
- *F. poae*
- *F. solani*
- *F. tricinctum*
- *F. proliferatum*
- *F. verticillioides*
- *F. langsethiae*
- *F. oxysporum*

Susceptible Plant Species

- *Acer negundo*
- *Carya illinoensis*
- *Ceratonia siliqua*
- *Cladrastis lutea*
- *Ficus retusa*
- *Persea americana*
- *Pistacia chiensis*
- *Pistacia vera*
- *Nyssa sylvatica*

Life Cycle

Fusarium is a host specific fungal pathogen that effects numerous genera of woody plant species. It spreads through asexual reproduction of spores that infect roots of susceptible plants. *Fusarium* favors temperatures between 75F and 86F but will not occur at temperature below 67F. Spores will cluster into large clumps known as sporodochia. Spores that start at the initial source of the infection will also act as overwintering structures (“Fusarium Wilt”, 2009). Overwintering spores subsist in soil and will repeat the infection cycle the following season. Overwintering structures can survive in the soil for years until optimal conditions are available for sporulation. After spores germinate, they will infect the roots of the host first. They will then spread from the roots through the stem and cause xylem tissue to become clogged and turn brown (“Fusarium Wilt”, 2009).

Common Signs and Symptoms

Fusarium wilt disease symptoms can vary from host to host and on the maturity of the host. Fully matured woody specimens will be able to tolerate a *Fusarium* infection and survive (“Fusarium Wilt”, 2009). However, a younger less mature specimen will not be able to tolerate the effects of an infection and will eventually die. Infected plants will begin to wilt and cause the lower leaves to yellow and dry. The xylem tissue will eventually decay and turn brown that will lead to the potential death of an infected plant. In the beginning stages of an infection roots will slowly begin to decline and start to slowly rot (“Fusarium Wilt”, 2009). In older plants infections cause the plant to yellow and cause stunting of its growth. Severe *Fusarium* infections will cause a mature plant’s seedlings to die.

Greenhouse Management Practices

Fusarium is a virulent pathogen that is best managed using cultural controls. One of the best ways to control infections is by using resistant cultivars. If a *Fusarium* infection has already started in a greenhouse area steps can be taken to minimize the spread to other plants. Preventing the movement of contaminated soil is one of the most important steps to reduce the rate of infection (“Fusarium Wilt”, 2009). Secondly, proper sanitation of pots and tools used in a greenhouse will reduce the potential of vectoring the pathogen. Removal and isolation of infected plants from the general population is an important preventive measure. If seed is being taken from an infected plant the seed is generally healthy. However, the seed coat will carry the pathogen so it necessary to treat the seeds with heat to destroy the potential of infection (“Fusarium Wilt”, 2009).

Pestalotiopsis



Pestalotiopsis

Species

- *P. palmara*
- *Pestalotiopsis* spp.

Susceptible Plant

Species

- *Thuja plicata*
- *Thuja occidentalis*
- *T. plicata* x *standishii*
- *Cupressocyparis leylandii*
- *Juniperus* spp.

Life Cycle

Pestalotiopsis is an opportunistic fungal pathogen that causes blight disease in a wide variety of plants including evergreen species and palms. The pathogen's main mode of entry into a host is through newly formed shoot tips and through pruning wounds (Brazeo, 2016). After the initial infection, the pathogen will spread to older, more established branches. Eventually, the pathogen will cause browning and dieback in stem tissue. Shoots and branches infected with *Pestalotiopsis* will eventually produce small amounts of fungal tissue beneath the surface (Brazeo, 2016). When moisture is abundant, the fungal tissue will rupture, releasing black spores. A distinctive characteristic of this fungus is its ability to live in a dormant state in plant tissue. This enables it to overwinter undetected in asymptomatic plant tissue until the following season (Brazeo, 2016).

Common Signs and Symptoms

The most common symptom that is caused by blight disease is shoot and branch dieback. Infected shoot tips will brown and become necrotic. Brownish dark lesions will form along branches and will eventually cause it to die due to damaged vascular tissue (Elliot, 2018). Foliage of infected plants will also develop dark brownish-black lesions that will adversely affect their photosynthetic capability (Brazeo, 2018). The only signs that are produced by the fungus are dark pads below the epidermis. These pads will eventually burst open, which will eject large masses of black spores to surrounding areas (Brazeo, 2018).

Greenhouse Management Practices

Due to the large amounts of spores produced by *Pestalotiopsis* fruiting bodies, sanitation, and water management is imperative to reduce the spread of infection. Plant wounds caused by human activity, insects, and other pathogens are another way infections proliferate through a greenhouse (Brazeo, 2016). These factors also need to be consistently monitored to reduce an increased rate of infection. The implementation of cultural control methods is the best way to control an outbreak of *Pestalotiopsis*. Water management requires the elimination of overhead watering and reduction of high levels of humidity in a greenhouse area (Brazeo, 2016). Furthermore, it is important to remove dead leaf litter and prune symptomatic trees to reduce the amount of spores released by infected plant material.

Phomopsis



Phomopsis Species

- *P. juniperovra*
- *D. helianthi*
- *D. gulyae*
- *D. kongii*
- *D. kochmanii*

Susceptible Plant Species

- *Platyclusus orientalis*
- *Thuja occidentalis*
- *Pseudotsuga menziesii*
- *Juniperus chinensis*
- *Prunus laurocerasus*

Life Cycle

Phomopsis is categorized as a virulent ascomycete fungal pathogen. It causes a serious blight disease in both woody and annual plants. The disease initially destroys new immature foliage, then moves into older stem and shoot tissue (“Phomopsis Cane”, 2016). Overwintering structures known as spores are dropped by fruiting bodies during the end of the pathogen lifecycle. These structures persist on shoots and stems that were killed during the previous year. Extended periods of warm and moist conditions exacerbate the severity of an infection and symptoms on the host plants. The central part of the infected plant will be more affected by the disease than the outer regions (“Phomopsis Cane”, 2016).

Common Signs and Symptoms

The first symptoms indicating a *Phomopsis* infection generally occur at the end of the spring season and early summer. Initial symptoms are denoted by die-back of new shoot growth. Immature shoots begin to turn yellow-green to red-brown then eventually ash-gray succumbing to the infection (“Phomopsis Blight”, 2019). The infection will spread from the immature tissue to the more mature connecting shoots. Lesions will begin to form on the on the intersecting healthy and diseased shoots. These lesions will be darker brown in color and are responsible for girdling young stems. Young stems will eventually die causing excessive tip die back (“Phomopsis Blight”, 2019). Older branches are more resilient to the more serious symptoms of the disease and can recover from girdling lesions. More advanced stages of *Phomopsis* infections will produce pycnidia on the surfaces of stems and leaves. Signs like pycnidia are physical manifestations of the fungus and appear as black specks on foliage (“Phomopsis Blight”, 2019).

Greenhouse Management Practices

The best way to control *Phomopsis* blight is through the implementation of genetic and cultural methods. Planting resistant varieties and cultivars will significantly reduce the occurrence of the disease in a greenhouse area. Furthermore, using practical cultural controls will prevent the spread of the pathogen and reduce the amount of overwintering structures on dead plant material. It is essential to prune out all dead or decayed plant material and immediately dispose of it. Another crucial cultural control is frequent sterilization of pruning tools used on infected plants (“Phomopsis Blight”, 2019).

Phytophthora



Phytophthora Species

- *P. capsici*
- *P. ramorum*
- *P. arenaria*
- *P. boehmeriae*
- *P. aini*
- *P. agathidicida*
- *P. bilobang*
- *P. caryotoga*

Susceptible Plant Genera

- Cornus
- Erica
- Malus
- Kalmia
- Picea
- Pieris
- Pinus
- Prunus
- Abies
- Buxus
- Chamaecyparis
- Daphne
- Calluna

Life Cycle

Phytophthora is a virulent pathogen that lives in soil and thrives in moist conditions. It is a unique pathogen because it formally was identified as a fungi. However, it has been reclassified as an oomycete which is a distinct category that is biologically different than fungi. Similarly to fungal pathogens *Phytophthora* produces resting spores that can subsist in the moist soil for years (Perry, 2006). If the soil is dry spores will only be able to survive a few months. When water and a host are available resting spores germinate producing mobile spores that directly infect roots, branches, and crowns (Perry 2006). Motile spores do not need an open wound to enter the plants outer surfaces. The pathogen can be easily spread by rain water, contaminated soil and irrigation water. In addition to spreading by water and soil contaminated equipment can act a vector to spread the pathogen (Babdoost, 2004).

Common Signs and Symptoms

Plants infected with *Phytophthora* rot disease suffer symptoms that are similar to abiotic drought stress. Leaves will change colors to a yellow, dull green, or reddish-purple color and begin to wilt. After showing initial symptoms of drought stress, trees and plants quickly succumb to the infection and die. *Phytophthora* rot will first cause a single branch or stem to develop symptoms before spreading to the rest of the plant. Plants that develop a crown infection will decline quickly and die in the matter of a one to two seasons. Root infections will cause plants to decline over years before dying (Perry, 2006). Unlike fungal infections, plants that develop *Phytophthora* infections do not produce fruiting bodies or mycelium and present very little signs of the disease (Perry, 2006).

Greenhouse Management Practices

The best strategy to use to minimize the risk of spreading a *Phytophthora* infections is good water management. It is crucial to reduce splashing water and soil by eliminating overhead watering (Perry, 2006). Furthermore, it is important to reduce periods that the soil is over saturated around the base of susceptible plants. Reducing soil compaction and providing plants with adequate soil drainage is key to preventing soil saturation. Eliminating weeds around plants and not watering the crown of the directly infected plant will also reduce the possibility of spreading the infection (Perry 2006). Isolation of infected plants is recommended to reduce the spread of possible plant material to uninfected areas of a greenhouse.

Shot Hole Disease



Shot Hole Species

- *Wilsonomyces carpophilus* (Fungi)
- *Xanthomonas pruni* (Bacteria)
- *Xanthomonas campestris* (Bacteria)
- *Cercospora circumscissa* (Fungi)
- *Microgleom pruni* (Fungi)

Susceptible Plant Species

- *Prunus laurocerasus*
- *Prunus persica*
- *Laurus nobilis*
- *Prunus amygdalus*
- *Prunus armeniaca*

Life Cycle

Shot hole disease is primarily caused by the fungal pathogen *Wilsonomyces carpophilus*. However, the disease can also be caused by several other fungal pathogens and bacteria. Shot hole is spread by overwintering structures that are housed by lesions on infected twigs and buds from the previous season (“Shot hole”, 2019). Only the current season’s new foliage, stems, and buds are susceptible to infection. Spores that land on new growth only take 24 hours to cause infection under optimal conditions of high humidity and temperature (“Prunus laurocerasus”, 2019). Infections are most likely to occur during the rainy season in the fall and spring. Spores spread predominantly through splashing water. Even under less than favorable conditions *Wilsonomyces* can germinate and infect new hosts at temperatures as low as 36°F (“Shot hole”, 2019).

Common Signs and Symptoms

The primary symptoms associated with shot hole disease are dark circular lesions that form on the leaves, twigs, and buds. On fruit plants such as *Prunus persica* small black lesions will form on fruit (“Shot hole”, 2019). Symptoms on twigs are distinct because they first appear as small, light-purple spots. Eventually these lesions will become enlarged and turn a dark brown with a purple center (“Shot hole”, 2019). At the center of the each lesion a small bump will form. These bumps are fruiting bodies that produce spores that will further spread the infection to surrounding plants. Comparatively, lesions that manifest on the foliage of infected hosts will become enlarged and turn light brown (“Shot hole”, 2019). At the center of these lesions small bumps will form and produce fruiting bodies. Eventually these lesions will abscise from the foliage leaving a “shot hole” appearance.

Greenhouse Management Practices

Cultural controls are the best method to prevent and reduce an infection of shot hole disease. A major control that reduces the transmittance of spores is avoiding the use overhead irrigation. Secondly, reducing the amount of time that plants are wet prevents conditions that could cause spores to germinate (“Shot hole”, 2019). Isolation is another preventative method that can help reduce the spread and reoccurrence of infections. It is also important to remove infected foliage, twigs, and buds to prevent the potential dispersal of spores in a greenhouse area (“Shot hole”, 2019).

Tubakia



Tubakia Species

- *T. dryina*
- *T. seorkanensis*
- *T. iowensis*

Susceptible Plant Species

- *Quercus wislizeni*
(Interior Live Oak)
- *Quercus falcata*
- *Quercus rubra*
- *Quercus macrocarpa*
- *Quercus agrifolia*
- *Castanea dentata*
- *Acer rubrum*
- *Acer saccharum*

Life Cycle

Tubakia is a foliar fungal pathogen that causes leaf spot on numerous plant species. It is responsible for causing circular red and brown lesions on the foliage of infected plants. The spots eventually form large necrotic patches that kill the leaves and reduce the photosynthetic capability of the plant (Brazee, 2018). The infections begin in mid-summer and continue into the fall. Brown lesions that form during the summer months give rise to fruiting bodies that will eventually eject spores and spread to other leaves. These spores act as overwintering structures that will subsist on the dead foliage that remain incompletely abscised from the plant (Brazee, 2018). Overwintering spores on the dead foliage will give rise to the fungus in the following season and continue the life cycle.

Common Signs and Symptoms

Tubakia leaf blot causes systems that are detrimental to the overall health of the plant if it is a significant infection. The first symptoms that appear are brown and red lesions that appear on the surface of an infected leaf during the early spring season. The lesions then begin to cluster and eventually form large necrotic spots (Pataky, 2016). These large necrotic areas eventually cause the leaf to die and abscise. If a tree is fully mature the disease can cause an overall change in the color canopy color and health. In younger more immature plants the disease can cause it to completely defoliate and cause the plant to die (Brazee, 2018).

Greenhouse Management Practices

Cultural controls are the best way to manage infections of *Tubakia*. Removing fallen leaf litter greatly reduces the amount of potential inoculum that could spread the pathogen. During the fall months removing all of the downed leaf litter out of pots is essential to disrupting the pathogen life cycle (Brazee, 2018). Furthermore, it is important to remove heavily infected foliage during the spring months before it is abscised. Chemical treatments can be applied but often times are not necessary.

References

- D'Arcy, C.J., Schumann, G.L. (2013) Essential Plant Pathology: Second Edition. St. Paul, Minnesota: The American Phytopathological Society Press.
- Babadoost, M. (2004) Phytophthora Blight: A Serious Threat to Cucurbit Industries. doi:10.1094/APSnetFeature-2004-0404.
- Borenstein, S. (2019, February 6) 2018 Was Fourth Hottest Year on Record, US Data Show. <https://www.nbcphiladelphia.com/news/national-international/2018-Fourth-Hottest-Year-on-Record-505420931.html>
- Braze, N.J. (2016, July1). Arborvitae Needle Blight. <https://ag.umass.edu/landscape/factsheets/arborvitae-needle-blight>
- Brazeem N.J. (2018, January 24). Tubakia Leaf Blotch. <https://ag.umass.edu/landscape/factsheets/tubakia-leaf-blotch>
- Brown, S. (2018, February 3). Fact Sheet: Anthracnose Disease of Ornamental Plants: A Pictorial. <http://blogs.ifas.ufl.edu/leeco/2018/02/03/factsheet-anthracnose/>
- Coats, L., Cooke, T., Forsberg, L. (2019, February 10). The Biology and Management of Colletotrichum Disease in Production Nurseries. https://www.ngia.com.au/Attachment?Action=Download&Attachment_id=1829
- Elliot, M.L. (2018, January). Petalotiopsis (Pestalotia) Diseases of Palm. <http://edis.ifas.ufl.edu/pp141>
- Fusarium Wilt. (2009, March). <http://ipm.ucanr.edu/PMG/r280100811.html>
- Kummer, F. (2018, December 31). 2018 has set rainfall records in the Philadelphia region- and the rain may not let up soon. <https://www.philly.com/news/rainfall-totals-record-philadelphia-region--20181231.html>
- Phomopsis Blight. (2019, February). <http://extension.illinois.edu/focus/index.cfm?problem=phomopsis-blight>
- Perry, E.J. (2006, August). Phytophthora Root and Crown Rot in the Garden. <http://ipm.ucanr.edu/PMG/PESTNOTES/pn74133.html>
- Phomopsis Cane and Leafspot. (2016, December). <http://ipm.ucanr.edu/PMG/r302100411.html>
- Pataky, N. (2016, September 11). Tubakia Leaf Spot of Trees. <http://hyg.ipm.illinois.edu/pastpest/200617b.html>
- Prunus laurocerasus*- Leaf Spots and Shothole. (2019, February). <https://pnwhandbooks.org/plantdisease/host-disease/prunus-laurocerasus-leaf-spots-shothole>
- Shot hole, or Coryneum blight- *Wilsonomyces carpophilus* (2019, February). <http://ipm.ucanr.edu/PMG/GARDEN/FRUIT/DISEASE/shothole.html>

Wollaeger, H. (2014, September 4). Fusarium Wilt of Cyclamen.
https://www.canr.msu.edu/news/fusarium_wilt_of_cyclamen