DISEASES OF AGRONOMIC AND VEGETABLE CROPS CAUSED BY PYTHIUM

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THE ORGANISMS

Pythium is a generic term used herein to represent numerous species of fungal-like organisms within the Genus *Pythium*. *Pythium* spp. occur throughout the world and are common in association with roots of plants and other plant parts in contact with or in the proximity of soil. When environmental conditions are favorable for these organisms and adverse for the plant, infection of plants may occur. Infections typically occur in roots, lower stems, fruit near or in contact with the soil, and soft plant tissues which exist naturally in seedlings of plants prior to or shortly after emergence from the soil. *Pythium* spp. that are not parasitic in plants have caused diseases in fish, crustacea, and even other *Pythium* spp.

Over time, taxonomists (scientists who study systematics, the system of classification) have changed the classification position of *Pythium* spp. from being within the kingdom Planta to being within the kingdom Chromista. The newest classification schemes place *Pythium* spp. as being more closely related to diatoms and brown or golden algae than fungi. In the newest classification systems, based upon single evolutionary lines and unique morphological and biochemical characteristics, most of the other fungi, such as *Fusarium* spp. or *Rhizoctonia* spp. that were formerly in the plant kingdom, are now placed in the kingdom Eumycota (named Mycota or Fungi by some authorities). A few of the fungi, such as *Plasmodiophora* spp., are in the kingdom Protozoa. All of these organisms, however, may still by referred to by the common or colloquial term fungi because they are all spore-bearing eukaryotes, without chlorophyll, that typically have a walled, filamentous or plasmodial thallus and the ability to absorb their food. Thus, although different fungi are classified in three biological kingdoms, they all retain the common name (fungus; fungi, pl.) based upon common life forms and functions. The reader should realize that these academic developments have not changed the life cycles of *Pythium* spp. nor have they effectually influenced our approaches used for control and management of the diseases caused by *Pythium* spp. This information provides the reader with some of the dynamic turns and twists that occur in science.

The most common species of *Pythium* that cause important plant diseases in Florida are *Pythium myriotylum* and *P. aphanidermatum*. Other species of Pythium that are sometimes associated with dysfunctional plants in Florida are *P. splendens*, *P. irregulare*, and *P. vexans*. It is generally considered that *P. myriotylum* and *P. aphanidermatum* abound in Florida because they are adapted to high soil temperature. Growth of these later two species can occur from 40 or 50° F to 105° F, but the optimum temperatures for their growth and infection of plants range between 86 and 98° F. In other locations in the world, other species of Pythium cause plant diseases. For example, in the northern United States, *P. ultimum* prevails in some situations. *Pythium ultimum* prevails in cooler to cold soils; it can grow across as wide a range of temperatures as the other two, but its optimum for growth is between 77 and 86° F. Interestingly, the optimum for infection of plant tissue by *P. ultimum* is slightly lower (74° F or slightly below). Typically, *Pythium* spp. are composed of microscopic, slender, round tubes (strands) called hyphae

(Fig.1). A mass of these hyphae is called a mycelium (mycelia, pl.) and is white. Sometimes large mycelial colonies can be seen growing on infected tissue (Figs. 18, 19, & 20). A colony of mycelium can grow more than an inch per day when moist and warm conditions prevail.

Multiplication of *Pythium* spp. is done by growth of the hyphae and production of microscopic spores. Four types of spores are produced, sporangia, zoospores, oospores and chlamydospores. Chlamydospores are formed as thickened segments of hyphae, but they are not considered important for *Pythium* spp. that cause plant diseases in Florida. Sporangia can germinate to form new hyphae, but typically the role of sporangia within the disease cycle is to produce vesicles in which zoospores are formed.

Zoospores are fragile, non-sexually produced spores without cell walls and they have two flagella (tails) that propel the organism in water. Zoospores are produced in microscopic vesicles (bulb-like, unwalled structures) that are attached to sporangia (also a bulb-like or lobe-like structures, with cell walls) which are in turn formed on stalks or formed as enlarged hyphae (Fig 1). Water is necessary for production of sporangia, vesicles, and zoospores, and thus, *Pythium* spp. have been referred to commonly as belonging to the Awater molds.@ Consequently, standing water in fields, ditches, ponds, lakes, and hydroponic systems are places that *Pythium* spp. can exist, multiply to great numbers and spread. To illustrate the small size of zoospores, it would take about 2500 zoospores in a line to equal one inch. Zoospores can swim for 20 to 30 hours and move three or more inches through soil. Without free water they die rapidly or sometimes they can encyst by forming a thick wall and may survive up to 7 days in soil. Zoospores swim against gravity and after reaching the surface of flooded soil, may be carried to new roots if the water is moving. The zoospores are then attracted by chemicals to root tips where infection typically occurs. Natural or artificial movement of water infested with *Pythium* spp. provides a method by which rapid spread of these plant pathogens can occur over greater distances.

An oospore (Fig. 2) forms after mating by male and female portions of the thallus (the entire mass of the organism). Most species of *Pythium* are hermaphroditic (homothallic) and thus are self fertile. Because oospores are the result of sexual mating, the organism has a mechanism for recombining genes to enhance variation within the species. Also, oospores provide an effective method for survival of *Pythium* spp. because oospores typically have thickened walls. Oospores survive in old crop debris such as undecomposed roots and stems that were infected earlier and they survive in soil or old containers or on implements that contain infected plant tissue or infested soil. Oospores are extremely durable and have survived for more than 10 years. *Pythium* spp. have survived passage through the intestinal tracts or earthworms, snails, and birds.

The primary habitat for *Pythium* spp. is in the soil or previous crop debris, such as roots and stems. *Pythium* spp. can be found typically in the upper 12 inches of soil, but they have been found as deep as 12 feet. *Pythium* spp. can also exist in old plant debris in cull piles or areas where infected plants are discarded. These fungi commonly exist in ponds, lakes, or other sources of standing water. Soil and these bodies of water are the most common sources of inocula (spores or hyphal fragments) for pathogenic species. *Pythium* spp. are not seedborne, but they can reside in clonally propagated stock such as seed pieces of potatoes, sweet potatoes, sugarcane or transplants of strawberry. Transplants of any crop can carry *Pythium* spp. in colonized tissue or by infestation of associated soil and transplant trays.

Most infections from *Pythium* spp. occur by the penetration of the root (particularly root tips) or other susceptible tissue from germ tubes that arise from the zoospores. Because zoospores can be produced in extremely high numbers, visible disease appears to occur Aalmost overnight.@ In fact, one generation (i.e. zoospore to zoospore) can occur in 18 hours or less. Hyphal infections can occur also, but they are less efficient and they would require significantly more time to attain an equivalent amount of disease to that resulting from zoospores. When these organisms colonize and then penetrate plant tissue, hyphae absorb nourishment from their living or non-living substrate. Colonization of plant tissue by *P. aphanidermatum* is assisted by the ability of this organism to produce pectolytic or cellulytic enzymes that breakdown tissue. *Pythium myriotylum* also may produce toxins that assist in breakdown of the host tisuue. Often, infections from *Pythium* spp. have a greasy or water-soaked appearance in the plant tissue because of leakage of the moist cellular contents from plant cells that occurs from the enzymatic activity mentioned earlier. Because the enzymatic activity from *Pythium* spp. Abreaks down@ the soft (parenchymous) tissue, it is common to see the outer portion of dysfunctional roots rotted and the harder vascular tissue in the center of the root remains intact (Fig. 3). This can be detected in the field by trying to slip the outer portion of the root off of the central vascular tissue (stele). Contrast this effect with a healthy appearing root seen microscopically in Fig. 4.

Infection is promoted as the population of a *Pythium* sp. increases. Factors that influence the population of *Pythium* spp. in the soil include soil water content, soil atmosphere (O_2, CO_2, and volatiles), soil temperature, soil pH, nutrient status of soil, usage of certain pesticides in the soil, and other microorganisms. For example, microflora in the soil, such as the fungi *Trichoderma* spp. and actinomycotic organisms such as *Actinomyces* spp., can interfere with the life cycles of *Pythium* spp. Roots or plant parts that are infected with *Pythium* spp.may be infected with other parasitic organisms. For example, infection with other organisms, such as *Rhizoctonia solani* or *Fusarium oxyspsorum* and nematodes, such as root knot nematode or sting nematode, can occur in the same tissue as that infected with *Pythium* spp. Conversely, some bacteria or fungi, such as the fungus *Trichoderma*, may colonize roots along with *Pythium* spp. and reduce damage.

The host range for *Pythium* spp. is extremely large. Broadleaf and grass plants are susceptible to multiple species of Pythium. For example, *P. myriotylum* and *P. aphanidermatum* are both capable of infecting broadleaf plants such as tomatoes, cucurbits, peanuts, or ornamentals, as well as grasses such as wheat, corn, or turfgrasses. The crop species that have been commonly infected with *Pythium* spp. in Florida include foliage ornamentals, turfgrasses, Bermudagrass used in pastures, peppers, tomatoes, beans, soybeans, southern peas, and small grains (e.g. wheat, oats, rye). Solanaceous weeds, *Crotalaria* spp., many weedy grasses, and other weeds may be hosts of *Pythium* spp. and serve as important sources of inocula.

With the anticipated loss of methyl bromide as a soil fumigant in 2005, it is likely that crops that are now commonly grown on methyl bromide/chloropicrin-fumigated field soil, such as tomatoes, peppers, strawberries, and many others, will incur greater incidences of visible disease from *Pythium* spp. Infection of roots by *Pythium* spp. has occurred to some degree in crops that have been grown in methyl bromide/chloropicrin-fumigated soil or treated with some other chemical, but the level of infection has generally been at a lower level and thus, symptoms have been suppressed. Chloropicrin, which is commonly formulated with methyl bromide, tends to be more fungicidal than methyl bromide but the combination of methyl bromide plus chloropicrin has had a synergistic effect on soilborne organisms such as *Pythium* spp., *Rhizoctonia* spp., *Fusarium* spp. and many others.

DIAGNOSIS AND SYMPTOMS

For accurate diagnoses of plants suspected of having Pythium-induced dysfunctions, it would be best to submit quality samples to a reputable diagnostic laboratory. With continued experience, you should be able to learn which situations will require submission of samples. You should realize that discolored roots or tissue are not always associated with parasitic organisms. Excess fertilizer, flooded soils, insect feeding, and nematode feeding are just a few of the other causes of dysfunctional roots. Generally, all dysfunctions where root rot is a portion of the problem should have a laboratory assessment to determine if *Pythium* spp. are involved by themselves, or in conjunction with infections from other organisms such as *Rhizoctonia* spp., *Fusarium* spp., *Macrophomina* spp. or a myriad of other possibilities. Diagnosticians use microscopic techniques and aseptic culturing to assess for the presence of *Pythium* spp. Some serological kits are available for use in the field but the user should realize that because of the diversity of *Pythium* spp. in the soil and in plant tissue, and because of the likelihood of mixed infections with other organisms, serological techniques for *Pythium* alone are not likely to provide a complete diagnosis unless a complete array of test kits are used for the one situation at hand.

Pythium spp. are often associated with seedling blights for many crops. Both grass crops and broadleaf crops incur this type of disease. Seedlings can be infected prior to (pre emergent damping off) or after (post emergent damping off) emergence from the soil. For the spinach and soybeans pictured herein (Figs. 5 & 6), the seedling blights were both pre emergent and post emergent for both crops and the damage was the result of infection by both *Pythium* spp. and *Rhizoctonia solani*. It is risky to decide what pathogens are involved with seedling blights, root rots, and lower stem rots without assessments in the laboratory, but one of the characteristics of tissue infected with *Pythium* spp. is the presence of water-soaked or greasy appearing tissue. In Figure 6, the water soaked tissue of soybean seedlings is caused by the infection with *a Pythium* sp. and the distinct, orange to red to dark, sunken lesions were caused by *Rhizoctonia solani*.

Cultures of a *Pythium* sp. were isolated from the water-soaked, lower stem tissue (Fig. 7) of these hydroponically grown tomatoes. The symptoms in the leaves include dried and necrotic (brown) areas that begin near the tips or margins of the leaflets. When roots or lower stems are infected with *Pythium* spp. or other pathogens, symptoms in the upper parts of plants are expressed indirectly because the effect from root and stem rots is to partially or totally inhibit the movement of water and nutrients from the soil to the upper portions of the plants. In this situation with tomatoes, the leaves turned brown, but as shall be seen later, chlorosis (yellowing) of leaves is another common indirect symptom.

In small plants planted thickly, such as in transplant trays in the greenhouse, *Pythium* spp. can infect and colonize the plants with the result that the entire plant is destroyed (Fig. 8). Note the water-soaked tissue in this situation with lettuce (Fig. 8). It is common to see white, mycelial growth associated with dead or dysfunctional plants that are infected with these pathogens. Mycelial growth was present in this situation, but a hand lens was necessary to see the hyphal strands.

Another major symptom in plants that possess root and lower stem rot caused by *Pythium* spp. is yellowing of leaves. Typically, the yellowing begins on the lower leaves first, but cases where yellowing begins on upper portions of the plant are not rare. In some situations, the entire plant will become yellow. This leaf yellowing occurs in both broadleaf plants and grasses (Figs. 9, 10, 12, 13, and 14). Lower leaf yellowing can also be caused by a deficiency of nitrogen.

The level of infection can be so severe that plants die (Figs. 9 and 13). In some situations, infections from *Pythium* spp. along with another pathogen may produce similar symptoms, as is the case with wheat infected with *Pythium* and soilborne wheat mosaic virus at the same time (Fig. 14). Field examination of roots infected with *Pythium* spp. may reveal an abbreviated root system, as was the case with the millet pictured herein (Figs. 10 and 11). Reductions in grain and fruit yield can occur and the quantity and quality of animal feed can be reduced. If Pythium root rot occurs early in the life of the crop, it may cause an infected root to produce multiple roots that are smaller in diameter, as occurs in carrot (Fig. 15). Such carrot roots are obviously unmarketable.

Infection with *Pythium* spp. can cause wilting of numerous crop species. Peppers commonly wilt when infected with *Pythium* spp. (Fig. 16). In peanut, Pythium root rot can cause wilt of the entire plant or a dark brown to black discoloration of the pods (Fig. 17). Sometimes infections by *Pythium* spp. are accompanied by infection with root knot nematode (Fig 17).

If wet and warm conditions prevail because of frequent rains or irrigation, moist and overcast days, or the site is typically wet, the white mycelia of *Pythium* spp. may become evident in the field. A common name for this disease is Acottony leak.@ The cottony portion of the name is from the white mycelial growth and the leak portion of the name is because the infected tissue is often greasy and water soaked as a result of tissue breakdown from the enzymes produced by *Pythium* spp. An enclosed crop canopy is another situation where moisture is retained, but if ambient conditions are wet, an enclosed canopy is not necessary for cottony leak to occur. Some of the crops where cottony leak is seen include bean (Fig 18), squash (Fig. 19), cucumber (Fig. 20), and salad crops such as lettuce.

CONTROL AND MANAGEMENT

Suppression of plant diseases caused by *Pythium* spp. requires a different sequence of tactics for different situations. For example, suppression of seedling blights, caused by *Pythium* spp., requires different tactics than suppression of cottony leak, caused by *Pythium* spp., in cucumber fruit. It is best to use all the tactics available for any situation because no one tactic is a panacea. A planned, systematic approach is best for controlling any plant disease. Resistant cultivars to *Pythium* do not exist and thus, the control program for *Pythium* spp. must be done without this important control measure. Hardened and woody tissue of all plants tend to be more resistant that soft and young tissue.

For all field situations, crop rotation with unrelated crops should be used. Many plant pests, such as nematodes, fungi that cause wilts, and some leaf spot pathogens, are significantly suppressed by crop rotation. Because *Pythium* spp. infect and colonize many broadleaf and grass crops, crop rotation may not provide the level of control attained with those pests that are more crop specific, such as a fungus that causes Fusarium wilt. However crop rotation may prevent a given Astrain@ of a *Pythium* sp. from increasing to unmanageable levels on a crop that is grown on the same soil over and over. Keep in mind that crop rotation refers to years and not seasons. For example, alternate cropping wheat and soybeans on the same land within the same year is considered double cropping and not crop rotation. The planting of wheat or soybean, in this case, one year after another is generally not considered an adequate period of time to suppress soil populations of *Pythium* spp. or other soilborne pests, such as other fungi or nematodes.

Crops should be planted in well drained soils because *Pythium* spp. thrive in moist soils. They multiply and move in free water with the production and movement of the swimming zoospores. One is most likely to encounter Pythium-induced diseases at sites that have standing water or saturated soils for long periods of time. However, zoospores are produced rapidly and may be detected within half an hour after a site is flooded and remains inundated. The sandy soils in Florida are generally considered quite well drained because of their porosity, but certain conditions can counteract this natural porosity. If enough rain or irrigation occurs, water can stand in portions of fields with sandy soils either because those portions of the fields are low and water accumulates or hard pans occur below the soil surface. Hard pans in soils are formed either from compaction by repeated use of tractor and implement usage or because of an underlying layer of a finer sand or clay that congeals. Hard pans may exist on new land. One of the characteristics of the Aflatwoods@ soils in peninsular Florida is the natural existence of a hard pan. Subsoiling equipment is available to break hard pans; this practice will enhance drainage and deeper penetration of roots. Where seepage irrigation is used on a natural hardpan, destruction of this hardpan would be counterproductive. Unnatural hardpans above this natural hardpan can form and may need to be disrupted.

Seed or transplants should not be placed too deep. The longer it takes for seedlings to emerge, the more likely seedling blights will occur. Prior to planting every effort should be made to suppress nematodes and insects in the soil. Damage from these pests to the roots or lower stems provides entry points for *Pythium* spp. and other pathogens.

High density plant populations should be avoided. While high density plantings have some advantages for some crops in some situations, they do create more favorable environments for growth of *Pythium* spp. and certain other pathogens because aeration and drying within the canopy is reduced.

Mechanical cultivation of an established planting for weed control can influence diseases caused by *Pythium* spp. and other pathogens. If the cultivating implement damages the roots of the crop, it would not be unexpected to have increased root or lower stem rots later. Also, when cultivating, avoid moving soil onto the established plant. The soil deposited onto the stem can contain disease-causing organisms which can infect the tender stem. An older and hardened stem is more resistant to such infections. Depositing hot soil on stems has caused heat scald in the stems, which was followed by infections by several parasitic organisms.

The time of year when a crop is planted may influence the qualitative and quantitative aspects of Pythium-induced diseases. For example, the planting of small grains, such as wheat, oats, or rye, early in the fall (September to mid October) in northern Florida, when the soil is still quite warm, is desirable for using the crop for livestock forage. However, such early plantings are commonly damaged by *Pythium aphanidermatum*. which causes seedling blights and root rots. Planting those small grains in November to early December progressively reduces the risk from *Pythium* spp. Vegetables, such as collards, turnips, and mustard, that are planted in early fall can incur the same problem as they grow best at cooler temperatures. For vegetables that grow best in warmer soils, such as okra, planting in warm soils promotes earlier emergence and reduces the possibility of seedling blight caused by *Pythium* spp.

To reduce problems with *Pythium* spp. in crops planted early in the fall, some control techniques are available in addition to the previously mentioned tactics. For the small grains planted in early fall, certain seed treatment chemicals are available. Some of the broad spectrum, non-systemic chemicals, such as captan and thiram, provide low levels of suppression. However, certain systemic chemicals (e.g mefenoxam) provide longer protection as the seedling enlarges. For the early fall-planted vegetables or vegetables planted at any time, one can bypass the highly susceptible seedling crop growth stage by using healthy transplants. Transplants can be infected with *Pythium* spp. or other pathogens during their production; thus, it is imperative to use pest-free transplants. Ask your supplier if the transplants were certified pest free by an authorized government agency. Although such an inspection and certification is not a guarantee for perfect plants, it is better than no inspection at all. If certified plants are not available from your supplier, start dealing with a supplier who provides quality plants.

Production of healthy transplants is the result of the deliberate use of sanitary practices. If the plants are produced outdoors in ground level beds, such as those used for tobacco in northern Florida for over 100 years, several tactics are available. Do not use the same site each year for producing transplants. Isolate the transplant production area from crop production fields. Choose a site that has adequate drainage for water. When preparing the site with tillage equipment, plow under old weed and crop debris at least 30 days prior to seeding the bed, particularly if a soil fumigant is not to be used. This interval of time allows beneficial organisms to build up in the soil and reduce parasitic fungi, such as *Pythium* spp. and *Rhizoctonia* spp. that can abound on recently plowed down plant debris. Wash off soil and crop debris from tractor tires and implements when moving from a field known to be infested with *Pythium* spp. or other pests. The finished transplant bed should be raised above the perimeter area by at least six inches to allow for run off of excess water and reduce the chance of the prepared bed from being further contaminated with disease-causing organisms. If a soil fumigant is used to reduce soilborne pests, such as *Pythium* spp. and *Rhizoctonia* spp., the use of a raised bed is even more important. Fumigated, sterilized or pasturized soil have minimal or no beneficial, soilborne organisms to compete against pathogenic organisms. Without competition, *Pythium* spp. and *Rhizoctonia* spp. tend to grow and multiply at faster rates when compared to their growth in the presence of competitors. Do not use pond or ditch water for irrigation; they are commonly infested with pathogenic organisms.

For transplants that are grown in a greenhouse-type situation in containers or trays, several sanitary tactics are available to minimize infestations and subsequent infection from *Pythium* spp. and other parasitic organisms. A soil mix that has been sterilized or sanitized, such as MetroMix, should be used. Use a loose mix that allows excess water to drain. Many commercial brands of such soil mixes are available or you can blend your own soil mix and then sanitize it with either dry heat, steam or an available soil fumigant, such as methyl bromide. However, note that at the time of this writing, methyl bromide is scheduled to be totally unavailable for any use except for quarantine purposes by the year 2005.

The site of the transplant production area should be away from production fields and the perimeter around the site should be a well maintained grass. The transplant production trays or containers should be on raised benches to minimize the chance of contamination with infested soil. They should never be placed on the floor anywhere within the premises. Hands should be thoroughly washed with soap and water before handling the planting equipment, containers or plants. Specific personnel should be assigned to the transplant production area, and they should not be allowed to return to the transplant production area if they leave the site and make any contact with soil until they have washed their hands and forearms. All implements for planting that are likely to come into contact with the containers or plants should be sanitized. If a tray or plant falls to the ground level soil, do not place it back onto the raised bench until it has been sanitized. The discharge end of hoses or watering devices, and other implements should not be allowed to be on the ground where they can become contaminated.

Walkways and access ways within the production area should be concrete or a material that can be easily washed. The soil under the raised benches or frames should be void of weeds and volunteer plants. Some greenhouse production sites have eliminated exposed soil by pouring the entire site with concrete for easier cleaning and maintenance. All soil mixes and containers should not be stored in contact with the flooring of the structure even if it is concrete. They should also be stored in such a way that when the concrete floor is washed, water splash from the floor will not contact the soil or containers. Do not use pond or ditch water for washing or irrigation. Cull piles of plants and used containers should not be near areas used for plant production or planting purposes and they should be buried or destroyed as soon as possible.

Containers used for transplant production can be reused repeatedly provided they are sanitized between uses. All cleaning operations should be away from transplant and production areas. Prior to sanitizing the containers or trays, wash off the clinging soil and plant parts. The washed containers can then be sanitized by soaking them for at least 30 minutes in a commercial bleach (5.25%) solution that is diluted to 10% (one part 5.25% bleach to nine parts of tap or well water). Other sanitizing agents and formulations are available, but the above suggestion is made because it is known to be effective. One logistical problem that exists when trying to submerge polystyrene trays in a sanitizing solution is their buoyancy. It will take significant overhead weight or mechanical force to keep them submerged. Solid, plastic trays are becoming increasingly popular because they are easily washed and they submerge easily. However, they will not float if one is using a float-type transplant production system.

At first sighting of some transplants having disease of any kind, the container or tray with those plants should be removed from the production area until the cause of the problem is determined. If they are not removed, these first groups of plants with disease may serve as a source of inoculum for the remainder of your operation. It is better to play it safe early rather than having a major problem later.

For crops such as tomatoes or cucumbers that are produced in hydroponic systems in the greenhouse, the same level of sanitation used for production of transplants must be utilized. Contamination of the rooting zone of plants must be eliminated whether the system is an ebb and flow water system or bags of moistened soil are used for growing the plants. The same sanitary techniques used for transplant production can be utilized for crop production in the greenhouse.

Several types of chemicals can be use for suppression of *Pythium* spp. As mentioned above, sanitizing compounds such as bleach are available and effective. Many chemical seed treatments have been used for decades. At the time of this writing, formulations of seed treatment fungicides that contain mefenoxam (e.g Apron) are best because they strongly suppress *Pythium* spp. and they are systemic. One of the negative characteristics of mefenoxam and certain other non-broad spectrum fungicides is that resistance within the population of the intended pest develops and renders the product ineffective against those non-sensitive strains. For this reason it is advised that a seed treatment be composed of a selective fungicide, like mefenoxam, and a broad spectrum fungicide, such as captan and thiram.

Pre-plant, soil fumigation with chemicals such as methyl bromide (available as limited supplies until 2005), chloropicrin and metam-sodium are available. They are effective if applied correctly. Soil fumigants are most effective if applied into well tilled soil that is slightly moist. If the soil is too wet, the vapors of the fumigant do not move adequately through the air pores in the soil. If the soil is too dry, the fumigant moves too quickly and the exposure time of the plant pest at any one site in the soil is not long enough. The linear air pockets from fumigant chisels, disks, or shanks that remain to the soil surface after the fumigation process must be solidly sealed. Failure to do so will allow for an immediate and premature escape of the fumigant from the soil which in turn, minimizes the needed effects from the fumigant. Each fumigant has a standard waiting time from time of application to time of planting or transplanting. With chloropicirin and metam-sodium, the waiting period can be as long as three weeks in heavier soils with clay. With sandier soils, slightly shorter waiting periods can be used, but if the soil is moist, it would be best to wait the full three weeks, even in sandy soils.

Some fungicides for suppression of Pythium-induced diseases are available as sprays. These products can be somewhat effective against diseases caused by *Pythium* spp. that occur above the soil surface, such as cottony leak Most fungicides that are applied as sprays will not adequately suppress disease below the soil surface. If the fungicide is water soluble and directed to the soil surface, the compound will leach into the rooting zone and suppress the fungal activity below the soil surface. Such is the case with mefenoxam-containing fungicides (e.g. Ridomil Gold) for suppression of seedling blights and root rots in young plants caused by *Pythium* spp. However, if the spray is applied after infection occurs, you will be less likely to attain a positive response. **WITH ALL CHEMICALS, READ AND UNDERSTAND THE INTENTIONS OF THE LABEL. IT HAS INFORMATION ON USE PATTERNS AND RESTRICTIONS.**

Heat can be used for suppression of diseases caused *Pythium* spp. For suppression of *Pythium* spp., the soil must be heated to at least 120° F for at least 30 consecutive minutes to reduce the population. This can be done with steam for use in greenhouse operations or solarization for use in the field or greenhouse. For greenhouse soil, steam can be released into an enclosed body of soil until the temperature of the soil at all sites reaches 120° F for at least 30 min. In reality, to control other fungal pathogens, insects and weed seeds, a temperature of 180° F throughout the soil mass for 30 consecutive minutes is recommended. Because the steam may not be able to permeate deeply into soil from its ejection site, smaller batchs of soil should be used to insure complete pasteurization. Start the 30 minute count when all the soil mass has achieved 180° F as indicated by a reliable thermometer. Dry heat can be used but it is typically not as effective as moist heat (steam).

In the field, solarization of soil before planting can increase the temperature of the soil and reduce populations of soil pathogens, such as *Pythium* spp. Solarization is done by securing clear plastic over the soil surface for up to six weeks. The soil temperature will increase provided that direct sunlight is available. The upper few inches of soil will incur the greatest increase in temperature, so it is likely that solarization will be most beneficial while the roots of the plants remain in the upper few inches of soil. This may provide some suppression of disease through the seedling or young plant stages. If cloudy conditions prevail during the solarization period, minimal benefit, if any, will result. Solarization has been most effective in drier climates, such as Israel and Oklahoma, where the number of cloudless days is greater than that in Florida.

Fire can be used to reduce levels of pathogens in the soil. The burning of brush piles on soil increases its temperature and will reduce pests in the soil where brush piles are burned. This is most likely to be useful in garden or small sites. Another advantage of such burns is the recycling of nutrients back to the soil.

Trellising crops to grow vertically rather than on bare soil will significantly reduce infection from *Pythium* spp., particularly in fruit. This technique has been extremely effective in reducing cottony leak in fruit of tomatoes, cucumbers, strawberries, and in beans that produce long vines. Similarly, the use of plastic mulch over the soil to grow a crop will significantly reduce fruit rots by simply having a barrier between the soil and the fruit.

Manipulating organic matter, either by the direct application of amendments or by planting crops for living or debris mulches, may by beneficial in developing soils with high levels of microorganisms that are antagonistic to or competitive with *Pythium* spp. Organic amendments, such as sewage sludge or cotton gin trash and mature composts from yard wastes and animal wastes, may be used to reduce damage from *Pythium* spp. in the greenhouse or field, but generally, very high, and often uneconomical, amounts of the amendments are needed. Solarization of soil that has been amended with aged chicken manure plus aged yard waste has successfully suppressed *Pythium* spp. Certain types of peat or composted hardwood bark have effectively suppressed *Pythium* spp. in potting media in greenhouse production systems.

Planting living mulches may support competing organisms in the field, but unless tested, may result in increased populations of the pathogen. Some soils are naturally suppressive to diseases caused by *Pythium* spp. or may become suppressive with increased organic matter, manipulation of soil pH, or some crop rotations. Combinations of minimum tillage and multicropping resulted in lower incidences of damage by *Pythium* spp. on some crops, such as soybean, rotated with corn with minimum tillage when compared to conventional tillage. Living mulches or plant debris used on the soil surface for mulch may restrict the movement of inoculum in splashing water and, thus, reduce spread of the disease. At the time of this writing, many claims have been made by others in relation to the use of suppressive mulches, soil mixes, and field soils. The positive side of this is that research is being conducted, but the negative side is that this desirable tactic is still a long way from being employed reliably.

Several biological control agents, including actinomycetes and other bacteria, fungi, and even selected species of *Pythium*, are available commercially individually or as combinations for suppression of soilborne plant pathogens. Although a great deal of effort has been expended for the development of these products, their success rate has been variable, at best. The most likely sites for their success are in highly controlled locations, such as hydroponic systems or containerized nursery systems, that allow the addition of the biological control agents to a pasteurized or sterilized growth medium prior to the buildup or recontamination by the pathogen, such as *Pythium* spp., or prior to a similar buildup of potential microbial antagonists to the biological agents.

Constant plant growth and proper nutrition of the plant are capable of reducing infection from *Pythium* spp. This is exemplified by increased plant growth when nitrogen fertilizer (ammonium nitrate) was applied to oats and millet (Fig. 10) that were yellow and slightly stunted because of infections from *Pythium* spp. in the roots. The nitrogen is not fungicidal; it allows the plant to grow quicker if even a slight nitrogen deficiency exists in the soil. If the plants are severely stunted and near death, this tactic will be useless. The suppressive effects of various nutritive amendments, such as calcium and potassium, have been studied for control of *Pythium* spp. No definitive statements can be made with reliability on this subject at this time except that some individuals claim that the addition of calcium or potassium ions have had suppressive effects against *Pythium* spp.

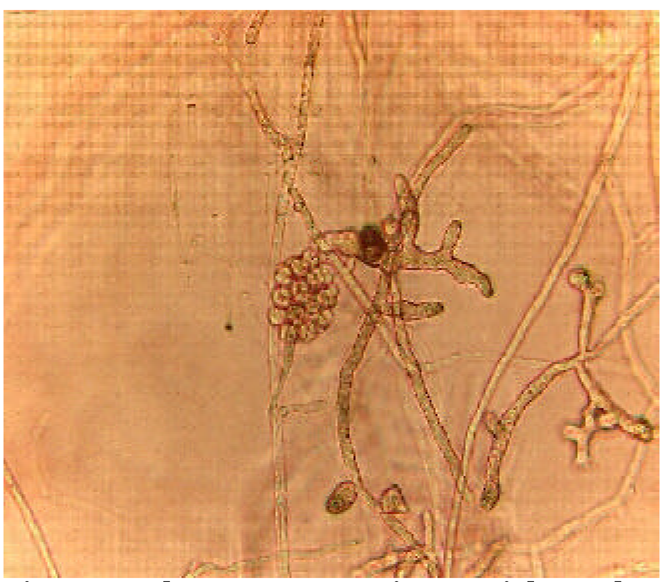

Fig. 1. Hyphae , zoospores in a vesicle, and sporangia of *Pythium aphanidermatum.*

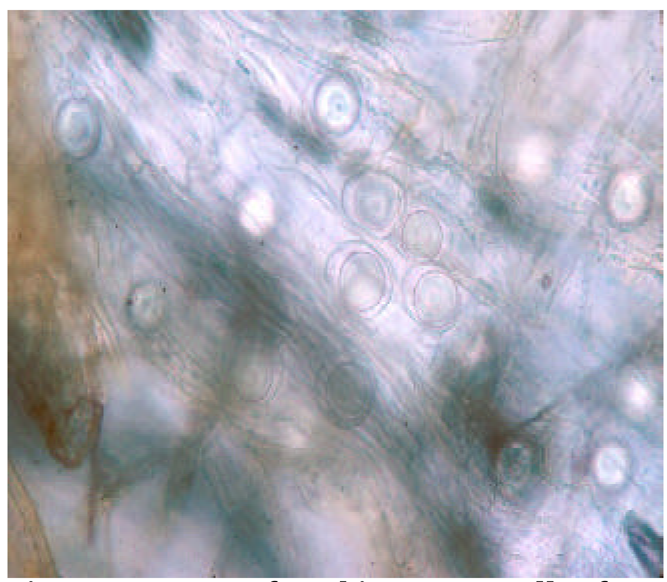

Fig. 2. Oospores of *Pythium sp.* In cells of root tissue.

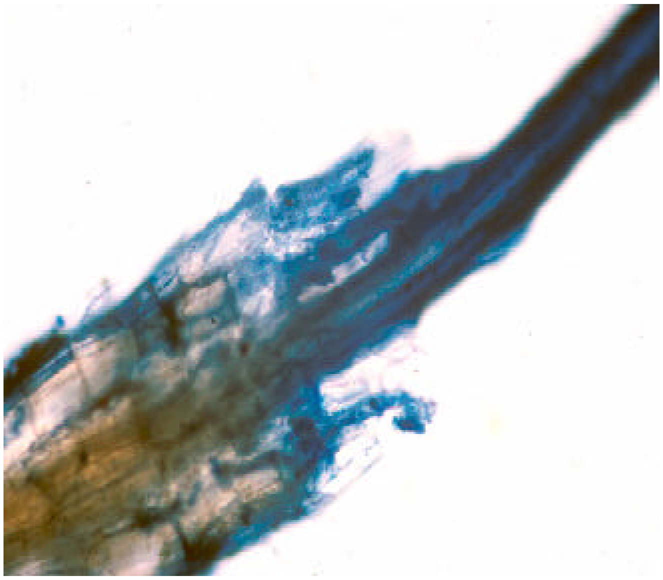

Fig. 3. Microscopic view showing sloughing off of root cortex from infection by Pythium.

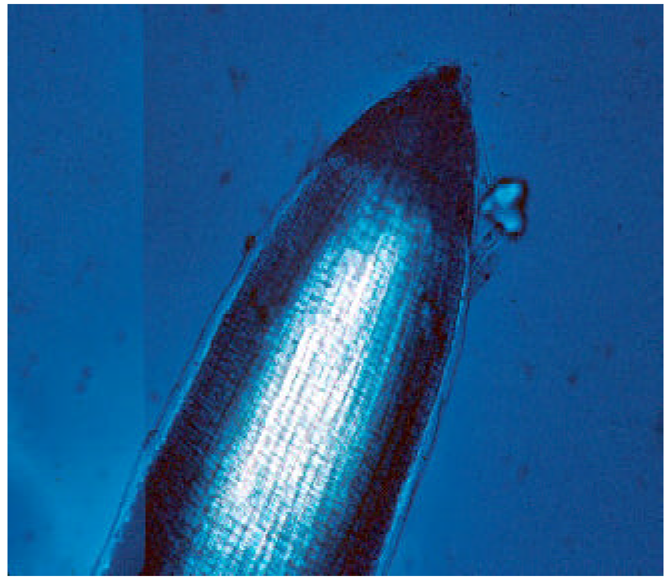

Fig. 4. Microscopic view of healthy root with intact cortex.

Fig. .5. Seedling blight of spinach caused by *Pythium* sp. and *Rhizoctonia* sp.

Fig. 6. Seedling blight of soybeans caused by *Rhizoctonia* sp. and *Pythium* sp.

Fig. 7. Stem rot of tomato caused by *Pythium* sp.

Fig. 8. Pythium blight in lettuce transplants.

Fig. 9. Yellowing of pepper seedlings from Pythium root rot.

Fig. 10. Yellowing of pearl millet from Pythium root rot.

Fig. 11. Root rot of pearl millet caused by *Pythium* sp. (on left) and healthier root system on right.

Fig. 12 Yellowing of wheat leaves caused by Pythium root rot.

Fig. 13. Death of wheat plants from Pythium root rot.

Fig. 14. Yellowing and stunting of wheat caused by infection by *Pythium* sp. And soilborne wheat mosaic virus.

Fig. 15. Pythium root rot (Brown rot) of carrot.

Fig. 16. Wilting of peppers caused by infection with *Pythium* sp. in roots.

Fig. 17. Pod rot of peanut (black) caused by *Pythium* sp. and galls caused by root knot nematode.

Fig. 18. Aerial blight (cottony leak) of young bean plants caused by *Pythium* sp.

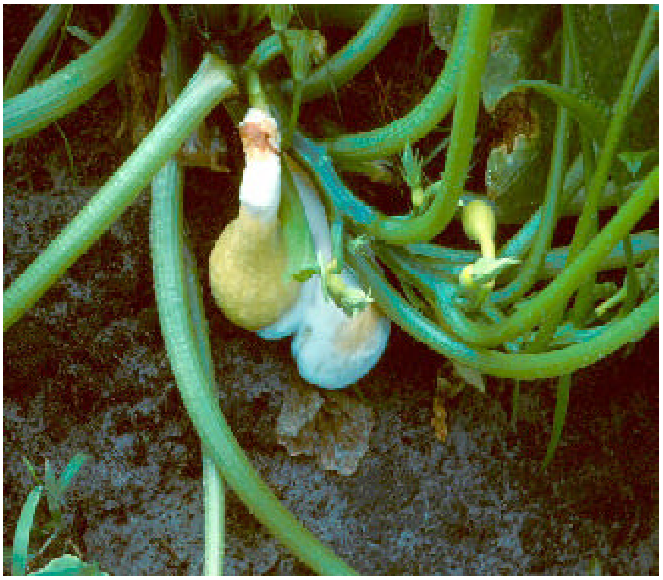

Fig. 19. Aerial blight (Cottony Leak) of fruit of yellow summer squash caused by *Pythium* sp.

Fig. 20. Fruit rot (Cottony Leak) of cucumber fruit caused by *Pythium* sp.