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Cultural Methods

Crop diseases can be managed by manipulating some cultural practices. The important useful cultural practices that help to reduce disease incidence are described in this chapter. Sanitation is important to prevent the introduction of pathogen inoculum into fields, farms, or communities, and to reduce or eliminate inoculum from diseased fields. Soil solarization and mulching are novel approaches, which are now widely practiced in different parts of the United States, Australia, and many other countries. Organic and inorganic soil amendments are increasingly used to manage diseases. Tillage practices may be useful in reducing disease incidence in some crops. Methods of sowing/planting, irrigation practices, and pruning methods also determine disease incidence. Adjustment of the crop sequence providing a fallow period and growing intercrops, living crop covers, and trap crops are other useful approaches in crop-disease management.

PREVENTION OF INTRODUCTION OF INOCULUM

Pathogens may be introduced into a field, farm, or region by means of seeds and vegetative propagating materials. Only seeds free from pathogens should be used for planting. Methods of indexing seeds for the presence of pathogens are described in Chapter 27, "Exclusion and Eradication."

Debris from infected plants may carry the primary inoculum and may serve as source for initial outbreak of diseases. Hence, removal of the debris may be one of the most important cultural practices in management of crop diseases. *Venturia inaequalis* survives the winter in diseased apple leaves on the ground. Pseudothecia and ascospores develop in these fallen leaves. Ascospores produced on diseased leaves in the leaf litter constitute the primary inoculum causing a scab. It has also been reported that viable conidia of *V. inaequalis* can overwinter within apple buds (Becker et al., 1992). Because the primary inoculum for the disease arises from the fallen leaves, crop-debris management may help in reducing disease outbreak. Infested fallen leaves found on the orchard floor should be removed or destroyed to reduce the overwintering inoculum. The degradation of fallen leaves can be enhanced by spraying urea in the fall. The fallen leaves can be deeply incorporated into the orchard soil by tilling and by chopping leaves with flail mowers (Sutton et al., 2000). Shredding the leaf litter in November or April reduces the risk of scab by 80 to 90 percent in the northeastern United States (Sutton et al., 2000). Urea applied to the leaf litter in April (before the bud break) reduced the number of the fungal ascospores trapped by 66 percent (Sutton et al., 2000). It appears that field sanitation, i.e., shredding the leaf litter or treating the leaf litter with urea, is very important in managing apple scab (MacHardy, 2000).

The citrus canker pathogen, *Xanthomonas axonopodis* pv. *citri,* survives in infested leaf litters, and the bacterium can be recovered up to four months after leaf fall. Soil treatments, including burial of leaves, reduce its survival significantly. The bacterium can be recovered from soil beneath diseased trees, but removal of the inoculum source leads to a demise of the bacterial populations within days (Graham et al., 1989). The lettuce bacterial leaf spot pathogen *Xanthomonas campestris* pv. *vitians* was recovered from lettuce plant debris after the one-month summer fallow and the disease developed on all subsequent fall lettuce crops (Barak et al., 2001). It stresses the need for removal of crop debris to manage the disease.

Pruning of infected parts may reduce the disease outbreak in many orchard trees, because the primary inoculum is from infected plant tissues. In fire blight-affected pome fruit trees, blighted blossom clusters and shoots should be pruned. Infected parts should be cut back up to shoot basis and branch ring. Once the disease has spread into the stem, the tree must be eliminated (Richter, 1999). Pruning alone reduced the bacterial infection by 62 percent in pear (Aysan et al., 1999). It may be possible to preserve *Erwinia amylovora*-attacked pear trees by pruning blighted blossom clusters and shoots. Leaf sanitation (removal of senescent and necrotic leaves) reduced *Botrytis* rot incidence in strawberry from 13 to 8 percent (Mertely et al., 2000).

Burning the infected organs may reduce the inoculum in the field. Pear trees in commercial orchards with shoots or blossoms naturally infected with *Erwinia amylovora* were burned for a few seconds with a propane flame torch on the tissue surrounding infected sites (Reuveni et al., 1999). Burning was highly efficient in eliminating *E. amylovora* in infected organs. Burning also prevented the spread of the bacteria from the infected organs to the main limb. No damage to tree viability and vitality was observed as a result of this treatment. Burning the infected organs before internal spread of *E. amylovora* to the main limb occurs can provide a safe and rapid measure to control fire blight in pear (Reuveni et al., 1999).

SOIL SOLARIZATION

Soil solarization, the process of heating soils under transparent plastic tarps to temperatures detrimental to soilborne pathogens, has successfully controlled a variety of plant diseases. Solarization targets mesophyllic organisms, which include most plant pathogens, without destroying the beneficial mycorrhizal fungi and growth-promoting *Bacillus* spp. Increased soil temperatures result in decreased populations of a range of plant pathogens, including fungi, bacteria, and nematodes. If not directly inactivated by heat, soilborne plant pathogens may be weakened and become vulnerable to soil fumigants, to other organisms, or to changes in the soil atmosphere in solarized soil (Pinkerton et al., 2000). The solarized soils are often more suppressive to certain soilborne pathogens than are nonsolarized soils. The effectiveness of solarization against *Verticillium* wilt of safflower and cotton, *Fusarium oxysporum* f. sp. *vasinfectum* wilt of cotton, and several species of *Phytophthora* has been reported (Pinkerton et al., 2000). When the soil was solarized for three weeks after the amendment with farmyard manure, the root rot of melon by *Phomopsis sclerotioides* was controlled to some extent (Itoh et al., 2000). Soil solarization by covering the soil with a 150 μm-thick transparent plastic film for two weeks brought about a high degree of *Pythium* spp. control in greenhouse-grown cucumber (Lopes et al., 2000). Solarization for three weeks using transparent polyethylene sheets for soil mulching provided effective control of wilts caused by *Fusarium oxysporum* f. sp. *lycopersici* and *Verticillium dahliae,* and corky root rot caused by *Pyrenochaeta lycopersici* on tomato plants (Ioannou, 2000). Solarization reduced black dot of potato caused by *Colletotrichum coccodes* by 45 percent when tarping was done for eight weeks and temperatures reached 56°C in the top 5 cm of soil. With a six-week tarping period and lower maximum temperature (50°C), there was no significant reduction in disease incidence (Denner et al., 2000). Soil solarization reduced severity of diseases caused by *Verticillium* spp. on eggplant and *Phytophthora* spp. on snapdragons (Pinkerton et al., 2000). *Agrobacterium* spp. population densities declined within solarized plots, and incidence of crown gall on cherry rootstock planted in solarized plots was reduced significantly (Pinkerton et al., 2000).

ORGANIC AMENDMENTS

Root rots are known to be greater in number and more severe in soil with low organic matter. Incorporation of organic matter reduced root rot in many crops (Tu, 1987). Addition of liquid swine manure to field soils killed

Verticillium dahliae microsclerotia and reduced *Verticillium* wilt of potato (Conn and Lazarovits, 2000). The efficacy of the swine manure was dependent on soil pH. Adjusting the soil pH from 5.0 to 6.5 eliminated the toxicity of the swine manure. Conversely, when soil from a location in which swine manure had no effect was reduced from its initial pH value of 7.5 to below 6, swine manure became effective in that soil (Conn and Lazarovits, 2000). Fresh chicken manure, or chicken manure composted for five weeks before incorporation into the potting mix (25 percent, vol./vol.), significantly reduced *Phytophthora cinnamomi* survival and the development of symptoms on *Lupinus albus* seedlings (Aryantha et al., 2000).

Addition of composts to the field reduces the disease incidence. However, the composting method may determine the efficacy of the composts. Composts were prepared by three different methods (Kannangara et al., 2000). Two of the composts were prepared from separated dairy solids either by windrow (WDS) or vermicomposting (VMC) while the third, obtained from the International Bio Recovery (IBR), was prepared from vegetable refuse using aerobic digestion. Amendment of WDS in the potting mix suppressed *Fusarium oxysporum* f. sp. *radicis-cucumerinum* infection on cucumber, while VMC and IBR had no effect. There was a large increase of fluorescent bacteria near the vicinity of roots particularly in WDS amended potting mixes. Contrasting effectiveness of the WDS and VMC made from the same waste suggests that composting method can influence the disease suppression properties of the finished compost (Kannangara et al., 2000).

Compost-amended potting mixes are used to manage soilborne diseases of floricultural crops caused by *Pythium, Phytophthora, Fusarium,* and *Rhizoctonia*. Several biocontrol agents such as *Trichoderma* spp., *Gliocladium* sp., fluorescent pseudomonads, and *Bacillus* spp. colonize the compost (Hoitink et al., 1991). Pine bark is used for preparing compost on a commercial scale. The raw pine bark is first hammer milled and screened so that all particles are < 1.25 cm in diameter. A small amount of nitrogen (0.6 kg/m^3 of bark), mostly as ammonia or urea, is added with water as the first step in the composting process. The wet and nitrified bark is stored in windrows on a concrete pad and turned several times during an eight- to eleven-week period. Temperature, electrical conductivity, pH, and moisture levels are monitored regularly to follow the type of composting. Adjustments are made to maintain optimum conditions for the process (Hoitink et al., 1991). A computer-controlled composting system has also been developed. This type of compost is used at incorporation rates of up to 25 percent. These mixes should be stored in 100 L polyethylene bags or in 2 m^3 nylon bags for days to months before their use. At least four days must be allowed for recolonization of high-temperature (40-50°C) compost with a mesophilic microflora to induce the natural suppression of *Pythium* damping-off (Hoitink et al., 1991). Growers in the eastern United States have consistently suppressed Fusarium wilt of cyclamen for over a decade by using composted pine bark mixes (Hoitink et al., 1991).

Incorporation of plant residues into soil suppresses certain soilborne diseases. The efficacy of various organic amendments for controlling soilborne pathogens has been attributed to the formation of toxic volatile compounds or to an increase in antagonistic soil microflora (Pinkerton et al., 2000). Brassicas, which contain glucosinolates that break down to toxic isothiocyanates, and Sudan grasses, which contain dhurrin that breaks down to hydrogen cyanide, have been reported to control fungal pathogens. Soil amendment with brassicas has a beneficial effect on the control of some soilborne pathogens. Residues from brassica crops could be incorporated directly into the soil or brassicas could be used as intercrops (Rosa and Rodrigues, 1999). Cauliflower wilt caused by *Verticillium dahliae* was effectively controlled by incorporating broccoli (*B. oleracea* L. var. *italica*) residues in soil in Salina Valley, California (Koike and Subbarao, 2000). Broccoli residue showed a detrimental effect on the viability of microsclerotia in soil. It also had an inhibitory effect on the root-colonizing potential of surviving microsclerotia (Shetty et al., 2000). Air-dried and crushed mustard *(Brassica juncea)* added to the soil effectively reduced the viability of sclerotia of *Sclerotium cepivorum,* the onion white rot pathogen, and chlamydospores of *Fusarium oxysporum* f. sp. *lycopersici,* the tomato wilt pathogen (Smolinska, 2000). Consequently, the reduction of white rot of onion and tomato wilt was observed. The addition of rapeseed *(Brassica napus)* residues to soil also resulted in a decrease of number of sclerotia of *S. cepivorum* (Smolinska, 2000). Amendment of soil with dried leaves of savoy cabbage (*Brassica oleracea* var. *sabauda*), red cabbage (*B. oleracea* var. *capitata* f. *rubra*), and fringed cabbage (*B. oleracea* var. *acephala*) significantly reduced the appearance of cucumber damping-off caused by *Pythium ultimum* (Burgiel and Schwartz, 2000). The dried leaves possessed fungistatic activity against *P. ultimum* (Burgiel and Schwartz, 2000).

The effect of cruciferous plant residues in reducing the disease incidence may be due to the glucosinolate content of these plants. *Aphanomyces euteiches* root rot of pea was significantly reduced (77 percent) in soil amended with rapeseed meal from *Brassica napus* cv. Dwarf Essex (high glucosinolate concentrations). Amendment with cv. Stonewall (low glucosinolate concentrations) did not control pea root rot (Dandurand et al., 2000), suggesting that a low concentration of glucosinolate may not be sufficient to control the pathogen in soil. The toxicity of glucosinolates may probably be due to isothiocyanates derived from the breakdown of glucosinolates (Rosa and Rodrigues, 1999).

Fresh broccoli or grass was incorporated into soil and covered with plastic sheeting. In this amended soil, anaerobic and strongly reducing soil conditions developed quickly, as indicated by rapid depletion of oxygen and a decrease in redox potential values to as low as –200mV. After 15 weeks, survival of *Fusarium oxysporum* f. sp. *asparagi, Rhizoctonia solani,* and *Verticillium dahliae* in inoculum samples buried 15 cm deep was strongly reduced in amended, covered fields. The pathogens were not or hardly inactivated in amended, noncovered soil or nonamended, covered soil, indicating that inhibitory action of fresh leaves or thermal inactivation due to increased soil temperatures under the plastic cover was not involved in pathogen inactivation (Blok et al., 2000).

MULCHING

Mulches are different from soil amendments in that amendments are incorporated into the soil, while mulches are spread on the soil surface. Mulches may consist of straw or stubble applied to the soil surface, or of plastic foil spread over the soil. Mulches are known to reduce various diseases. Silver-painted mulch suppressed yellow mosaic virus symptoms in squash, while nonreflective (black) mulch did not have any effect on the disease incidence. The reflective mulch was effective only under slight virus pressure (Boyhan et al., 2000). Reflective mulch significantly reduced the vector thrips and *Tomato spotted wilt virus* in tomato (Riley and Pappu, 2000). Black plastic mulch reduced the *Verticillium* wilt symptoms in eggplant (Elmer, 2000).

LIVING GROUND COVERS

Living covers, such as perennial peanuts *(Arachis pintoi),* cinquillo *(Drymaria cordata),* and coriander *(Coriandrum sativum),* grown along with tomato mask the tomato crop from immigrating viruliferous whiteflies *(Bemisia tabaci).* These covers minimize contact between the vector and the tomato plant. The living covers reduce whitefly adult numbers, delay *Tomato yellow mottle virus* dissemination, reduce disease severity, and provide higher yields in tomatoes (Hilje, 2000). The forage groundnut *Arachis pintoi* was grown as a ground cover with bell pepper *(Capsicum annum).* Approximately four times as many whiteflies were observed on bell pepper plants grown without ground cover than on plants with cover. Onset of the gemini virus disease in bell pepper was earlier and frequency was greater in plants without cover than in plants with cover (Rafie et al., 1999).

CATCH CROPS

Control of some soilborne pathogens may be achieved by use of decoy or catch crops. These crops stimulate the germination of resting spores, resulting in limited expression of disease symptoms. Chinese cabbage plants grown in pots inoculated with *Plasmodiophora brassicae* (the clubroot pathogen) that had previously contained leafy daikon (radish, *Raphanus sativus* var. *longipinnatus*) showed less disease incidence compared to control pots in which no plants had been grown before. Numbers of resting spores of *P. brassicae* in soil in pots after cultivation with leafy daikon were reduced by 71 percent compared to control pots (Murakami et al., 2000).

TILLAGE

Some tillage operations may help to reduce disease incidence. Moldboard plowing to a depth of 30 cm reduced black dot of potato caused by *Colletotrichum coccodes* by 34 percent and was twice as effective as plowing to a depth of 60 cm (Denner et al., 2000). Fall chisel plowing plus spring raised seedbed preparation significantly reduced pea root rot (*Fusarium solani* f. sp. *pisi* and *F. oxysporum* f. sp. *pisi*) severity, compared to conventional fall plowing plus spring flat seedbed preparation. Root rot was most severe with fall plowing plus compaction, followed by fall plowing plus fall seedbed preparation (Tu, 1987). Reduced tillage that leaves 30 percent or more of the soil surface covered by crop residue after planting completely or partially controls several wheat root rot and foot rot pathogens, such as *Bipolaris sorokiniana, Fusarium graminearum, F. culmorum, F. avenaceum,* and *Pseudocercosporella herpotrichoides.* Root rot is favored by drought stress. The increased moisture available to the crop under reduced tillage might have led to reduction in disease incidence (Bockus and Shroyer, 1998). The prevalence of Sclerotinia stem rot *(Sclerotinia sclerotiorum)* of soybeans was less in no-till than in minimal-till fields in the north central United States (Workneh and Yang, 2000).

SPACING

Spacing between plants plays an important role in disease incidence. Wider plant spacing reduces Botrytis fruit rot incidence in strawberry (Legard et al., 2000). Good aeration around host tissues often minimizes the incidence and severity of diseases caused by *B. cinerea* (Cooley et al., 1996). Paired rows, as opposed to evenly spaced rows, reduce wheat root rots by allowing the top layer to dry more rapidly because of openness between every other row of plants (Cook and Veseth, 1991). It has been suggested that opening the trees to sunshine and air should be the first measure taken to control sooty blotch and flyspeck of apple caused by four different fungi (Williamson and Sutton, 2000). Pruning creates an environment less favorable to the diseases. The sooty blotch and flyspeck could be reduced by an average of almost 30 percent by severe pruning (Williamson and Sutton, 2000).

MANIPULATION OF SOIL pH

Potato common scab *(Streptomyces scabies)* can be suppressed by lowering the soil pH. When ammonium sulfate was applied into the rows where potato plants were to be planted, the soil pH was lowered and the concentration of water-soluble aluminium was increased. Potato common scab was suppressed in the soil containing water-soluble aluminium in concentrations of 0.2 to 0.3 mg/liter or higher (Mizuno et al., 2000).

INORGANIC AMENDMENTS

Several inorganic compounds alter the severity of disease incidence in the field. Infection of avocado seedlings by *Phytophthora cinnamomi* in infested soil was decreased by 71 percent by the addition of gypsum soil amendments (Messenger et al., 2000b). Sporangial production of *P. cinnamomi* buried in gypsum-amended avocado soil for two days was reduced by as much as 74 percent (Messenger et al., 2000a). Soil extracts from gypsum-amended soil (1, 5, or 10 percent gypsum) reduced in vitro sporangial production. Zoospore production and colony-forming units of *P. cinnamomi* were reduced in soil amended with calcium sulfate, calcium nitrate, or calcium carbonate. It suggests that calcium may be playing a key role in suppressing sporulation and multiplication of the pathogen in soil (Messenger et al., 2000a).

Calcium application effectively controlled bacterial wilt of tomato caused by *Ralstonia solanacearum* (Yamazaki et al., 2000). Adding $CaCO_3$, $Ca(OH)_2$, and $CaSO_4$ to the soil reduced wilt of banana caused by *Fusarium oxysporum* f. sp. *cubense*. Smaller amounts had the greatest effect, and the amounts of calcium compounds used were insufficient to change the pH. Calcium treatment has been shown to inhibit germination of chlamydospores of the pathogen and suggests that calcium may act directly on the pathogen (Peng et al., 1999).

High nitrogen application increases *Rhizoctonia* stem canker in potato; less nitrogen and high potassium and phosphorous application results in decrease in the disease incidence (Crozier et al., 2000). Nitrogen application may have different actions on different pathogens in a host (Hoffland et al., 2000). N application increased susceptibility to the bacterial speck pathogen *Pseudomonas syringae* pv. *tomato* and the powdery mildew pathogen *Oidium lycopersicum* in tomato. It did not have any effect on the wilt pathogen *Fusarium oxysporum* f. sp. *lycopersici*. However, increased application of nitrogen increased resistance to the gray mold pathogen *Botrytis cinerea* (Hoffland et al., 2000).

Different forms of nitrogen may affect the disease incidence differently. The ammoniacal form of nitrogen, as opposed to the nitrate form, reduces wheat take-all disease by producing a more acidic root surface, inhibiting the alkaline-loving pathogen *Gaeumannomyces graminis* (Huber and McCay-Buis, 1993). Fertilization with $(NH_4)_2SO_4$ showed less *Verticillium* symptoms in eggplant than with $Ca(NO_3)_2$ fertilization (Elmer, 2000).

CROP ROTATION AND INTERCROPPING

Diseases can be managed by proper planning of the crop sequence. A rotation including barley, field peas, and wheat for three years following canola *(Brassica napa)* helped to eliminate potential disease sources in canola *(Leptosphaeria maculans)* in Canada (Turkington et al., 2000). Rotation to grain sorghum to produce a one-year break from wheat resulted in effective control of tan spot of wheat. This was true even when the maximum amount of wheat residue was retained on the soil surface (without tillage). The time during the rotation in which there is no susceptible host present may serve to sensitize the soil by utilizing the native microorganisms to weaken and kill residue-borne pathogens (Bockus and Shroyer, 1998). Soils from two orchards in the United States were cultivated with three successive 28-day growth cycles of wheat in the greenhouse and subsequently planted to apple seedlings. Cultivation of wheat in orchard replant soils prior to planting of apple seedlings resulted in reduction in apple root infection by *Rhizoctonia* and *Pythium* spp. In replant soils cultivated with wheat, the antagonistic bacteria *Pseudomonas putida* population dominated (Mazzola and Gu, 2000).

Strawberries are grown as green manure in Italy. Sown in autumn, the strawberry crop is cut and buried when in full flower. It is useful for management of diseases of *Brassica juncea* grown after strawberry. The hydrolyzed glucosides from strawberry are toxic to *Phytophthora, Pythium, Rhizoctonia,* and *Sclerotium* species (Frabboni, 2001). *Fusarium oxysporum*

f. sp. *apii* infection in celery is suppressed with amendments of onion or peppermint crop residues. Celery grown after an onion crop is less affected by the Fusarium yellows fungus (Lacy et al., 1996).

During four consecutive years of experiments in the Netherlands with carrots grown as sole crops or undersown with subterranean clover (*Trifolium subterraneum*), it was shown that intercropping significantly reduced the cavity spot caused by *Pythium* spp. (Theunissen and Schelling, 2000).

IRRIGATION

Irrigation practices determine the severity of disease incidence in many crops. Overhead sprinkling irrigation enhanced production of oospores of *Phytophthora infestans* in field-grown crops of potato (Cohen, Farkash, et al., 2000). Frequent irrigation increased the *Verticillium* wilt incidence in cauliflower. Deficit irrigation suppressed the wilt incidence; however, it also reduced the yield (Xiao and Subbarao, 2000). Hence, irrigation methods should be properly planned to control diseases without any reduction in crop yield. When compared to pipe irrigation, trickle irrigation (at a depth of 30 cm) reduced damage by plant diseases and increased crop yields of both fennel and cauliflowers in Germany (Eberhard, 2000). Daily irrigation increased *Monosporascus* wilt of melons, while in a less frequently irrigated field, symptom development was delayed and disease incidence was decreased (Cohen, Pivonia, et al., 2000).

HYDROPHOBIC PARTICLE FILMS

Hydrophobic particle film technology has been exploited to manage diseases. Hydrophobic particle film is based on the inert mineral kaolin, which is surface treated with a water-repelling agent. Dust application of hydrophobic particles on plant surfaces results in envelopment of the plant in a hydrophobic particle film barrier that prevents disease inoculum or water from directly contacting the leaf surface. By this method, disease development is suppressed. This technology could offer broad-spectrum protection against several diseases in agricultural crops (Glenn et al., 1999).

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