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Sustainable Management of Soilborne Plant Diseases

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SUMMARY

The significant problems caused by soilborne pathogens in crop production worldwide include reduced crop performance, decreased yield, and higher production costs. The threats of soilborne disease epidemics in crop production, high cost of chemical fungicides and development of fungicide resistance, climate change, new disease outbreaks and increasing concerns regarding environmental as well as soil health are becoming increasingly evident. These necessitate the use of integrated soilborne disease management strategies for crop production. This article summarizes methods for management of soilborne diseases in crop production which includes the use of sanitation, legal methods, resistant cultivars/varieties and grafting, cropping system, soil solarization, biofumigants, soil amendments, anaerobic soil disinfestation, soil steam sterilization, soil fertility and plant nutrients, soilless culture and biological control in a system-based approach. Different methods with their strengths and weaknesses, mode of action and interactions are discussed, concluding with a brief outline of future directions which might lead to the integration of described methods in a system-based approach for more active Sustainable management of soilborne plant diseases.

INTRODUCTION

Soilborne diseases are considered a major limitation to crop production. Soilborne plant pathogens such as Rhizoctonia spp., Fusarium spp., Verticillium spp., Sclerotinia spp., Pythium spp., and Phytophthora spp. can cause 50%–75% yield loss for many crops such as wheat, cotton, maize, vegetables, fruit and ornamentals as reported. They often survive for long periods in host plant debris, soil organic matter, free-living organisms or resistant structures like microsclerotia, sclerotia, chlamydospore or oospores. Accurate diagnosis of a particular disease is difficult due to the similarity in symptoms such as seedling damping, root blackening, root rot, stunting, wilting, yellowing, bark cracking and twig or branch dieback which in turn makes the disease harder to manage. To control these disease outbreaks, conventional synthetic chemical fungicides and fumigants need to be applied at regular intervals throughout the growing season of the crop. However, it should be noted that there are evident issues with the use of synthetic fungicides which include ecological disturbance, human health hazards, damage to aquatic ecosystems, reduction of beneficial microorganisms in the soil and even ozone layer depletion. In many parts of the world, methyl bromide was extensively used to control those pathogens before the implementation of the Montreal Protocol in 1986—an international treaty to protect the ozone layer which also agreed to phase down the production and use of hydrofluorocarbons in 2016 with the Kigali amendment. the increasing environmental constraints. Some environment-friendly approaches such as the use of crop rotation, soil solarization, anaerobic soil disinfestation, soil steam sterilization, biofumigants, resistant cultivars/varieties or grafted plants and biocontrol products have been developed to control soilborne diseases while maintaining the environment. Studies on disease suppressive soils have led to the development and adoption of new approaches, and to a better understanding of soil microbial community responses. These advances show that active management of soil microbial communities could be an active method to develop natural suppression of soilborne plant pathogens. As soil comprises a full ecosystem including many fungi, bacteria, insects, nematodes and other microbes, it is very important to understand those interactions to develop a soil health management strategy instead of focusing on individual disease causing species. This article seeks to summarize the current methodology used for management of soilborne diseases including sanitation, legal methods, resistant cultivars/varieties and grafting, cropping system, soil solarization, biofumigants, soil amendments, anaerobic soil disinfestation, soil steam sterilization, soil fertility and plant nutrients, soilless culture and biological control in a system based approach.

Soilborne Disease Management Methods

Sanitation

With the resting structures like chlamydospores, microsclerotia, oospores or sclerotia and basic reproductive systems, soilborne plant pathogens can survive in the soil for a very long time, even in the absence of a living host or plant debris and soil organic matter. Therefore, it becomes very important to remove the plant debris away from growing areas whenever possible or accelerate residue breakdown. Sanitation includes any sort of activities which are aimed to prevent the spread of pathogens by removing diseased and infected plant parts, decontamination of tools and equipment and washing hands. Weeds and volunteer plants should be destroyed as they can function as a host for pathogens as well as increase the relative humidity around the crop canopy, creating an environment in which many pathogens thrive. Plouging under infected crop debris is also a good sanitation measure to control certain soilborne plant pathogens as tillage can expose the infected plant materials to the direct sunlight, which can kill some plant pathogens. The diseased plants and the immediate soil around its canopy should be removed to reduce the further spread of some diseases like lettuce drop or white mold caused by S. sclerotiorum. Tools that are used should be disinfected or cleaned at a minimum, when moving equipment between different plants or fields using different methods such as heat treatment, ultraviolet (UV) treatment and chlorine treatment. Thus, preventative measures should be adopted to avoid pathogen contamination. Field sanitation in combination with many other methods, can yield a desirable outcome. This is the first step for the management of soilborne diseases in an integrated system.

Cropping System

Mixed cropping, intercropping and crop rotation are important practices that are widely emphasized around the world to avoid the inoculum buildup of soilborne pathogens. When the same crop is grown in a field year after year, development and persistence of soilborne pathogens is almost certain. Crop rotation is also associated with enhanced soil fertility, improvement in soil chemical and physical properties, good soil water management and soil erosion control. Although crop rotation is a valuable method of plant disease management, it is less effective against soilborne pathogens that have a wide host range or produce long-living survival structures like sclerotia, oospores or chlamydospores. In many cases, cover crops are only effective against pathogens which are surviving in soil or residing on crop residue but not against the wind-blown or vectored, thus it is recommended to use the combination of disease-free planting materials and crop rotation. Rather than considering individual crops, rotation based on the plant family is a better approach for many soilborne diseases. For example, tomato should be rotated with legumes, cole crops, or lettuce but not within the Solanaceae family (eggplant, chili, potato etc.) to reduce *Fusarium* wilt (*F. oxysporum*). Crop sequences like oat-potato, annual ryegrass-potato or clover-potato reduces *R. solani* inoculum levels in the soil and suppresses disease development. With the wide host range of certain plant pathogens or production of durable resting structures to avoid harsh environmental conditions, modifications of the cropping system alone may not be an efficient method to manage many soilborne pathogens. The future research focusing on suitable agronomic practices integrated with promising soilborne disease methods, is aspired by the growers.

Biofumigants

The crops in the family Brassicaceae, such as cabbage, broccoli, kale, turnip, radish, canola, cauliflower, rapeseed and various mustards contain substances which can be effectively used to control soilborne pathogens and pests. A sulfur compound, glucosinolate, is produced by Brassica crops and releases biologically active products upon hydrolysis such as isothiocyanates (ITC), which are found to be toxic to many soil organisms such as *P. nicotianae* and *R. solani*. This method has been used effectively against soilborne pathogens and is widely known as biofumigation. These biochemical compounds either directly control the growth of harmful soilborne plant pathogens or create a favourable environment for beneficial ones; which in turn increases the competition among the microorganisms resulting in an antagonistic relationship among the microorganisms. Plants belonging to Alliaceae, like onion and garlic, also contain molecules which can be used to control soilborne pathogens.

Soil Amendments

Organic amendments to the soil are traditionally used for improving soil conditions and crop productivity, but they can also aid in suppressing soilborne pathogens. Composts and liquids enriched with essential oils, phenols, organic acids and many other biocidal compounds from herbs could be effective against soilborne diseases, although the use of these soil amendments is rare. Organic manures made up of organic wastes, composts and peats, have been proposed to control soilborne diseases and pests. *R. solani*, *Thielaviopsis basicola*, *V. dahliae*, species of *Fusarium, Phytophthora, Pythium and Sclerotium* are found to be managed effectively by the application of organic amendments. These organic amendments not only improve soil structure and increase water holding capacity, they also support other beneficial microorganisms which help to suppress soilborne pathogens. The increase in activity of microorganisms in the soil creates competition, which may lead to effective suppression of harmful soilborne pathogens. The use of compost extract containing huge populations of microbiota, *e.g., Rhizobacteria, Trichoderma and Pseudomonas* species, can enhance crop production and produce plant growth regulators and chemicals such as phenols or tannins which may have an antagonistic effect on soilborne pathogens. Soil organic amendments also provide diversified food base, which can diversify and change the microbial population equilibrium in the soil which is also explained by the recent sequencing-based research.

Biological Control

Chemical methods are easy, quick and effective; yet, they can cause a disturbance in the environment, adversely affect human health, damage aquatic ecosystems, harm pollinators and reduce populations of beneficial microorganisms in the soil. The application of biocontrol agents to the soil is an alternative to suppress soilborne plant pathogens through parasitism, production of antagonistic chemicals, competition for the host and nutrients, and induction of resistance in plants against disease-causing pathogens. Several organisms are successfully used as biocontrol agents for controlling soilborne pathogens . The bacterial and fungal genera that are commercially employed as biological control agents include Bacillus, Pseudomonas, Rhizobium, Serratia, Streptomyces, and Trichoderma. The application of biocontrol agents in soil such as *T. viride, T. harzianum, fluorescent Pseudomonas* and *B. subtilis* have been found to be effective against root rot caused by soilborne plant pathogens in a number of crops. Trichoderma species are known to produce large quantities of fungi toxic metabolites.
They are the active mycoparasites which have been used as effective biocontrol agents against foliar and soilborne disease, as well as plant parasitic soilborne nematodes. Although the use of biological control methods for the effective management of soilborne diseases has been a long-term goal in sustainable agriculture, the efficacy of this method is highly dependent on the integrated approaches to maintaining soil health and controlling soilborne pathogens. Some important biological control agents with their mode of action and target soilborne pathogens.

Biocontrol Agents	Target Pathogen	Mode of Action
Bacillus spp. (B. subtilis)	*Pythium spp., Fusarium spp., Rhizoctonia solani, Aspergillus flavus*	Competition, direct antibi osis, induced resistance
Pseudomonas spp.	*Pythium spp. R. solani*	Production of antibiotics, siderophores, volatiles
Pythium oligandrum	*Species of Alternaria, Botrytis, Fusarium, Pythium, Sclerotinia and Sclerotium*	Hyperparasitism
Streptomyces spp.	*Species of Fusarium, Rhizoctonia, Phytophthora, Pythium, Aphanomyces, Monosprascus, Armillaria, Sclerotinia, Verticillium*	Mycoparasitism
Trichoderma spp	*Species of Rhizoctonia, Fusarium, Alternaria and Colletotrichum as well as oomycetes, such as Pythium and Phytophthora*	Competition, resistance and hyperparasitism

CONCLUSION

Soilborne diseases are among the most destructive elements in crop production. Many vegetable crops, other high-value crops and ornamentals are vulnerable to the wide range of disease-causing organisms that either reduce the yield, aesthetics, marketability or many aspects combined. The phase-out of many chemicals and rising awareness towards resistance development, environmental health, and climate change necessitates the quest for alternative suitable management options. Many non-chemical options such as sanitation, legal methods, resistant cultivars/varieties and grafting, cropping system, soil solarization, biofumigants, soil amendments, anaerobic soil disinfestation, soil steam sterilization, soil fertility and plant nutrients, soilless culture and biological control methods may prove costly and inefficient when used alone. However, soilborne plant pathogens can be managed below the economic threshold level when these methods are applied as a system approach. Although the integrated soilborne disease management strategies may not eradicate all the pathogenic organisms from the soil, it entails continuous exploration and research for sustainable crop production which will secure a sustainable future for an ever-growing population.

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