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INTEGRATED TECHNIQUES FOR ADVANCED PLANT DISEASE MANAGEMENT

Kartikay Bisen, Aneeta Yadav, Vinay J Silas

Faculty of Agricultural Sciences and Allied Industries, Rama University, Kanpur-209217

Corresponding Author Email: kartikaybisen.fas@ramauniversity.ac.in

Introduction

Plant diseases can be defined as abnormal changes in physiological processes that permanently disturb the normal activity of plant organs (Julius Kuhn, 1858). Horsfall and Diamond (1959) described plant diseases as a "malfunctioning process in the plant body due to continuous irritation which results in suffering producing symptoms." A plant is specifically termed 'diseased' only when its malfunctioning process involves association with a pathogen.

All plant diseases result from a three-way interaction between a susceptible host, a virulent pathogen, and a favorable environment. An epidemic develops if all three of these factors are conducive to disease development. Recently, two more components have been added to this triangle after evaluating their significant role in disease development: time and human activity. Principally, all plant diseases can be controlled by manipulating one or more of these factors to create conditions unsuitable for the replication, survival, or infection by the pathogen.

Need for Plant Disease Management

Agriculture is essential for meeting basic human needs and serves as the foundation for modern civilization. The domestication of crop plants requires protection from various biotic and abiotic stresses. Consequently, the necessity to maintain plant health led to the establishment of the scientific discipline known as plant pathology, which focuses on the study and management of plant diseases.

Historically, plant diseases have led to devastating crop losses and posed significant threats to human survival. Consumption of food contaminated with fungal toxins has resulted in numerous fatalities. Several historical epidemics have had profound economic and social impacts (Madden et al., 2007). The Irish Potato Famine of 1845, caused by *Phytophthora infestans*, is one of the most notorious, resulting in massive deaths and migration. Other significant epidemics include the Bengal Famine of 1943 due to rice brown spot, coffee rust in Sri Lanka in the 1870s caused by Hemileia vastatrix, downy mildew of grapes in France in 1878 caused by *Plasmopara viticola*, and Sigatoka disease of banana in America in the 1930s caused by *Mycosphaerella musicola*.

The primary goal of plant disease management programs is to mitigate the economic and aesthetic damage caused by plant pathogens. Historically, the term "plant disease control" was used, but modern perspectives favor "management" over "control." The term "management" suggests a more balanced approach, aiming to reduce pathogen populations to levels that do not cause significant economic harm rather than seeking complete eradication. This approach aligns better with contemporary social and environmental values.

Basis of Plant Disease Management

The primary approach for disease management includes the prophylaxis i.e. immunization system (Fry, 1982). It is often considered that cure of a diseased plant is not possible as the disease becomes visible only after injury has occurred. Thus from the management point of view, preventive measures are vitally important. This approach is considered to be the backbone of all methods included under integrated pest management.

Principles of Plant Disease Control

1. ***Avoidance***

Plant disease management involves practices designed to prevent disease by planting crops at times or in locations where pathogen inoculum is absent or inactive due to environmental conditions. The primary goal of this approach is to avoid contact between the host plant and the pathogen, ensuring that the susceptible stage of the plant does not coincide with favorable conditions for the pathogen (Jenifer et al., 2006). The main practices under avoidance are include Choice of Geographical Area, Choice of Planting Date, Planting of Early Maturing Varieties, Selection of Seed and Planting Material.

2. ***Exclusion***

It involves preventing or restricting the inoculum from entering a field or area where it did not exist before, thus limiting the entry of a pathogen in an unaffected area (Kahn, 1991). It can be achieved through seed certification, crop inspection, eradication of insect vectors and quarantine measures. Exclusion include Quarantine Inspection and Certification Seed Treatment and Eradication of Insect Vectors (Singh, 2002).

Table 1: Seed Treatment

Hot Water Treatment of Propagative Organs			
Crop	**Disease**	**Causal organism**	**Treatment**
Wheat	Loose smut	*Ustilago tritici*	52˚C for 11 minutes
Sugarcane	Red rot	*Colletotrichum falcatum*	54˚C for 8 hours
Sugarcane	Ratoon stunting	*Rathayabacter xyli*	50˚C for 3 hours

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Crucifers	Black rot	*Xanthomonas campestris* pv. *campestris*	50˚C for 30 minutes
Sugarcane	Whip smut	*Ustilago scitaminae*	52˚C for 30 minutes
Wheat	Tundu	*Anguina tritici*	54˚C for 10 minutes
Banana	Toppling	*Radopholus similis*	50˚C for 10 minutes
Sugarcane	Grassy shoot	Mycoplasma	52˚C for 30 minutes
Wet Seed Treatment by Chemicals			
Sugarcane	Red rot, Whip smut	*Colletotrichum falcatum*, *Ustilago scitaminae*	Dipping the setts in carbendazim 5g/10L
Rice	Bacterial leaf blight	*Xanthomonas campestris* pv. *oryzae*	Dipping seeds in 250 ppm agrimycin solution for 12 hours
Cabbage, Cauliflower	Black rot	*Xanthomonas campestris* pv. *campestris*	Dipping seeds in 100 ppm streptocycline solution for 30 minutes
Cotton	Black arm	*Xanthomonas axonopodis* pv. *malvaceae*	Dipping seeds in 1000 ppm streptomycin sulphate solution
Turmeric	Rhizome rot	*Pythium aphanidermatum*, *P.debaryanum*	Dipping rhizomes in 0.3% mancozeb solution for 30 minutes
Chilli	Virus infection	Leaf curl virus	Dipping seeds in Trisodium orthophosphate solution 90g/L for 15 minutes.

3. *Eradication*

It is the process of reducing, inactivating, removing or destroying inoculum at the source, either from an area or from an individual crop in which it is already established. Eradication aims at complete elimination of the pathogen from infested areas. These practices are invariably employed to achieve eradication of inoculums including eradication of alternate and/or collateral hosts, crop rotations, field sanitations, heat or chemical treatments of plant materials or soil, etc. Eradication includes Biological Control of Pathogens- (Hornby, 1990), Crop Rotation- (Curl, 1963), Removal and Destruction of Diseased Plants, Soil Treatment, Soil Sterilization by Heat- 82°C for at least 30 minutes (Agrios, 2005); Soil Solarization –(Katan, 1981; Katan and Devay, 1991); Soil Treatment with Chemicals (Munnecke and Vangundy, 1979).

4. ***Protection***

The protection of infection court against the upcoming inoculums of polycyclic pathogen is necessary. The principles of avoidance, exclusion and eradication may be insufficient to prevent the contact of host with pathogen, thus there is likelihood of development of the disease. So the protective measures are essential to protect host plants from invading inoculums. It can be met through creating toxic barrier between the plant surface and the inoculums. Methods employed to achieve such results are chemical sprays, control of insect vectors, modification of environment, and modification of host nutrition. This include Chemical Treatment Control of Vectors, Modification of Environment, Modification of Host Nutrition.

5. ***Development of Resistance in Host***

It utilizes inherent mechanism of the plant to resist diverse activities of pathogens. There is a popular assumption that "Resistance is a rule while, disease is an exception". The infection or consequent damage caused by pathogen can be made ineffective through genetic manipulations or by chemotherapy. The host resistance can also be induced by the use of certain biotic and abiotic factors. This is achieved by Selection and Hybridization, Genetic Manipulation through Biotechnology, Induction of Acquired Resistance (Homa, 1990; Debata, 1983). Chemotherapy, Host Nutrition (Nene, 1966).

6. ***Therapy***

It is the treatment of infected host plants and is chiefly practiced for curing commercially important horticulture crops. The diseased host plants are cured or rejuvenated by the use of physical or chemical agents. The first five principles are mainly preventive in nature and are applied prior to the infection in plant whereas therapy is a curative method and is applied only after infection has taken place. Therapy include Chemotherapy Thermotherapy and Tree Surgery.

Methods of Plant Disease Management

1. **Physical Methods**

The diseases can be effectively managed through various physical methods such as heat, hot water treatment, ionizing radiations, refrigeration, and hot air treatment are incorporated in integrated disease management programs.

Heat Treatment, Hot Water Treatment, Solar Heat Treatment, Hot Air Treatment-Irradiation, Radio-frequency Treatment

2. Biological Method

Mechanism of Biological Control

Competition for Resources

One of the primary mechanisms by which *Trichoderma* spp. exert biocontrol is through competition for space and nutrients. *Trichoderma* fungi are fast-growing and can colonize root surfaces and the rhizosphere more effectively than many pathogenic fungi. By occupying these niches, *Trichoderma* spp. reduce the available resources that pathogens need to establish and proliferate. This competitive exclusion is a critical first line of defense against soil-borne diseases (Pal *et al.,* 2006). (Lorito *et al.,* 1994). (Nelson, 1990). (Kloepper *et al.,* 1980).

Mycoparasitism

Trichoderma spp. exhibit mycoparasitic behavior, directly attacking and parasitizing pathogenic fungi. This involves several steps: recognition, attachment, coiling around the pathogen, and secretion of lytic enzymes. Enzymes such as chitinases, glucanases, and proteases degrade the cell walls of the pathogenic fungi, leading to their destruction. This process not only kills the pathogens but also releases nutrients that can be utilized by plants and beneficial microorganisms (Pal *et al.,* 2006, Adams, 1990; Tiwari, 1996; Chet, 1987, Harman and Nelson, 1994; Handelsman and Parke, 1989; Altomare *et al.,* 1999).

Antibiosis

Another significant mechanism of biocontrol by *Trichoderma* spp. is antibiosis, which involves the production of secondary metabolites with antimicrobial properties. These metabolites include antibiotics, volatile organic compounds (VOCs), and non-volatile compounds that inhibit the growth of pathogens. For example, *Trichoderma* produces compounds such as gliotoxin, viridin, and peptaibols, which have been shown to have strong antifungal and antibacterial activities. These compounds can disrupt cellular processes in pathogens, leading to their death or reduced virulence Weller, 1988; Pal and Gardener, 2006).

Induction of Systemic Resistance

Trichoderma spp. can induce systemic resistance in plants, enhancing their ability to resist a wide range of pathogens. This phenomenon, known as induced systemic resistance (ISR), involves the activation of the plant's immune system. When *Trichoderma* colonizes plant roots, it triggers signaling pathways that lead to the production of defensive compounds such as phytoalexins, pathogenesis-related proteins, and reactive oxygen species. This heightened state of alert helps plants to respond more rapidly and effectively to pathogen attacks (Bailey *et al.,* 1998; Desmukh *et al.,* 2006; Martine *et al.,* 2001).

Promotion of Plant Growth and Health

In addition to their biocontrol properties, *Trichoderma* spp. promote plant growth and health through several mechanisms. They enhance root growth and development, increase nutrient uptake, and improve soil structure. *Trichoderma* spp. produce growth-promoting hormones such as indole-3-acetic acid (IAA) and solubilize phosphates, making essential nutrients more available to plants. Improved root systems lead to better water and nutrient absorption, contributing to overall plant vigor and resilience against stress.

Merits of Biological Control

- Generally less toxic than conventional pesticides.
- Generally affect only the target pest and closely related organisms.
- It does not have any residual effect.
- Cost effective and ecofriendly in nature.
- Helps in Rejuvenating soil fertility.
- Helps in maintaining sustainability in agriculture.

Limitations of Biological Control

- Efficacy of the commercial formulations gets reduced after a prolonged time period.
- Field performance of the bioagents fluctuates with variable environmental condition.
- Slow in action as compared to chemical control.
- Limitation in storage of formulations.

3. **Cultural Methods**

Crop Rotation: Crop rotation involves the sequential planting of different crops in the same field over successive years. The selection and sequence of crops are planned to reduce the inoculum of soil-borne pathogens by depriving them of their primary host (Curl, 1963). The effectiveness of crop rotation depends on the timing and duration of the rotation. This practice is particularly successful for controlling pathogens with short soil survival periods, such as Gaeumannomyces graminis, Pyrenophora tritici-repentis, Colletotrichum, Phoma sp., and certain pathogenic bacteria (Bruehl, 1987). However, it is less effective against pathogens like Pythium sp., Fusarium sp., Sclerotinia sp., Macrophomina phaseolina, and Plasmodiophora brassicae, which can survive in the soil for extended periods. Beyond pathogen control, crop rotation also enhances soil fertility, moisture retention, and soil texture.

Flooding: Flooding fields with water can significantly control plant diseases and weeds by reducing the amount of inoculum from soil-borne pathogens. It also diminishes alternate hosts of pathogens and insects, and destroys crop debris harboring inoculum. For example, flooding is known to control Panama wilt of banana. Angular leaf spot of cotton caused by Xanthomonas campestris pv. malvacearum can be managed by flooding fields for four days. However, this practice requires large quantities of water, keeps fields occupied for extended periods, and is costly, making it less viable for commercial cultivation.

Fallowing: Fallowing involves leaving a field uncultivated for a year or more to break the cycle of a crop. During this period, weeds and pathogens starve in the absence of a host, eventually leading to their decline. In some regions, fallowing during hot summer months exposes the soil to intense heat, which reduces the population of soil-borne pathogens and nematodes. This method is effective against sclerotia-forming pathogens such as Sclerotium, Sclerotinia, and Verticillium sp. (Garren, 1961).

Tillage Practices: Tillage, a cultural practice dating back to 1500 BC, exposes harmful insects, pathogens, and weed seeds to the sun, where they die from desiccation or heat. Tillage also incorporates crop residues, manure, and green manure into the soil, improving its organic matter content (Stone et al., 2004). Additionally, tillage enhances soil structure, aeration, bulk density, moisture content, and nutrient release. It has been used successfully to control diseases such as groundnut stem rot, Verticillium wilt, and Sclerotinia stem rot.

Roguing: Roguing involves the removal and destruction of diseased and undesirable plants to prevent pathogen spread. This includes eliminating alternate and collateral hosts, off-type plants, and volunteer plants harboring pathogens. Systematic roguing is effective in managing diseases like loose smut of wheat, covered smut of barley, green ear disease of pearl millet, okra yellow vein mosaic, and katte disease of cardamom (Mehrotra, 1980). Early-stage roguing reduces primary infection foci, curbing disease spread. Although effective for managing smut and ergot diseases, roguing is labor-intensive and costly, limiting its feasibility in many crop management programs.

Sanitation: Sanitation is defined as a process that reduces, completely eliminates, or excludes the initial inoculum from which epidemics are likely to start (Vanderplank, 1963). This practice involves activities aimed at minimizing or eliminating inoculum presence on plants, in fields, or in storage facilities to prevent disease spread from infected to healthy plants. Sanitation is a balance between what is desirable and what is practically achievable. For example, Hardison (1976) noted that fire can effectively control plant diseases. Diseases such as red rot of sugarcane, powdery mildew of wheat, Panama wilt of banana, koleroga of arecanut palms, and brown rot of stone fruits can be significantly reduced through proper sanitation practices.

4) Regulatory Methods

Quarantine

Quarantine measures include

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Domestic Quarantine The Destructive Insects and Pests Act (1914), empowers the Indian government to monitor and regulate the movement of plants or plant products from one state to another state. All states (except Assam, J&K, Meghalaya and Nagaland) have the pests and disease act which authorize the government to act within the state.

List of Restricted Agricultural Commodities as Enforced by Domestic Quarantine

Name of the Disease	**Area From Where Export Is Prohibited**
Apple scab	J&K, Himachal Pradesh
Bunchy top of banana	Assam, Kerela, Odisha
Mosaic of banana	Maharastra and Gujrat
Katte disease of cardamom	Maharastra
Koleroga of arecanut	Karnataka
Golden nematode of potato	Nilgiri Hills
Wart disease of potato	Darjeeling

Conclusion

Plant diseases have historically caused devastating losses, impacting not only economic stability but also the global standing of nations. In developing countries, where annual production often falls short of meeting the needs of one-third of the population, crop losses are particularly distressing. Effective management of plant diseases is crucial to feed the growing global population. Various approaches exist for managing plant diseases, and it is essential that these methods are integrated to maximize effectiveness and minimize environmental risks. Coordinated strategies that combine different management practices can lead to better outcomes, ensuring sustainable agriculture and food security for the future.

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