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A Perspective on Integrated Disease Management in Agriculture

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ABSTRACT: In this review we have described the history, biotic and abiotic stress of plant disease, types of plant disease, and its integrated management. The history of plant disease management is showing the traditional, chemical and integrated approach for the plant disease management. The abiotic means environmental factors while biotic includes microbes, phanerogamic plants, viruses, nematodes etc. These abiotic and biotic factors cause several diseases in plants like necrotic symptoms, abnormal growth and development of plant tissues, gummosis, wilting, rust, mildews etc. A number of factors responsible for the transmission of these diseases, they are described under this chapter. Besides, disease triangle and disease cycle are also described. Furthermore, disease diagnostic procedure has been given in fragment of sample collection method, sample submission method etc. Integrated disease management has been described here which comprises cultural, physical, mechanical, genetic, biological and chemical. Institutional, sociological, economic and political constraints in integrated disease management are also mentioned.

Key Words: Plant Diseases, Cultural practices, Physical and Mechanical practices, Biological control, Chemical control

INTRODUCTION

Any biotic or abiotic agents, which induce the disease in plant, are referred as the cause of diseases. Organisms that cause infectious disease include fungi, bacteria, viruses, viroids, virus like organisms, phytoplasmas, protozoa, nematodes and parasitic plants and environmental conditions such as lack or excess of nutrients, moisture, light, etc. to presence of toxic chemicals in Air or soil. Plant disease can be defined as "a series of harmful physiological processes caused by continuous irritation of the plant by a primary agent" or "physiological or structural dis-balance in plant caused by certain external agencies.

However, the definition which is accepted by American Phytopathological Society and the British Mycological Society states that "Disease is a malfunctioning process that is caused by continuous irritation which results in some suffering-producing symptoms". Therefore, the plant disease is a structural abnormality or physiological disorder or both due to an organism or unfavorable conditions that may affect the plant or its parts or products or may reduce their economic value. Integrated Disease Management (IDM) is a concept derived from the successful Integrated Pest Management (IPM) systems which consists of scouting with timely application of a combination of strategies and tactics. These may include site selection and preparation, utilizing resistant cultivars, altering planting practices, modifying the environment by drainage, irrigation, pruning, thinning, shading, etc., and applying pesticides, if necessary. But in addition to these traditional measures, monitoring environmental factors (temperature, moisture, soil pH, nutrients, etc.), disease forecasting, and establishing economic thresholds are important to the management scheme. These measures should be applied in a coordinated integrated and harmonized manner to maximize the benefits of each component. The main goal if IDM are:

-Eliminate or reduce inoculum
-Reduce the effectiveness of initial inoculum
-Increase resistance within the host
-Delay the onset of disease
-Slow the secondary cycles
-Uses several methods in which routine use provides disease control

IMPORTANCE OF THE PLANT DISEASE

Plant disease sometimes spread as epiphytotics and destroy the crops growing in the very large areas. They damage the crop growing in the field as well as stored products in the storage. The disease can occur any time and at any stage of the plant growth from the time of sowing of seeds to the storage of the products and cause a great economic loss. In Asia alone, the food grains amounting millions of dollars are being destroyed every year due to crop diseases. One such case, which is often quoted in the plant disease history is an example of famine caused due to plant disease. Such diseases include late blight of potato by fungus *Phytophthora infestans* in Ireland (1847), coffee rust by *Hemileia vastatrix* in Srilanka (1870), sigatoka leaf spot disease of banana by *Mycosphaerella musicola* in Central and South America (1930). In India, the famous Bengal famine in 1942 was due to leaf spot disease of rice caused by *Helminthosporium oryzae* and approximately two million people died of starvation. Due to impact of plant disease and economic losses caused by them, the science of plant pathology is attracting interest of all most all the countries of the world.

A. Milestone in Disease Management

Farmers have been at the mercy of plant diseases since plants were first domesticated. The mysterious appearance of blights and mildews, apparently coming from nowhere, led to theories of gods, vapors, demons, and decay as causes of disease. Beginning in the early 1800s, plant scientists and chemists began the long journey to discover and invent fungicides that would reduce disease losses. In 200, Cato mentioned the fumigation of trees with bitumen and sulphur. Prevost (France) (1807) recommended copper sulphate for wheat seed treatment against bunt and demonstrated first time the fungitoxic value of copper compounds. During 1821-1851 sulfur was emerge as effective fungicide for the control of powdery mildew disease. Millardet (French) (1882) discovered Bordeaux mixture to control downy mildew of grapevine. Bewley (1921) developed chestnut compound to control damping –off disease as a soil drench in nursery beds. Sanford (1926) conducted first experiment on biological control of plant pathogens with antagonistic (*Bacillus subtilis*) in Canada. In 1932, Weindling suggested use of *Trichoderma* spp. as biocontrol agent. Waksman and Schatz (1943) discovered first broad spectrum antibiotic streptomycin. During 1952-1978 fungicidal properties of first heterocyclic nitrogen compound captan, systemic fungicide Oxanthin, benomyl (against powdery mildew fungus of cucurbits), metalaxyl (against oomycetes) and fosetyl-Al (against phycomycetes) were investigated. In 1996 first strobilurins fungicide launched which was isolated from wood rotting mushroom fungi.

B. Scope of Integrated Disease Management

Several synthetic fungicides have been used for the management of diseases of commercially important agricultural crops. However, their continuous use in agriculture system causes several side effects in agro-ecosystem as well as in consumer's health. Numerous health and environmental reasons to use non-toxic alternatives to pesticides exist. Use of integrated disease management strategies can be certainly an answer to these problems. The principles of plant disease management should always be based on the integration of basic concepts such as avoidance, exclusion, eradication, protection, resistance and therapy. Adoption of Integrated Disease Management against the diseases encountered in crops is of utmost importance because dependency on chemicals for the management of various diseases is a great health hazard to the consumer. This assumes greater importance in the developing countries where the farmers are not educated enough to follow some cutoff date for application of chemicals to the standing crops. All these factors along with the growing awareness among the users regarding fungicides residues, pollution to the environment and sub-soil water and increased problem of pathogen resistance towards the fungicides, have been the compelling reasons for moving away from the total dependence upon the fungicides and to adopt IDM strategies that would involve one or more than one concepts of plant disease management. Use of such integrated approach in plant disease management is cost effective, renewable, eco-friendly and non-toxic to the plants as well as non-target organisms.

HISTORY OF PLANT DISEASE MANAGEMENT

A century ago the science of plant pathology was just being born and L. R. Jones wondered, at a meeting in Atlanta in 1913, whether it was a good thing to separate plant pathology as a discipline from botany. This was only a few decades after the idea that fungi were causal agents of plant diseases had been accepted and that the concept of "spontaneous generation," which regarded fungi as symptoms on plants suffering from bad environmental conditions, had been on its way out. This new concept of germs being causal agents of disease had its earliest supporters among plant pathologists like Tillet for bunt in 1755, Prevost for smut in 1807, Berkeley and de Bary for the late blight fungus of potatoes in the 1850s. Unfortunately, the broader significance of these findings was not recognized, and it was only in the 1860s that the work of Pasteur and Koch on human pathogens led to the breakthrough of the germ theory. Therefore, it is not surprising that the understanding and the standard of fungicides a century ago was very rudimentary. The history of disease management thus has three distinct phases, viz., the era of traditional approaches, the era of fungicides/bactericides and the era of IDM.

A. Era of traditional approaches

About the time humans started aggregating into villages and began planting selected food crops in clusters near rivers in fertile valleys, pests became an increasing challenge. Through trial and error, humans began to learn how to improve conditions and control the environment. People learned to perform cultural and physical control practices for crop protection. Methods such as flooding, destroying or using crop refuse, roughing diseased plants, tillage to expose and eliminate soil borne pathogens, removal of alternate hosts of pathogens and insects, timing of planting, crop rotation, trap crops, determining optimum planting sites, pruning, dusting with sulphur, and others reduced damage potential to many crops from many pests. This was followed by the use of plant products from neem, chrysanthemum, rotenone, tobacco and several other lesser known plants in different part of the world. These cultural and physical control methods are still viable today.

B. Era of fungicides

As with many inventions, "development" of the first fungicide was the result of good observations. The first use of brining of grain with salt water followed by liming took place in the middle of the 17th century to control bunt, and followed the observation that seed wheat salvaged from the sea was free of bunt. Up until the 1940s chemical disease control relied upon inorganic chemical preparations, frequently prepared by the user. The major products used for the disease management are given in the Table 1.

Year	Fungicide	Primary Use
1637	Brine	Cereal seed treatment
1755	Arsenic	Cereal seed treatment
1760	Copper sulfate	Cereal seed treatment
1824	Sulfur (dust)	Powdery mildew and other pathogens
1833	Lime sulfur	Broad spectrum foliar pathogens
1885	Bordeaux mixture	Broad spectrum foliar pathogens
1891	Mercury chloride	Turf fungicide
1900	$CuOCl_2$	Especially Phytophthora infestans
1914	Phenylmercury chloride	Cereal seed treatment
1932	Cu_2O	Seed and broad spectrum foliar diseases
1934	Dithiocarbamates patented	Broad spectrum protectants
1940	Chloranil, Dichlone	Broad spectrum seed treatment

Table 1: Fungicides in use up until 1940.

From 1940 to 1970 there were a number of new chemistry classes introduced as fungicides. The decade from 1960 to 1970 the most widely used protectant fungicides, mancozeb and chlorothalonil, were introduced. The decade also gave us the first broad-spectrum foliar systemic, thiabendazole, and the systemic seed treatment carboxin. The first case of resistance to benzimidazoles occurred in powdery mildew in greenhouses in 1969, one year after introduction. During the 1980s fenpropidin and fenpropimorph were key fungicides in the European cereal market, while tridemorph was used extensively for sigatoka followed by the seed treatment carboxin (Vitavax), which is highly effective on bunts, smuts and assorted Basidiomycetes such as *Rhizoctonia* spp.

The intensive and extensive use, misuse and abuse of synthetic fungicides during the ensuing decades caused widespread damage to the environment. Additionally, disease problems in some crops increased following the continuous application of fungicides. This, in turn, further increased the consumption of fungicide resulting in the phenomenon of the fungicide treadmill. The combined impact of all these problems together with the rising cost of pesticides provided the necessary feedback for limiting the use of chemical control strategy and led to the development of the IDM concept.

C. Era of IDM

The IDM terms came from integrated pest management (IPM).In the late 1960's, a movement to develop more environmentally benign crop protection methods began. Although economics was the prime driver to use crop scouting to determine spray schedules, it was a first real step toward an IPM approach. IDM calls for minimal use of pesticides, and only if deemed necessary. IDM gives preference to other control methods such as host-plant resistance, cultural practices and biological control. In the 21st century, the term of "agricultural sustainability" has become a norm for modern agriculture and numerous non-chemical methods for control of crop diseases such as pathogen-free seeds, disease resistance, crop rotation, plant extracts, organic amendments and biological control are considered less harmful than synthetic chemical pesticides and, therefore, offer great potential for application in conventional agriculture, organic farming and/or soilless culture. No single method can provide satisfactory control of crop diseases. Integration of all effective and eco-friendly measures in accordance with the dynamics of the agroecosystem management would be the best strategy for efficient control of diseases in crops.

CONCEPT OF PLANT DISEASE

The Greek philosopher Theophrastus (300, B.C) was the first to study and write about diseases of trees, cereals and legumes. He believed that god controlled the weather that brought diseases. Plant diseases were a manifestation of the worth of God. It is due to religious belief, superstitions or it is the effect of star moon and bad wind. E.g. Romans actually created a special rust God called Robigo for rust diseases of grain crops. They offered sacrifice of red dogs and sheep. After invention of compound microscope in the mid 1600 scientist enable to see many microorganisms associated with diseased plants and they come to believe that the mildews, rust, and other symptoms observed on plants and microorganisms found on diseased plant. Louis Pasteur (1860-63) provided irrefutable evidence that microorganisms arises only from pre-existing microorganisms and fermentation is a biological phenomenon not just a chemical one. It is accepted that a plant is healthy or normal when it can carry out its physiological functions to the best of its genetic potentials. The pathogen may cause disease in plant by:

- -Weakening the host by continuously absorbing food from the host cells for their own use.
- -Killing or disturbing metabolism of host cells through toxins enzymes or growth regulating substances, they secrete.
- -Blocking the transportation of food, mineral, nutrients and water through the conductive tissues.
- -Consuming the contents of the host cells upon contact.

A. Disease triangle

The interactions of the three components such as host, environment (physical viz., climatic, soil and topographical and biotic) and pathogen of disease have been visualized as a triangle generally referred to as the "disease triangle". Each side of the triangle represents one of the three components (Fig. 1). The length of each side is proportional to the sum total of the characteristics of each components that favour disease i.e. if the host is resistant, matured and widely spaced, the host side and amount of disease would be small or zero, whereas if the host or plants are susceptible, at susceptible stage of growth or densely planted, the host side would be long and the amount of disease could be great. Similarly, the virulent, abundant and active the pathogen, the longer the pathogen side and greater is the amount of disease. Also more favourable the environmental conditions (e.g. temperature, moisture and wind) help the pathogen or that reduces the host resistance, longer will be the environmental side and greater will be the amount of disease. When these three components of the disease triangle are quantified, the area of the area of the triangle represents amount of disease in a plant or in a plant population. If any of the three components is zero, there can be no disease.

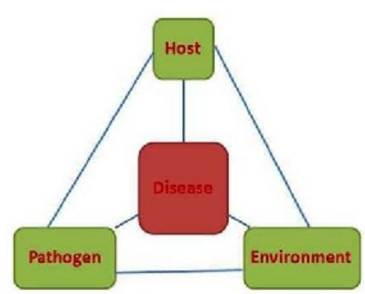

Fig. 1. Disease Triangle.

B. Mode of disease transmission

Transport of spores or infectious bodies, acting as inoculum, from one host to another host at various distances resulting in the spread of disease, is called transmission or dissemination or dispersal of plant pathogens. There are 2 major types of transmission of plant pathogens i.e. direct and indirect transmission.

Direct transmission: Disease transmission, where the pathogen is carried externally or internally on the seeds or planting materials like cuttings, sets, tubers, bulbs, etc. It may be

(a) Germinative transmission, where plant pathogens are transmitted by seeds or propagules of host plants, e.g. loose smut of wheat, loose smut of barley, leaf blight of wheat and TMV etc.

(b) In vegetative transmission pathogens are transmitted through tubers, bulbs, rhizomes, cuttings, graft, e.g. ring and brown rot of potato, late blight of whip smut red rot of sugarcane etc.

(c) In adherent transmission the propagules of the pathogens are carried over the surface of the seeds or vegitatively propagated parts e.g. Bunt of wheat, covered smut of barley, ergot of rye and bajra, wart disease of potato etc.

Indirect transmission: The pathogen spreading itself by way of its persistent growth or certain structures of the pathogen carried independently by natural agencies like wind, water, animals, insects, mites, nematodes, birds, etc. are the different methods of indirect transmissions.

(a) Autonomous transmission. Some root rotting fungi infecting certain seasonal crops also are transmitted by this method. Wood rotting fungi such as *Armillaria, Fomes, Polyporus* etc. migrate from plant to plant through soil. Others include root rot of cotton and wilt disease caused by *Phymatotrichum omnivorum* and *Fusarium* sp. etc.

(b) Wind dispersal: Pathogens causing powdery, downy mildews, leaf spots, blasts, blights and rust diseases are transmitted through wind.

(c) Water dissemination: Certain soil inhabiting pathogenic fungi and bacteria causing root and collar rots, wilts, foot, rots, etc. are likely to be transmitted to much longer distances through the agencies like irrigation water, streams and rivers, etc.

(d) Transmission by insects, mites and nematodes: Most of the viral diseases of plants are transmitted through the agency of different insects (Fig. 2). Both types of insects viz., sucking and chewing or/biting are capable of transmitting viral diseases. Insects in such cases are called the ‘vectors’ for the particular viral pathogen.

The insects responsible for transmission of viral diseases belong to the species of aphids, thrips, jassids (leaf hoppers), whiteflies, mealybugs, etc. Certain bacterial and several fungal pathogens are also known to be carried by insects. Many bacterial diseases such as cucurbit wilt, black leg of potato are transmitted by maggot and fire blight of apple is transmitted by bees. It is suspected that some viral diseases of chillies, tomato, brinjal and pigeon pea etc. have vector relationship with mites. Nematodes are soil borne organisms which sometimes act as agent for dissemination of bacterial, fungal and viral pathogens. For example yellow ear rot disease of wheat is transmitted by ear cockle nematodes.

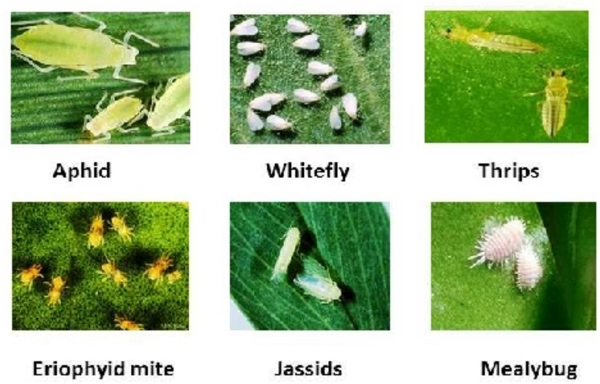

Fig. 2. Some insect vectors responsible for transaction of plant disease.

(e) Biological transmission: Dodder, a higher flowering parasite is known to transmit certain viral diseases which remain ‘persistent’ in the dodder plant.

(f) Cattle and birds: Cattle while feeding on contaminated fodder ingests the viable fungal propagules into the intestine which pass out as such in the dung and when such dung is used as manure may be source of inoculum *e.g.* smut spore.

(g) Human dispersal: While handling the diseased material and unknowingly and indirectly transmit the pathogens to healthy seedlings or plant parts through his contaminated hands. This is a kind of ‘continuous’ mode of transmission.

(h) Farm implements tools: The pathogens in this case are usually carried in the form of bits of plant disease debris lying in the soil. Similarly tools used for carrying out operations like cutting, pruning, budding, grafting, thinning etc. also help in the transmission of certain diseases from plant to plant. Several viral diseases are disseminated through the budding and grafting operations.

C. Biotic and abiotic stress

There are so many agents which initiate the reactions in host plant causing diseases. Such agents are called causal agents of the disease and are basically two types i.e. biotic and abiotic. Abiotic disorders are caused by nonliving factors, such as drought stress, sunscald, freeze injury, wind injury, chemical drift, nutrient deficiency, or improper cultural practices, such as overwatering or planting too deep. Mango necrosis or black tip of mango is caused due to brick kiln fumes containing SO_2, coal gas and chlorine. Despite of these problems, excessive mineral or deficiency of minerals are also responsible for major diseases. Some mineral deficiency symptoms includes red leaf of cotton (nitrogen), dwarfing of cotton (phosphorus), cotton rust and little spot of alfalfa (potassium), heart rot of beet, brown heart of cabbage, internal cork of apple (boron), die back of citrus (copper), gray speck disease of oat (manganese), whiptail disease of cauliflower (molybdenum) and khaira disease of rice (zinc). Biotic plant problems are caused by living organisms, such as fungi, bacteria, viruses, nematodes, insects, mites, parasitic flowering plants and animals. Unfortunately, the damage caused by these various living and nonliving agents can appear very similar.

D. Parasitism and pathogenesis

An organism that lives on or in some other organism and obtains its food from the latter is called a parasite. Parasitism is the removal of nutrients from a host by a parasite. There are two major types of parasitism: obligate and non-obligate.

-Obligate parasites are biotrophs depend on living cells for their existence. This group includes rust and mildew fungi, viruses, viroids, mollicutes, fastidious bacteria, nematodes, protozoans, and parasitic plants.

-Non-Obligate parasites can be biotrophic or necrotrophic. Necrotrophic pathogens kill their host's cells in advance of colonization. The necrotrophs typically use enzymes and toxins to kill the cells they feed on.

-Facultative saprophytes are parasites that typically depend on living material, but can utilize necrotic materials in situations where no live material is available. Facultative parasites live predominately as saprophytes, but under specific conditions can parasitize living organisms.

Pathogenicity is the ability or capacity to incite disease. Relating to pathogenicity, the terms virulence and aggressiveness are often used. Aggressiveness is the relative ability to colonize and cause damage to plants. In short, it's whether the pathogen causes a little or a lot of disease under standard conditions.

Virulence is the degree of pathogenicity of a given pathogen. Pathogenesis is the sequence of progress in disease development from the initial contact between a pathogen and its host to the completion of disease symptoms. The event of pathogenesis consisted of three steps i.e. pre-penetration, penetration and post penetration. Pre-penetration is the stage that includes the interaction of host pathogen before entry of pathogen into the host. Once a pathogen reaches a suitable infection site at the plant surface, it must breach a series of barriers to gain entry into its host before establishing a parasitic relationship during the penetration stage. After successful penetration, the pathogen proceeds further to establishment of proper infection. This stage is called invasion.

After successful infection, the pathogen derives its nourishment from the host, starts multiplication and secretes some chemical substances to express the symptom of the disease. The haustoria absorb nutrients from the host and supply it to the main body of pathogen. These pathogens soon start reproduction and multiplication.

E. Disease cycle

Plant disease cycles represent pathogen biology as a series of interconnected stages of development including dormancy, reproduction, dispersal, and pathogenesis. The progression through these stages is determined by a continuous sequence of interactions among host, pathogen, and environment. The main events of stages comprising the disease cycle include the following: production and dissemination of the primary inoculum, primary infection, growth and development of the pathogen, secondary infection, and overwintering (Fig. 3).

1. The primary inoculum is the part of the pathogen (that is, bacterial or fungal spores or fungal mycelium) that overwinters (over-seasons) and causes the first infection of the season, known as primary infection.
2. Dissemination refers to the spread or dispersal of the pathogen from an inoculum source to a host. Dissemination can occur by wind, splashing rain, insects, infested pruning tools, infected or infested transplants, and other means.
3. Primary infection occurs when the pathogen comes into contact with a susceptible host under favorable environmental conditions. Most

fungal and bacterial pathogens require free water for spore germination; consequently, infection is favored by prolonged warm, wet periods with high relative humidity.

4. Growth and development of a pathogen usually occurs on or within infected plant tissue. Fungi grow and spread within their host by means of mycelium. Bacteria spread by rapidly increasing in numbers.
5. Secondary infection results from spores or cells produced following primary infection or from other secondary infections. The secondary infection cycle can be repeated many times during the growing season. The number of cycles is dependent on the biology of the pathogen and its host and the duration of environmental conditions needed for infection.
6. Overwintering or over seasoning is the ability of a pathogen to survive from one growing season to the next.

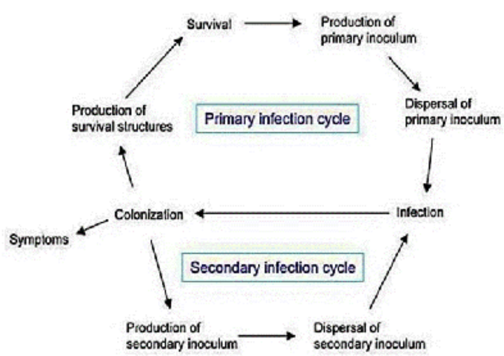

Fig. 3. Stage in disease cycle.

F. Causes and Identification of Plant Diseases:

A plant disease is the resultant of close interaction between the host plant and the disease inciting agent. There are so many agents which initiate the reactions in host plants causing the diseases. Such agents are called cause of disease. Such agents include living and non-living as well as viruses and have been described earlier.

Classification of plant disease: Plant disease may be classified in various ways on the basis of casual agencies, spread and severity of infection, their perpetuation and transmission, the part of host affected and symptoms produced by the host plants.

Classification based on causes of diseases: On the basis of causes of the diseases, they can be divided into noninfectious and infectious disease.

a. Non-infectious diseases: Such types of diseases are not caused by living organisms and usually occur by lack of environmental conditions, nutritional deficiencies, and physiological disorders i.e. heat canker of flax caused by high temperature, apple scald and black tip mango caused by injurious atmosphere, whiptail disease of cauliflower caused by deficiency of molybdenum, tip rot or necrosis of mango fruits caused due to boron deficiency etc.

b. Infectious disease: Such diseases are caused by living organisms (bacteria, mycoplasmas, fungi, nematodes, algae, protozoans) and viruses and are parasitic in nature. These types of diseases show presence of sign and can be easily transmitted form diseased plants to healthy plants thus, are infectious in nature.

Classification based on spread and severity of infection: On the basis of geographical distribution and severity of infection, plant diseases are classified into following categories i.e. endemic, epidemic, sporadic, etc. on the same lines of insect pests.

Classification based on the part of host infected: On this basis disease may be localised or systemic. In **localised infection**, disease occurs in a particular part or organ of the host plant. Such types of example include root disease, stem disease, foliage disease, spike disease, depending upon the organ infected. In **systemic infection** the disease spread throughout the plant body.

Classification based on perpetuation and dispersal of diseases: On this basis, diseases are categorized into following parts.

a. Soil borne diseases: Inoculum of the diseases causing pathogen remains in soil and penetrate the plant resulting in diseased condition e.g. root rot, wilt.

b. Seed borne diseases: The micro-organisms are carried along with seeds and cause diseases when congenial condition occurs e.g. *Alternaria* leaf spot.

c. Air borne diseases: The micro-organisms are spread through air and attack the plants causing diseases e.g. blight, rust, and powdery mildew.

d. Water borne disease: This category of plant disease includes those in which primary inoculum is perpetuated and transmitted through water e.g. blight of paddy.

e. Diseases spread by insects: The viral diseases are spread by insects. The insects which carry the viruses are known as vectors.

Classification based on diseases symptoms: Such categories include smut, anthracnose, canker, mosaic, powdery and downy mildew damping off, rots, gall etc.

Symptoms of plant diseases: The symptoms are external or internal expressions of a plant that indicate that it is suffering from. Generalized symptoms may be classified as local or systemic, primary or secondary, and microscopic or macroscopic. Local symptoms are physiological or structural changes within a limited area of host tissue, such as leaf spots, galls, and cankers. Systemic symptoms are those involving the reaction of a greater part or all of the plant, such as wilting, yellowing, and dwarfing. In general, the kinds of systems produced by specific groups of casual organisms can be listed as follows:

Symptoms caused by fungi: Fungi and fungi like organisms (FLOs) such as P*ythium* and *Phytophthora* collectively cause more diseases in the plants then do rest of the pathogen as a whole. These symptoms can be broadly categorized as following depending upon the processes involved in the appearance of disease symptoms on the host.

a. Necrotic symptoms

b. Abnormal growth and development of plant tissues

c. Other symptoms

a. Necrotic Symptoms: These symptoms involve the death and destruction of plant tissues resulting in brittle appearance of the tissue.

1. Leaf spot: Localized lesions produced on the leaves of the host plants as a result of pathogen infection (Fig. 4 A).Examples: *Alternaria* sp.*, Cercospora* sp.*,* and *Pyllachora* sp. spots the dead tissue of the spot is shed leaving a circular hole, called shot hole e.g. etc. (Fig. 4 B).

2. Blight: Blights are the general and rapid destruction of the growing succulent tissues like leaves, shoots, twigs and blossom. For e.g., *Phytophthora* sp., *Cryophonectria parasitica*, *Ascochyta* sp. (Fig. 4 C).

3. Blast: Necrotic lesions are visible on the leaves, nodes, and at the base of heads resulted to rapid browning and death of the tissue. Example: Rice blast by *Pyricularia oryzae* (Fig. 4 D).

4. Cankers: The localized necrotic lesions are sunken and surrounded by successive layers of cork cells. For eg.: *Phytophthora* sp., *Nectaria* sp. (Fig. 4 E).

5**. Scab:** These are the localized lesions which are due to the slightly raised and cracked outer layer of the fruits, leaves or tubers etc. The cracked tissue becomes dry and corky. Example: apple scab by *Venturia inaequalis* (Fig. 4 F).

6. Anthracnose: It is a type of disease in which dark necrotic, sunken lesions are produced on mainly leaves, fruits and stem. Example: *Elsinoe veneta* on raspberry and *Colletotrichum* spp. cause anthracnose of cotton (Fig. 4 G).

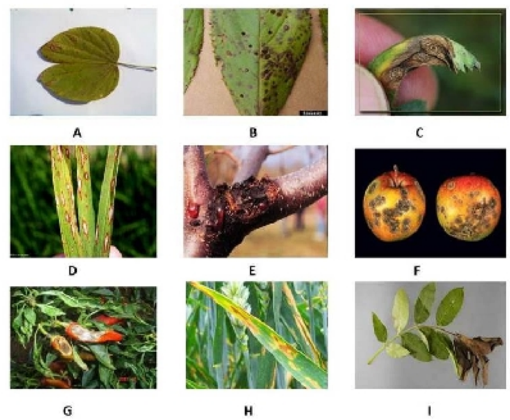

Fig. 4. Symptoms of fungal diseases. A. Leaf spot, B. Shot holes, C. blight, D. Blast, E. Canker, F. Scab, G. Anthracnose, H. Blotch, I. Dieback.

7. Blotch: These are usually large, irregular shaped spots on the surface of the plant leaves, stem or flowers. At initially spots appear purplish, circular on upper surface and later on lower and later become glossy dark purple and then beown. Example: *Septoria tritici* blotch of wheat and *Cladosporium* leaf blotch of peony (Fig. 4 H).

8. Dieback: It is the progressive and extensive death of the shoots and roots that starts from the tip of the shoots. Example: *Lasiodiplodia theobromae* cause dieback of mango (Fig. 4 I).

9. Damping off: The young or seedlings collapse at the back due to pathogen attack before or after the germination. Example: *Pythium* sp., *Phytophthora* sp., *Rhizocto nia solani* (Fig. 5 B).

10.Basal stem rot: The pathogen destruct the cambium and vascular tissue hence the plant shows typical symptoms of wilting. Example: *Ganoderma zonatum* cause basal stem rot in palms (Fig. 5C).

11. Root rot: The disintegration and decay of the tissues of roots by various fungal pathogens. Example: *Phymatotrichum omnivorum* cause root rot of cotton (Fig. 5D).

12. Soft and dry rot: Wet rots are caused by certain fungi which caused by disintegration of the tissues in leaves, fruits, wood, tubers etc.

Example: *Rhizopus* spp. cause soft rot of sweet potato (Fig. 5E).

b. Abnormal growth and development of plant tissues: These symptoms results due to the hypertrophy (increased cell size) and hyperplasia (increased number of cells) due to the interaction of chemicals produced by the pathogen and the tissues of host. The tissues show abnormal growth pattern which result in altered morphology and physiological functioning of the affected part or entire plant.

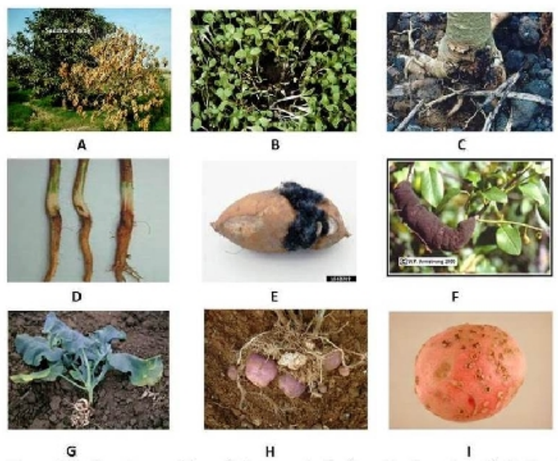

Fig. 5. Symptoms of fungal diseases. A. Decline, B. Damping off, C. Basal stem rot, D. Root rot, E. Soft rot, F. Galls, G. Club root, H. Wart, I. Powdery scab.

1. Galls: Abnormal growths (swollen/raised tissues) formed by the interaction of the certain fungi on the host leaves, stems, roots or flowers. Example: *Dibotryon morbosum* causes "poop gall" of choke cherry (Fig. 5F).

2. Club-root: Gall formation or distortion take place in the roots giving the appearance of spindle or clubs.

Example: *Plasmodiophora brassicae* cause club root of crucifers (Fig. 5G).

3. Warts: Hard, benign protuberances (called warty excrescences) produced on the stems or tubers and caused by fungal or viral pathogen. Example: *Synchytrium endobioticum* cause potato wart disease (Fig. 5H).

4. Powdery scab: The infected tissue has brown spongy spots, which are dry and in severe conditions give appearance of warts. Example: *Sponiophora subterranean* causes powdery scab of potato (Fig. 5I).

5. Witchs' broom: Profuse branching of the twigs takes place in which the new twigs are turned upward, short, and bear small leaves giving the appearance of witches' broom. Example: *Moniliophthora perniciosa* cause witches' broom disease (WBD) in cocoa (Fig. 6A).

6. Leaf curling: Easily distinguishable symptoms like distortion, discoloration and curling of the leaves due to fungal pathogen (*Taphrina deformans*). In the early stages the leaves show red colouration, thicker and softer than normal mature leaves (Fig. 6B).

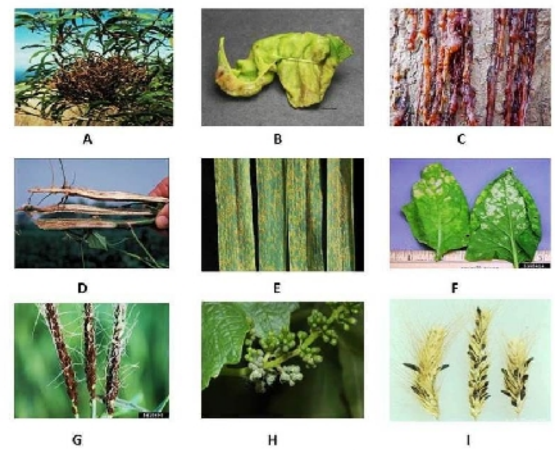

Fig. 6. Symptoms of fungal diseases. A. Witches broom, B. Leaf curl, C. Gummosis, D. Wilt, E. Rust, F. White rust, G. Smut, H. Downy mildew, I. Ergot.

7. Atropy: It is the reduction in size due to the parasitic fungi which induce hypertrophy and the growth is said to be suppressed. Example: *Peranospora brassicae* suppresses the floral buds in *Brassica* sp.

c. Other Symptoms:

1. Gummosis: It is the oozing out (seeping) of the amber coloured exudate from the diseased tissue which may be bark of the stem, leaves or fruits and later sets into solid mass. Different species of *Botryosphaeria* cause gummosis in different plants (Fig. 6C).

2. Leaf dropping and fruit drooping: Dropping of leaves or fruits is also very common symptom associated with infection of any fungal pathogen. Example: *Phytophthora* attack on palm, *Cercospora* and *Hemileia.*

3. Wilt/Vascular wilt: Vascular bundle is blocked out by the pathogen and results in the loss in turgidity and drooping of the leaves and shoots of the plant leading to permanent wilting. Most common vascular wilts are caused by *Fusarium* and *Verticillium* (Fig. 6D).

4. Rust: Rusty appearance on the leaves and stems of the host plant as a result of the infection, produced by the fungal pathogen belonging to the order Uredinales (rust fungi) (Fig. 6E).

5. White rust: White coloured spots of conidia spores of oomycete *Albugo candida* in brassica family (Fig. 6F).

6. Smuts: It is a disease characterized by masses of dark, powdery spores of smut fungi belonging to order Ustilaginales (Fig. 6G).

7. Mildews: Presence of whitish mycelium and fructification covering the areas on leaves stems or fruits. In **Powdery mildew** mycelium is on the upper surface while in **Downy mildew** it present on the lower surface. Example: *Bremia, Peranospora, Plasmopara,* and *Pseudoperanospora* cause downy mildews of dicotyledonous plants such as lettuce, tobacco, grapes and cucurbits. *Peronoslerospora, Sclerophthora* and *Sclerospora* cause downy mildews of monocots such as corn, sorghum and sugarcane (Fig. 6H).

8. Ergot: The grains in the heads of the cereals are replaced by black or purple colour edsclerotia of ergot fungus *Claviceps purpurea*, just before the harvest (Fig. 6 I).

Symptoms caused by bacteria: Bacterial diseases in plants may affect stems, leaves or roots or be carried internally. Some examples of common bacterial diseases of vegetable crops are provided in the Fig. 7.

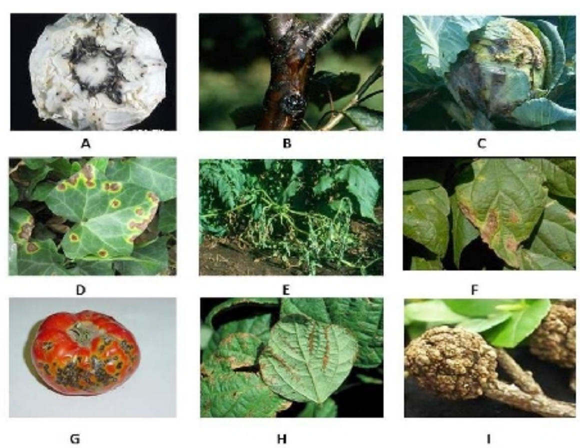

Fig. 7. Symptoms of bacterial diseases. A. Black rot, B. Scab/bacterial canker, C. Bacterial soft rot, D. Bacterial leaf spot, E. Bacterial wilt, F. Bacterial blight, G. Bacterial speck, H. Bacterial brown spot, I. Tumors and Galls.

1. Black rot: Light-brown to yellow V-shaped lesions on the leaf, this becomes brittle and dry with age. Vein blackening occurs with the necrotic area. E.g. *Xanthomonas* species (Fig. 7A).

2.Scab/Bacterial canker: Scabs and cankers are corky outgrowth which is formed on leaves, twigs and all other plant parts above the ground. Scab is formed by epidermal infection while canker is deep seated. E.g. *Clavibacter michiganensis, Streptococus* etc (Fig. 7B).

3. Bacterial soft rot: Wet, slimy, soft rot that affects any part of vegetable crops including heads, curds, edible roots, stems and leaves. E.g. *Pseudomonas* spp., *Erwinia* spp (Fig. 7C).

4. Bacterial leaf spot/Bacterial spot: Large brown to black circular areas that start as small translucent spots; water soaked, usually on outer leaves. E.g. *Xanthomonas campestris* strains (Fig. 7D).

5. Bacterial wilt: Plant wilt rapidly and die without any spotting or yellowing; vascular tissue appears brown and water-soaked; white ooze appears when pressure is applied to affected tubers or stems. E.g. *Ralstonia solanacearum* (Fig. 7E).

6. Bacterial blight: Water-soaked spots on leaves and stipules which become dark-brown and papery in warm weather or black in cool weather. E.g. *Pseudomonas syringae* strains (Fig. 7F).

7. Bacterial speck: Small dark spots surrounded by a yellow halo on leaves; dark raised specks on fruit. E.g. *Pseudomonas syringae* strains (Fig. 7G).

8. Bacterial brown spot: Water-soaked spots which enlarge and become sunken and tan with distinctive reddish-brown margins. E.g. *Pseudomonas syringae* strains (Fig. 7H).

9. Tumors and Galls: In many bacterial diseases the effect of invasion by the pathogen is hyperplasia and hypertrophy of invaded tissues. As a result, tumours develop on the affected organs. E.g. Crown gall tumors by *Agrobacterium tumefaciens* (Fig. 7I).

Symptoms caused by viruses:

The most obvious symptoms of virus infected plants are usually those appearing on the leaves but some viruses may cause striking symptoms on the stem, fruits and roots.

a. Local: These are the symptoms produced at the site of artificial inoculation on leaves with virus.

-*Chlorotic local lessions:* Infect cell loose chlorophylls and other pigments. Ex. TMV on Cowpea host.

-*Necrotic local lessions:* Infect cell die. Ex. TMV on *Nicotiana glutinosa* host.

-*Ring spot local lesions:* Consist of central group of died cells near inoculated area (Necrotic ring) Ex. Potato Virus: On *Chenopodium amaranticolar* host.

b. Systemic: In almost all viruses of plant occurring in field, the virus is present throughout the plant. Such types of disease include decolouration in patches on leaves, sharpness of boundaries and distribution and discolouration of lamina.

1. Mosaic: Light green yellow or white areas intermingled with normal green of leaves of fruit or of whitish areas are intermingled with the areas of the normal colour of flowers or fruits. Example: Streak or stripe (Red stripe of jowar), Vein clearing (BCMV), Vein banding (Beat curly top) and Inter veinal mosaic light discolouration restricted in between veins (Fig. 8A-D).

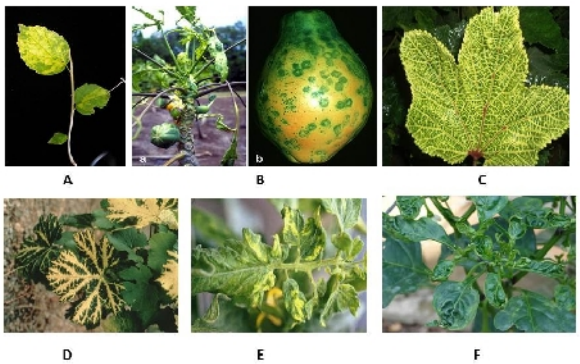

Fig. 8. Symptoms of viral diseases. A. Chlorosis, B. Ring spot, C. Vein clearing, D. Vein banding, E. Mottling, F. Leaf curl.

2. Mottling: If the discoloured patch of a variegated leaves are rounded the variegation is usually designated as mottling (Fig. 8E).

3. Malformation: This includes uneven growth of leaf lamina leaves becomes curled, brittle (Crinkling) and show, prominences and depressions (puckering) upward and downward curling, vein distortion, leaf enation, galls and tumours (Fig. 8F).

4. Stunting and premature defoliation: Disease is characterized by under development of tissue as a result of which normal growth of plant become arrested and suppressed leads to the stunted growth of the plant and premature defoliation.

5. Others: Other viral symptoms include blistering, (Dark green area may be raised to give blistering effect), enations (These are the out growth in different shape and form either on veins), leaf roll, dwarfing galls and stem pitting etc.

Symptoms caused by mycoplasmas, spiroplasmas and fastidious bacteria:

(i) They are known to cause "Yellows" disease in plant. Economically important plant disease caused by mycoplasmas are sandle spike aster yellows, mulberry dwarf, grassy shoot of sugarcane, citrus greening, sesame phyllody, little leaf of brinjal, etc. (Fig. 9). The plants give a bushy appearance, show stunting growth and fail to produce flowers and fruits. The flowers commonly become phyllody.

(ii) Spiroplasmas are helical prokaryotes lacking a rigid cell wall. Unlike Phytoplasma, they can be cultured on artificial media. They transmitted mostly by leaf hoppers. Common symptoms due to spiroplasmas include citrus stubborn (*Spiroplasma citri*), leaf roll, yellow dwarf of rice, pear decline, corn stunt, etc.

(iii) On the other hand fastidious bacteria also called RLO (Rickettesia Like Organisms) confined either to phloem or xylem of the host plant and causes disease. Stunting is the main disease caused by RLO e.g. Sugarcane ratoon stunting (*Clavibacter xyli* pv. *xyli*) and Bermuda grass stunting.

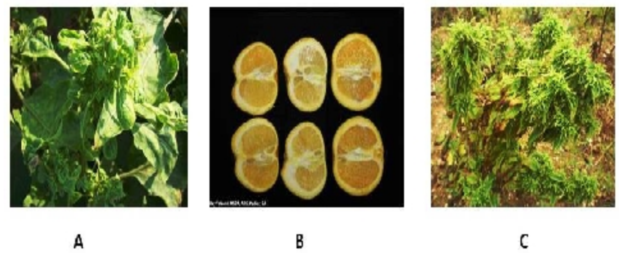

Fig. 9. Symptoms of phytoplasmal/spiroplasmal diseases. A. Little leaf, B. Citrus stubborn, C. Phyllody.

Symptoms caused by viroids: Common symptoms include retardation of plant growth and stunting. Potato plants infected with the potato spindle tuber viroid are smaller than healthy plants. The diseases tubers are spindle shaped. Stunting is the important symptom of tomato plants affected by the tomato bunchy top viroid, hop plants infected by the hop stunt viroid and chrysanthemum plants infected by the chrysanthemum stunt viroid and the chrysanthemum chlorortic mottle viroid. Viroids are highly contagious and mechanically transmitted. Potato spindle tuber viroid has been reported to be transmitted by aphids, grass hoppers, flea beetles.

Phanerogamic plant parasites: There are few seeds plants called flowering parasites (Phanerogams) which are parasitic on living plants. There are two types of phanerogamic parasites.

a. Root parasites: They include Striga (Partial root parasite which attacks sugarcane jowar, Maize, cereals and millets; Fig. 10A) and *Orobanche* (Complete root parasite which attack tobacco, tomato, brinjal, cabbage, cauliflower Fig. 10B).

b.Stem parasites: They include Dodder (*Cuscuta* Fig. 10C) (Complete stem parasite which attacks

attacks berseem alfalfa, clover, flax, onion, potato, ornamental and hedge plants) and *Loranthus* (Partial Stem Parasite which attacks mango, citrus, apple, guava; Fig. 10D).

G. Disease diagnostic procedures

Proper diagnosis may be extremely important in preventing the problem on other plants or in preventing the problem in the future. How does a plant pathologist go about diagnosing plant problems? The diagnostician must have very good observation skills, and s/he also needs to be a good detective. It is important to keep an open mind until all of the facts related to the problem can be collected. The possibility of multiple causal factors must also be considered. Control measures depend on proper identification of diseases and of the causal agents. Therefore, diagnosis is one of the most important aspects of a plant pathologist's training. Without proper identification of the disease and the disease-causing agent, disease control measures can be a waste of time and money and can lead to further plant losses. Proper disease diagnosis is therefore vital.

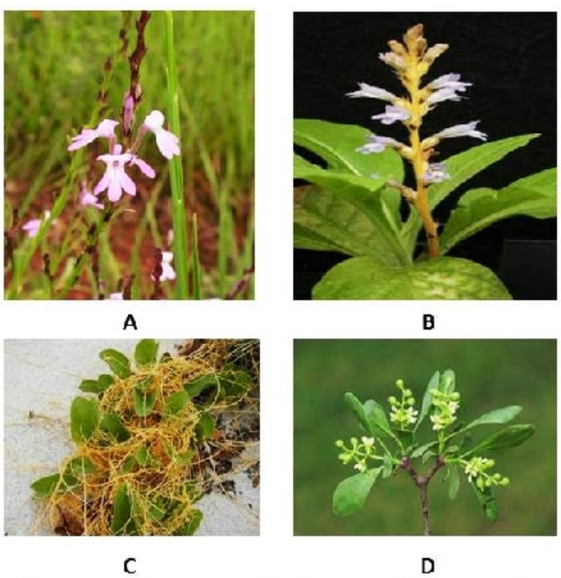

Fig. 10. Phanerogamic plant parasites: A. Striga; B. Orobanche; C. Cuscuta; D. Loranthus.

Sample collection methods: Before going to the field for the collection of diseased plant samples the field kits to be taken with are plastic and paper bags, pruning shears, pruning saw, wire twist ties, paper towels Knife, hatchet, increment borer, plastic/rubber gloves, trowel, shovel, soil probe, rubber bands, hand lens 5-10X, forms, pencil, labels vials/jars with lids, padded collection boxes, camera, maps, field manuals, disinfectant for hands & tools, portable soil pH and soluble salts meter. After deciding what to include in the sample, the following procedures for obtaining, packaging, and submitting the sample are suggested:

a. Obtain fresh material in reasonable quantity, several examples of the various symptoms being expressed. Be certain to include as many identifiable stages of the disease as are represented. Most recently developed symptoms usually afford the best material for diagnosis.

b. Lift roots carefully so as not to leave feeder roots or rotted roots behind. Include about a liter of soil for pH, soluble salts, and possibly a nematode assay.

c. Place samples in appropriately sized plastic bags, including a paper towel for a blotter, if sample is very wet. Duplicate dry samples are recommended if the sample is succulent or fragile.

d. Wrap a wire twist-tie around stem at ground line to keep soil off of above-ground plant parts. Accurately label samples. Place the entire sample in a paper bag or an unsealed plastic bag.

e. Keep samples cool, protected from crushing.

f. Gather following information from the grower:

1. Host: Cultivar/variety; age; propagation method; site prep; names; dates and rates of fertilizer, pesticide history and schedule*, growth regulator applications; pruning; pinching; transplant; omissions or additions to usual / conventional culture program.

2. Irrigation: Frequency, rate, timing; water quality; determination of need.

3. Soil/media: pH, soluble salts, texture, drainage, homogeneity, aeration, temperature, planting depth, cultivation, cropping history, earth moving/construction, burial/disposal site, trash burning.

4. Environmental conditions: Temperature, humidity, ventilation, wind, lightning, exposure, light intensity, air quality, method of heating and cooling, etc. during syndrome development.

5. Date of first symptoms and rate of syndrome development, coincident with any treatment or environmental event.

6. Recent human, animal, insect, mite activity around or on symptomatic plants.

7. Habits of plants in question, predisposition (plant made more susceptible) by cultural or environmental conditions

g. Make pertinent observations.

1. Spatial and chronological pattern of disease in crop, on individual plants. Are symptoms different or consistent, uniform or scattered?

2. Are symptoms spreading across crop or progressing on individual plants?
3. What is the frequency and intensity of the syndrome?
4. Any signs of pathogen/causal agent? (Fruiting structures, chemical residues, insects/mites, frass, etc.).
5. Any evidence of host recovery?
6. Nearby plants (same or different) show any symptoms? Are root zones shared?
7. Inspect interior, crown, roots of plant. Cut open stems, crowns, flowers, fruits, and roots. Are there any hidden, internal symptoms/signs of disease?

Sample Submission methods: The methods include:
a. Take samples before applying pesticides, otherwise the ability to recover pathogens may be limited.
b. Submit generous amounts of plant material representing a range of symptoms.
c. Don't add water or pack a sample that is wet.
d. Keep samples refrigerated after collection until they are submitted. After collecting good samples, do not allow them to bake in the sun or on the back seat of a car prior to submission because doing so will ruin them.
e. Do not mix different samples in the same submission bag. Moisture from root samples will contribute to the decay of foliage samples if they are mixed together.
f. Plant disease identification procedures do not utilize soil. Excess soil can be hand shaken from root systems, but leave enough soil to keep roots at field moisture levels.
g. Please mark sample packages with "Warning" if sample has thorns or spines.
h. All samples must be accompanied with a completed Plant Clinic Diagnostic Form. These are available at all county Extension offices or online. Give complete information on the form and keep it separate from the sample. Complete a separate form for each sample and plant problem.
i. Remember to note recent pesticide history on the Plant Diagnostic Form accompanying the sample.
j. Mail samples early in the week to avoid the weekend layover in the carrier facility.
h. For emergency samples, use overnight courier services or surface mail. Complete mailing addresses and map locations are necessary if owners want to be informed of diagnosis or site must be revisited.

Diagnostic methods: *Diagnostic tests for identification of biotic causal agents:* A major problem in identification of biotic causal agents is the inability of some infectious pathogens to grow on artificial media. Viruses, as well as some fungi (e.g. powdery and downy mildew causing agents) and some prokaryotes (e.g. phytoplasmas), require a living host in order to grow. In cases where the plant pathogen is difficult or impossible to grow on artificial media, other methods may be used for their detection, such as the use of serological tests for viruses. Viral identification is often accomplished utilizing ELISA (enzyme-linked immunosorbent assay). Other techniques used for the identification of viruses include negative staining and electron microscopy to view the viral particles in plant tissue or suspensions. PCR and ELISA tests, as well as other laboratory tests, may be used for organisms that will grow on artificial media. Additional tests may include analysis of fatty acids of organisms, carbohydrate utilization (i.e. BIOLOG test), and enzyme activity testing (i.e. pectinase, isozyme patterns).

Diagnostic tests for identification of abiotic plant disease causal agents:It is extremely important to look for abiotic factors that may be important in observed symptoms. Soil and water tests may be necessary to determine pH, nutrient composition, salinity, and other factors such as pesticide residues that may induce various symptoms. It may also be important to get samples of plant tissue analyzed for nutrient content to determine if there is macro- or micronutrient deficiencies or toxicities.

Plant Disease Management: The goal of plant disease management is to reduce the economic and aesthetic damage caused by plant diseases. Traditionally, this has been called plant disease control, but current social and environmental values deem "control" as being absolute and the term too rigid. Disease management might be viewed as proactive whereas disease control is reactive, although it is often difficult to distinguish between the two concepts, especially in the application of specific measures.

Principles of plant disease management: The basic principles are:

Avoidance of pathogen: It comprises proper selection of geographical areas, selection of the field, sowing date, choice of disease escaping varieties, selection of diseases free seeds and planting stock and cultural practices.

Exclusion of the pathogens: It includes quarantine measures, seed certification, plant disease notification and prevention of sale of diseased plants.

Reduction and eradication of pathogen inoculum: This can be performed by adopting cultural, physical, mechanical, biological and chemical practices.

Resistance to pathogens: Host resistance and production of resistance varieties.

Integrated approach: It comprises of combination of disease management strategies with overall aim to develop sustainable system of disease management based on a sound understanding or whole crop ecosystem.

Disease epidemiology and factors affecting spread of disease: Epidemiology or epiphytology is the study of the outbreak of disease, its course, intensity, cause and effects and the various factors governing it. Based on the occurrence and geographical distribution they are classified as endemic, epidemic and sporadic which are descried earlier. An epidemic may cause widespread and mass destruction of crop in a short time or may persist for long periods depending upon the three factors host, pathogen and environment. A disease is sometimes sporadic and assumes epidemic proportions under special circumstances. The essential conditions for an epiphytotic or the factors governing epidemics can be grouped under the three heads i.e. Nature of host; Nature of the pathogen and Environment.

Components of integrated disease management: The components of IDM include quarantine & regulatory measures, cultural, genetic resistance, physical and mechanical, biological and chemical.

Quarantine and regulatory measures:

-Plant quarantine is the legally forced restriction on the movement of diseased plant materials or of fungi, bacteria or viruses that cause disease in plants.

-The legislation has been placed on the statute-book in most agriculturally advanced countries. When plant pathogens are introduced into an area in which they did not previously exist, they are likely to cause much more catastrophic epidemics than do the existing pathogens.

-Some of the worst plant disease epidemics that have occurred throughout the world, for example the downy mildew of grapes in Europe and the bacterial canker of citrus, the chestnut operation of the quarantine regulations.

-It is extremely difficult to predict accurately whether an exotic organism will become established, and once established, become economically important.

-The purpose and intent of the Quarantine Act in a country is to prevent the introduction of any insect, fungus or other pest, which is or may be destructive to crops.

-Further, the significance of Plant Quarantine has increased in view of Globalisation and liberalisation in International trade of plants and plant material in the wake of Sanitary and Phytosanitary (SPS) Agreement under WTO.

-The phytosanitary certification of agricultural commodities being exported is also undertaken through the scheme as per International Plant Protection Convention (IPPC), 1951.

Cultural Practices: Cultural practices serve an important role in plant disease prevention and management. The benefits of cultural control begin with the establishment of a growing environment that favors the crop over the pathogen. Reducing plant stress through environmental modification promotes good plant health and aids in reducing damage from some plant diseases.

1. Deep ploughing of the field results in exposure of propagules to elevated temperatures and physical killing of the pathogen. This can be regarded as dry soil solarization. Summer ploughing was effective at reducing populations of cyst nematodes and increasing wheat yield.
2. Flooding of the field somewhat resembles soil disinfestation. Long-term summer soil flooding, with or without paddy culture is found to be decreased populations of soil borne pathogens.
3. Sanitation practices aimed at excluding, reducing, or eliminating pathogen populations are critical for management of infectious plant diseases. It is important to use only pathogen-free transplants.
4. In order to reduce dispersal of soil borne pathogens between fields, stakes and farm equipment should be decontaminated before moving from one field to the next. Reduction of pathogen survival from one season to another may be achieved by crop rotation and destroying volunteer plants.
5. Avoid soil movement from one site to another to reduce the risk of moving pathogens. For example, sclerotia of *Sclerotinia sclerotiorum* and *Sclerotium rolfsii* are transported primarily in contaminated soil. Minimizing wounds during harvest and packing reduces postharvest disease problems. Depending on crops and other factors, soil sanitation can be achieved to some degree by solarization.
6. Crop rotation is a very important practice, especially for soil borne disease control. For many soil borne diseases, at least a 3-year rotation using a non-host crop greatly reduces pathogen populations. This practice is beneficial for

Phytophthora blight of pepper and *Fusarium* wilt of watermelon, but longer rotation periods (up to 5–7 years) may be needed. Land previously cropped to alternate and reservoir hosts should be avoided whenever possible. Vegetable fields should be located as far away as possible from inoculum and insect vector sources.

6. Weed control is important for the management of viral diseases. Weeds may be alternate / collateral hosts for many important vegetable viruses. Eliminating weeds might reduce primary inoculum. Non-host cover crops help to reduce weed populations and primary inoculum of soil borne pathogens.

7. Excessive handling of plants, such as in thinning, pruning, and tying, may be involved in spreading pathogens, particularly bacteria. It is advisable to handle plants in the field when plants are driest. Because some pathogens can only enter the host through wounds, situations that promote plant injury should be avoided.

8. If applicable, plants can be staked and tied for improved air movement in the foliar canopy. A more open canopy results in less wetness, discouraging growth of most pathogens.

9. Soil aeration and drying can be enhanced by incorporating composted organic amendments in the soil. The pathogen inoculum can be reduced by removing plant material (infected and healthy) after harvest.

10. Polyethylene mulch can be used as a physical barrier between soil and aboveground plant parts. This is an important practice for fruit rot control in the field for vegetables. Highly UV-reflective (metalized) mulches repel some insects that transmit viruses as vectors.

Genetic resistance: It is the inherent ability of a plant to prevent or restrict the establishment and subsequent activities of potential pathogens. A particular host may be resistance against all races of the pathogens (i.e. horizontal resistance) or may be effective against a few races of the pathogens (i.e. vertical resistance). Control measures by the development of new varieties resistance to diseases are being applied in almost all the economically important plants. If a new variety with high yield is produced by the breeders and if it is not resistant to the local pathogens and pests, it cannot be recommended to the farmers.

Breeding of the disease resistance is achieved by usual methods such as introduction, selection, hybridization, mutation, polyploidy, budding and grafting. For the resistant varieties farmers should contact to nearest research centres / local extension functionaries.

Physical and mechanical measures: Mechanical and physical controls kill a pathogens directly or make the environment unsuitable for it. The common methods are:

1. Collect and destroy the disease infected plant parts.

2. Soil sterilization at 50-60ºC for about 30 min kills the all soil borne pathogens.

3. Some seed borne diseases like loose smut of wheat (52ºC for 11 min), leaf scald (50ºC for 2-3 h), red rot (54ºC for 8 h) and ratoon stunting of sugarcane (50ºC for 3h), black rot of crucifer (50 ºC for 20-30 min) etc. can be treated by hot water treatment by immersing infected seeds in hot water at recommended temperature and time.

4. Hot air treatment is given to remove excess of moisture from plant organs and protect them from fungal and bacterial attack. Several virus infected dormant plants are treated by hot air treatment at a temperature ranging from 35-54ºC for 8 h.

5. Refrigeration (low temperature treatment) is most common method used to prevent post-harvest diseases of perishables fruits and vegetables.

6. Use various traps like yellow (aphids, whitefly)/blue (thrips) for the control of insect vectors that are transmission carrier of various viral diseases.

Biological Control: The use of biocontrol agents in disease management is increasing, especially among organic growers. These products are considered safer for the environment and the applicator than conventional chemicals. Examples of commercially available biocontrol agents include the fungi *Trichoderma viride/harzianum* and *Gliocladium virens*, an actinomycete *Streptomyces griseoviridis*, and a bacterium *Bacillus subtilis*. Bacteriophages (phages) have been found to be an effective biocontrol agent for managing bacterial spot on tomato. Phages are viruses that exclusively infect bacteria. *Paecilomyces lilacinus* is a common saprobic, filamentous fungus has been isolated from a wide range of habitats frequently been detected in the rhizosphere of many crops. The fungus has shown promising results for use as a bio-control agent to control the growth of destructive root-knot nematodes.

Cross protection is also a one of the modern bio-control method for the disease management. In this method mild strain of virus or microorganisms is inoculated in host plant. These provide protection of host plants from those viruses and microorganisms which may cause much more severe damage e.g. papaya ring spot disease, citrus tristiza disease, etc. One of the limitations of using biocontrol agents is their inability to survive in certain field conditions. However, biocontrol agents have the ability to improve disease management when integrated with other management options described in this document.

Table 2: Commercially available bio-control products to control plant disease.

Bio control Product	Source	Target pathogens
Bacterial		
Galltrol	*Agrobacterium radiobacter* strain 84	Crown gall (*A. tumefaciens*)
Dagger G	*Pseudomonas fluroscens*	*Pythium, Rhizocto*nia
Actinovate	*Streptomyces lydicus*	Soil borne pathogens
Messenger	*Erwinia amylovora* hairpin protein	Wide spectrum
Kodiak	*Bacillus subtilis* strain GB03	*Fusarium, Rhizoctonia, Alternaria* etc.
Bio-save 10 LP, 110	*Pseudomonas syringae*	Postharvest *Botrytis*, *Mucor*, *Penicillium*
Blightban A506	*Pseudomonas fluorescens* A506	*Erwinia amylovora*, russeting bacteria, frost injury
Fungi		
Kalisena	*Aspergillus niger* AN-27	*Rhizoctonia solani*
Biotrox C	*Fusarium oxysporum* (non-pathogenic)	*Fusarium oxysporum*
Root Shield, Plant Shield T-22 Planter Box	*Trichoderma harzianum strain,* KRL-AG2 (T-22)	*Pythium, Fusarium, Rhizoctonia*
Soil Gard (Gliogard)	*Trichoderma virens* GL-21	*Rhizoctonia solani, Pythium*
Trichodex	*Trichoderma harzianum*	*Colletotrichum, Plasmopara, Sclerotinia*
Trichopel	*Trichoderma harzianum* and *T. viride*	*Armillaria, Botryosphaeria, Fusarium*
Trichojet	*Trichoderma harzianum* and *T. viride*	*Phytophthora, Pythium, Rhizoctonia*
Aspire	*Candida oleophila 182*	*Botrytis* spp. and *Penicillium* spp.

A number of botanicals are also tested against fungal disease like sheath blight. Some commercially used botanicals against plant diseases are extract of Neem (*Azadirachta indica*, A. Juss), Garlic (*Allium sativum*, Linn., *Eucalyptus* (*Eucalyptus globulus*, Labill.), Turmeric (*Curcuma longa* Linn.) Tobacco (*Nicotiana tabacum* Linn.) Ginger (*Zingiber officinale* Rosc.) and essential oils of Nettle (*Urtica* spp.), Thyme (*Thymus vulgaris* Linn.), *Eucalyptus* (*Eucalyptus globules* Labill), Rue (*Ruta graveolens* Linn.), Lemon grass (*Cymbopogon flexuosus* (Steud. Wats.) and Tea tree (*Melaleuca alternifolia*).

Foliar sprays with Neem gold @ 20 ml /l or Neemazal @ 3ml/l has been found to be effective in reducing sheath blight and increasing grain yield. Leaf extracts of *Eucalyptus globosus* (5%) and *Azadirchta indica* (5%) have been proved to exhibit greater antifungal activity against *A. brassicae* and *Albugo candida* and showed significant reduction in the severity of *Alternaria blight* and white rust diseases.

Chemical measures: When all the above methods are not-effective and pathogens cause destructive loss of the crops then we should go for chemical measures. Fungicides and bactericides are an important component of many disease management programs. It is important to remember that chemical use should be integrated with all other appropriate tactics mentioned in this chapter. Information regarding a fungicide's physical mode of action helps producers improves fungicide application timing. Physical mode of action of fungicides can be classified into four categories: protective, after infection, pre-symptom, and anti-sporulant (post symptom). Protectant fungicides include the bulk of the foliar spray materials available to producers. In order to be effective, protectant fungicides, such as copper compounds and mancozeb, need to be on the leaf (or plant) surface prior to pathogen arrival. Systemic (therapeutic) fungicides, based on their level of systemic nature are active inside of the leaf (can penetrate at different rates through the cuticle). Systemic fungicides may stop an infection after it starts and prevent further disease development.

Constraints in IDM and future thrust: The consultant group of the IDM Task Force has conducted as in-depth study of the constraints on the implementation of IDM in developing countries, which are mainly institutional, sociological, economic and political.

a. Institutional constraint: IDM requires interdisciplinary approach to solve pest problem. Lack of coordination among different institution is a constraint. Research programme based on farmer's need - is lacking.

b. Informational constraint: Lack of information on IDM among farmers and extension worker. Lack of training on IDM.

c. Sociological constraint: Some farmers feel it is risky to adopt IDM compared to use of pesticides alone. Our farmers are habituated to using more pesticides.

d. Economic constraint: Lack of funds for training farmers and extension workers on the use of IDM.

These are the some other constraints for the implementation of IDM:

1. By offering seeds, fertilizers and fungicide on credit to the farmers, fungicide dealers pose a threat to IDM.
2. Pesticides companies use mass media like television and newspapers for popularizing their products through attractive advertisements.
3. Farmers are addicted to subsidy and they always look for some financial support for adopting NPM methods.
4. Bio-pesticides, bio control agents and other IDM components are not readily available.
5. Large farmers discourage small farmers in adopting IDM methods by emphasizing more on their risky and unstable nature.
6. Scientific community is constrained in recommending use of IDM technology because farmers may ask for compensation in case of failures.

THE FUTURE THRUST

All of the above considerations illustrate that by using fungicides reduction techniques in agriculture is a wise shift in ecological stewardship. Recent market trends show the public is increasingly recognizing the need to go fungicide-free as organic sales are growing for virtually every commodity, from vegetables to pet food to lawn care products. Adopting IDM practices that emphasize fungicide reduction, and organic practices, provide real-world solutions for a healthier environment.

CONCLUSION

The disease occurs in plant is by biotic and abiotic means and causes a significant loss in agriculture system. The success and sustainability of IDM strategy, especially with resource poor farmers greatly depends on their involvement in helping to generate locally specific techniques and solutions suitable for their particular farming systems and integrating control components that are ecologically sound and readily available to them.

Training and awareness raising of farmers, disease survey teams, agricultural development officers, extension agents and policy makers remains to be an important factor for the successful implementation of IDM strategies. All direct stakeholders including farmers, extension workers, and local crop protection technicians should have a practical understanding of the ecology, etiology and epidemiology of the major diseases of the crop. Intensive training using participatory approaches should be used to empower farmers with the appropriate knowledge to become better managers of their own fields translating this knowledge into appropriate decision-making tools and practical-control tactics.

ENDNOTES

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