Cultural Practices and Management of Plant Diseases

Rupjyoti Gogoi[1], Dipanjali Devi[2] and Phatik Tamuli[2*]

[1]Department of Botany, Gauhati University, Guwahati, Assam-781 014
[2]PG Department of Botany, Darrang College, Tezpur, Assam-784 001

Abstract

Since the dawn of history, cultural practices have been the main or only techniques available for reducing the incidence of soil-borne diseases and pests. Methods to control plant disease vary depending on the host plant, the pathogen, the interaction between the two, as well as environmental conditions. Cultural control aims to protect crops against pathogens rather than curing them once they have been infected by creating environmental conditions unfavourable to the pathogen or at least to avoid favourable conditions, or to reduce the amount of pathogen inoculum available to infect crop plants. The cultural practices to prevent or control plant diseases include the selection of disease-free seed or propagating materials, removal of crop residue, eradication of pathogen carrying plants, crop rotation, tillage, soil amendments, sowing and harvesting practices, irrigation, flooding, mulching, trap, and decoy crops and improving crop growth conditions, for example through appropriate fertilizer use. Cultural practices are often overlooked though they provide the foundation for disease control in crops. In organic farming, cultural methods can be incorporated to control plant diseases as most of the cultural practices do not rely on chemicals. This chapter provides a brief history of cultural practices adopted by man and focuses on the various cultural methods used to prevent or control crop diseases and the importance of these methods in improving crop health and productivity.

Keywords

Disease triangle, host, pathogen, sustainable agriculture, traditional control

Introduction

Cultural practices are the activities of humans aimed to control plant diseases through cultural manipulation of plants. Humans have been adjusting crop management practices to prevent or minimize disease development since ancient times and these are the oldest and most applicable approaches to control plant diseases. These practices mainly aimed to avoid disease or suppress causative agents. For many crops, cultural practices may be economically less expensive methods. These control practices are the features of traditional agriculture which have been employed by indigenous people all around the globe. The successful application of cultural practices to control or manage plant diseases requires knowledge of the interaction between the host plant, pathogen, and environment. Such understanding comes after encountering plant disease shows the effectiveness of a particular practice in preventing or minimizing the impact of the disease. Numerous observations and long term experience have served to discover practices for pest control through trial and error, which in the end became traditions. For example,

[*]***Corresponding author's e-mail***: tamuliphatik@gmail.com

the application of crop rotation is one of the oldest techniques to suppress soil-borne pathogens. Cultural practices are an indispensable part of integrated disease management for most crops. Cultural practices can be harnessed for the management of soil-borne and leaf borne diseases by creating an environment which is suitable for the crop and unsuitable for the pathogen. Recent developments in plant pathology have provided a scientific basis for the systematic development of disease control and the elucidation of the mechanisms involved. However, in the 19^{th} century, the development of powerful and effective chemicals for controlling crop diseases has resulted in a declining interest in cultural practices for disease control. Nevertheless, nowadays, cultural practices are gaining importance due to the non-involvement of chemical pesticides. Most cultural practices used to control plant diseases are preventative. They may reduce the amount or activity of pathogen inoculum, as in the use of disease-free seed or planting stock, crop rotation, tillage practices, mulching, and rouging, etc; or they may help to avoid disease by, for example, the choice of field location, time of planting, seedbed preparation, plant spacing, and host nutrition. Integration of cultural practices, host resistance, and pesticides or biocontrol agents may be necessary to provide the optimal level of control for economically important plant diseases (Andrews, 1983; Baker, 1983).

A Brief History of Cultural Practices for Plant Disease Management

Man began cultivating plants for food about 8000 B.C. (Buttrick *et al.*, 1962; Crim *et al.*, 1962). At first, he planted the progenitors of wheat, barley, and millet, and later nuts, and pulses. Some early archaeological surveys suggest that fire may have aided primitive man in controlling plant diseases. The fire was the first great force employed by man, and the discovery of a method to ignite organic matter is one of his greatest achievements (Hardison, 1976). Early humans often burned over the land to clear forests and grasslands for agriculture. In doing so, they would have inadvertently destroyed plants and plant materials infested with diseases, pests, and disease vectors. Such methods were used for many centuries to prepare plant beds for seedlings of tobacco and other crops until they were replaced by chemical fumigants in the twentieth century. Notwithstanding, it is also known that some growers planted their grain crops in regions less prone to rust as a means of avoiding this disease.

In the medieval times, remedies used for disease control were based on tradition rather than scientific reason. Many formulations discussed throughout the book *Geoponica*, (an agricultural text written about 650 A.D.) were interesting but probably of little value, e.g. "against rust, burn three crabs together with cuttle-fish; if fruits begin to rot, treat the roots with ashes and vinegar; against barrenness, split the roots and insert stone or wedge." Like the *Geoponica,* a twelfth-century Arab writer Ibn al-Awam, in his treatise entitled *Kitab al-Felalah* discussed the prevention and cure of plant diseases (Orlob, 1971). Compounds such as urine, vinegar, oil dregs, and ash were recommended against various diseases of fruit trees and grapes. In Gottfried of Franken's *Pelzbuch*, published about 1470, a major collection of remedies and cures were described (Orlob, 1971). This treatise had affinities with the *Geoponica* but was more progressive in its approach. Gottfried was skilled in pruning, grafting, and tree nursing, and this was reflected in his discussions of tree pathology, e.g. he recommended scraping off cankered tissue clear down to the greenwood, then dressing the wound with cow dung. In India, abiotic stresses such as cold climate (low temperature), wind (dryness), and sun (heat) were recognized as causes of plant diseases (Bose *et al.*, 1971). *Vrksayurveda* written by Surapala, about the tenth century A.D., gave interesting accounts of treating tree diseases. Flesh, lymph, liquorice, ghee, milk, and honey, and fumigations with soapberry, cow's horn, black pepper, horse's hair, and other mixtures were prescribed as the result of the pseudomedical interpretation of plant diseases (Howard, 1996). During the Vedic, prehistoric, and historic periods, farmers used plant pathogen control methods such as the storage of grains in cylindrical pits, in granaries or containers made of rope and plastered with mud, and in well-baked clay pots. They also scared birds away by slinging balls, used mixed cropping techniques, and implemented controlled field-irrigation systems (Kannan *et al.,* 2015). In several other countries, however, human sacrifices were symbolically or realistically performed in connection with crop growth rituals. In parts of Europe, a straw man was burned on Easter Eve and the ashes scattered over the crops to protect them against blight and other maladies (Howard, 1996). A terrible scourge of ergotism flourished in Europe during the Middle Ages (Horsfall & Cowling, 1978). The first recorded epiphytotic was in 857 A.D. when thousands died in the Rhine Valley. Based on its major symptoms, doctors gave it a Latin name, *Sacer ignis,* the Holy Fire (Howard, 1996). Plant materials, cow dung, and urine (animal and human) were also frequently used to control plant pathogenic bacteria (Narayanasamy, 2002).

During the renaissance, science shared with the arts, literature, and commerce in a great forward movement toward the beginning of a new era. As commercial agriculture became established, growers began to realize that losses from the disease were increasing. They took more care in selecting, cleaning, and storing their seed; they devised cultural practices to reduce losses, e.g. burning crop residues; and as ploughs were made available some fields were turned under. Drainage helped to improve growing conditions in low areas of fields, and crop rotation was beneficial in controlling soil-borne diseases, nematodes, and other pests. In Rouen, France, the first known attempt to control a plant disease by legislative measures was made by decreeing the destruction of barberries (Stakman, 1959).

By the middle of the nineteenth century, plant pathology had emerged as an independent scientific discipline. There was optimism at the beginning of the twentieth century that both diseases and insects would ultimately be controlled with chemicals (Apple, 1977). The emergence of highly effective organic compounds after World War II promoted further enthusiasm and even offered the promise of a pest-free environment.

Plants resistant to diseases were recognized in the nineteenth century, but the deliberate development of disease-resistant varieties by controlled breeding accelerated only after the rediscovery of Mendel's laws of heredity in 1900 (Apple, 1977). Following this breakthrough, systematic breeding was quickly exploited to control important diseases of many crops, Success in controlling plant diseases with chemicals and host resistance in the early twentieth century distracted plant pathologists from cultural control (Stevens, 1960). The plant pathology literature between 1930 and 1965 attests to the preoccupation with the development of better resistant varieties and more improved chemicals. Comparatively less attention was paid to pathogen ecology and environmental manipulation.

Prerequisites for Controlling Plant Diseases

The success of cultural control practices ultimately depends on understanding the biology of the pathogen and response of the host to infection. It is important to understand the disease cycle of each disease to make the most effective management decisions. The disease cycle describes the interaction of the pathogen with the host. The cycle starts with the production of inoculum by the pathogen. The inoculum (spores, bacterial cells, nematode eggs) is dispersed (by wind, water, insects, etc.) and if it comes into contact with a susceptible host under the right environmental conditions, infection occurs. The pathogen colonizes the host tissue and disease symptoms develop. The pathogen forms survival structures in the diseased host tissue that enable it to survive in the absence of the host. The goal of plant disease management is to interrupt the disease cycle and stop it from completing a full cycle. It is important to understand the disease cycle of each disease to make the most effective management decisions.

Plant diseases, their occurrence, and severity result from the impact of three factors: the host plant, the pathogen, and the environmental conditions. This is represented by the disease triangle. If anyone of the three factors is missing, the triangle is not complete, no disease will occur. Simply, plant disease will not occur if there is no viable pathogen or no susceptible host plant, or the environmental conditions are not favorable. The severity of the disease depends on the favorable level of each factor. How susceptible is the plant? How virulent is the pathogen? How conducive are the existing environmental conditions in supporting disease and pathogen spread? The triangle also helps illustrate that the three factors are interacting with each other. The clearest example of this is how the environment factor interacts with the pathogen and host factors. Long durations of free water on a susceptible plant can increase pathogen infection and disease severity. At the same time, the low- sunlight conditions, when these wet periods could occur (e.g. winter), could also be stressful to the plant, and the plant is less likely to mount defensive reactions to fend off infection. Learning about the biology of a disease is very important in terms of managing the disease. Considering the disease triangle and the three interacting factors, management practices can be employed that might help weaken or break the triangle's bond. For example, non-susceptible plant varieties or species can be grown, proper judicious sanitation practices can be forced into effect to eliminate pathogens or by managing leaf wetness and relative humidity to create unfavorable environmental conditions for disease.

Approaches to Manage Plant Diseases through Cultural Practices

To prevent or control plant disease outbreaks, cultural practices rely on two basic approaches

(i) Reduction of the initial level of inoculum

(ii) Reduction of rate of spread of the established pathogen

Cultural practices to reduce the initial level of inoculum

Selection of resistant cultivars

Cultivar resistance is an important part of controlling disease in many agricultural systems. The selection of the cultivar(s) to be grown is a critical decision in crop production. Some cultivars have an inherent resistance to some particular pathogens and are less affected by pathogen than other genetically related plants growing in the same region. Resistant cultivars have served as one of the most successful approaches to control pathogens of many crops, especially those which cannot be prevented by other means. For example, control of soilborne pathogens in tomatoes such as *Fusarium oxysporum* f. sp. *lycopersici*, *F. oxysporum* f. sp. *radicis-lycopersici*, *Pyrenochaeta lycopersici*, and *Meloidogyne* spp., has been successful using resistant rootstocks in grafted plants (Mihajlović *et al.*, 2017).

Selection of seeds and propagating materials

The major plant pathogens such as many fungi, bacteria, viruses, and phytoplasmas can be transmitted by seed or propagating materials and may introduce these pathogens into the field, i.e., seeds and propagating materials form the primary source of infection. Seed and propagating materials like cuttings, tubers, grafts, setts, etc., should be well matured, disease-free, uninjured, and have a high germinating capacity. Materials that have been certified free from pathogen following field inspection and laboratory testing provide a useful safeguard to growers. Efficient seed cleaning protocols before sowing also help to control some diseases. The absence of initial inoculums in seeds helps delay or suppress the incidence of the disease. It is a preventive method. The diseases like foot rot, brown spot, short smut of sorghum, loose smut of wheat, the bacterial blight of rice, the bacterial blight of cotton, leaf crinkle of black gram, etc., are transmitted through seeds. Virus diseases and black ring of potatoes, foot rot of ginger, foot rot of betel vine, Panama disease of banana, red rot of sugarcane cassava mosaic, bunchy top and virus diseases of fruit trees are transmitted through tubers, setts, rhizomes, corms, grafts and bud woods (Agrios, 2005). Pathogens may enter into healthy materials may be by contaminated knives and secateurs during the preparation of vegetatively propagated materials. So in such situations, growers should practice proper hygiene procedures to prevent transmission of pathogens.

Removal of crop residues by burning and burying

Crop residues are favourable substrates for many pathogens. Cultural practices such as burning, burying, and removal of post-harvest crop residues during successive cropping periods are important to control the spread of diseases. Hardison (1976) defined this burning approach as thermo-sanitation and described many examples of controlling diseases by burning. The basic idea (established long ago) is to achieve the thermal killing of the resting structures of the pathogens. This can be done by burning the dry plant residues. Residue decomposition can vary with the depth of placement in the soil, crop type and residue quantity, allelopathic interactions between existing soil biota, and time (Bailey and Lazarovitz, 2003). In 1660, a law was passed in France requiring the eradication of barberry bushes because of conclusive evidence that rust of cereals was most prevalent in their vicinity (Stakman and Harrar, 1957). The soil-borne pathogen *Cochliobolus sativus* (Ito and Kuribayashi) Drechs. ex Dastur, used as a model for residue management which causes root rot of cereals (Bailey and Lazarovitz, 2003).

Some potential pathogens may be either killed or inhibited by burying crop residues. Crop having shallow root systems can also be controlled from severe infection if debris from the previous crop is ploughed in deeply. While burying crop residues can effectively reduce inoculum, if the form of tillage redistributes pathogens horizontally rather than vertically in the soil, it may promote, rather than reduce, future crop damage. Crop residues and other organic matter can also be composted before reuse. During residue decomposition heat is generated which kills pathogens, provided the material is turned regularly during composting so that all of the organic matter has a turn at being in the hottest part of the compost pile.

Eradication of living plants that carry pathogens

Eradication is the elimination of a pathogen after it has become established in the area where the host is growing. Crop plants remaining from previous seasons and volunteer host plants that establish in fallowed land or around cropping areas when climatic conditions are suitable during intercrop periods may provide sources of inoculum for succeeding crops. These act as reservoirs of pathogens of the annual crop. Reservoir hosts help the pathogen to continue the infection chain. The primary inoculum is produced on and dispersed from these hosts to the cultivated crop hosts. If these wild or uneconomic host plants of the pathogen are destroyed, the sources of primary inoculum are eliminated and chances of initiation of the disease in the crop hosts are reduced. Destruction of these hosts breaks the life cycle of the pathogen and the infection chain. Reservoir hosts or indigenous plant species which are not involved with the life cycle of the pathogen but provide additional sites for its persistence and multiplication. In some cases, such plant species act as symptomless carriers, especially for viruses and root pathogens. Regional elimination of such hosts requires careful attention to roadside areas and other non-agricultural lands also. Self-sown crops/volunteer plants help the pathogen to overwinter/oversummer in the absence of economic hosts. In Sudan, it was enforced through legislation to pull out the cotton plants to prevent regrowth which facilitates the carryover of the cotton leaf curl virus. Wheat streak mosaic virus has been effectively controlled by eliminating the volunteer wheat plants that served as reservoirs for the virus.

Removal of alternate hosts helps to prevent and check the spread of the disease caused by heteroecious rust pathogens in the primary hosts. Some pathogens require two alternate hosts to complete their full life cycles. For example, *Puccinia graminis tritici* requires wheat and barberry. In these cases, eradication of the wild or economically less important alternate host interrupts the life cycle of the pathogen and leads to control of the disease (Agrios, 2005).

Eradication of affected plant parts (tree surgery) is also practiced in certain cases which reduces the source of primary inoculum.

Crop rotation

Crop rotation may be defined as the growth of economic plants in recurring succession and definite sequence on the same land, as distinguished from a one-crop system usually lacking a definite plan (Curl, 1963). The sequential sowing of crops may or may not include fallow or green manure. Fallowing, namely, the absence of crops, may contribute to a reduction in disease incidence, although in certain cases continuous cropping (monoculture) may lead to disease decline (Cook and Baker, 1983). The crop rotation program determines the frequency of growing each crop, the list of crops (and fallow periods) during a defined period (cycle), the order (history) of crops (and fallow periods), and the agricultural practices which will be employed during the whole cycle. Monoculture is the opposite of such a practice and is applied, ironically, both in very primitive agricultural systems (out of ignorance) and in the most advanced ones, e.g. greenhouses because out of necessity, specialization in crop production and economic considerations (Katan, 1996).

Crop rotation is essentially a preventive measure and has its effect mainly on the succeeding crop. Crop rotation is the oldest and cheapest method adopted in agriculture for the eradication of certain types of pathogens from infested soil. Continuous cropping or monoculture provides an opportunity for the perpetuation of pathogenic organisms in the soil when the same crop is raised year after year in the same field. The soil-borne pathogens of that crop easily penetrate in the soil and increase in their population. After some time, the soil becomes so heavily infested that it becomes unfit for cultivation of the particular crop. Virus diseases of crop plants and their vectors are found to increase after every crop if a crop is cultivated continuously in a field. On the other hand, when resistant or non-host crops are grown for a definite duration after a susceptible crop in the field it is expected that in the absence of nutrition, the pathogen will be starved off and the population of such pathogens consequently decreases. It is also possible that different crops release some biochemical substances in their root exudates which either directly kill the pathogen or encourage the development of antagonistic microorganisms in the soil. In this way, crop rotation is one of the most effective methods of root disease control. Potato cultivation rotated with wheat, sweet potato, maize, millet, carrots, sorghum, or phaseolus beans reduced the incidence of wilt by 64 to 94% while the yield of potatoes was 1- to 3-fold higher than that of monocultured potatoes (Katafiire *et al.,* 2005). For example, the onset of bacterial wilt was delayed by 1 or 3 weeks and wilt severity was reduced by 20–26% when a susceptible tomato variety was grown after corn, lady's fingers, cowpea, or resistant tomato (Adhikari and Basnyat, 1998). Potato cultivation rotated with wheat, sweet potato, maize, millet, carrots, sorghum, or phaseolus beans reduced the incidence of bacterial wilt by 64 to 94% while the yield of potatoes was 1- to 3-fold higher than that of monocultured potatoes (Katafiire *et al.,* 2005).

Cultural practices to reduce the rate of spread of the established pathogen

Cultural practices to reduce the rate of spread of established pathogen mainly emphasize on creating conditions unfavourable for the development of pathogens. These practices also are employed to improve the growing conditions by providing nutrition, light, moisture, and lack of competition from other plants. The various ways of creating environments and improving plant growth in the crop field to discourage the spread of pathogens from diseased plants to healthy plants are discussed in the next section.

Tillage practices

Tillage means to plough and prepares the soil for seed sowing. It can be defined as the mechanical and physical manipulation of soil for obtaining ideal conditions for seed germination, seedling establishment, and crop growth. It is among the most practiced method in crop growing which indirectly control the transmission of plant pathogens. It can reduce the population of volunteer plants and weeds that can carry pathogens between crops. Primary tillage practice i.e. ploughing buries the plant pathogen from topsoil into deeper soil layer which results in less or no disease. Deep ploughing buries the inocula of soil-borne pathogens. Further infected self-sown plants, volunteer host plants, weed hosts, regrowths from the plant roots, and alternative hosts are also destroyed. Groundnut blight (*Corticium rolfsii*) is controlled by ploughing the soil to a depth of 20 cm (Colvin and Brecke, 1988). Bunt and smut spores of wheat, smut spores of sugarcane, and sorghum and microsclerotia of *Verticillium* in cotton are buried deep into the soil by deep ploughing. In tomatoes, the incidence of the southern blight disease was lower after deep ploughing (25 cm depth), compared with shallow tillage employing a harrow (Worley *et al.*, 1966). Summer ploughing was effective at reducing populations of cyst nematodes thereby increasing wheat yield (Mathur *et al.,* 1987).

If successive tillage operations continue for several days or weeks, the increased soil temperature from solar heat, known as solarization, inactivates (kills) many soilborne pathogen fungi, nematodes, and bacteria near the soil surface, thereby reducing the inoculum and the potential for disease.

Tillage practices such as raised beds and fields, mounds, and ridges not only provide better drainage and irrigation but also are significant in controlling the soil-borne pathogens. Soil-borne pathogens such as *Phytophthora*, *Phythium* and

Aphanomyces are favoured by high soil moisture so improving soil drainage or sowing or transplanting into raised beds, ridges, mounds or hills reduces the incidence of disease (Thurston, 1992). In Asian countries, most vegetables are cultivated with the use of mounds, ridges, and raised beds; for root and tuber crops, these are the only approaches used because they reduce root rot (Thurston, 1992). These practice helps to optimize the supply of green manure and thereby improves the nutrient availability, increase crop vigour thereby provides resistance against soil-borne diseases.

Reduced tillage systems resulted in the accumulation of organic matter by sequestering carbon in the soil (Lupwayi *et al.,* 1999) and also by increasing the rate at which soil microfloral and microfaunal decomposition progresses (Doran, 1980; Kennedy and Smith, 1995). It has been observed that soils with high levels of organic matter have been shown to prevent spores of *Crocus sativus* from germinating (Chinn, 1967). Total microbial populations were also found to be higher in peat soils (40.3% organic matter) than in sandy soils (2.3% organic matter), and the cause of reduced spore germination was attributed to an undetermined fungistatic principle. It has been seen that the spore populations of *C. sativus* in the soil are generally correlated with the incidence of cereal common root rot (Chinn *et al*., 1962), so tillage practices that remove crop residue (i.e. a primary source of inoculum) can lower the potential for this disease.

Sowing and harvesting practices

Many crops are vulnerable to pathogen attacks in specific stages of their development. Changing the usual time of sowing of a crop is a method to impart unfavourable weather conditions for the spread of pathogens as well as their vectors which reduce crop losses. While choosing the time of sowing it should be taken into consideration that the susceptible stage of the crop growth and soil conditions and other environments favourable for maximum activity of the pathogen does not fall at the same time. By adjusting properly the sowing dates can give good dividends. For example, the groundnut rosette is transmitted by *Aphis craccivora.* In Nigeria, the population of this vector is low in crops sown in June than in July (Hooker, 1963).

Farmers aim to optimize germination and early growth at densities which give maximum yields in the particular environment. The depth of sowing is usually determined by seed size and the moisture status of the soil. Deeper sowing may promote germination but it also lengthens the (usually) susceptible pre-emergence seedling phase. Smuts and seedling diseases caused by *Fusarium* spp. and *Rhizoctonia* spp. are more serious if seeds are planted deeply (Ogle and Dale, 1997). Similarly, potato seed pieces are more readily attacked by *Rhizoctonia* if planted too deeply. Shallow planting in wet soils protects wheat plants from *Urocystis tritici* (flag smut) of wheat (Ogle and Dale, 1997).

Crop density is another cause of disease development. Generally, as the density of a crop increases, the incidence of disease also increases. There are several reasons why high plant densities increase disease incidence. Most are associated with the ease of transferring inoculum from one plant to another when the plants are close together. Besides, with denser plantings, more plants may be wounded during cultivation creating more opportunities for weak pathogens to infect. Farmers can manipulate plant densities by varying sowing or planting rates and may use increased rates to compensate for expected crop losses from pathogens. Crop density can also be manipulated by pruning, thinning, trellising, fertilization, water management, staking, and harvesting plants or plant parts, depending on the types of crop

The time of harvesting affects the cleanliness of the seeds. Delayed harvesting of grain crops in temperate climatic conditions enables the pathogen more time to contaminate the seeds. The best example is grain mould of sorghum where contamination by species of *Fusarium, Curvularia, Alternaria, Aspergillus, Phoma* is seen. In Dharwar, India, late plantings of sorghum had an increased incidence of Sorghum downy mildew (Balasubramanian, 1974). Potato tubers harvested when the tops are green get easily contaminated by the late blight pathogen present on the leaves. Removal of tops and making them dry before digging the tubers kills the sporangia and avoids contamination of tubers harvested later.

Irrigation

Irrigation to the crop in the field is to wet the soil to the extent that roots easily get water and nutrients. It can reduce the level of inoculums and retard disease development. Overhead irrigation may reduce or inactivate airborne inoculums by washing it out of the atmosphere. It alters the moisture content of the soil and consequently influences its aeration and temperature, and these, in turn, affect the incidence of diseases through their impact on biotic and abiotic processes in the soil or foliage. Irrigation also affects disease incidence indirectly due to changes in the agricultural regime, such as intensification of cropping, and changes in the date of sowing and growing seasons (Katan, 1996). Irrigation alleviates the water stress which predisposes the plants to certain diseases. Water stress had a predisposing effect on the severity of *Phytophthora* root rot in safflower (Dunniway, 1977) and on disease caused by *Macrophomina phaseolina* (Ghaffar & Erwin, 1969), and an adequate irrigation regime reduced disease incidence. Generally, sprinkler irrigation increases diseases by increasing leaf wetness and by dispersing propagules of the pathogens by water splashes just like rainwater. At the same time, it has some advantages also such as washing off of inoculum from the leaf surface. Irrigation especially at the seed-development stage may favour seed infection. Stem rot, sheath blight, and bacterial blight diseases of rice, damping-off of vegetables, and *Macrophomina* root rots of many crops spread mainly through irrigation and drainage water. Hence care should be taken not to irrigate a healthy field using drainage/irrigation water from a diseased field.

Flooding

Flooding is one of the oldest methods of paddy system of growing rice to control plant diseases. It reduces the number of weeds that may harbour rice pathogens and insects. However, it also reduces the number of fungal propagules, insects, and nematodes in the soil probably by subjecting them to attack by soil-borne bacteria. The destruction of crop debris carrying inoculum can also be hastened by flooding. This practice was known in ancient civilizations in the Near and Far East (Katan, 2010). A classical example of controlling disease on a large scale was demonstrated with the Panama wilt disease of bananas caused by *F. oxysporum* f. sp. *Cubense* ((Stover, 1962). Flooding also apparently destroys *Pseudomonas solanacearum*, and the nematode *Radopholus similis* (Stover, 1962). Pullman and DeVay (1982) demonstrated that long-term summer soil flooding, with or without paddy rice culture, decreased populations of *Verticillium dahliae* and the incidence of Verticillium wilt in cotton, and increased yields.

Mulching

Mulching is one of the most used cultural practices of covering the soil surface with a layer of material. Natural materials used for mulching include cereal straw and stalks, crop debris, sawdust, leaves, grass, manure, weeds, reeds, Spanish moss, and various aquatic plants. Also, manufactured products such as plastic materials, aluminium foil, asphalt paper, glass wool, and paper can be used. Mulches conserve soil moisture and organic matter and reduce soil erosion. When crop residues are used as a mulch they provide many pathogens with a food source as well as an environment in which to live and reproduce and can, therefore, influence disease incidence. Mulches of non-host origin should be used in the field. These mulches are known to release inhibitory substances in the underlying soil and also promote the development of parasites and predators of nematodes. Reflective surfaces (mulches) laid on the soil around the crop plant, be highly effective in controlling aphid vectors. In the Gunanacaste region of Northern Costa Rica, traditional farmers adopted a system called *frijol tapado* (covered beans) in which bean seeds are mulched with chopped weeds that cannot regrow but conserve soil moisture to prevent this web blight disease caused by *Thanatephorus cucumeris* (Galindo *et al*., 1983). The infection of apple roots by *Sclerotium rolfsii* in Israel was reduced by the application of mulches, which decreased soil temperature enough to kill the soilborne pathogen on the root surfaces (Narayanasamy, 2002). Black spot disease of citrus caused by *Guignaradia bidwelli* can be controlled by mulching with *Panicum maximum* and fungicidal sprays; in one case, the percentage of disease-free fruit was increased to 13%–16% (Kannan *et al.* 2015). Various types of organic mulches are used in traditional plant disease control. For example, cellulose-rich wood mulches are used to controlling root rot caused by *Phytophthora*, *cinnamomi.* In wood mulches, cellulose plays a major role in pathogen suppression by reducing the sporangial production of the pathogen of *P. cinnamomi* (Narayanasamy, 2002).

Organic soil amendments

Organic amendments traditionally used for improving soil conditions and crop productivity may suppress soil-borne pathogens. Organic amendments, such as animal manures and composts, were commonly used in agricultural production for their fertility value before the availability of chemical fertilizers. Soil amendments not only provide nutrients but also improve plant health due to the reduction of pathogens (Lazarovits *et al.*, 2000). *Aphanomyces* root rot of peas can be controlled when cruciferous plant residues such as dries leaves and stems of *Brassica napus*, *Raphanus sativus*, and *Sinapis alba* are incorporated in the soil (Chan and Close, 1987). Organic manures made up of organic wastes, composts, and peats, have been proposed to control soilborne diseases and pests. Apart from improving soil quality and water holding capacity, organic amendments also support other beneficial microorganisms that help to suppress soilborne pathogens (Panth *et al.*, 2020). *Rhizoctonia solani*, *Thielaviopsis basicola*, *Verticillum dahliae*, species of *Fusarium*, *Phytophthora*, *Pythium*, and *Sclerotium* are found to be managed effectively by the application of organic amendments (Bonanomi *et al.*, 2007; Shafique *et al.*, 2016). Soil organic amendments also provide a diversified food base, which can diversify and change the microbial population equilibrium in the soil (Bonanomi *et al.*, 2018). The use of compost extract containing huge populations of microbiota, e.g., *Rhizobacteria*, *Trichoderma*, and *Pseudomonas* species, can increase crop production and produce phytohormones and chemicals such as phenols or tannins which may have an antagonistic effect on soil-borne pathogens (Welke *et al.*, 2005). Jaiswal and his colleagues (2019) demonstrated the use of biochar as an effective method to control the disease severity caused by *Pythium aphanidermatum* in cucumber seedlings. Unfortunately, the addition of amendments to the soil does not always achieve the desired effect. Disease incidence or severity may increase because the pathogen thrives on the amendment.

Roguing

Roguing is the complete elimination or uprooting of diseased plants or rogues to prevent further transmission of disease. Affected plants need to be removed as soon as possible after symptoms are observed to minimize the transmission of disease. Roguing may need to be repeated regularly as newly diseased plants appear. Roguing of infected plants is a cultural method for virus disease control in cassava and sweet potato (van den

Bosch *et al.*, 2007). It has been estimated that between 1890 and the mid-1950s, more than 40,000 ha of Gros Michel variety of banana were destroyed (Stover, 1962). Root rot and wilt attached plants after their death should be uprooted and burnt when noticed in the field to check the inoculum build-up in the soil.

Decoy crop and trap crop

Decoy crops (hostile crops) are non-host crops sown to make soilborne pathogens waste their infection potential. These crops stimulate the hatching of nematode eggs or the germination of resting structures or seeds of other pathogens, but the pathogens are unable to establish a compatible relationship with the decoy crop host and eventually die. As a result, the level of inoculum of the pathogen declines. For example, ryegrass (*Lolium* spp.) reduces the incidence of clubroot of crucifers (*Plasmodiophora brassicae*) in infested soil (Ahmed *et al.*, 2011). White (1954) found that thorn apple (*Datura stramonium*) is a good catch crop for powdery scab of potatoes (*Spongospora subterranea*). Winter & Winiger (1983) in Switzerland also reduced disease levels by preceding a potato crop with *D. stramonium*. Trap (or catch) crops are host crops of the pathogen, sown to attract pathogens but destined to be harvested or destroyed before they complete their life cycle.

Intercropping

Intercropping, or mixed cropping, is a common farming practice utilized by subsistence farmers in tropical and subtropical areas of the world. For example, intercropping and rotating banana with Chinese chive can control Panama disease and increase cropland biodiversity. Traditional cassava production is characterized by intercropping and cultivar mixtures. Several crops, such as maize, yam, sorghum, assorted vegetables, and cowpea, are usually intercropped with cassava in the humid tropics of West Africa (Okoli, 1996). Cassava-maize intercropping reduced cassava mosaic virus disease (Ahohuendo & Sarkar, 1995) and was recommended for the reduction of bacterial blight (Fanou, 1999). In mixed cropping, the incidence of the disease is less than monocultures because the intervening plants act as a physical barrier to the dispersal of aerial pathogens from one host to another.

Fertilizer application and plant nutrients

The soil nutrients may increase or reduce the resistance in plants to diseases. Increased applications of nitrogenous fertilizers commonly thought to increase the incidence of many diseases. High nitrogen supply increases the severity of the infection caused by the obligate parasites, e.g., *Puccinia graminis* (Howard *et al.* 1994), *Erysiphe graminis* (Buschbell and Hoffmann, 1992), and *Oidium lycopersicum* (Hoffland *et al.*, 2000). On the other hand, when the disease is caused by facultative parasites such as *Fusarium oxysporum* (Woltz and Engelhar, 1973), *Alternaria solani* (Blachinski *et al.*, 1996), and *Xanthomonas* sp. (Chase, 1989), high nitrogen supply decreases the severity of the infection. Potassium application could reduce the diseases like peanut rust, potato scab, bacterial leaf blight in rice, leaf curl virus disease in tobacco, pod and stem blight in soybean, blast disease in rice, brown stripe disease in sugarcane, and cowpea anthracnose, and *Rhizoctonia* root rot disease in faba bean (Gupta *et al.*, 2017). On the contrary, some other studies reported that the application of potassium may increase the severity of diseases caused by the rust in sugarcane, *Sclerotinia* in many garden plants, and flag smut in wheat (Huber, 1980). It has been observed that the intensity of several infectious diseases of obligate and facultative parasites can be reduced by the application of K fertilizer (Gupta *et al.*, 2017). In potato, K fertilization was found to decrease the incidence of several diseases, such as late blight (*Phytophthora infestans*), dry rot (*Fusarium* sp.), powdery scab (*Spongospora subterranean*), and early blight (*Alternaria solani*) (Marschner, 1995). Calcium affects the incidence of various bacterial diseases. A sufficient amount of Calcium at soils with pH 7 to slightly alkaline pH can reduce clubroot disease in crucifer crops, e.g., broccoli, cabbage, and turnips (Campbell and Arthur, 1990). Ko and Kao (1989) reported that the reduction of damping-off disease in various crops is caused by *Pythium* sp. after amending the soil with calcium. Calcium also confers resistance against *Rhizoctonia, Sclerotinia*, and *Botrytis* (Graham 1983; Huber 1980).

Conclusions

Cultural control can be a productive and sustainable approach to integrated disease management programs. Due to the emergence of bactericide, nematicide, and fungicide resistant pathogens and breakdown of host plant resistance, together with increasing concern for the environment means, the cultural practices for the management of crop diseases is gaining importance. However, the choice and use of cultural practices will depend on the crop and the pathogen, although it might be possible to integrate the management of more than one disease by combining several appropriate cultural practices. To augment the potential of cultural practices in disease control, a sound understanding of the mechanisms by which they exert their effects is required. Integrated management is less convenient, but it reduces the risks and hazards stemming from the use of a single method of control. There is increasing interest in cultural practices for disease control that can replace the use of chemical pesticides, and that can be integrated into pest-management programs.

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