DISEASE MANAGEMENT: CULTURAL PRACTICES

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Contents

25.1 Introduction ........................................................................................................... 390
25.2 Cultural practices which reduce initial levels of inoculum ........ 391
Selection and preparation of planting materials ........................................... 391
Destruction of crop residues ................................................................. 392
Elimination of living plants that carry pathogens ..................................... 394
Crop rotation ............................................................................................. 395
25.3 Cultural practices which reduce the rate of spread of disease. 396
Tillage practices ......................................................................................... 396
Sowing and harvesting practices ............................................................... 397
Intercropping ............................................................................................. 398
Mulching and soil amendments ................................................................. 399
Flooding ....................................................................................................... 400
Irrigation .................................................................................................... 400
Roguing ...................................................................................................... 401
Fertiliser applications and crop nutrition .................................................. 401
Strip farming ............................................................................................... 403
Trap and decoy crops ................................................................................ 403
Miscellaneous practices ............................................................................... 404
25.4 Further reading ............................................................................................... 404

25.1 Introduction

The term cultural control describes the activities of humans aimed at controlling disease through the cultural manipulation of plants. At present, cultural control practices find their greatest value in large area and low unit value crops such as temperate cereals and forests. For some crops, such control practices may be the only economically viable methods available. Many cultural practices were features of ‘traditional’ farming and have been replaced as cropping has become more intensive. High labour costs in modern agriculture may prohibit the use of many of these practices. Cultural control practices could be considered a form of biological control and tend to be preventative and indirect in their actions against pathogens. The success of cultural control practices ultimately depends on understanding the biology of the pathogen and the response of the host to infection. Such knowledge facilitates management decisions which ‘attack’ parasites at vulnerable stages of their life cycles. It may be difficult to assess their effectiveness because the farming operations are often performed well in advance of expected pathogen attacks.

In some cases, disease can be avoided altogether by planting a crop in different sites or regions or at different altitudes from those in which it normally grows. For example, vegetatively propagated crops such as cassava, potatoes, yams, sugar cane and sweet potatoes grown at lower elevations in the tropics often become heavily infected with pathogens, especially viruses. Crops grown to
produce planting material for the next crop may be grown at higher altitudes where there are fewer insects to transmit viruses and conditions do not favour disease development. Colombian farmers traditionally obtained their seed potatoes from high altitude areas where there were few aphids and transmission of virus diseases was minimal. Diseases of stored products have been avoided traditionally by storing produce at high altitudes to make use of the effect of low temperatures in slowing the spoiling process. In choosing a site for a crop, it is wise to check the previous cropping history of the land to ensure that pathogens that may be present from a previous crop will not infect the crop to be planted. For example, chickpeas should not be planted on land on which lucerne was previously grown as Phytophthora root rot affects both crops.

To prevent or control disease outbreaks, growers can either reduce the initial levels of inoculum or reduce the rate of spread of established pathogens. This chapter discusses cultural practices which attempt to destroy inoculum or inhibit the spread of plant pathogens.

25.2 Cultural practices which reduce initial levels of inoculum

Historical evidence indicates that where pathogens have been introduced into previously clean sites, disease epidemics usually follow. The spread of disease to new areas, new plants or new plant products can be prevented or reduced by practising quarantine and sanitation (crop hygiene or ways of maintaining plant health) which are discussed more fully in Chapter 23 together with methods for disinfesting soil, potting media and irrigation water so they do not carry inoculum.

Selection and preparation of planting materials

A critical decision in crop production is the selection of the cultivar(s) to be grown. Some cultivars are resistant to particular pathogens and are inherently less damaged than other genetically related plants growing in the same location. Resistant cultivars (Chapter 26) have provided one of the most successful approaches to the control of pathogens of many crops, especially those which cannot be controlled by other means. However, continuous plant breeding programs are often necessary to overcome the effects of the development of new races of pathogens and 'breakdown' of host resistance. Growers therefore need to be aware of the availability of new cultivars and be able to evaluate their potential in relation to other agronomic characteristics.

In natural plant communities, the diversity of species results in the spatial separation of individual plants of a particular species (see Chapters 26 and 32). Discontinuous distributions tend to reduce the spread of pathogens from one susceptible host to another. Many agricultural production systems, however, emphasise the growing of crops as dense populations with genetic homogeneity (monocultures). Such practices facilitate the spread of pathogens because all plants may be susceptible to attack. In an attempt to correct this situation, a number of mixed cultivars and multiline cultivars have been released incorporating a range of resistances (Chapter 26).

All of the major plant pathogens can be transmitted by seed or propagating material. Materials which have been certified free from disease following field inspection or laboratory testing provide a useful safeguard to growers (Chapter 23). The value of certified seed is further enhanced if the parent crops have been grown in areas where particular parasites are unknown. For example, commercial lettuce seed production for export can be undertaken in some areas of Australia because of the absence of lettuce mosaic virus. Alternatively, rigorous chemical
control programs for selected organisms may be instituted during crop growth and storage to reduce or eliminate pathogens from planting materials. If these procedures are not followed, growers may have to treat seed (Chapter 22) or other propagating structures prior to sowing. Efficient seed-cleaning procedures also contribute to the control of some diseases such as earcockle of wheat caused by the nematode *Anguina tritici* by removing infected seeds and leaving only uninfected material.

Pathogens can be transmitted to healthy material by contaminated knives and secateurs during the preparation of *vegetatively propagated material* for planting. In such situations, growers need to practise proper hygiene procedures to prevent transmission of pathogens (Chapter 23). For vegetatively propagated crops such as carnations and chrysanthemums, tissue culture techniques may be necessary to obtain disease-free planting stocks. For example, viruses and vascular wilt fungi such as *Fusarium* and *Verticillium* do not reach the apical meristems of their hosts until late in the development of the disease. Pathogen-free meristems can be tissue-cultured and used as the basis of a vegetative propagation program.

Even if planting materials are apparently free from parasites, infection may occur if they are damaged during planting operations. Common causes of damage include incorrect adjustment of mechanical planting devices and seedling injury during transplanting. Seedling tobacco plants can also be infected with tobacco mosaic virus via workers' hands during transplanting operations. In such situations, growers need to practise proper hygiene procedures to prevent transmission of pathogens.

**Destruction of crop residues**

Crop residues provide suitable substrates for many pathogens. Burying, burning and removal of postharvest crop residues are important cultural control practices performed during intercrop periods. The effect of destroying crop residues on particular pathogens depends on the type of crop (annual, perennial or harvested product), the extent of the cropping area and the survival mechanisms and host ranges of the target pathogens.

If crop residues are buried, some potential pathogens may be either killed or inhibited in their development. Deeply inverted surface trash assists in the control of groundnut (peanut) blight because the causal fungus (*Sclerotium rolfsii*) requires a food source near the surface of the soil. Plants with shallow root systems may also escape infection if debris from the previous crop is ploughed in deeply. This practice has been relatively successful in controlling verticillium wilt of mint (*Mentha* spp.). Fungal pathogens such as *Sclerotinia* and *Claviceps* which produce sclerotia can be controlled to some extent by burying surface soil. 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. Heat generated during the composting process 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.

Burning the stubble of harvested cereal crops has been a common practice throughout the world. Rice stubble is burned in many areas of Asia to reduce the inoculum of *Sclerotium oryzae* (stem rot), *Curvularia lunata* (black mould) and *Corticium sasaki* (sheath blight). In Australia, fire has been reported to control *Septoria* spp. and flag smut (*Urocystis agropyri*) on wheat, *Septoria avenae* on
oats and *Pyrenophora teres* and *Rhyncosporium secalis* on barley. For example, the incidence of flag smut in wheat was significantly reduced in crops in which the previous year's stubble had been burnt (Table 25.1). Good control of *Cephalosporium gramineum* and *Pseudocercosporella* spp. in cereal crops has been obtained following stubble burning in other countries.

**Table 25.1** The effect of stubble burning on the incidence of flag smut in a commercial crop of a susceptible (cv. Gamut) and a resistant (cv. Timgalen) cultivar of wheat in the North Star area of northern New South Wales in 1968. (Unpublished data of P. B. Metcalfe and J. F. Brown.)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Percentage of infected plants*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamut</td>
<td>Timgalen</td>
</tr>
<tr>
<td>Unburnt</td>
<td>44.0</td>
</tr>
<tr>
<td>Burnt</td>
<td>1.3</td>
</tr>
</tbody>
</table>

* The areas assessed were sown to the cultivar Gamut in the previous season (1967) in which 12% of plants were diseased.

Burning crop debris is not restricted to cereal crops. Burning potato leaves after harvest reduces inoculum of *Alternaria solani* (early blight) for the next season. It also helps control weeds in the potato crop. In the slash and burn method of agriculture practised in some tropical countries, burning a 10 cm layer of litter on the soil surface destroys nematodes to a depth of 9 cm. In many areas of the world, sugar cane crops are routinely burned to facilitate harvesting operations. Many pathogens are eliminated by the intense heat produced. Where this practice does not occur, postharvest burning of trash may be employed as a disease control practice.

The success of burning in destroying inoculum is determined by the intensity of the burn which is, in turn, influenced by the amount, moisture content and quality of the plant debris, the wind velocity and the duration and temperature of the burn. However, any advantage in disease control has to be weighed against the adverse effects of burning. These include loss of nutrients, contamination of the environment with smoke, addition of carbon dioxide to the atmosphere contributing to warming of the earth and increased soil erosion following the removal of protective vegetation.

Experience with yellow spot (*Pyrenophora tritici-repentis*) of wheat has shown that stubble burning can be used to reduce the level of inoculum of a fungus without contributing to soil erosion. Inoculum of *P. tritici-repentis* survives between crops in wheat and triticale stubble and while stubble burning soon after harvest was practised, the disease was of minor importance. Unfortunately, stubble burning left the soils exposed to loss of water through evaporation and severe erosion by run-off following high intensity summer storms. Farmers stopped burning their stubble and yellow spot increased in importance, reducing yields. To prevent erosion and improve water infiltration, stubble now is left on the soil surface over the summer months and ploughed in, burnt or grazed shortly before sowing the next season's crop in autumn or early winter. This practice has resulted in considerable yield increases under conditions suited to the development of severe yellow spot.

Because burning can totally destroy a source of inoculum, it is widely used in eradication campaigns to remove inoculum of newly introduced pathogens and
prevent an epidemic developing. A notable example is the removal and burning of citrus trees infected with citrus canker (*Xanthomonas citri*) in many countries.

In Australia, sheep or cattle are widely used to remove crop stubble after harvesting. Sheep are also used to remove fallen fruit in apple orchards.

**Elimination of living plants that carry pathogens**

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. Unwanted crop plants should be destroyed by either cultivation or the application of herbicides.

Weeds or wild plants may act as **alternative hosts** of plant parasites allowing the pathogen to survive between seasons and providing a source of inoculum in the new growing season. For example, grasses such as *Hordeum leporinum* are hosts of the wheat take-all fungus *Gaeumannomyces graminis*; many dicotyledonous weeds contain *Meloidogyne* spp. and other nematodes and certain leguminous green manure crops maintain the halo blight organism, *Pseudomonas syringa* pv. *phaseolica*. Removing the overseasoning host eliminates or reduces inoculum for the following season. However, the relationships between weeds and crop parasites are often obscure and many weeds are symptomless carriers of various viruses. In other situations, it may not be practicable to eliminate alternative hosts because they can be commercially valuable crops. Only cooperative action by growers to delete crops, rearrange crop rotation sequences or undertake concerted efforts to destroy virus vectors can overcome these problems.

Other important inoculum sources are the **alternate hosts** of many destructive rust fungi. Some rusts cannot complete their life cycles in the absence of alternate hosts, which also provide the opportunity for the rust fungus to undergo sexual recombination, possibly producing new races of the fungus. However, the influence of an alternate host on a rust disease can be highly variable and the effectiveness of campaigns to eradicate alternate hosts can be unpredictable.

Two important macrocyclic cereal rusts, *Puccinia graminis* and *P. coronata* require alternate hosts (*Berberis* spp. and *Rhamnus* spp., respectively) to complete their life cycles. In the absence of their alternate hosts, both rusts survive on susceptible hosts (mainly volunteer plants) via urediniospore infections. This is the way wheat stem rust oversummers in Australia. In colder climates, such as North America, where urediniospores cannot survive the severe winters, the alternate host may play a greater role in providing primary inoculum in a growing season. There has been a concerted effort to eradicate *Berberis* spp. in the United States. However, infections in wheat crops still arise from urediniospores carried by air currents from the warmer southern states or from Mexico. For these rusts, removal of the alternate host tends to postpone a disease outbreak by eliminating a primary source of inoculum. It also prevents sexual reproduction reducing the probability of producing recombinant genotypes.

In contrast, *Gymnosporangium sabina* (the causal agent of cluster cup rust of pears in North America) always requires the presence of its alternate host, juniper, to complete its life cycle. Removal of juniper plants in the vicinity of a pear orchard prevents establishment of the disease. Sometimes the alternate host of a rust has greater economic importance than the primary host. *Cronartium ribicola* is a widespread rust of *Ribes* spp. and its alternate hosts are various five-leaved *Pinus* spp. Attempts to control the devastating pandemic of this pathogen
in North America have largely concentrated on the eradication of *Ribes* spp. near forests containing more valuable *Pinus* spp.

**Removing diseased plants or plant parts** to eliminate sources of inoculum is carried out routinely in many nurseries, greenhouses and high-value crops. Strawberry leaves infected by various leaf-spotting fungi are removed early in the season. Diseased parts of larger plants such as tree crops are often removed by pruning. Infected branches are removed in cases of fireblight of pome fruit (*Erwinia amylovora*), apple canker (*Nectria galligena*), powdery mildew of apples (*Podosphaera leucotricha*) and silver leaf of plums (*Chondrostereum purpureum*). Mummified fruit as well as diseased twigs should be removed from pome and stone fruits to reduce the inoculum of *Sclerotinia* spp. Subsequent sanitation measures usually involve burning pruned material and treating cut surfaces with suitable fungicides. Pruning inevitably influences the microclimate within the tree canopy indirectly affecting any subsequent disease development. In mixed farming enterprises, livestock can be used to 'graze off' crop residues.

**Crop rotation**

Crop rotation, the successive planting of different crops in the same area, is one of the oldest and most widespread cultural practices. It may also include a fallow period in which land is 'rested' from cultivation. Crop rotation improves soil fertility, moisture and texture and assists in weed and pathogen control. The most successful rotations employ intervals between susceptible crops which are longer than the known survival period of pathogens. Rotations are most likely to be effective in controlling pathogens such as *Gaeumannomyces graminis*, *Pyrenophora tritici-repentis*, various *Colletotrichum* and *Phoma* spp. and some pathogenic bacteria which only survive in the presence of a specific host (or its residues) or as resistant propagules. They are less likely to be effective in controlling damping-off and root-rot fungi such as *Pythium* and *Aphanomyces*, *Fusarium* spp. including the vascular wilt pathogens, *Sclerotinia* spp., *Macrophomina phaseoli* and *Plasmodiophora brassicae* which can survive for long periods in the soil as saprophytes.

Probably the most widely used rotations are for the control of soil-borne pathogens of cereals. These often include either a non-host leguminous crop which can improve soil fertility as well as reducing inoculum or a fallow period during which alternative weed hosts and volunteer plants are removed or destroyed. Take-all (*G. graminis*), foot-rot (*Pseudocercosporella herpotrichoides*), *Ascochyta* sp. and some other pathogens of wheat have been controlled in some regions by removing grass hosts, especially during fallow periods. Long term (long course) rotations are required to control pathogens such as *Streptomyces scabies*, *Phymatotrichopsis omnivora* and *Rhizoctonia solani* which survive in the soil as resistant spores or as sclerotia. In some European countries, yields from sugar beet crops may become uneconomic due to infection by the nematode *Heterodera schachtii*. When non-host crops are grown or the land is fallowed, populations of the nematode fall to about half their initial level. This trend must continue until a 'safe' population level is attained before another sugar beet crop can be grown. The composition and length of rotations to be grown on 'beet-sick' soils is controlled by legislation. Regular cultivation of fallow land during dry seasons can destroy pathogens such as the bacterium *Ralstonia solanacearum* because crop debris is repeatedly brought to the surface of the soil and exposed to the drying effects of the atmosphere. However, extended fallow periods are of dubious value because the land is unproductive.
Some rotations may include a crop which inhibits the development of a specific pathogen. High levels of root knot nematodes (Meloïdogyne spp.) occur in soils following crops such as maize, sweet corn and capsicum. However, other crops such as forage sorghum, pinto peanut, watermelon, Rhodes grass, green panic and cowpea host few nematodes. Crops of susceptible plants following these crops show little sign of nematode damage. Legumes such as Crotalaria and Stylosanthes spp. have also been used to reduce populations of the nematode Pratylenchus spp. in soils. Similarly, Tagetes spp. (marigolds) inhibit the development of a range of nematode species. Many brassica crops produce glucosinolates that break down to produce isothiocyanates which are active against several soil-borne pathogens.

25.3 Cultural practices which reduce the rate of spread of disease

In many cases, cultural practices are directed at improving the growing conditions of plants by providing proper nutrition, moisture, light and lack of competition from other plants. They may also be aimed at creating conditions unfavourable for the development of pathogens. A grower's ability to manipulate the environment is somewhat limited in the field but in greenhouses or storage facilities, high levels of control over environmental parameters can be achieved.

In simple greenhouses, proper spacing of plants and the provision of good ventilation reduces humidity and inhibits infection by pathogens such as Botrytis. In more sophisticated greenhouses, growers frequently lower the relative humidity, especially at night, to dry the surfaces of plants and discourage the spread of pathogens such as Botrytis spp. and Diplodocapron rosae. In the field, more rapid drying of plant surfaces can be achieved by improving air movement through the crop by sowing or planting at lower densities, orienting rows in the direction of the prevailing wind and by irrigating in the morning so plants can dry off during the day. Crops on northern facing slopes (in the southern hemisphere) dry more quickly than crops on other aspects. Pruning or training procedures that open the canopies of fruit trees to allow light penetration also improve ventilation of the canopy and reduce the incidence of disease. Conversely, practices which allow plants to stay moist for long periods favour disease development. Thus windbreaks or other structures that interfere with airflow or irrigating late in the day so plants remain wet all night encourage disease development.

Other aspects of the environment can be manipulated to reduce disease development. To control the spread of fungi that require ultraviolet or near-ultraviolet light for sporulation, growers may cover plants with films that block out radiation in these wavelengths to stop the fungi sporing. In storage facilities, proper aeration hastens drying of a product's surface and inhibits germination and infection by bacterial or fungal pathogens. Rapid cooling after harvesting and storage under conditions of low temperature and appropriate levels of carbon dioxide not only prolongs the life of fresh produce, but also inhibits disease development.

The remainder of this section discusses ways of improving plant growth and creating environments in the field that discourage spread of pathogens from one host to another.

Tillage practices

Tillage incorporates various types of organic matter including crop residues, manure, green manure, volunteer crop plants and weeds into the soil. Tillage practices tend to have indirect effects on the spread of plant pathogens, although
some forms of inoculum can be widely dispersed by implements. Tillage reduces populations of weeds and volunteer crop plants that harbour pathogens between crops. It also buries plant pathogens from the top soil into deeper layers of the soil where they cause less or no disease. Practices involved in the preparation of seed beds can greatly modify physical properties of soils such as moisture characteristics, bulk density, aeration and temperature profiles which in turn influence the incidence of disease. Forming the soil into hills, ridges or raised beds provides better drainage and irrigation. Tillage may also influence nutrient release mechanisms and the total effect is often expressed as increased crop vigour. Healthy plants may be more resistant to some pathogens but the more humid microclimate within the crop can be conducive to the spread of other pathogens. Successive tillage operations can reduce inoculum levels of some pathogens through exposure of the inoculum to desiccation by the sun.

Modern agriculture has moved away from regular cultivation of soil between crops towards a system of minimum tillage, or even no-tillage. Minimum tillage is a method of planting crops that involves no seed bed preparation other than opening the soil to place the seed at the intended depth. Usually the soil is not cultivated during crop production and chemicals are used for weed control. Minimum tillage reduces injury to the roots of crop plants caused by mechanical tillage or hand weeding, reducing the opportunities for opportunistic pathogens to infect. It also reduces the spread of pathogens by tillage practices. However, it may favour the development of some diseases such as those that can be controlled by burying inoculum too deep for infection of plant roots to occur. In no-tillage systems, crop residues are left on the surface of the soil. The residues may become a food source for pathogens or alter the physical environment occupied by both the host and its pathogens.

The effect of tillage practices on the soil microflora is often overlooked. Many of these organisms are competitors or antagonists of soil-borne pathogens. Minimum tillage practices are thought to promote greater microbial antagonism in the vicinity of cereal roots than normal cultivation practices. However, little is known about the influence of cultivation on these activities although incorporation of organic matter (e.g. green manure crops) is known to reduce the incidence of some diseases. Plant residues intensify the microbial activity of the soil which may result in the formation of fungitoxic or even phytotoxic compounds.

**Sowing and harvesting practices**

Many crop plants tend to be more susceptible to attacks by various parasites at certain stages of their development. Changing the usual sowing time of a crop can exploit weather conditions which are unfavourable for the spread of pathogens or their vectors and reduce crop losses. These practices often necessitate introductions of new cultivars which are adapted to the selected growing period. However, the introduction of a 'new' cultivar with different growth characteristics may also create other disease problems. In temperate climates, the crop growing season is largely influenced by the prevailing temperature regime, providing that rainfall is adequate or irrigation is possible. Other strategies may be applied in tropical climates so that a susceptible growth phase occurs in relatively dry periods. Greatest variation in sowing times is possible in greenhouses where considerable manipulation of crop microclimates is practicable.

Methods of sowing vary considerably between crops and even with the same crop in different regions. It is therefore difficult to generalise about the effect of
sowing methods on the spread of diseases. Farmers aim to optimise germination and early growth at densities which give maximum yields in the particular environment. **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. Similarly potato seed pieces are more readily attacked by *Rhizoctonia* if planted too deeply.

**Crop density** can influence disease development. Generally as the density of a crop increases, the incidence of disease also increases. For example, in the 1950s, due to an increased demand for seedlings, nurseries expanded in size and increased the density of seedlings in their nursery beds. This practice lead to crowding of the seedlings and serious epidemics of damping-off caused by fungi such as *Pythium*, *Fusarium*, *Rhizoctonia* and *Cylindrocladium*. There are a number of 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. For example, the distance pathogens or their vectors have to travel from one host to the next is reduced, splash dispersal of inoculum is easier and there is also increased contact between the leaves or roots of neighbouring plants. In addition, with denser plantings, more plants may be wounded during cultivation creating more opportunities for weak pathogens to infect. Finally, the micro-environment within the crop is altered. Temperatures are more uniform, the relative humidity increases and leaves stay wet longer after rain or dew. All these conditions favour the development of disease.

Sometimes, dense stands may reduce disease incidence and increase yields. In Africa, the aphid vector of the groundnut rosette virus is attracted to broken ground cover rather than continuous ground cover so dense planting inhibits the landing response of the vector. In this case, weeding actually increases disease incidence because it leaves breaks in the ground cover.

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, fertilisation, water management, staking and harvesting plants or plant parts, depending on the types of crop. All these practices are designed to prevent foliage or root contact.

The **direction of sowing** in some row crops may influence disease incidence. Reports from northern Australia suggest that blue mould of tobacco (*Peronospora hyoscyami*) can increase in severity if rows are aligned in an east-west direction because plants are less exposed to the drying effects of sunlight than in rows oriented north-south.

Germination and early seedling growth can be promoted by **modifying the soil environment** around the seed. Practices such as lime pelleting may either directly inhibit some infection processes or indirectly reduce disease via greater seedling vigour. Soil-borne pathogens such as *Phytophthora*, *Pythium* 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.

**Intercropping**

Intercropping, the growing of a crop or crops between the rows of another crop, is more common on smaller farms and is very popular in China. Labour requirements increase as the number of crops increases, but total production is
generally higher where intercropping is practised. In Nigeria, where cassava is grown with maize, melons or other crops which increase the ground cover, water splash of soil is reduced and the incidence of soil-borne bacterial blight (Xanthomonas campestris pv. manihotis) is decreased.

The incidence of disease is often less in mixed plantings than in monocultures because the distance between similar plants is greater than in more intensive growing systems so it is less likely that propagules or vectors of pathogens will successfully move from one host to another. The intervening plants pose physical barriers to the dissemination of aerial pathogens or their vectors. However the incidence of disease may be higher in intercropped plantings. For example, where soybeans and maize are grown together, soybean rust (Phakopsora pachyriza) is more severe and where maize and cowpea are grown together, anthracnose (Colletotrichum lindemuthianum) is more severe on the cowpea than when the crops are grown apart. The increased incidence of anthracnose on cowpea is attributed to stimulation of the germination of conidia of the causal fungus by pollen of the maize plants which falls onto the cowpea leaves.

**Mulching and soil amendments**

Mulching, the application of a covering layer of material to the soil surface, is a commonly used cultural practice, especially in horticulture. Natural materials used for mulching include cereal straw and stalks, crop debris, sawdust, leaves, grass, manure, weeds, reeds, Spanish moss (Tillandsia usneoides) and various aquatic plants. In fact, almost any readily available, preferably cheap, organic material is used. In addition, 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 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. Crop residues may also affect disease incidence by altering the physical environment of the host and the pathogen. Organic mulches reduce loss of water from the soil, increase infiltration and absorption of water, smother weeds, lower soil temperature (by as much as 5°C), enrich soil by supplying nutrients and organic matter and protect seedlings against the impact of rain, hail and wind (important in the tropics where rain is heavy). All these factors may influence disease development. Spread of soil-borne diseases is reduced because a layer of mulch on the soil surface reduces water splash dissemination of bacterial and fungal propagules and prevents leaves, flowers or fruits from directly contacting the soil and disease propagules in the soil. Crop residues generally enhance competition among soil micro-organisms for nitrogen, carbon or both resulting in fewer problems with soil-borne pathogens. However, in some cases the incidence and severity of disease has increased with mulching, perhaps because the microclimate within the system has changed in ways which favour the pathogen.

Organic amendments incorporated into the soil may suppress pathogens by increasing the level of activity of organisms that reduce their growth or survival. In Australia, Phytophthora cinnamomi causes severe root rot of avocados. The addition of large amounts of chicken manure to the soil around the base of plants almost completely eliminates the problem. Similarly, the addition of chitin from crustacean, fish or other animal wastes to soil stimulates the parasitism of nematode eggs by fungi and reduces the level of inoculum. Unfortunately, the addition of amendments to soil does not always achieve the desired effect. Disease incidence or severity may increase because the pathogen thrives on the
amendment. In addition, some organic soil amendments form phytotoxic substances as they decompose.

Flooding

The paddy system of growing rice is perhaps the oldest example of using flooding for plant disease management. The primary purpose of flooding is to control weeds. 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. By reducing the number of weeds which may harbour rice pathogens and insects, it also indirectly affects disease development. The destruction of crop debris carrying inoculum can also be hastened by flooding. Rice blast (Pyricularia oryzae) is less severe on flooded paddy rice than on upland or non-irrigated rice because fewer hours of dew occur in paddy than in upland rice and because populations of fungi, bacteria, nematodes and actinomycetes are lower in flooded soils. On the other hand, flooding can predispose some plants to disease, floodwaters can carry propagules of pathogens such as Phytophthora and algae growing in flood waters produce oxygen which encourages the growth of some fungi.

Like tillage practices, flooding may influence both the level of initial inoculum and the rate of spread of diseases. Flooding diseased cotton 'trash' for up to six weeks reduced the incidence of bacterial leaf blight (Xanthomonas campestris pv. malvacearum). In contrast, flooding seems to have little effect on verticillium wilt fungi. Banana wilt (Fusarium oxysporum f.sp. cubense) can be partially controlled by flooding infected soils for up to six months. Such practices are expensive, require large amounts of water and keep land out of production for considerable periods of time. However, these disadvantages may be overcome if wetland rice can be incorporated into a rotation. This strategy occurs in areas of south east Asia where satisfactory results have been obtained in the control of Phytophthora parasitica (black shank of tobacco) and Sclerotinia spp. attacking vegetable crops. Flooding has also been used to control nematodes. Hydrogen sulphide produced by anaerobic organisms under flooded conditions kills nematodes but the cost of such treatment is prohibitive.

Some soil-borne pathogens may be controlled by manipulating soil water potentials in relation to their growth requirements because they vary considerably in the minimum water potentials required for spore germination and for hyphal growth. However, if a soil is drained or irrigated to limit the activities of a pathogen the imposed conditions may favour the development of other pathogens and stress plants sufficiently to cause production losses.

Irrigation

Irrigation can have a major influence on the spread of some pathogens and on disease development. Irrigation applied during dry seasons means the propagules of pathogens are not exposed to desiccation during periods of drought. Consequently, the level of inoculum increases. The seriousness of this situation is compounded in areas where, because of irrigation, it is possible to grow two susceptible crops in the same field in one year. In addition, irrigation water may contain propagules of pathogens which it carries from one place to another unless carefully treated before use (Chapter 23). Overhead watering may promote disease by increasing the period of time a layer of free moisture remains on leaf surfaces (leaf wetness period). The longer leaf wetness periods increase the likelihood that sufficient time will be available for fungal spores to germinate, form infection structures and penetrate the plant surface to the relatively
constant and favourable environment within the leaf. Irrigated crops may become a green island in an otherwise dry environment and attract insect vectors of virus diseases. In such cases, it is often better to delay sowing an irrigated crop for some time after other vegetation has dried up and the vector population has been reduced by desiccation.

On the other hand, irrigation can be used as a tool to reduce the level of inoculum and to retard disease development. Alternately drying and rewetting soil encourages the activity of micro-organisms that destroy sclerotia. Overhead irrigation can reduce or inactivate airborne inoculum by washing it out of the atmosphere. Short daily waterings encourage the germination of powdery mildew spores but the plants do not stay wet enough for long enough for the fungus to penetrate. Overhead sprinkling of dormant fruit trees reduces the incidence of apple scab because the short-lived ascospores are released in response to temperature changes whilst the tree is dormant and can not survive until leaves are present.

Flood, furrow and overhead (spray, sprinkler) irrigation can facilitate the spread of pathogens. Flood irrigation can spread soil-borne inoculum all over an area while furrow irrigation disperses inoculum along rows. The action of overhead irrigation systems washes inoculum out of the air and facilitates the spread of pathogens that rely on water splash for dispersal. Many important foliage and fruit pathogens such as Phytophthora infestans and Alternaria solani form their spores at night and release them during the day. Overhead irrigation in the early part of the day washes these spores from the air and splashes them about. If overhead irrigation is delayed until the evening or early night, spores of P. infestans dry out on the plant and cannot infect. However, spores of A. solani are resistant to drying out and can survive until a dew forms at night so the timing of overhead watering has little influence on disease development. Overhead irrigation plays a role in the distribution of inoculum within a crop as it washes inoculum from higher to lower parts of the plant.

Trickle or drip irrigation, developed in response to the need to conserve water, supplies water directly to the root zones of individual plants and the rate of application is insufficient to disperse pathogens. Moreover drip irrigation produces a mosaic of soil moisture conditions, rather than uniformly moist conditions, which probably inhibits the spread of root pathogens.

Roguing

Roguing involves the removal (and destruction) of diseased plants (rogues) to prevent further spread of the pathogen(s). It is practicable in small gardens, where labour is cheap or the cost of labour is not important, when a crop is very valuable or if the level of infection is low. With larger plantings, roguing is only worthwhile if the crop has a relatively high economic value, the disease symptoms are conspicuous and the pathogen has a limited dispersal potential. To minimise disease spread, affected plants need to be removed as soon as possible after symptoms are observed. Roguing may need to be repeated regularly as newly diseased plants appear. To reduce the spread of banana bunchy top virus, both affected plants and adjacent, apparently healthy, plants are removed and destroyed.

Fertiliser applications and crop nutrition

Soil nutrient status may influence the susceptibility of plants to attack by pathogens. Farmers aim to provide their crops with a well-balanced supply of nutrients. The resultant healthy, vigorous plant should have a greater chance of
withstanding attacks by pathogens. However, this is not always the case. The same conditions that favour the growth of the plant may also encourage development of biotrophic pathogens. For example, many viral diseases of crop plants are promoted by fertiliser applications.

Deficiencies of nutrients in soils increase the susceptibility of many crops to certain pathogens. In this context, fertiliser applications are sometimes recommended as a control strategy. The influence of the major nutrients nitrogen, phosphorus and potassium, as well as calcium, on disease development will be discussed further. Applications of some of the minor nutrients can also decrease host susceptibility to disease. Applications of zinc reduce the incidence of maize downy mildew, while sulphur fertilisation inhibits the occurrence of cercospora leaf spot in groundnuts and copper applications reduce take-all in wheat.

Heavy applications of nitrogenuous fertilisers are commonly thought to predispose plants to disease. The often observed increase in infection by obligate parasites such as the powdery and downy mildews and rusts lends support to this contention. However, it is unlikely that such an apparently direct interaction promotes disease and the effect of a nutrient is probably more indirect. Nitrogen applications tend to delay crop maturity by prolonging vegetative development. Increased risk of infection may result because plants are susceptible to attack for longer periods. In contrast, the stimulation of vegetative growth may allow plants to 'outgrow' an infection and compensate for any damage. High nitrogen levels are also thought to influence the production of host metabolites which can either inhibit or promote infections by various pathogens. For example, rice blast (Pyricularia oryzae) and scald (Rhynchosporium oryzae) generally increase on plants grown in high nitrogen soils whilst maize head smut (Sphacelotheca retliana) tends to decrease in severity.

Nitrogenous fertilisers also indirectly affect the spread of disease by modifying crop environments. Reduction in the incidence of Rhizoctonia solani following nitrogen fertilisation is thought to result from stimulation of certain soil micro-organisms which compete for nutrients. If the density of the crop canopy increases, a microclimate favouring certain foliage pathogens will develop. Rank (overly lush) growth in cereal crops resulting from liberal fertiliser applications can lead to lodging (breaking, bending over or lying flat on the ground of the above ground parts of plants) which is often associated with increased disease incidence (e.g. rice blast).

The form of nitrogen available to the host (and not total soil nitrogen) probably has most influence on disease susceptibility. Nitrogen is absorbed as either nitrate or ammonium ions and their effects have to be largely assessed in relation to specific host/pathogen relationships. In addition, other cultural factors such as rate, time and method of fertiliser application, soil properties including texture, pH and microbial populations and previous cropping history require consideration.

The effects of phosphorus fertilisers on disease incidence are not well understood. Fertilising with phosphates can delay the onset and lessen the severity of take-all in barley (Gaemumannomyces graminis) and reduce the incidence of potato scab (Streptomyces scabies) but increase the incidence of cucumber mosaic virus in spinach. The effects of phosphorus fertilisers are attributed to correction of phosphorus deficiency in the soil resulting in healthier plants more able to resist attack by pathogens. In addition, phosphorus hastens the maturity of the crop so young susceptible tissues are not exposed to the inoculum of obligate parasites for long periods of time.
Adequate potassium levels inhibit the development of a wide range of parasites including fungi (e.g. *Fusarium oxysporum f.sp. vasinfectum*), bacteria (*Corynebacterium insidiosum* and *Xanthomonas* spp.), various viruses and nematodes. Application of potassium fertilisers also seems to reduce some of the disadvantages of excessive nitrogen applications. The effect depends on the nutrient status of the soil, the rate of application and the buffering effect of potassium on other elements, especially nitrogen. Potassium directly stimulates or reduces penetration of the host by the pathogen as well as its multiplication and survival, aggressiveness and rate of establishment in the host. It also indirectly influences aspects of disease development. For example, potassium promotes wound healing, reducing infection by wound parasites such as *Botrytis*. Potassium fertilisation also heightens resistance to frost injury and delays maturity in some crops, postponing the strain of senescence and reducing the risk of infection by facultative saprophytes.

**Calcium** is another nutrient which can influence disease incidence. Its principal effect is on the composition of the cell walls of the host. Adequate supplies of calcium make cell walls more resistant to penetration by facultative pathogens such as *Rhizoctonia*, *Sclerotium*, *Botrytis* and *Fusarium*. However, soils high in calcium favour the development of diseases such as black shank of tobacco (*Phytophthora parasitica* var. *nicotianae*). Alternatively, high levels of calcium (lime) in soils can raise their pH to the detriment of pathogens such as *Plasmodiophora brassicae* which are favoured by acid soils.

**Strip farming**

This practice separates areas of one crop with intervening strips of another crop or fallow. Part of the rationale for adopting strip farming practices is that crops in adjacent strips rarely share common pathogens. The rates of spread of more specialised parasites are also restricted because of the discontinuous distribution of suitable hosts. The major problems associated with strip farming are increased costs of production relative to monocultures, selection of crops for adjacent strips which have few common parasites and weed control between the strips. Strip farming has an additional role in reducing soil erosion.

**Trap and decoy crops**

Trap (or catch) crops are susceptible plants that are grown on land known to contain various pathogens. The pathogens infect the crop which must be destroyed before the life cycles of the pathogens are complete. Suitable methods of destroying the crop include ploughing in, applying various biocides or grazing-off with livestock. For example, the parasitic plant *Striga* spp. can be partially controlled by ploughing in infected cereal crops. Trap crops can be grown simultaneously with more valuable crops. The efficiency of trap crops in reducing the spread of pathogens depends on the plant, growth habit differences including height differentials and position relative to the 'protected' crop.

Decoy 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 while the poisonous weed thornapple (*Datura stramonium*) reduces the incidence of powdery scab of potatoes (*Spongospora subterranea*). Ideally, a decoy crop would be of economic value and included in a normal crop rotation.
**Miscellaneous practices**

Virtually any management decision in crop production can have some influence on the spread of pathogens. Although some of the more obvious and better understood cultural practices have been discussed in previous sections, there are probably many others which have not been studied. Further investigation of certain traditional practices which are peculiar to specific crops is also useful for devising disease management programs. One practice which has attracted new attention is the placement of barriers around fields. These may take the form of fences, hedges or windbreaks. All interfere with the movement of air currents and create various degrees of turbulence. Pathogen propagules are dispersed in the crop in patterns reflecting resultant air movement.

### 25.4 Further reading

