Cultural methods – Rouging, eradication of alternate and collateral hosts, crop rotation, manure and fertilizer management, mixed cropping, sanitation, hot weather ploughing, soil amendments, time of sowing, seed rate and plant density, irrigation and drainage

Eradication

Eradication is the elimination of pathogen after it has become established in the area where host is growing. The following are the important methods followed to prevent the spread of the disease:

i. eradication of alternate hosts,
ii. eradication of collateral and self sown overwintering hosts
iii. eradication of the affected plants or trees,
iv. eradication of pathogens from infected plant parts by surgery and
v. eradication of culled out plant materials, debris, etc., through different cultural practices

i. Eradication of alternate hosts

Removal of alternate hosts helps to prevent and check the spread of the disease caused by heteroecious rust pathogens in the primary hosts. Barberry bush is the alternate host for black stem rust pathogen *Puccinia graminis tritici* on wheat where the pathogen survives in the off-season. Barberry was eradicated in Canada, Denmark, France, Hungary, Norway and in the U.S.A. by passing stringent laws in each country. The eradication of barberry had two benefits i.e., it elimination of early spring primary inoculum and prevention of the formation of new physiologic races of the pathogens. In the U.S.A. white pine blister rust *(Cronartium ribicola)* was controlled by eradication of alternate host, *Ribes*. In Australia, Europe and the U.S.A. the apple rust (*Gymnosporangium juniperi-virginianae*) is controlled by eradication of alternate host, cedar.

ii. Eradication of collateral and self sown overwintering hosts

There are many weed hosts or wild species of cultivated plants act as collateral hosts or volunteer plants of an economic crop which act as reservoirs of pathogens of 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 actually 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 land also.

Crop	**Disease**	**Pathogen**	**Collateral hosts**
a. Fungi 1. Rice	**Blast**	***Pyricularia oryzae***	*Brachiaria mutica* *Dinebra retroflexa,* *Leersia hexandra,* *Panicum repens.*
2. Sorghum	Ergot	*Sphacelia sorghi*	*Panicum* spp.
b. Bacteria 1. Rice	Bacterial leaf blight	*Xanthomonas oryzae* pv. *oryzae*	*Cyanodon dactylon, Cyperus rotundus, Leersia hexandra, Leersia oryzoides, Panicum repens, Paspalum dictum.*
2. Apple and pear	Fire blight	*Erwinia amylovora*	*Hauthom* bushes *Crataegus* sp.
3. Cotton	Bacterial blight	X. *axonopodis* pv.*malvacearum*	*Eriodendron anfructuosum, Jatropha curcas, Thurbaria thespesoides*
c. Viruses 1. Potato	Rugose mosaic	Rugose mosaic virus	*Physalis* spp.

2. Bean	Yellow mosaic	Bean yellow mosaic virus	Sweet clover
3. Bhendi	Yellow vein mosaic	Bhendi yellow vein mosaic virus	*Hibiscus tetraphyllus*
d.Phytoplasma 1. Brinjal	Little leaf	Phytoplasma	*Catharanthus roseus, Datura* sp.

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 facilitate 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.

iii. Eradication of affected plants or trees

In some threatening plant diseases, it is essential to eradicate the host and the pathogen from an area. Citrus, canker (*Xanthomonas axonopodis* pv. *citri)* is an example of success of an eradication programme. This disease was first noticed in Florida citrus trees in 1913. An eradication campaign was started in 1915. All the citrus nurseries and orchards were inspected and the infected trees were cut and burnt. The eradication programme continued till 1927 and no citrus canker was present in that area. Peach yellows and peach rosette were also controlled by removal and destruction of diseased trees. In Tamil Nadu also there were some eradication campaigns launched under Destructive Pests and Diseases Act. Eradication programme was set up to control bud rot of palms and completed with success. At Sathyamangalam eradication of sandal wood tree affected by spike disease was also made to contain this disease.

iv. Eradication of pathogens from infected plant parts by surgery

Eradication of affected plant parts (tree surgery) are also practiced in certain cases which reduces the source of primary inoculum. Lesions caused by fire blight bacterium *(Erwinia amylovora)* on pear and apple trees are removed during winter months. This not only prevents further spread in the affected trees but also reduces the amount of inoculum that can spread to other branches and trees. The cankered areas in the branch or trunk of almond and pear trees caused by *Ceratocystis fimbriata* are surgically removed and the trees are saved. Tree surgery is also practiced in coconut trees affected by stem bleeding disease *(Ceratocystis paradoxa),* citrus gummosis (*Phytophthora citrophthora*), *Dendrophthoe* spp. on citrus, bud rot of palms (*Phytophthora palmivora*) and koleroga of arecanut (*P.arecae*)

v. Eradication of culled out plant materials, debris etc. through different cultural practices

2. Crop rotation

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 eradication of certain types of pathogens from infested soil. Continuous cropping or monoculturing provides opportunity for 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 perennate in the soil and increase in their population. After sometime, 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 immune, 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 development of antagonistic microorganisms in the soil. In this way, crop rotation is one of the most effective methods of root disease control. Organisms which are soil inhabitant types remain in soil for a very long time, even more than five years in the absence of the host. Long-lived spores or the organisms by themselves, subsist as saprophytes and therefore their presence in soil is long term. Onion smut (*Urocystis cepulae*)and club root (*Plasmodiophora brassicae*)organisms are producing resistant type of spores while *Rhizoctonia*, *Fusarium* and some species of *Pythium* are those which could remain in soil as saprophytes for a very long time.

Eradication of such organisms becomes fairly difficult. Soil also harbours soil invaders. These organisms are not persistent and they can live as long as the host residues serve as substrate. They perish when they are forced to exist in the soil in competition with soil inhabitants and disappear gradually in due course. Bean anthracnose fungus *Colletotrichum lindemuthianum,* cabbage black rot bacterium, *Xanthomonas campestris* pv. *campestris* are some examples, which live in soil for 1 to 2 years. They can be eliminated from soil by adopting 3 or 4 year rotation with non-host crops. Crop rotation is effective in the control of brown stem rot of soybean (*Cephalosporium gregatum*). The disease incidence can be reduced to a great extent by rotating with corn for 4 to 5 years between two soybean crops.

Crop rotation with sugarcane or paddy is effective in the control of 'Panama wilt' of banana (*Fusarium oxysporum* f.sp. *cubense*) and crop rotation with paddy or green manures is effective in the control of red rot of sugarcane (*Colletotrichum falcatum*). Rotation of cereal crops like pearlmillet, finger millet or fox-tail millet is recommended for the control of *Macrophomina* root rot of pulse crops. Two year crop rotation with lucerne is recommended in the control of *Verticillium* wilt of cotton. Many diseases such as *Fusarium* wilt of pigeonpea (*F. udum*), foot rot of betelvine (*Phytophthora capsici*), bacterial leaf blight of rice (*Xanthomonas oryzae* pv. *oryzae*), bacterial blight of cotton (*X.campestris* pv. m*alvacearum*) etc., are controlled by this method. Soybean seed infection by *Phomopsis* sp. can be reduced by rotating soybean with maize. Pathogens are reduced or eliminated by following the crop rotations given in the table.

Table. Effect of crop rotation in reduction / elimination of plant pathogens

Beneficial crop	Pathogen reduced or eliminated	Preceding crop
1.Rice	*Verticillium dahliae*	Cotton
2.Pea	*Gaeiimannomyces graminis*	Wheat
3.Sudan grass	*Pseudomonas solanacearum*	Tomato

3. Fallowing

Fallowing starves the pathogen and helps in reduction of the inoculum by elimination of the host. Diseases like *Macrophomina* root rot on different crop plants is controlled by following this method. Flood fallowing is to a depth of 0.6 to 1.5 m for 4 to 6 months markedly reduced the Panama wilt pathogen *Fusarium oxysporum* f.sp.*cubense* inoculum in banana. Soil inoculum of *Phytophthora parasitica* var. n*icotianae,* the causal organism of black shank of tobacco was destroyed by flooding the field for 3 to 4 months and by raising swamp rice in a 2 year rotation with tobacco-rice crop in Java. Flooding the soil strewn with debris infected by *Xanthomonas axonopodis* pv. m*alvacearum* for 4 days reduced the inoculum level and thus the incidence of disease was only 2.1% as against 69.5% in unflooded fields. Wet fallowing makes the pathogenic propagule in or on the soil to germinate, spent them, is become susceptible attack of saprophytes. Example, *Sclerotium rolfsii* and *Verticillium dahliae*. The sclerotia or microsclerotia of these fungi are activated in the absence of root exudates of this host. They germinate quickly when there is alternate wetting and drying of the soil. When the population of *Pythium myriotylum* is not high wet fallowing is successful in reducing the population. Wet fallowing reduces saprophytic survival of *Alternaria solani* on crop debris.

4. Application of organic manures

Addition of organic manures like farm yard manure or green manures or oil cakes to the soil increases the antagonistic microorganisms in the soil. Build up of antagonistic microorganisms reduces the population of soil borne plant pathogens and the diseases caused by them. Application of farm yard manure at the rate of 12.5 tonnes/ha reduced the incidence of *Macrophomina* root rot of cotton. Application of 5 kg of neem cake/tree three times in a year reduces the basal stem rot (*Ganoderma lucidum)* of coconut. In the control of sesame root rot *(Macrophomina phaseolina)* application of neem cake at the rate of 150 kg/ha is recommended. Application of neem cake at the rate of 2 tonnes/ha in two split doses and covering with mud reduced foot rot disease in betelvine garden.

Soil amendment

It has been proved that the organic amendments rich in carbon and deficient in nitrogen control the take-all disease (O*phiobolus graminis*) of wheat. There is considerable liberation of CO_2 by soil saprophytes which suppresses the pathogenic activity of this fungus .In the process of survival also, low nitrogen content in the soil reduces the longevity of the fungus. *Phytophthora* root rot of avocado is controlled by amending the soils with alfalfa meal- a material of low C/N ratio. The other diseases are pea root rot *Aphanomyces euteichus* when cruciferous plant residues were incorporated into the soil. Alfalfa meal and barley straw application in the soil reduced the root rot of cotton and sorghum caused by *Macrophomina phaseolina.* Black scurf of potato (*Rhizoctonia solani*) is less in the field where wheat straw was incorporated.

5. Summer ploughing

Deep ploughing during summer periods buries the inocula of fungi of soil borne nature. Fungal propagules, sclerotia and different types of spores conidia on plant refuses die when exposed to sunlight due to the higher temperature prevailing during the summer. Further infected self sown plants, volunteer hosts plants, weed hosts, regrowths from the plant roots, alternate hosts and alternative hosts are also destroyed. Here, the spread of the disease is avoided. Groundnut blight (*Corticium rolfsii*) is controlled by ploughing the soil to a depth of 20 cm. The inverted plough sole soil buries the sclerotia of the fungi, *Claviceps, Sclerotium* and *Sclerotinia* in association with plant or alone, impedes the discharge of ascospores from perithecia. Bunt and smut spores of wheat, smut spores of sugarcane and sorghum and microsclerotia of *Verticillium* in cotton are buried deep in to the soil by deep ploughing.

6. Crop growing seasons

Rice blast becomes serious when the rice crop is raised from August to September in Tamil Nadu. Ragi blast becomes serious when sowing is made between June and August. Similarly yellow mosaic of blackgram/green gram and phyllody of sesame are serious during kharif season in South India. Incidence of powdery mildews of different crops is found to be high during rabi when compared to kharif and summer seasons. In bhendi, yellow vein mosaic incidence is very high during summer. The seasons with high incidence of diseases should be avoided in the epidemic areas.

a. Adjustment of sowing time

In many diseases the incidence is more severe when the susceptible stage of the plant growth and favourable conditions for the pathogens coincides. While choosing the time of sowing it should be taken into consideration that 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. Properly adjusting the sowing dates can give good dividends. Late planted wheat crops contract less infection than wheat planted on normal dates. Early and late sown crops have been found to be free from Oodhubathi disease of rice.

Avoiding cool and cloudy days for planting will help to reduce red rot of sugarcane. Late sowing of winter wheat and barley is considered to be the most effective measures in reducing take all disease of wheat. Rapeseed sown in mid to late August is more liable to attack by leaf spot (*Alternaria brassicae*) than late-sown crops. Pea and gram planted soon after rains when soil temperature and moisture are at a high level, show high incidence of root rot and blight. As the soil temperature falls and moisture becomes less (Nov-Dec) these diseases are also reduced. In areas where these diseases are serious, late sowing helps in saving the crop. Stem rust of wheat damages the late sown crop more than the early sown crop. Because, time of onset of disease and ear formation coincides. Sowing from January to April or October to December is advocated to escape from the attack of neck blast of finger millet. Peas and chickpea sown in October usually suffer heavily from root rot and wilt (a complex of *Fusarium, Rhizoctonia* and *Sclerotium*). When these crops are sown late, the diseases are not so severe or almost absent. 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. The sowing time is adjusted in cumbu and sorghum in such a way that the flowering stage does not coincide with the rainy season to avoid the sugary diseases. Early sown crops show decreased incidence of curly top and yellows on sugarbeet, rosette on groundnut and barley yellow dwarf on cereals. Delayed sowing on the other hand is beneficial to maize rough dwarf disease.

b. Adjustment of harvesting time

Harvesting of groundnut should not coincide with the rainy days and it helps to avoid infection by *Aspergillus flavus*. Freedom of onions and roses grown in rainless seasons from downy mildew diseases and freedom of beans, chilli and cucurbits from bacterial diseases in such seasons are the best examples for sowing of crops at correct season to avoid disease outbreaks. In the case of deciduous fruit trees and grapevines, the season of sprouting, flowering and fruit set can be advanced or delayed by pruning practices or by treatments to break dormancy. Advantage can sometimes be taken of this fact to avoid coincidence of all or one of these phases of host growth with weather periods particularly favourable to specific pathogens that attack trees in the phases.

7. Growing of seed crops

Coffee can be grown in the western Hemisphere usually free from coffee rust which causes heavy losses in Eastern Hemisphere. In the case of virus diseases this will be more useful. By growing seed materials in isolated places where the population of vectors is very low and the condition is uncongenial for the vectors. Virus free potato tubers to be used as seeds are grown in cool and windy places in many parts of the world. Under tropical and subtropical countries, such conditions prevail in the hills at high altitudes. Obtaining seed from disease-free localities has been very successfully resorted to the elimination of many seed –borne diseases. In the U.S.A. seed-potatoes are invariably grown in northern snow-clad sections, where viruses are practically absent and then exported to various other sectors in the south. Similar practice has been in vogue in India, where seed-potatoes are annually imported in southern states from Simla hills for control of virus diseases and bacterial ring. In the U.S.A, the seed growing areas have been shifted to arid pacific regions for crops like cabbage, turnip, beans and peas for obtaining disease-free seed and indirectly controlling such diseases like black leg and black rot of cabbage and turnip and anthracnose of beans and peas. Similar practice is obtained in parts of Bombay, where the foot rot of ginger (*Pythium myriotylum*) prevalent in the southern parts, is controlled through the importation of seed-rhizomes from disease-free arid regions of the north, where the disease is practically non-existent on account of the dry climate, lighter soils and moderate rainfall.

8. Selection of seeds and seed materials

Seeds and seed materials carry many fungi, bacteria, viruses and phytoplasmas and may introduce these pathogens into the field, i.e., seeds and seed materials form the primary source of infection. Seed and seed materials like cuttings, tubers, grafts, setts etc., should be well matured, disease free, uninjured and have a high germinating capacity. The absence of an initial inoculum in seeds is definitely helpful in delaying or suppressing 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, bacterial blight of rice, bacterial blight of cotton, leaf crinkle of blackgram etc., are transmitted through seeds. Virus diseases and black ring of potatoes, foot rot of ginger, foot rot of betelvine, Panama disease of banana, red rot of sugarcane cassava mosaic, bunchy top and virus diseases of fruit trees are transmitted through tubers, setts, rhizomes, corns, grafts and budwoods. 'Tuber indexing' is a special method to obtain disease free seed materials in potato. It is commonly practiced by nurseries and seed merchants selling potato seed tubers. Use of seeds in the place of rhizome/sucker is recommended in the control of 'katte' disease of cardamom.

9. Leveling of the field and provision of drainage facilities

Water stagnation in different patches of field favours the fungi like *Pythium, Phytophthora, Rhizoctonia solani*, etc., for which proper leveling of the field before sowing or planting is very essential. Further improving the drainage is necessary in the control of sheath blight of rice. Provision of drainage channels in orchard crops like citrus, jack, mango etc., in the garden is necessary before planting. In the control of damping-off diseases of vegetable and other crops, raising seedling in the raised beds method is followed. Foot rot of ginger (*Pythium myriotylum*) is also controlled by following the raised bed system of nursery.

10. Seed rate

Use of higher seed rate in the nursery creates favourable microclimate for the pathogens causing damping-off in vegetables, tobacco, chillies and forest nurseries. Hence, use of optimum seed rate should be adhered in such crops.

11. Burning of stubbles and crop residues

Burning of plant wastes, crop residues, stubbles, *etc.*, in the areas selected for raising nurseries for vegetable crops, tobacco, chillies and forest trees etc. heats the soil and kills the inoculum of the pathogens present in the top layer of the soil. When nurseries are raised in these areas incidence of damping off disease is highly reduced. This practice is also followed in pits made for planting coconut, banana, fruit trees etc., Burning of wheat plant every second or third year is suggested for eradication of pathogen in the field when *Cephalosporium gramineum* infects wheat. Otherwise, debris in the field helps the perpetuation of the pathogen and the disease. Burning of rice crop residues avoid carryover of sheath blight (*Rhizoctonia solani*); stem rot (*Sclerotium oryzae*) of rice and bacterial blight of cotton.

12. Depth of sowing

Depth of sowing greatly influences seed transmission of smuts. Shallow planting in wet soils protects wheat plants from U*rocystis tritici* (flag smut) of wheat. Deep planting may cause delay in the emergence of seedlings, which may be vulnerable to pre-emergence damping off. Early emergence results in early lignification of tissues which become resistant to attack of soil-borne pathogens.

13. Spacing

Closer spacing invariably alters the microclimate underneath the canopy of the crop which may provide favourable environment for development of diseases. Boll rot in cotton is quite common in crowded crop. Defoliation of plants or skip cropping gives better control against the boll rot disease. In certain virus diseases like groundnut rosette the incidence is observed to be less when wider spacing is adopted. Closer spacing favours many air borne diseases because of high humidity in the crop canopy. Early and late blight of groundnut and blister blight of tea are more in dense canopy. Early spread of black rot of cabbage takes place in closer spacing. Crowded stands may reduce some systemic diseases. Cotton wilt caused by *Verticillium albo-atrum* will be less in closely planted crop if the fungal inoculum is less in the soil. Similarly closer spacing of rice reduces rice tungro virus infection particularly when vector population is less. Avoiding shade and providing wider spacing reduces the incidence of powdery mildew of tobacco. Late blight of potato and downy mildew of grapevine spread fast in closer spaced crops. In the case of bud necrosis of groundnut caused by tomato spotted wilt virus, seeds are sown adopting closer spacing of 15x15cm to compensate the rogued out plants with regard to plant population and yield. These are examples where dense sowing helps in disease reduction.

The virus of tomato leaf curl, transmitted by *Bemisia tabaci*, is less severe in a crowded planting than in spaced planting. Same is true for cucumber mosaic, transmitted by *Aphis gossypii* and groundnut rosette transmitted by *Aphis craccivora*. The fungal diseases for which the phenomenon of lower incidence at closer spacing of the crop has been studied most profitably is the wilt caused by *Verticillium albo atrum* and V.*dahliae* in cotton. This is ascribed to the reduction of effective inoculum per plant in proportion to the increase in the number of plants per unit area in the densely sown field. The incidence of brown rot (*Cephalosporium gragatum*) of soybean is also higher in widely spaced planting than in closer rows.

14. Method of sowing/planting

In places where water accumulation is a problem to the crop growth sowing of seeds on the sides or ridges is found effective in reducing the incidence of *Sclerotium rolfsii* on groundnut and vegetable crops and *Sclerotinia sclerotiorum* and *Rhizoctonia solani* on vegetable crops and *Phytophthora* blight of pigeonpea. High ridging prevents infection of potato tubers, by zoospores from leaf lesions in late blight diseases. Ridging is disadvantageous in water deficit areas where it encourages pathogens like *Macrophomina phaseolina.*

15. High budding

High budding is a practice to avoid infection by gummosis fungus of citrus trees. In low budded plants the bud point is close proximity to infection centre (the soil), become readily diseased. High budding is a simple device for lengthening this distance between the bud point and infected soil. In this method the soil borne pathogens (*Phytophthora palmivora* and *P.citrophthora*) have no chance of reaching the bud point, through which they enter the bark. Staking of lower most branches arising close to the soil, increases the distance between the fruits and soil inoculum and removes the chances of brown rot (*Phytophthora sp*) infection and buck-eye rot of tomato (*P. nicotianae* var. p*arasitica*).

16. Avoiding injury

Injury of plant parts should be avoided in order to check the entry of pathogens. Clipping of tips of tall rice seedlings favours the entry of bacterial blight pathogen and incidence of the disease. Hence clipping should be avoided at the time of transplanting of rice. While harvesting the pods in groundnut, fruits in tree crops and vegetable crops injuries to the fruits pave the way for the pathogen and causing pod/fruit rot. It also reduces the storage life of fruits and vegetables. Hence much care should be given to avoid wounds during the harvest time.

17. Altering the soil pH

In certain soil borne diseases adjustment of soil reaction helps in the reduction of inoculum level of the pathogens. The altered pH of the environment forms a barrier against the pathogen. A very low pH less than 5.2 is unfavourable to common scab bacterium on potato (*Streptomyces scabies*). Thus, use of acid forming fertilizers (like sulphur) and avoiding lime and calcium ammonium nitrate application are effective in controlling the common scab disease.

On the other hand the club root pathogen of cabbage (*Plasmodiophora brassicae*) cannot live and infect when the soil pH is 7.0 or more. Hence liming which increases the soil pH gives satisfactory control of club root disease. In Punjab, root rot of tobacco (*Macrophomina phaseolina*) has been overcome by application of 2.5 to 5.0 tons of lime /ha to the soil.

18. Mixed cropping

Mixed cropping materially helps in checking certain diseases. Blight of pulse crop (*Phyllosticta phaseolina)* has been successfully overcome by growing pulses as a mixed crop with cereals like sorghum and pearlmillet.

19. Intercropping

Intercropping is also a device in the control of some soil borne diseases. Intercrops should be properly chosen so that they should not have any common pathogen for e.g., *Macrophomina phaseolina* has got wide host range and hence common host should not be grown as intercrops. Intercropping with moth bean (*Phaseolus aconitifolius*) in a cotton field reduced the root rot (*M.phaseolina*) incidence.

Due to reduction in the number of host plants there is sufficient spacing between them and chances of contact between foliage of roots of diseased and healthy plant are greatly reduced. Therefore, root pathogens are unable to spread from diseased to healthy roots and spread of foliar pathogens is also reduced to a great extent. Intercropping of sorghum in pigeonpea field reduced the wilt (F. *udum*) incidence. The roots of non-host plants may act as a barrier obstructing the movement of pathogens in soil. They may release toxic substances from their roots which may suppress the growth of the pathogens attacking the main crop. Hydrocyanic acid (HCN) in root exudates of sorghum is toxic to *F. udum*, the pigeonpea wilt fungus. Intercropping of sorghum or mothbean in a crop of clusterbean reduced the incidence of root rot (*R.solani*) and wilt (*F.coeruleum*) from 50 to 60% in single crop to 8 to 15% in the mixed crop.

Intercropping of pigeonpea with gingelly at 1:6 ratio reduced the incidence of phyllody disease. In Jordan, intercropping tomatoes with cucumber is found to be effective and cheaper in controlling the whiteflies and lowering the incidence of tomato yellow leaf curl virus. (TYLCV) Cucumber is planted one month before tomato. Cucumber is known to be a preferred host for whiteflies and immune to TYLCV. Insecticides are applied when adult whitefly populations are at high levels, usually two weeks after planting of cucumber and the second one before tomato planting. Growing of an intercrop of cereals such as corn or sorghum between rows of peach trees is an effective method in combating Texas root rot (*Phymatotrichum omnivorum*) infection in the U.S.A.

20. Barrier cropping

Taller crops can be grown to protect a crop of lesser height from virus vectors. The insects may land at the taller crops (barrier crops) and the dwarf crop may escape from virus diseases by those insects. Barrier cropping with 3 rows of maize or sorghum or pearlmillet around the main crop namely blackgram or greengram is effective in reducing the vector population and incidence of yellow mosaic. Another best example is growing of 3 rows of kale or barley as barrier crops in cauliflower seed beds and undersown beet steckling against cauliflower mosaic and beet yellows diseases respectively. The incoming aphids are thought to land on the barley or kale and probe briefly, causing them to lose the non-persistently transmitted virus they are carrying. Maize or sunflower are the other barrier crops considered for these crops.

21. Decoy crop and trap crop

Decoy crops (hostile crops) are non-host crops sown with the purpose of making soil-borne pathogens waste their infection potential. This is effected by activating dormant propagules of fungi, seeds of parasitic plants, etc. in absence of the host. A list of pathogens that can be decoyed is given in table.

Table. Decoy crops for the reduction of pathogen populations

Host	**Pathogen**	**Decoy crops**
1. Sorghum	*Striga asiatica*	Sudan grass
2. Cabbage	*Plasmodiophora brassicae*	Rye grass, *Papaver rhoeas*, *Reseda odorata*
3. Potato	*Spongospora subterranea*	*Datura stramonium*
4.Tomato, tobacco	*Orobanche* spp.	Sunflower, safflower, lucerne, chickpea etc.

Trap crops are host crops of the pathogen, sown to attract pathogens but destined to be harvested or destroyed before they complete their life cycle. Fodder sorghum can be raised as a trap crop to reduce downy mildew of sorghum.

22. Trenching

Trenching between rows of trees in orchards has been effectively utilized in arresting the growth and spread of the pathogen in the soil to the neighbouring trees. *Ganoderma lucidum* root rot infected citrus trees should be isolated by digging a trench of 30 cm wide and 60 cm to 90 cm deep around the tree at a distance of 2.5 to 3.0 m from the base to prevent the contact of diseased roots with healthy roots. Thereby the spread of the pathogen to neighbouring tree is prevented. Similar method is also followed in the control of basal stem rot (*Ganoderma lucidum*) of coconut in India.

23. Isolation distances

The distance between seed production and commercial plots has been worked out for reducing seed borne loose smut of barley and wheat. Barley and wheat crops should be isolated by at least 50 m from any source of loose smut infection for production of certified seeds in the U.K.

The number of viruliferous insects reaching a healthy crop from a diseased one decreases with distance between them so that cultivation of susceptible crops at a distance from each other delays or reduces the severity of virus diseases. Incidence of lettuce and cucumber mosaic viruses is about 3% if the new lettuce crop is sown 0.8 km away from an old lettuce field Much greater incidence of mosaic in sugarbeet fields occurs within 90 metres of a seed crop than in the fields at a greater distance. Beet mosaic and beet yellows are markedly reduced by isolating beet fields by 19 to 24 km and 24 to 32 km mites respectively from a large source of infected beets.

24. Yellow sticky traps

Sticky, yellow polythene sheets erected vertically on the windward side of red pepper fields have been sown to reduce the incidence of potato virus Y (PVY) and cucumber mosaic virus (CMV) in the crop. The aphids are attracted to the yellow colour and are caught on the sticky polythene. The control obtained was so successful that the method has become a standard control procedure in red pepper crops in Israel. Similar traps have also been used to protect 'seed' potato crops, against potato leaf roll virus. Yellow sticky traps are in use to attract and kill the whitefly vectors which spread yellow mosaic of blackgram and greengram and bhendi yellow vein mosaic.

25. Mulching

Mulching or covering of top soil with organic residues often helps in reducing plant diseases. 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 development of parasites and predators of nematodes. Reflective surfaces (mulches) laid on the soil around the crop plant, have been found to be highly effective in controlling aphid vectors. Aluminium strips or grey or white plastic sheets are used as mulch and it has successfully protected red peppers against CMV and PVY in Israel and summer squash against watermelon mosaic virus in the Imperial valley of California. Straw mulches have been successfully used to control the white fly – transmitted tomato yellow leaf curl virus in tomato crops in Israel. It is believed that the colour of the straw attracts the whiteflies and they are subsequently killed by the reflective heat. The disadvantage with straw mulches is that they eventually lose their yellow colour, but prolonged control may be obtained if straw is replaced by yellow polythene sheets.

26. Irrigation water management

Irrigation to the crop in the field is to wet the soil to the extent that roots easily get water and nutrients. If excess water is added to soil, it may directly affect activity of pathogens and/or it may affect disease incidence through the effect on the host. Scab attack on potato tubers is prevented by maintaining soil moisture near field capacity during tuber formation. Bacterial flora antagonistic to *Streptomyces scabies* increases under high moisture conditions. The charcoal rot pathogen, *Macrophomina phaseolina* attacks potatoes and cotton when the soil temperature rises and there is water stress. By irrigating the field, soil temperature is brought down, stress is removed and the disease is suppressed. When excess irrigation is made the juvenile stage of plants is lengthened making it susceptible to attack of fungi like *Pythium*. Supply of frequent but low quantity of irrigation water is, therefore, recommended for reducing chances of damping off in nurseries.

Under conditions of excess water, respiration of roots is inhibited and many soluble salts accumulate in toxic amounts around the roots and base of the stem. This increases disease proneness of the roots. Irrigation increases guttation. Guttation drops on leaves serve as media for multiplication and penetration of many pathogens, such as *Helminthosporium* spp. on cereals and *Xanthomonas campestris* on *Brassica* spp. Cereal rusts usually are more severe when the crop is grown in wet soil than in relatively drier soils. Vascular wilts appear aggravated soon after irrigation. These effects are through the host.

Pathogens directly taking advantage of excess water are those that need wet soil for (i) activation of their resting structures and (ii) for movement of these propagules. Thus, in presence of excess free water bacterial cells and zoospores of Pythiaceous fungi are dispersed easily. Therefore, at the plant stage when these pathogens can attack the crop irrigation should be avoided. Generally, sprinkler irrigation increases diseases by increasing leaf wetness and by dispersing propagules of the pathogens by water splashes just like rain water. At the same time, it has some advantages also such as washing off of inoculum from the leaf surface.

Irrigation especially at seed-development stage, may favour seed infection. Irrigation time and amount of water should be controlled so that the relative humidity is not raised to such an extent that it becomes conducive for seed infection. Control of seed-borne diseases favoured by wet climate can be achieved by raising the seed crop in dry areas. Some examples are anthracnose of bean and cucurbits (*Colletotrichum* spp.), *Ascochyta* blight of pea (*Ascochyta* spp.) and bacterial blight of legumes. Such crops can be grown in dry areas with the help of irrigation so that these aerial parts remain dry and do not contact infection. Virus-free potato seed tubers can be produced more successfully in areas where temperature and moisture conditions do not favour buildup of populations of the insect vectors.

Sclerotia, smut spores, chlamydospores, oospores and mycelium found in the soil are carried from one field to another through irrigation and drainage water. 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.

27. Field and plant sanitation

Field and plant sanitation is an important method of disease control through cultural practices. The inoculum present on field plants in the field may multiply on the plant or in the soil and in due course of time may be sufficient to nullify or reduce the effect of control practices. Many pathogens overwinter or oversummer on plant debris during the off-seasons and become active when the crop is again grown in the field. Hence plants bearing pathogens or plant debris introducing inoculum into the soil should be removed as early as possible. In most of the soil borne diseases like wilt and root rot, it has been reported that as long as the dead roots and other roots and other affected parts are present in the soil, the fungus continue its growth. When such diseased plant materials are removed, there is quick decline in the population of pathogens in the soil.

In this manner *Fusarium* wilt of cotton, pigeonpea and banana, *Verticillium* wilt of cotton, root rot of beans, downy mildew of pearlmillet, sorghum, maize and peas, foot rot of betelvine, bacterial blight of cotton, white rust of crucifers, black spot of rose, powdery mildew of pea and cereals are reduced. In certain areas the linseed rust fungus (*Melampsora lini*), the rice blast and brown spot fungi and the fungus causing early blight of potato also perennate through dormant stages in diseased crop debris. Destruction of crop debris by burning immediately after harvest reduces the amount of inocula which survive through debris.

It has been observed that leaf blight disease or rice particularly one caused by *Helminthosporium oryzae* is carried over in the stubbles and primary infection is evident in the self-sown tillers arising from these stubbles. Infection of *Sclerotium rolfsii* on jute is carried over in the foot and root regions in the stubbles left over after harvest of the jute plants. Sugarcane stubbles left over in the field help to carry over red rot fungus *Glomerella tucumanensis*, *Xanthomonas oryzae* pv. *oryzae* causing bacterial leaf blight disease on rice is capable of surviving for some time in rice stubbles. In many cases, diseased planting materials left in the field after discarding them, serve as sources of infection as in the case of late blight of potato where piles or refuses of rejected tubers later become an important source of infection. Left over plant parts of maize infected with the smut *Ustilago zeae* constitute an important source of infection later.

Avoidance of the transfer of inoculum from one field to another by man, machine or water is one of the ground rules of cultural control. Where soil-borne diseases are concerned, anything that carries soil is suspect, this includes wheels, boots and water flowing either from adjacent fields, or through drainage ditches from distant fields. As regards sap-borne viruses, attention must be paid to disinfection of wheels and of the hands of labourers, as they pass from one field to another. Where such virus can also be carried on clothing. The work should be planned so that the labourers do not go from older to younger fields on the same day.

Many pathogens are capable of surviving on implements and materials used in sequential seasons. Tobacco mosaic virus has been shown to survive on iron stakes used for tomato trellises and disinfection of such stakes has been recommended. Soil adhering to plastic sheeting may carry sclerotia and other overseasoning bodies.

28. Roguing

Roguing consists of completely removing or uprooting the diseased plants to prevent further spread of the disease. This method is widely adopted in the control of virus diseases spread by insects (cassava mosaic, yellow mosaic of blackgram and greengram, citrus tristeza, katte disease of cardamom, bunchy top of banana) and basal stem rot of coconut, green ear of pearlmillet and broomrape (*Orobanche*) in tobacco. The whip smut of sugarcane (*Ustilago scitaminea*) in the canal areas of Bombay in Co.475 variety has been greatly checked by roguing carried out over wide areas and long period. In Jamaica, a country-wide campaign of destroying infected plants has succeeded in the control of Panama wilt of banana. Root rot and wilt attached plants after their death should be as and when noticed in the field uprooted and burnt to check the inoculum build up in the soil.

29. Management of plant nutrients

The plant nutrients in general when applied in excess may increase or reduce the resistance in plants to diseases. Increased application of nitrogenous fertilizers increases the incidence of many diseases. Crops fed with heavy doses of nitrogenous was fertilizers grow robust with foliage and succulent tissue but become highly susceptible to the attack of diseases like rust powdery mildew, blast, tobacco mosaic and some bacterial diseases .In the case of blast of rice optimum dose of nitrogenous fertilizers are recommended and it is applied in 3 split doses viz. 50% as based at transplanting, 25% at tillering and 25% at panicle initiation stage. Late application of nitrogenous fertilizers increases wheat leaf blotch (*Septoria nodorum*) and powdery mildew (*Erysiphe graminis tritici*).

Some diseases are favoured by ammoniacal form of nitrogen while others are favoured by nitrate form of nitrogen. In general wilts (*Fusarium* sp.) and root rots (*Rhizoctonia* spp.) are favoured by ammoniacal nitrogen while *Verticillium* wilts and root rots due to *Pythium* spp. are favoured by nitrate nitrogen. In rice, blast disease is favoured by ammoniacal nitrogen while brown spot (*Helminthosporium oryzae*) is favoured by nitrate nitrogen. In maize Northern corn leaf blight caused by *H. turcicum* is favoured by ammoniacal nitrogen while stalk rot (*Diplodia maydis*) is favoured by nitrate nitrogen.

In wheat, sharp eye spot (*Rhizoctonia solani*) is favoured by ammoniacal nitrogen while stem rust (*Puccinia graminis tritici*) is favoured by nitrate nitrogen. In potato, wilt (*Verticillium albo-atrum)* and scab (S*treptomyces scabies)* are favoured by nitrate nitrogen while ammoniacal nitrogen increases black scurf (*R. olani*) .

Effects of nitrogenous fertilizers on major soil borne diseases have been studied. Their effect on the disease i.e., whether increased or decreased incidence by nitrogen in different forms are given in the following table.

Table. Effects of different forms of nitrogen on soil-borne diseases

Pathogen	Host	Amendment
Diseases increased		
Fusarium oxysporum f.sp.	Tomato	NO_3
lycopersici	Sorghum	$NaNO_3$ - NH_4NO_3
F.moniliforme	Carnation	NO_3
F. roseum	Bean	NH_4
F.solani f.sp. *phaseoli*	Wheat	$(NH_4)_2SO_4$
Gaeumannomyces graminis	Tabacco	NO_3
Phytophthora nicotianae	Cotton	$(NH_4)_2SO_4.Ca(NO_3)_2.KNO_3$
var. *nicotianae*	Potato	NH_4 NO_3+$CaCO_3$
Verticillium albo-atrum		
Streptomyces scabies		

Disease decreased		
F. oxysporum f.sp.*cubense*	Banana	Urea(nitrite)
F.solani f.sp. *phaseoli*	Bean	KNO_3
Gaeumannomyces graminis	Wheat	$(NH_4)_2SO_4$
Phytophthora cinnamomi	Avocado	KNO_3
Sclerotium rolfsii	Tomato	$Ca(NO_3)_2$
S.rolfsii	Sugarbeet	$NH_3.(NH_4)_2SO_4.Ca\ (NO_3)_2$

Repeated application of phosphatic fertilizers delays the onset and lessens the severity of take-all disease of barley (*Gaeiimannomyces graminis*). Potassium application reduces the disease incidence in many crop diseases probably by increasing phenolics synthesis in plants. Application of potash induces resistance in groundnut against root rot caused by *Macrophomina phaseolina*. Calcium application suppresses the lesions due to the *R.solani* on bean roots. It is due to formation of calcium pectate, which is less available to action by polygalacturanase (PG) enzyme than is pectic acid.

Calcium has also been shown to affect *Sclerotium rolfsii* by neutralizing the oxalic acid produced by the fungus. Application of molybdenum reduces infection of potato tubers by *Phytophthora infestans* and also diminishes incidence of *Ascochyta* blight on beans and peas. Manganese reduces late blight of potato, ferric chloride controls rice brown spot and silicon application reduced rice blast.

30. Time of harvesting

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. 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 to dry before digging the tubers kills the sporangia and avoids contamination of tubers harvested later.

31. Avoiding ratoons

Ratooning is a general practice in sugarcane when the incidence of grassy shoot disease and red rot are very high. Hence ratooning should be avoided.

32. Solar heating

When the soil is covered with white polythene sheets during hot seasons, soil temperature increases. Increased soil temperature eliminates wilt pathogens like *Fusarium oxysporum* f.sp. *lycopersici* and V*erticillium dahliae* from tomato field. High soil temperature also favours antagonistic fungi.