Important Soil Borne Pests and their Integrated Management in Arid Ecosystem

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ABSTRACT

Management of soil borne insects/nematodes/diseases plays a vital role for crop production. In the absence of exact estimates in India, it is nearly assumed that more than 50% of the crop loss is due to soil inhabiting microorganisms. It is emphasized in this manuscript about integrated approach of soil borne insect-pest and disease management especially in the tropical and subtropical ecosystems. Integrated pest and disease management practices are useful in reducing the quantity and effectiveness of primary stages of soil dwelling arthropod pests or disease causing primary inoculums of pathogens below economic threshold levels. Sowing disease free seed or propagative material is of paramount importance as preventive measure. The proper seed treatment and cultural practices like deep summer ploughing, crop rotation etc. are suggested for minimizing the risk. It is also advocated that the soil solarization significantly reduces the population of harmful soil organisms. The importance of different soil amendments are described for increasing antagonistic activities against soil borne pathogens. Use of bio-agents like *Ttichoderma*, *Pseudomonas* etc. has great potential to control the disease causing soilborne pathogens. Bio-pesticides/ botanical pesticides are comparatively slower than chemicals but have a great stability in managing pest population without affecting beneficial microorganisms. The techniques for controlling nematodes are also elaborated and it is emphasized to use trap crops like marigold, chrysanthemum etc. However, the limited use of chemical pesticides in high value cash crops is also suggested. There is an urgent need for balanced use of chemical pesticides and promotion of bio-pesticides for maintaining the ecology of soil micro-flora with sustainable pest and disease management.

1 INTRODUCTION

Healthy soil is a primary requirement to grow a plant. A wide range of insects-pests, fungi, bacteria and nematodes are present in soil which causes damage to underground parts of plants. Once seeds or plants are planted, soil borne pests are difficult to control and may begin feeding immediately on the crop. There is a real need for producers to inspect fields for soil insects prior to planting. Sometimes soil borne pests are clumped in a field; they may be in one area and not in another. Low areas or those areas which have more vegetation often hold the most insect-pests. Soil conditions play an important part in plant disease affecting the survival of the pathogen, movement through the soil to a potential host or interaction with an antagonist. The amount of water can affect some disease organism more than others. Above ground, very humid conditions tend to promote infection whereas below ground, high levels of water due to poor drainage promote anaerobic conditions which deplete the amount of oxygen available thereby reducing root health leading to greater susceptibility to infection and also to greater movement of pathogen.

Plant diseases of economic crops alone cause 13 to 20 percent annual loss in production representing US\$ 50×10^9 (James, 1981). In the absence of exact estimates in India, it can be assumed that more than 50% of the crop loss is due to soil inhabiting microorganisms. Ten fungal genera have been recognized playing a major role in the root disease complex causing seed decay, damping off, root rot, seedling blight, collar rot, crown rot, foot rots and wilt (Cook and Baker, 1983). Sasser (1989) reported an overall average annual loss of world's major crops due to damage by plant parasitic nematodes as 12.3 percent.

Soil borne pathogens need to be controlled to maintain the quality and abundance of food, feed, and fiber produced by growers around the world. Different approaches may be used to prevent, mitigate or control plant diseases. Beyond good cultural practices, growers often rely heavily on chemical fertilizers and pesticides. However, the indiscriminate use of pesticides causes soil pollution. Many beneficial microbes persist in soil which helps the plants by increasing the nutrient availability as well as releasing antagonistic chemicals to disease producing pathogens.

These soil dwelling insect-pests and diseases can be effectively controlled, if control measures are applied before planting. Cultural practices like application of organic amendments, seed treatment, soil solarisation, crop rotation, chemical fumigation etc. play an important role to prevent soilborne pests away from plants. The soils of arid region are heavily infected with soilborne fungus causing wilt, damping-off and root rot and some nematodes which cause severe damage in field crops as well as horticultural crops. For the management of these pathogens an integrated approach should be necessary as discussed in the current chapter.

2 IMPORTANT SOIL DWELLING INSECTS AND THEIR MANAGEMENT

Soil-dwelling insect-pests can seriously reduce plant establishment, populations and subsequent yield potential. These insects can be damaging because they feed on the roots and stems of plants. Often soil borne pests, especially cutworms are common in uncultivated fields infested with grass and weeds and abandoned fields after growing the previous season. The important soil dwelling insects which damage agricultural crops are white grub, termite, wire worms, mole cricket, earwigs, black scarab beetles, cutworms, fire ant etc.

2.1. White grub: (*Holotrichia consanguinea*, Order Coleoptera, family: Scarabaeidae)

2.1.1. Description

Whitegrub, *Holotrichia consanguinea* is the most serious scarab pest in India. This is a polyphagous pest in nature and prefers light sandy soils. This species predominantly found in Rajasthan, Gujarat, M.P., U.P., Haryana, Punjab and Bihar. Rajasthan and Gujarat have a long history of whitegrub. *H. consanguinea* infestation occurs in most of the *kharif* crops. The damage in different crops ranges from 20 to 100 per cent. This pest most preferably feeds on groundnut and bajara.

2.1.2. Nature of damage

The beetles of *H. consanguinea* emerge from soil during dusk after good pre-monsoon or monsoon rain in mid-May or late June. The beetles are polyphagous, and may feed on the foliage of a wide variety of host trees and bushes found in the nearby places. However, they have some preference for certain hosts like Jujube or ber, Khejri (*Prosopis cineraria*), Neem (*Azadirachta indica*), Clusterbean (*Cyamopsis tetragonoloba*), Jambolana (*Syzygium cumini*) and Drumstick (*Moringa oleifera*).

The grubs make chamber by compressing the surrounding soil particles and then eats the rootlets exposed into the chamber; thereafter it little bit moves vertically into the roots to eat more of the same root. Then the grubs move horizontally making chambers and feeding on the exposed roots. The grubs continue active feeding from July to mid-October.

2.1.3. Life cycle

The biology, of *H. consanguinea* has been worked out in Gujarat State (Desai and Patel, 1965) and Patel *et al.* (1967), and in Rajasthan (Rai, *et al.*, 1969). All the grubs pupate by the beginning of November. Before pupation the grubs enter deep into the soil to the depth of 40 to 70 cm or more in search of suitable moisture zone. The average pupal length and width is 27.3 mm and 14.2 mm, respectively. The freshly emerged beetle is white in colour but with the lapse of time it becomes dull brown with light brown abdomen and dark brown legs. The beetles remain in the soil in inactive state up to middle of May at a depth of about one metre. The average duration of one life cycle is 122 days and there is only one generation in a year.

2.1.4. Management

- The cultural management of white grub through deep summer ploughing exposes the grubs which are fed by birds and adult of grub can be killed by light trap.
- Annihilation of white grub beetles on host trees by application of insecticides and pheromone loading of selected host trees.
- Among the microbial control agents, entomopathogenic fungi, *Metarhizium anisopliae* and *Beauvaria bassiana* were more effective, when placed at soil depth of 10-15 cm. Nematodes, *Setainernema glaseri* and *Heterorhabditis* sp. were found to be pathogenic to several whitegrub species including *H. consanguinea*.

- Seed furrow application of Phorate 10G @ 20 kg ha^{-1} or Quinalphos 5G @ 30 kg^{-1}/ha or Imidacloprid 17.8 SL ml^{-1}/kg seed.
- In groundnut, seed treatment with Clothinaidin 50 WG (Dantotus) @ 2g kg^{-1} seed or Imidacloprid 17.8 SL @ ml^{-1}/kg seed.
- In standing crop, chlopyriphos 20 EC or quinalphos 25 EC @ 4l^{-1}/ha applied with irrigation water after 3 weeks of first shower of monsoon.

2.2. Termite: (Order: Isoptera, Family: Termitidae)

2.2.1. Description

Termite attacking on annual and perennial crops, especially in the semi-arid and sub-humid tropics cause significant yield losses. In general, damage by termites is greater in rain-fed than irrigated crops, droughts than periods of regular rainfall, in lowland rather than highland areas, and in plants under stress (lack of moisture, disease or physical damage) than in healthy and vigorous plants. Termites causing greater losses in agriculture belong to the following families and genera: Hodotermitidae (Anacanthotermes and Hodotermes), Kalotermitidae, Rhinotermitidae (Copotermes, Heterotermes, and Psammotermes), and Termitidae (Amitermes, Ancistrotermes, Cornitermes, Macrotermes, Microcerotermes, Microtermes, Odontotermes, Procornitermes, and Syntermes as reported by Krishna *et. al.* (2013).

2.2.2. Nature of damage

Many species of termites build large mounds often containing many thousands of individuals. Termites construct shallow subterranean foraging galleries radiating from the nest for distance of upto 50 m. They feed on roots and underground portions of stem causing wilting and withering of the affected plants. Patchy gaps are formed due to the death of seedlings resulting in poor and uneven plant stand. The workers of the termite may invariably be found in soil or at the base of freshly damaged or wilting seedlings. At the early stage when plant is attacked the roots are completely or partially eaten, which directly kills the plant or indirectly lowers the yield through decreased translocation of water and nutrients. Such plants dry up without producing any grains and can be easily pulled out. Termites damage all the food material which contains cellulose.

2.2.3. Life cycle

They are social insects and lives in colonies known as termitaria. The pest remains active throughout the year. The propagation of colony takes place generally during the rainy season when atmospheric conditions are favourable; the colonizing forms are leaving their parent colony. The members of the swarm comprise individuals of both sexes. Both the male and female participate in the early operation of forming a nest. The queen termite (egg laying machine) is the most important termite in the life cycle. The queen is responsible for laying eggs and hence starting the entire cycle. The king is responsible for mating with the queen for her life. Both king and queen can live up to 25 years. The egg stage of the termite life cycle lasts for about 30 days and within 180 days the larvae develop to form soldiers or workers. After the king and queen, workers are arguably the most important parts of a colony. They are responsible for foraging, food storage, feeding the queen and defence (in certain species, although soldiers are the main ones responsible for the colony defence). They are mainly the ones which damage the crops and other wood material by digesting the cellulose. The lifespan of a worker termite is 1 to 2 years. Both worker and soldier caste are sterile and the reproduction caste (king, queen and nymphs; supplemental reproductive) when produced mature in 12-24 months.

2.2.4. Management

- Deep ploughing or hand tillage exposes termites to desiccation and to predators, thus reducing their number in the soils.
- Mounds are physically destroyed, flooded or burnt with straw to suffocate and kill the colony.
- Crop rotation may be useful in reducing the buildup of termites since intensive monoculture for long periods makes plants more susceptible to termite attack.
- Seed treatment with entomopathogenic fungus, *Metarhizium anisopliae* or *Beauveria bassiana*, provide promising results.
- Before sowing treat the seed with Regent 5% SC (fipronil) @ 6 ml or Dursban/Ruban/ Durmet 20 EC (chlorpyriphos) @ 4 ml^{-1}/ lit.
- In standing crop, apply chlorpyriphos @ 1 to 1.5 litre ha^{-1} with irrigation water.
- Swabbing with Neem oil 5% once on the base and upto 2 m height of the infested tree trunk for effective control.

Seed treatment is the most effective and economical method of termite control as compared to broadcasting of treated soil or fertigation.

2.3. Cutworms, *Agrotis* sp. (Order: Lepidoptera, Family: Noctuidae)

2.3.1. Description

Cutworms are the caterpillars of various moths in the family Noctuidae. The insect belonging to genus Agrotis are subterranean in habit. The pest remains active throughout the year but minor pest during August to October and is major limiting factor in certain regions (Bharadwaj *et al.*, 1980). This pest is distributed in India, Burma, Sri Lanka, China, Indonesia, Australia, America, Europe and North Africa. It has been reported from Kashmir, Tarai area of Uttar Pradesh and Bihar. The moths pollinate flowers, and do not do any direct harm to garden crops. This pest feed on various plants such as maize, okra, tomato, chillies, egg plant, cabbage, potatoes, corn, peas, beans, celery, carrots, lettuce, and many other common garden crops. Different cutworm species prefer different host plants (Mitchell *et al.,* 2006).

2.3.2. Life cycle

The pest is active from October to April. The female lays about 199 to 344 creamy white, dome shaped eggs in clusters of about 30 each either on under surface of the leaves of the food plants or in the soil. The eggs hatch in 2 days in summer to 8-13 days in winter. The larval period is 30-34 days in February- April and full grown larva makes earthen chamber in the soil for pupation. The pupal period is 10 days and 30 days in summer and winter, respectively. The total life cycle is completed in 48-77 days. Three generations are found in a year.

2.3.3. Nature of damage

The caterpillar, which hide during day time in cracks and crevices in the soil, become active at dusk, feed on leaves and also cut growing seedlings and tender shoots of the young plants.

Initial damage is done by feeding on leaves by the younger larvae, while the older larval in stars of 4th, 5th, and 6th kill the plants by cutting it just above the soil surface (Jarvis *et al.*, 1981).

2.3.4. Management

- Remove weeds and plant residue to help reduce egg-laying sites and seedling weeds that nourish small cutworms.
- Use light trap for mass trapping of cutworm moths from 3rd week of March to last week of July.
- Deep summer ploughing of fields before planting which helps expose and kill over wintering larvae which also helps to discourage egg laying sites and avoid green manuring to reduce egg laying.
- Pick the larvae from the base of the plants, where they take shelter under the clods during daytime.
- Flooding of field could control the pest effectively.
- Placing of aluminum foil or card board collars around the transplants as physical barrier which prevent cutworm larvae from feeding on garden plants.
- Give prophylactic treatment of phorate 10G or or carbofuran 3G @ 15 kg ha^{-1}. Carbaryl 5% @ 25 kg ha^{-1} was found superior and gave good control of cutworms under artificial infestation conditions in tobacco field at Anand, Gujarat (Patel, 2002).

2.4. Mole Cricket, *Gryllotalpa orientalis* and G. *africana* (Order: Orthoptera, Family: Gryllotalpidae)

2.4.1. Description

Mole cricket prefers light soils (sandy soils, heavier soils that are made friable by cultivation and mud) which are easier for them to dig into.

2.4.2. Nature of damage

Seedlings are cut at the base leading to, poor seedling growth, seedling death, missing plants. root damages (Gerasimov and Osnitskaya, 1961). *G. africana* feed on roots and near ground plant parts of tobacco, but the main harm to tobacco is through physical damage to seedbeds by creating the burrows just under the surface, which uproot the germinating seedlings.

2.4.3. Life cycle

The eggs are deposited in a hole constructed by the adult female. Neonate nymph has a white and bluish prothorax and legs. With age, it turns gray to black with white markings. The adult mole cricket is brownish and very plump. It measures 25-40 mm long. The enlarged front legs, which are modified for digging, have strong teeth-like structures.

2.4.4. Management

- Cultural control includes maintaining standing water, which can help to remove the eggs from the soil.
- Construction of a raised nursery should be avoided to reduce feeding damage on seedlings.

- Conserve natural predators like sphecid wasp, carabid beetle and nematodes.
- Poisoned baits made by mixing moistened rice bran and insecticide that can be placed along rice bunds can kill night-foraging mole crickets in rice crop.
- Drenching of chlorpyriphos 0.04% effective to control the pest.

2.5. Earwigs: *Forficula auricularia* (Order: Dermaptera, Family: Dermapteridae)

2.5.1. Description

Earwigs feed most actively at night and seek out dark, cool, moist places to hide during the day. Common hiding places are under loose clods of soil, boards, or dense growth of vines or weeds or even within fruit damaged by other pests such as snails, birds, or cutworms. The adult earwig is readily identified by a pair of prominent defence appendages that resemble forceps at the tail end of its body.

2.5.2. Nature of damage

Earwigs may attack soft fruit such as apricots, strawberries, raspberries, or blackberries but do not harm hard fruit such as apples. On corn, earwigs feed on silks and prevent pollination, causing poor kernel development. Earwigs may also seriously damage flowers including zinnias, marigolds, and dahlias. This insect causes damage in night and can be seen in flashlight.

2.5.3. Life cycle

Female earwigs dig cells in the ground in the fall and winter where they lay masses of 30 or more eggs. Eggs hatch into small, light brown nymphs and remain in the cell protected and fed by their mother until their first molt. Generally there is one generation a year, but females produce two broods.

2.5.4. Management

The following insecticides can be used as baits, liquids, sprays, granules, or dusts: carbaryl, acephate, cyfluthrin, fenvalerate, and propoxur.

2.6. Black scarab beetles (Order: Coleoptera, Family: Scarabaeidae)

2.6.1. Description

Most scarab beetles are robust, convex insects with brown or black coloring. Whatever the colouration, size, or shape, scarabs beetles have a key common feature; lamellate antennae that can be closed tightly. Scarab beetle larvae (grub) are c-shaped and usually live in the ground, feeding on roots.

2.6.2. Nature of damage

In many species, the larvae feed on plant roots, though some feed directly on dung or carrion. The scarabs found in black soils have a two year larval stage. The eggs would have been laid in the pasture in spring/summer and the small larvae developed while feed on the roots of the pasture grasses. The larvae are large (up to 30 mm), and feed voraciously. When the pasture was removed and the winter cereal planted, the scarab larvae start feeding on the emerging cereal plants.

2.6.3. Life cycle

Scarabs complete metamorphosis with four stages of development; egg, larva, pupa, and adult. Scarab beetles generally lay their eggs in the ground, in dung, or in other decomposing materials including carrion.

2.6.4. Management

- The rapid removal of plantings following harvest and pre-plant fumigation destroy beetle larvae and pupae in the soil.
- Soil solarisation may be effective for beetles in the Central Valley.
- The use of sudan grass as a cover crop may serve to increase the population levels in the field.
- Parasitic nematodes like *Setainernema, Heterorhabditis* that target immature insects in the soil are available commercially.

3 PLANT PARASITIC NEMATODES (PPNS) AND THEIR MANAGEMENT

Plant parasitic nematodes have been recognised as important limiting factor for crop production particularly in the tropics in last two decades. Several species of plant parasitic nematodes have been reported to cause serious losses in agricultural as well as horticultural crops. These are tiny microscopic worms in size and occur abundantly in soil. When seen under microscope, plant parasitic nematodes are slender, unsegmented usually shorter than 2 mm in length with serpentine mode of locomotion. At least 2500 species of plant parasitic nematodes have been described. Nematodes are characterized by the presence of a stylet, which is used for penetration of host plant tissue. Most of the PPNs attack roots and underground parts of plants, but some are able to feed on leaves and flowers. It has been estimated that about 10% of world agricultural production is lost due to nematode damage (Whitehead, 1998). Plant parasitic nematodes are ubiquitous and yet their presence is generally not felt till faced with the problem of continuous decline in yield in spite of best agronomic practices. The losses incurred as a result of nematode attack do not consist of yield reductions alone but other aspects like lesser ability of infected roots to utilize fully the available nutrients from soil, or the necessity to grow uneconomical rotational crops in an effort to control the nematodes.

3.1. Habitat and survival

These microscopic organisms complete their life cycle in the soil as eggs, juveniles and adults. The nematodes may feed ecto (feed from outside), semi-endo (feed partially inside) or endo (feed internally) parasitically. Plant parasitic nematodes feed with a narrow mouth spear called stylet.

These nematodes may survive adverse conditions in several ways. In most cases eggs can survive drought better than juveniles or adults. Some juvenile stages may be more tolerant than others. Eggs may be retained in female body, which becomes thickened and becomes a cyst or eggs may be laid in gelatinous egg sac, which offers protection to the eggs. Thus the nematodes having very wide plant host range get better protection from hostile environment. Migration into deep soil may protect some vulnerable species from desiccation in the top soil.

3.2. Important plant parasitic nematodes in India

Plant parasitic nematodes broadly divided into two groups above ground feeders and underground feeders. On the basis of feeding behaviour, underground feeders are falling under different sub groups like ecto-, endo- and semi-endoparasites. Further, they classified as sedentary endoparasites (*Meloidogyne and Heterodera*), migratory endoparasites (*Pratylenchus and Radopholus*), semi-endoparasites (*Tylenchulus and Rotylenchulus*), sedentary ectoparasites (Sheath nematode, *Hemicriconemoides*) and migratory ectoparasites (*Longidorus, Xiphinema, Trichodorus*). We dealt here only endo- and semi-endoparasites.

3.2.1. Root-knot nematode, *Meloidogyne* spp.

The root-knot nematode, being sedentary endoparasites, a common name collectively given to *Meloidogyne* spp. It produce knots/ galls of various sizes and shapes on the roots of wide varieties of plants. They are considered as number one farmers' enemy of agricultural crops in the most developing nations. The crop diseases produced by root-knots was first reported on the greenhouse grown cucumbers in England by Berkley (1985). In India, Barber (1901) recorded this nematode for the first time on tea from Kerala. The four most common species in the world are *M. incognita, M. javanica, M. arenaria and M. hapla*. Patel *et al*., (1988) first time reported *M. javanica pathotype* 2 on peanut in Kapdwanj area of Kheda district of Gujarat State.

3.2.1.1. Host range

Meloidogyne spp. is noticed to attack over 2500 hosts. The more preferred hosts are dicot vegetables, pulses, fibers, fruit crops (papaya, grapes, pomegranate etc.), tobacco, peanut, tea, coffee, mulberry, flowers, spices, ornamentals and some monocots like sugarcane, sorghum, banana, rice as well as large number of weeds.

3.2.1.2. Symptoms

The root-knot nematodes basically parasitise plant roots or underground stem, pods, rhizomes, corms etc., and lowers ability of roots in its function of nutrient and water uptake and translocation. The nematode infected plants exhibit yellowing, dwarfing, stunting, and drying of leaf margins and such other symptoms as if it is suffering from nutritional deficiencies.

3.2.1.3. Disease complex with other pathogens

Root-knot nematode interacts with a variety of fungal and bacterial pathogens leading to disease complexes. Galled roots are extensively colonised by rotting fungi *Rhizoctonia solani* and the damage is compounded. Nutrient rich giant cells provide substrates for the proliferation of wilt causing micro organisms like *Fusarium, Verticillium* and *Pseudomonas solanacearum*.

3.2.2. Cyst nematode, *Heterodera* spp.

The second most threat to farmers next to root-knot nematode is cyst nematode (sedentary endoparasites) because of its wide distribution and protection to eggs by cyst formulation. More than 81 *Heterodera* spp., 12 *Globodera* spp. and 9 *Cactodera* spp. are recorded in the world. The first report of *Heterodera* sp. from India was that of *H. avenae* which was then reported to be associated with molya disease of wheat and barley crop in Rajasthan. *H. avenae*, *H. cajani* and *H. zeae* were key cyst nematodes having wide distribution in various states of the country. *Globodera rostochiensis* and *G. pallida* are still major constraints to potato production in Tamil Nadu.

3.2.2.1. Host range

Heterodera spp. is known to attack over 1500 hosts. The most preferred hosts are cereals, pulses, tobacco, sugarcane, potato, sugar beet, rye, some vegetables as well as some weed species.

3.2.2.2. Symptoms

Nematode attacked plants initially exhibit patches of stunted plant growth and chlorosis appear when the crop is about 1-2 month old. With continuous cropping of hosts, such patches gradually increase in size. Tillering is greatly reduced, clums become thinner and weaker. The affected plants may flower prematurely and earheads bear few grains. Roots become typically bushy with slight swelling marking the sites of nematode infection. On uprooting such plants. several whitish to brown females are seen on the roots.

3.2.3. Potato cyst nematode, *Globodera rostochiensis* and *G. Pallida*

It was first discovered by Kuhn in Germany, but he considered it as a form of *H. schachtii*. Potato cyst nematode is distinct from *H. schachtii*. It was later renamed as *H. rostochiensis* after the name of the place (Rostoch) from where it was recorded originally. In India this nematode first time recorded by F. G. W. Jones ins 1961. *H. rostochiensis* and *H. pallida* transferred to separate genus *Globodera* on the basis of round cysts in contrast to lemon-shaped cysts of *Heterodera*.

3.2.3.1. Host range

This nematode feeds on the roots of Solanaceae family plants, such as potatoes and tomatoes.

3.2.3.2. Symptoms

Yellowing of leaves and stunting growth of plants with patchy appearance of plant stand. Nematode cause early senescence and proliferation of lateral roots. Roots are covered by white and yellow coloured small immature females at flowering. Females can be observed on the tuber surface but with less frequency.

3.2.4. Lesion nematode, *Pratylenchus* sp.

The genus Pratylenchus was reported in 1936. It has a cosmopolitan distribution prevalent in temperate, sub-tropical and tropical regions. The species of *Pratylenchus* are popularly known as lesion nematode or meadow nematode. They are migratory endoparasites and various pulses crops are damaged by them. Walia and Seshadri (1986) reported the *P. Thornei* attacks chickpea. *P. zeae* on mungbean and *P. mulchandani* on urdbean (Nanadkumar *et al*., 1969).

3.2.4.1 Host range

The species of *Pratylenchus* infect pulse crops like chickpea, green gram, black gram, lentil. pigeon pea, cowpea, grass pea, french bean and faba bean besides wheat, rice, barley, maize. sorghum, pearl millet, cotton, peanut, sunflower, potato, ginger, turmeric, coffee, cabbage. cauliflower, carrot, radish, turnip, banana, mandarin, tobacco, apple, plum, grape, poppy. avocado, lima bean, common bean and alfalfa etc.

3.2.4.2. Symptoms

The infested plants exhibit various types of symptoms and results in heavy yield losses. At seedling stage infection is manifested by patchy appearance, stunted growth and pale green colour of the lower foliage. Root lesions vary with the cultivars but small lesions are common symptom of this nematode. The lesions may appears on young feeder roots but may be formed anywhere on roots. Later on, the lesions enlarge, coalesce and may girdle the entire root. The secondary attack is by bacteria and fungi resulting in rotting. The severely infected plants are easily pulled out from the soil due to destruction of the root system. Generally the individual roots are discoloured, stubby and mutilated.

3.2.5. Citrus nematode, *Tylenchulus semipenetrans*

The common name 'citrus nematode' signifies its host specificity. In India, it was first reported by Siddique (1961) from Aligarh (Uttar Pradesh). This nematode encountered throughout the world wherever citrus is grown. In India also it has been recorded from almost all the states.

3.2.5.1. Host range

All species of citrus and 11 other species of Rutaceae are hosts of *T. semipenetrans*. Besides, some populations (biotypes) attack olive, grapes, loquat etc.

3.2.5.2. Symptoms

By the attack of this nematode leaves become smaller and chlorotic and leaf drop is more pronounced producing exposed branch terminals. Early wilting occurs during water stress. Infected roots are dirty in appearance with poor development. Faster decay of feeder roots and in severe infestation of nematode root may die. Infested trees are smaller and less productive than normal ones.

3.2.6. Reniform nematode, *Rotylenchulus reniformis*

This nematode first described from Hawaii, USA has widespread presence in the tropics and subtropics. Seshadri and Sivakumar (1963) recorded it for the first time on cotton in India. As the name indicates, reniform nematode female is characterized by typical kidney shaped female. There also exist two races i.e. A and B for Reniform nematode.

3.2.6.1. Host range

It has a wide range of host plants that includes fruit trees, lentil, cotton, pigeonpea, tea, tobacco, soybean, pineapple, banana, okra, coconut, cabbage, sweet potato, alfalfa, corn, asparagus, palm, cucumber, tomato, squash, cassava, radish, eggplant, guava, melon, and ginger etc. (Robinson, 1997).

3.2.6.2. Symptoms

Above ground symptoms on host plants include dwarfing, shedding of leaves, formation of malformed fruit and seeds, and general symptoms of an impaired root system. Roots are discoloured and necrotic with areas of decay. Heavy infestations lead to plant mortality.

3.2.7. Burrowing nematode, *Radopholus similis*

The burrowing nematode was first observed by Cobb in 1890-91 while investigating a banana disease in Fiji, but a complete description of this species was published by him in 1915 under the name *Tylenchus similis.* Thorne (1949) created the new genus *Radopholus* to include *T. similis*, as well as other species.

3.2.7.1. Host range

Banana, citrus, coconut, ginger, tea, black pepper, are the preferred plants but potato, eggplant, tomato, bird of paradise, some ornamentals, and some grasses and weeds may serve as the alternate hosts.

3.2.7.2. Symptoms

Infected plants remain stunted in growth with reduction in size and number of leaves and bunch weight also reduced. Reddish elongated lesions that first appear on roots gradually enlarge and coalesce leading to rotting. On banana, the damage starts when the nematode enters into the primary roots and attacks the corm that cause reddened spots around the feeding sites. This infection is called as 'Blackhead toppling disease', wherein the entire feeding site is exposed, showing the blackened and broken primary roots. Nematode feeding and movement cause severe necrosis and cavity formation within the cortex of banana. *R. similis* interacts with *Fusarium oxysporum* f. sp. *Cubense* and cause Panama wilt in banana.

3.3. Integrated nematode management

Management of nematodes may be approached by using a combination of methods in an integrated pest management system or may involve only one of these methods. Some of the most commonly practiced methods include physical control, cultural management, crop rotation, use of trap crops, use of resistant and tolerant cultivars and chemicals.

3.3.1. Physical control

Nematodes in soil may be killed by soil solarisation. Soil is covered with one or two layers of polyethylene film and sun light is used for raising soil temperature. This is very effective for top soil in hot tropical summer months. Eggs and juveniles of nematodes get killed by exposure for 1-24 h at 41-47°C and repeated exposure to lethal temperature for sub lethal period has been observed to have cumulative lethal effect.

3.3.2. Cultural management

Cultural management methods have the advantage of offering low cost options for nematode management without toxicity or residue problems. Cultural practices includes sanitation of field, deep summer ploughing, fallowing, crop rotation with non-host crops, application of organic manures etc.

3.3.2.1. Sanitation

Age old practice of burning crop residues that lies on field surface should be promoted. It is suggested that root systems of susceptible crop should be removed and destroyed immediately after harvest. Keeping fields weed free is advocated to keep the nematode populations in general under check.

3.3.2.2. Fallowing and deep summer ploughing

Fallowing is a common practice of keeping the soil free from all vegetations for specific period by occasional ploughing during hot and dry weather. Complete fallow without any plant or weed to grow is the best method. This method invariably ensures that parasitic nematodes will have no host to feed and thereby will not be reproduced. Hot summer months in India can be utilised profitably for summer ploughing as it is known to be a very effective farm operation in reducing nematode population by exposing the egg and juvenile stages to high temperature.

3.3.3. Crop rotation

Control of plant parasitic nematodes by crop rotation is based on the fact that some species of nematodes are able to feed and multiply on certain crop plants but not on others. Hosts on which they cannot feed but can abundantly reproduce but can are referred to as non-host. The crops to be grown in between the susceptible host crops should be either resistant or immune to nematodes. Rotation with graminaceous poor hosts such as wheat, barley, ragi, maize, sorghum, etc. or dicot like mustard, sesame, asparagus and so on has some antagonistic effects to suppress root-knot nematodes (Gaur and Mishra, 1983). Haque and Gaur (1985) reported that the incorporation of mustard, sesame, maize, wheat etc. suppressed nematode population in India. Tomato cv. SL 120, castor cv. A 39-1 and cotton cv. Hy-6 cultivated in *Kharif-Rabi* followed by summer green gram in summer effectively checked root-knot nematode (13-17%) and enhanced grain yield of summer green gram cv. Gujarat 2 by 53-76%. In general, the inclusion of Marigold (*Tagetes patula*), Zinnia (*Zinnia elegans*), Sugarcane (*Saccharum officinalis*), Maize (*Zea mays*) and chilli in cropping sequence reduces reniform nematode population.

3.3.4. Application of organic manures

Incorporation of organic substances includes organic manures, green manures and soil amendments like oil cakes (neem and castor cake) reduce the population of nematodes. Mojumder and Mishra (1991) reported the nematicidal effects of water soluble portion of oil seed cakes of neem, mustard, karanj and groundnut against *M. incognita*.

3.3.5. Use of trap crops

Several species of Crotalaria (*C. spectabilis*) and Castor (*Ricinus communis* L.) reported to trap *M. incognita* and *M. javanica* and thereby deplete the nematode population. Antagonistic plants such as Marigold (*Tagetes erecta* and *T. patula*) and Chrysanthemum proved to be effectively reduces *Meloidogyne* population. Sannhemp (*Crotolaria spectabilis*) which traps root-knot larvae can be grown and used as a green manure.

3.3.6. Host resistance

Replacing the susceptible varieties with genetically resistant ones is a convenient option for nematode management. In India, earlier several attempts have been made to screen the available indigenous and exotic crop germplasm to locate resistance sources by many researchers but still work is restricted to evaluation of germplasm against root-knot and reniform nematodes. Khana and Nirula (1964) reported a potato selection HC 294 resistant to *M. ingonita*. Similarly, a tomato selection Pusa 120 exhibited resistance to this nematode (Prasad and Dasgupta, 1964; Singh and Choudhary, 1973). Patel *et al.*, (1990) evaluated different tomato cultivars like NT 3, NT 8, NT 12 and SL 120 and proved that cultivar NT 8 and SL 120 were highly resistant whereas NT 3 and NT 12 were resistant to *M. incognita*. The resistant lines need to be utilised in breeding programme.

3.3.7. Biological control

Soil incorporation with predatory fungus, *Paecilomyces lilacinus* reduced the nematode population by egg parasitisation of some nematodes including *M. Incognita*. Seed treatment (@ $5g^{-1}$/kg seed) as well as soil application (@ 2.5 kg^{-1}/ha) with *Pseudomonas fluorescens or Trichoderma viride* is effective against most of the nematodes. Soil application with *Pseudomonas fluorescens* @ $10g^{-2}$/m reduced the nematode population in vegetable nurseries.

3.3.8. Chemical control

Nematicides are generally not recommended, particularly in vegetable crops, in view of their high cost and residue problem in fruit. However, intensive cultivation of high-value crops make their use unavoidable. Following nematicides are recommended for judicious use:

- Treatment of nursery beds along with carbofuran @ 3kg a.i.$^{-1}$/ ha (0.3g a.i.$^{-1}$/ m^2) in case of transplanted crops at sowing.
- Seed dressing of bold seeded crops like okra, cucurbits, cowpea etc. with carbosulfan 25 EC @2-3% w/w.
- Before transplanting of seedlings dipping of root in Thiaonazin 500 ppm for 15 min or carbosulfan 1000 ppm solution for 1 hr.
- Before sowing or pre-plant soil application of carbofuran @ 1-2 kg a.i.$^{-1}$/ ha in field crops and @ 50-100g^{-1}/ tree in horticultural crops.

4 SOIL BORNE DISEASES AND THEIR MANAGEMENT

"The diseases that are caused by pathogens which persist or survive in the soil matrix and in residues on the soil surface are defined as soilborne diseases". Thus the soil is a reservoir of inoculum of these pathogens, the majority of which are widely distributed in agricultural soils. Most often damage to root and crown tissues of the plant is hidden in the soil. Thus these diseases may not be noticed until the above-ground (foliar) parts of the plant are affected severely showing symptoms such as stunting, wilting, chlorosis and death. Generally these pathogens are difficult to diagnose accurately because they are difficult to grow on artificial media. Soilborne diseases are difficult to control because they are caused by pathogens which can survive for long periods even in the absence of host plants and often have a wide host range including weeds acting as alternate host for several fungal and bacterial pathogens. Chemical control often does not work well in standing crop. The effective control of the soilborne diseases is possible only through detailed study on survival, dissemination of pathogens; effect of environmental conditions, role of cultural practices, host resistance and susceptibility (Jones, 1926).

4.1. Survival and distribution of pathogen in the soil

The pathogens survive as soil inhabitants relatively persist in soil for longer period as compared to soil invaders. Some of the soilborne pathogens survive as non-pathogenic and generally in the form of saprophytes live on decaying organic matter. In certain conditions these saprophytes may turn into pathogenic form.

The distribution of soilborne pathogens depends on cultural practices for crop production, cropping history, types of soil fauna and a variety of other factors. Most of the soil pathogen inoculum present in the upper surface of soils or up to 10 inches depth from the top where host roots, tissues and other organic elements provides food. On the other hand the distribution of inoculum in a field based on the crop susceptibility or host preference.

4.2. Important soil borne pathogens distributed in Indian soils

Soil borne diseases are mostly caused by fungi and bacteria, but several nematode species are also present in soil which enhance the disease development by puncturing the roots and make them more vulnerable to fungal attack. For example; *Fusarium* wilt are more prevalent in the crop fields where *Meloidogyne* nematode also distributed in the soil. These soilborne pathogens are categorized under the following categories:

- Fungi: *Fusarium* sp, *Sclerotium rolfsii, Rhizoctonia solani, Pythium, Phytophthora* etc.
- Bacteria: *Erwinia, Raltsonia, Rhizomonas, Agrobacterium, Streptomyces* etc.

4.3. Factors affecting the distribution of soilborne pathogens

Many factors such as moisture, temperature, soil type, texture, pH and nutrient levels influence the distribution of pathogens in the soil.

4.3.1. Moisture

Moisture is important for sporulation and take-off spores for secondary spread in most of the plant pathogens. For example; survival and distribution of disease causing fungi such as *Pythium* and *Phytophthora* favoured by poorly drained soils. Similarly, *Fusarium* and *Verticillium* wilts can also be more severe in wet soils than in dry soils whereas some pathogens like sugarcane wilt, *Fusarium moniliforme* and common scab of potato, *Streptomyces* scabies favoured by drier soil.

4.3.2. Temperature

Low temperature reduces the amount of inoculum of oomycetes, bacteria and fungi that survives under cold conditions while high temperature reduces the inoculums of viruses and mollicutes that survive under hot summer temperatures. For example; black root rot of tobacco, *Thialaviopsis basicola* becomes highly damaging when the soil temperature is between 17-23°C. The optimum temperature for growth of citrus root rot, *Armillaria mellia* is 21-25°C but it cause infections to roots between 10-18°C when root growth is slow.

4.3.3. Soil Reaction (soil pH)

Diseases favoured by alkaline soils include wilt of pea, *Fusarium oxysporum* f. sp. *pisi*, common scab of potao, *Streptomyces* scabies etc. whereas diseases favoured by acidic soil include cotton wilt (*F. oxysporum* f. sp. *vesinfectum*), tomato wilt (*F. oxysporum* f. sp. *lycopersici*), club root of crucifers (*Plasmodiophora brassicae*) etc.

4.3.4. Oxygen and carbon dioxide concentration

Flooding of soil after crop harvest decreases *Fusarium* sp., *Sclerotinia sclerotiorum* and plant parasitic nematodes due to harmful effects of carbon dioxide concentration. *Phytophthora* sp. requires oxygen for zoospore production.

4.3.5. Light

Low light intensity predisposes tomato plants to attack by *Fusarium*.

4.4. Important plant diseases caused by soilborne pathogens

4.4.1. Root rot

The most important fungal genera which include *Pythium, Phytophthora* and *Rhizoctonia* causes root rots. These diseases are characterised by a decay of the true root system; some pathogens are generally confined to the juvenile or newly developed roots while others are capable of attacking older parts of the root system. Symptoms like wilting, leaf death and leaf fall, death of branches and limbs caused by root rot fungi and in severe cases death of the whole plant. For examples; *Rhizoctonia* is a destructive plant pathogen with an almost unlimited host range. The fungus inhabits in the soils and causes damping-off seedlings, roots, crown and stem rots, and occasionally foliar blight (Backer, 1970). In this disease the invasion of the fungus is limited to the outer cortical tissues which develop elongate tan to reddish brown lesion. Later on these lesions may increase in length and width until they finally girdle the stem and the plant may die.

Phytophthora is one of the major genera of soil borne plant pathogenic fungi belonging to oomycetes group. There are about 60 described *Phytophthora* spp. (Erwin and Ribielo, 1996), which are primary invaders of healthy plant tissue with limited saprophytic ability.

4.4.2. Stem, collar and head rot

These diseases are also caused by a diverse group of pathogens including species of *Phytophthora, Sclerotium, Rhizoctonia, Sclerotinia, Fusarium* and occasionally *Aspergillus niger*. The most obvious symptom of these diseases is the decay of the stem at ground level. Sometimes this decay can lead to symptoms of wilting, death of leaves and to death of the plant. Some examples are heart rot of pineapple, blight of potato and tomato and some fruit rots caused by *Phytophthora* spp. *Similarly Rhizoctonia* spp. can cause leaf blight in maize and head rot of cabbage in warm wet weather.

4.4.3. Wilt

The main genera of fungi that cause these diseases are *Fusarium* spp. and *Verticillium* spp. The greatest number of fungal wilt diseases in higher plants is caused by species of genera *Fusarium*. The fungal pathogen *Fusarium oxysporum* affects a wide variety of hosts of any age. Tomato, tobacco, legumes, cucurbits, sweet potatoes and banana are a few of the most susceptible plants, but it will also infect other herbaceous plants. During the period from 1886 to 1925, *Fusarium* wilt were reported on tomato, crucifers (Smith, 1899), peas, watermelon (Smith, 1899), bananas (Brandes, 1918) etc. *Fusarium oxysporum* generally produces symptoms such as wilting, chlorosis, necrosis, premature leaf drop, browning of the vascular system, stunting, and damping off. The most important of these is vascular wilt. *Fusarium* wilt starts out looking like vein clearing on the younger leaves and drooping of the older lower leaves, followed by stunting of the plant, yellowing of the lower leaves, defoliation, marginal necrosis and death of the plant. On older plants, symptoms are more distinct between the blossoming and fruit maturation stages (Smith *et al.*, 1988). For example; *Fusarium* wilt of cotton (*Fusarium oxysporum* f. sp. *vasinfectum*), castor (*F. oxysporum*), cumin (*F. oxysporum* f. sp. *cumini*), tomato (*F. oxysporum* f. sp. *lycopersici*) coriander (*F. oxysporum* f.sp. *corianderii*) etc. Some bacterial genus like *Pseudomonas* (Bacterial wilt of brinjal, *P. solanacearum*) can also cause similar types of diseases. Symptoms caused by bacterial wilt is almost similar as *Fusarium* wilt except, in bacterial wilt bacterial ooze come out from the affected parts of the plants.

4.4.4. Damping-off

Various common names are used for diseases of seedlings such as seedling blight and damping-off. The fungi that commonly cause seedling death include *Pythium, Phytophthora, Rhizoctonia, Sclerotium rolfsii* and less commonly *Fusarium* sp. These fungi can infect the seedling during the germination, pre-emergence or postemergence phases of seedling establishment. In the pre-emergence phase the seedlings are killed just before they reach the soil surface. The young radical and the plumule are killed and there is complete rotting of the seedlings. The post-emergence phase is characterised by the infection of the young, juvenile tissues of the collar at the ground level. The infected tissues become soft and water soaked. The seedlings are attacked at the collar region and the attacked seedlings are toppled down.

Most often damping-off causing *Pythium* spp. are *Pythium debaryanum, P. ultimum, P. aphanidermatum*, and *P. graminicola*. The disease often occurs in roughly circular pattern because of the tendency of fungi to grow radically from the point of origin, which distinguishes the diseases from other factors that cause the same symptoms. Oomycetes fungi, *Phytophthora syringae, P. cactorum, P. fragaria*, and *P. palmivora* cause primarily low stem rot, damping-off of vegetables, forest trees, and ornamentals. Initially affected tissue develops a soft, watery brown rot and within several days, the affected plant parts may dry. Unlike *Pythium, Phytophthora* is aggressive in warmer soil temperatures (15-23°C), but still exist in cool conditions.

4.5. Integrated management of soilborne diseases

Management of soilborne diseases depends on a thorough knowledge of the pathogen, the host plant, and the environmental conditions that favours the infection. In order for a disease to develop, all three factors must be present. The pathogen (a virulent, infectious agent) must have viable inoculum, such as zoospores, available to infect the host. The host (a susceptible plant) must be exposed to the pathogen's inoculum, and be physiologically susceptible to infection. Finally, the environmental conditions must be favourable for the infection of the plant and growth of the pathogen. For example, the soil must be saturated with water for a certain period of time in order for water moulds to develop and infect roots. An understanding of these pathogen-host-environment dynamics will help to devise a disease management strategy.

Integrated disease management (IDM) can be defined as a decision-based process involving coordinated use of multiple tactics for optimising the control of pathogen in an ecologically and economically fit manner. In most cases IDM consists of scouting with timely application of a combination of strategies and tactics. These may include site selection and preparation, utilising resistant cultivars, altering planting practices, modifying the environment by drainage, irrigation, pruning, thinning, shading, etc., and applying pesticides, if necessary. But in addition to these traditional measures, monitoring of environmental factors (temperature, moisture, soil pH, nutrients, etc.), disease forecasting and establishing economic thresholds are important to the management scheme (Khoury and Makkouk, 2010).

The timing of control measures is also critical. Management of a destructive disease such as *Phytophthora* root rot may require early implementation of appropriate management measures. Management of soil borne diseases is often difficult. Since there is no silver bullet to control these important diseases, it is always advisable to follow all available methods in an integrated manner to better manage soil borne diseases. The major components of disease management summarised here are: host-plant resistance, cultural practices, biological control and chemical control. Even though these components will be dealt with individually, it should be mentioned that often the different components are complementary to each other with strong interaction among and between them and the environment and that it is essential to break away from relying on a single-technology and to adopt a more ecological approach built around a fundamental understanding of population biology at the local farm level and to rely on the integration of control components which are readily available to the resource-poor farmers (Thomas, 1999).

4.5.1. Cultural control

4.5.1.1. Fertiliser application

Excessive use of nitrogenous fertilisers should be avoided and instead balanced applications of fertilisers are to be followed. Application of fertilizers along with irrigation improves the overall plant health and plants stay away from diseases. Application of phosphatic and potasic fertilizers help to increase the immunity in host plants by enhancing the production of phytoalexins. For examples;

- Management of Pythium and Phytophthora by application of phosphoric acid.
- Application of gypsum reduces the incidence of Macrophomina in groundnut.
- Application of ammonium bicarbonate reduces the viability of sclerotial bodies of *S. rolfsii*.

4.5.1.2. Flooding

Flooding can leads to starvation, lack of oxygen and desiccation to plant pathogens which persist in the soil. For example;

- Flooding fields for long periods or dry fallowing reduce the *Fusarium, Sclerotinia sclerotiorum* and nematodes.
- Irrigation also helps to reduce the soil borne disease eg: charcoal rot caused by *M. phaseolina*.

4.5.1.3. Drainage

Good drainage system can help in air circulation among plant roots for growth and also helpful in reducing the distribution of soilborne pathogen which can move by the help of excessive amount of water so management of irrigation water is necessary to minimize water dispersal of soil borne pathogens. For example; good soil drainage reduces the number and activity of certain oomycetes fungal pathogens (e.g. *Pythium*) and nematodes.

4.5.1.4. Rouging

Timely removal of infected and died plants from the field population, known as rouging. It can reduce the potential for inoculum build up.

4.5.1.5. Tillage practices

Summer deep ploughing of crop residues present in field which harbours the pathogen is more effective in reducing this important source of infection. Sub-soiling prior to planting was found to increase the green pea yields of root rot susceptible and tolerant cultivars planted in the soil infested with *F. solani* f. sp. pisi and *Pythium ultimum* (Singh, 2001).

4.5.1.6. Plant density

Plant density influences the micro-climate and spread of the diseases. High density (closer spacing) raises atmospheric humidity and favours multiplication of many pathogenic fungi and bacteria. For example;

- Wider spacing reduces the *F. oxysporum* f.sp. *ciceri.*
- Severity of crown rot population in wheat increased due to high plant population.
- High density planting in chillies leads to high incidence of damping off in nurseries.

4.5.1.7. Weed control

Both host and non-host weeds favour disease development by influencing the factors resulting in more inoculum. This includes shading the soil and serving as organic substrate or food base for infection of the host crop. These also change the crop micro-climate and affect soil microflora.

4.5.1.8. Growing of cover crops

Cover crops increases soil microbial diversity by enhancing the soil microflora.

- Mustard and *Brassica* sp. (Broccoli) helps to reduce the load of soilborne pathogens.
- The *Brassica* spp with high content of glucosinolates in their tissues and allylisothiocyanate in leaf extracts create unfavorable conditions for microbes.
- The incorporation of leaves and/or roots of *B. juncea* is suggested against *Rhizoctonia solani* and *Gaeumannomyces graminis* var. *tritici.*

4.5.2. Crop rotation

Generally soilborne pathogens survive in the soil and plant debris up to several years. Crop rotation will be helpful to control the soil borne inoculum because if the host is not present for particular number of years then the amount of inoculum will be reduced. Satisfactory control through crop rotation is possible with pathogens that are soil invaders in comparison to soil inhabitants. Crop rotation can still reduce populations of the pathogen e.g. *Verticillium, Fusarium* etc. in the soil and appreciable yields from the susceptible crop can be obtained every third or fourth year of rotation.

4.5.3. Soil Solarisation

In this practice, the upper soil surface (5 cm soil) temperature increases up to 52°C by using the plastic mulch sheet over moist soil during sunny summer days. If sunny weather continues for several days, the increased soil temperature from solar heat, known as 'soil solarisation'. This increased temperature inactivates or kills many soilborne pathogens such as fungi, nematodes, and bacteria near the soil surface, thereby reducing the inoculum and the potential for disease. For example; *Fusarium, Verticillium* wilt and bacterial canker of tomato, *Clavibacter michiganense*, can be controlled by soil solarisation.

4.5.4. Soil amendments

Application of organic amendments like well decomposed FYM, saw dust, oil cakes, sulphur, lime etc. reduce the by producing several antagonistic chemicals toxic to disease producing soilborne pathogens. For examples;

- Application of lime (2500 kg ha^{-1}) reduces the club root of cabbage by increasing soil pH to 8.5 (Utkhede and Gupta, 1996). Similarly application of sulphur (900 kg ha^{-1}) to soil brings the soil pH to 5.2 and reduces the incidence of common scab of potato caused by *Streptomyces scabies* (Davis *et al.*, 1974).
- Application of organic amendments like saw dust, straw, oil cake, etc., will effectively manage the diseases caused by *Pythium, Phytophthora, Verticillium, Macrophomina, Phymatotrichum* and *Aphanomyces*
- Application of castor cake and neem leaves helps to reduce the foot rot of wheat (Utkhede and Gupta, 1996).

4.5.5. Seed treatment

Seed treatment plays an important role in soilborne disease management. In this method very less quantity of pesticides are required as compared to foliar applications. Seed treatment with thiram and carbendazim @ 2-3 g kg^{-1} seed give satisfactory control against soilborne pathogens like *Fusarium, Pythium, Rhizoctonia* etc. Nasreen and Ghaffar (2010) conducted an experiment on cucurbits to know the efficacy of fungicides as seed treatment against *Fusarium solani* and found that the maximum reduction in seedling mortality was obtained where seeds were treated with Topsin-M (4%) followed by *Ridomil, Aliette, Benlate, Carbendazim,* Mancozeb and Vitavax. Similarly root infection was significantly controlled by fungicidal treatments but with varied effect. Carbendazim and Topsin-M controlled maximum root infection by 6 and 8% respectively. Several antagonistic fungi (*Trichoderma, Gliocladium*) and bacteria (*Pseudomonas, Penicillium, Bacillus, Enterobacter*) are isolated for bio-control of disease causing pathogens present in soil. These bio-agents are commercially available for seed treatment as well as soil application. Fusarium wilt can be effectively controlled by seed treatment with Trichoderma @ 4g kg^{-1} seed and soil application of 2.5 kg Trichoderma mixed in 25 kg FYM for one hectare.

4.5.6. Biological control

Biological control is the reduction of the amount of inoculums or disease producing activity of a pathogen accomplished by or through one or more organism other than inoculums. It is the use of organism, gene or gene product to regulate a pathogen (*i*) by keeping below the economic threshold level (*ii*) retard or exclude infection (*iii*) maximising plant self defence. There are, for example, several diseases in which the pathogen cannot develop in certain areas either because the soil, called suppressive soil, contains microorganisms antagonistic to the pathogen or because the plant that is attacked by a pathogen has also been inoculated naturally with antagonistic microorganisms before or after the pathogen attack. Sometimes, the antagonistic microorganisms may consist of avirulent strains of the same pathogen that destroy or inhibit the development of the pathogen, as happens in hypo virulence and cross protection. Success in using microorganisms against plant pathogens started with the control of crown gall with *Agrobacterium radiobacter* K 84 (Kerr, 1980), and that of seedling blights caused by *Pythium* and *Rhizoctonia* with *Trichoderma harizanum* (Harman and Bjorkman, 1998), *Gliocaladium virens* and *Streptomyces griseus* (Cook *et al*., 1996). The strains of *Trichoderma* spp are opportunistic invaders, fast growing, prolific producers of spores and powerful antibiotic. These are some of ideal characters which make them a very successful bioagent (Kubicek *et al*., 2002). This process is often accelerated by adding composts or manures, which enrich the soil with antagonistic microflora.

4.5.6.1. Vesicular Arbuscular Mycorrhizal (VAM) and disease suppression

Mycorrhizae are formed as a result of mutualist symbioses between fungi and plants and occur on most plant species. Because they are formed early in the development of the plants, they represent nearly ubiquitous root colonists that assist plants with the uptake of nutrients (especially phosphorus and micronutrients). The mycorrhizal fungi protect plant roots from diseases in several ways.

- By providing a physical barrier to the invading pathogen: Physical protection is more likely to exclude soil insects and nematodes than bacteria or fungi. VAM fungi have been found to reduce the incidence of root-knot nematode (Linderman 1994). However, some studies have shown that nematodes can penetrate the fungal mat.
- Various mechanisms also allow VAM fungi to increase a plant's stress tolerance. This includes the intricate network of fungal hyphae around the roots which block pathogen infections. Inoculation of apple-tree seedlings with the VAM fungi *Glomus fasciculatum* and *G. macrocarpum* suppressed apple replant disease caused by phytotoxic myxomycetes (Catska 1994).
- By providing antagonistic chemicals: Mycorrhizal fungi can produce a variety of antibiotics and other toxins that act against pathogenic organisms. VAM fungi indirectly suppress plant pathogens and enhances nutrition to plants; bring about morphological changes in the root by increased lignification and cause changes in the chemical composition of the plant tissues like antifungal chitinase, isoflavonoids, etc. (Morris and Ward 1992).
- By competing with the pathogen.
- By increasing the nutrient-uptake ability of plant roots. For example, improved phosphorus uptake in the host plant has commonly been associated with mychorrhizal fungi when plants are not deprived of nutrients, they are better able to tolerate or resist disease-causing organisms.
- By changing the amount and type of plant root exudates. Pathogens on certain exudates will be at a disadvantage as the excudates change. Two pot experiments were carried out in the greenhouse at Agriculture Research Center, Giza, Egypt, to study the effect of VAM and *T. viride* as deterrents against *R. solani and F. solani* disease on growth and quality of sugar beet (Aly and Hussein, 2009). Among all the treatments plants treated with mycorrhiza and *T. viride* recorded higher survival rates in sugar beet plants.

In field studies with eggplant, fruit numbers went from an average of 3.5 per plant to an average of 5.8 per plant when inoculated with *Gigaspora margarita* mycorrhizal fungi. Average fruit weight per plant went from 258 grams to 437 grams. A lower incidence of *Verticillium* wilt was also realized in the mycorrhizal plants (Matsubara *et al*., 1995).

4.5.7. Chemical Control

Chemical pesticides are generally used to protect plant surfaces from infection or to eradicate a pathogen that has already infected a plant. From many decades fungicides played an important role in disease control. In the 1960s, systemic fungicides started gradually to replace the older non-systemic chemicals with more effectiveness and specificity in disease control. However, the non-systemic fungicides such as mancozeb, chlorothalonil, copper and sulphur based products continued to have a good share of the market, especially in developing countries because of their lower cost. More recently, new classes of fungicides were developed with significant impact on disease control. These include anilinopyrimidines, phenoxyquinolines, oxazolidinediones, spiroketalamines, phenylpyrroles, strobilurins and activators of systemic acquired resistance. The availability of a variety of new products with narrow and broad specificity, offer important disease control options, however, their practical application continues to face the risk of creation of resistant pathogen populations (Gullino *et al.*, 2000). Experience accumulated over the last few decades clearly showed that fungicidal application had a better impact when used within an IDM strategy (De Waard *et al.*, 1993). In addition, public concern has increasingly influenced the fungicide industry in developing effective products with low mammalian toxicity and environmental impact and low residues in food, to meet international health standards and compatibility in integrated pest management programs (Knight *et al.*, 1997). Chemical control includes soil treatment (such as fumigation), disinfestations of warehouses, sanitation of handling equipment and control of insect vectors of pathogens.

4.5.7.1. Soil Treatment by chemicals

Pre-planting and post-planting application of chemicals for soil treatment is effective preventive method for controlling the soilborne pathogens but pre-planting application more effective to escape the plants from pathogen infection. Fungicides used for soil treatments include metalaxyl, carbendazim (Bavstin), diazoben, pentachloronitrobenzene (PCNB) etc. Chemicals in plant disease are used to create the toxic barrier between the host surface and pathogen. Drenching with copper oxychloride 0.2% or Bordeaux mixture 1% suitable for controlling the damping-off diseases while soil drenching with Trifloxystrobin + Tebuconazole @ 0.75g litre^{-1} water for control the Rhizoctonia spp.

4.5.8. Host-plant Resistance

Host plant resistance has been an apt choice in all the crop improvement programs and is essential to recommend the cultivars directly for cultivation in endemic areas, infested with soil borne fungus. Although the resistant variety is always one of the best way in reducing the loss due to soli borne plant pathogens. Disease resistant plants are obvious and effective control measure because resistance can be both competing and long lasting. A plant can express the resistance through the action of a single gene that confers the immunity (resistance to certain races of *Fusarium*) or through multiple genes that results in a broad resistance to many pathogens. Single-gene resistance, called the *vertical resistance*, limits both the level of infection and the production of the inoculums. This sort of resistance can be overcome, however, by new strain of the target pathogen. Multi-gene resistance, called horizontal resistance, allows some disease to develop but limits it to a tolerable level.

Efficient field, greenhouse and laboratory procedures to evaluate chickpea and pigeonpea lines for resistance to *Fusarium* wilt have been developed and standardised at ICRISAT (Nene *et al.*, 1981; Nene and Kannaiayan, 1982; Nene *et al.*, 1989). In India, host plant resistance to *Fusarium* wilt of tomato was studied by evaluating a collection of 134 cultivars, breeding lines and alien species of tomato. Out of these genotypes, eight possessed high degree of resistance to race of *F. oxysporum f.* sp. *Lycopersici* (Kesavan and Chowdhary, 1977). Similarly, Chauhan (1988) studied the reaction of several varieties lines of tomato to *Fusarium* wilt at Hissar. Out of 142 advance lines of chilli, 16 were resistant and 48 were moderately resistant (Ahmed *et al.*,1994).

Incorporation of resistance by conventional breeding techniques in susceptible cultivars has been achieved against many vescular wilt pathogens such as *Fusarium* and *Verticillium* spp. in a few crops. However, it is too much to expect in case of soil borne pathogens such as Fusarium to have stable resistance because of variability of the pathogen.

4.6. General preventive measures to avoid soilborne diseases occurrence

- Select resistant cultivars seed from certified agency and should be free from pathogens.
- Avoid mechanical damage to plants.
- Balanced use of fertilisers; raising the soil pH to 6.5–7 by using appropriate soil amendment and fertilisers will decrease the development of *Fusarium* Wilt.
- Avoid excessive use of nitrogenous fertilizers.
- Crop rotation for 3-4 years should be adopted or avoid monoculture.
- In vegetative propagation, plant parts should be sterilised or free from any infection.
- Always, nursery should be grown on raised beds or on well drained soil surface.
- Restrict the use of machinery in infested areas, particularly when soil is wet.
- Prevent movement of soil from infested to non-infested areas of nursery.
- Avoid over watering to puddle or run-off point.

4.7. Future strategies for successful IPM and IDM programme

- The success and sustainability of IPM and IDM strategy need components that are locally specific, ecologically sound and readily available to farmers.
- Training and awareness programs organized by different departments like disease survey teams, agricultural development officers, extension agents and policy makers remains to be an important factor for the successful implementation of IDM strategies.
- All direct stakeholders including farmers, extension workers, and local crop protection technicians should have a practical understanding of the ecology, etiology and epidemiology of the major diseases of the crop.
- Training programs should be oriented on specific topic like importance of seed treatment, soil solarisation, use of resistant/ tolerant cultivars, use of bio-agents etc.
- Future research in entomology and plant pathology should be focused on augmentation and conservation of bio-agents to promote the biological control for sustainable IPM and IDM.
- Policies should be eliminated that promote environmentally unsustainable pest and disease management techniques and strengthening regulatory institutions.

5 CONCLUSIONS

Integrated pest and disease management is a control approach that uses all available management strategies to maintain insect-pests and disease pressures below an economic threshold level. It is stated that the management of soil borne pathogens is most successful and economical when all the required information such as cropping pattern, damage causing pathogens, life history of these pathogens, resistance or tolerance level of host plants and set of different abiotic factors prevailing there. Soil dwelling insects and primary stages of inoculum of pathogens effectively managed by integration of different approaches like treatment of seed or propagative material, cultural practices, soil solarisation, manipulation of host plant resistance, use of bio-agents, botanical/bio-pesticides and chemical pesticides. It is concluded that sowing of disease free seed or propagative material is of paramount importance in soilborne pest and diseases. Seed or propagative material should be treated with any systemic insecticides/ fungicides/ bactericides and/ or bio-control agents like Trichoderma. It is suggested that proper cultural practices like deep summer ploughing, crop rotation, fallowing etc. should be followed with application of soil amendments like oil cakes (neem, castor, karanj & mustard cake) for increasing the organic matter and antagonistic activities of beneficial soil microorganisms against harmful pathogens. Lowland areas should be well drained to avoid congenial conditions of disease causing pathogens. The continuous use of chemical pesticides causes hazardous to beneficial soil micro flora and disturbed the natural control of these pathogens. For eco-friendly management of soilborne pests, it is advocated that more emphasis should be given on bio-pesticides/ botanical pesticides rather than chemical pesticides. So many locality specific resistant cultivars have been developed which can be best for successful pest and disease management. Trap crops like African marigold, sannhemp, chrysanthemum planting effectively manage the nematode population by attracting them from main crop. Even after all these strategies, if insect-pest and disease appears, soil drenching with granular insecticides and fungicides may be given in high value cash crop. Each one of these measures must be used and combined for reaching a target of no insect-pest and disease in the crop.

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