REVIEW OF LITERATURE
2. REVIEW OF LITERATURE

In nature plants are exposed to large number of microorganisms both in aerial and soil environment. Soil is a complex ecosystem, inhabiting a wide variety of life forms, pathogenic as well as saprophytic, which often show synergistic, symbiotic and antagonistic relationships between themselves. It has been estimated that 1 m² of highly fertile field soil may contain as many as $3 \times 10^{14}$ bacterial cells (300g), $5 \times 10^{8}$ protozoa (39g), $1 \times 10^{7}$ nematodes (12g) and 400g of fungi (Richards, 1976). Many of these microorganisms have capacity to cause plant diseases independently, while some require association of other organisms. Thus, sometime plant damage aggravates when two or more pathogens attack simultaneously. Plant-parasitic nematodes, for instance, have unique position in such situations; this is evident by the work of Mayol & Bergeson (1970) and Starr & Mai (1976) who have found that root-knot nematodes cause greater damage in natural soil than in autoclaved soil.

Several possibilities have been suggested by workers by which plant-parasitic nematodes interact with other microorganisms. According to Pitcher (1965), nematode may acts as: (i) vectors of pathogens capable of self-establishment once in contact with the host, (ii) vectors of pathogens incapable of self-establishment unless introduced below the
epidermis, (iii) mechanical wound agents, (iv) providers of necrotic infection-courts, (v) modifiers of the substrates, (vi) breakers of the disease resistance and (vii) deterrents of plant diseases.

Plant-parasitic nematodes have also been found interfering the activities of rhizobia present in special structures called root-nodules of leguminous plants and thus cause much loss to the fertility of soil.

Recently several workers have reviewed the work on various associations of plant-parasitic nematodes with other microorganisms, e.g., fungi (Powell, 1971a,b,1979; Pitcher, 1965,1978; Mai & Abawi, 1987), root-nodule bacteria (Pitcher, 1978; Norton, 1978), pathogenic bacteria (Powell, 1971; Pitcher, 1978), viruses (Powell, 1971; Martelli, 1978; Lamberti, 1981) and other nematodes (Powell, 1971; Dropkin, 1980; Eisenback & Griffin, 1987). Various aspects of interactions between plant-parasitic nematodes and soil pathogenic fungi and rhizobia are discussed hereunder:

NEMATODE-FUNGUS INTERACTIONS:

The literature on interactions of nematodes with fungi is more extensive than those concerning with other pathogens. For convenience it is categorized according to the nature of fungi involved.
1. Interaction between nematodes and wilt-fungi:

Although these pathogens may be destructive when acting alone, their combined pathogenic association may be greater than the sum of their individual effects. The first such study was carried out by Atkinson (1892) who found that root-knot nematode (*Meloidogyne* spp.) increased the severity of *Fusarium* in cotton. Since then large number of workers have studied the association between two or more pathogens. Root-knot nematode and *Fusarium* spp. together caused greater damage to several crops than their association with other pathogens. However, there are many reasons for their selective action of these pathogens. Being a sedentary endoparasite, the females of *Meloidogyne* spp. which settle in the vascular region form a special relationship with wilt fungi which are also pathogens of vascular system; this results in increased severity of the disease. Atkinson's work was later supported by Smith (1941, 1954).

There are several reports which show that root-knot nematode was capable of breakdown of plant resistance against wilt fungi. Significant increase in the *Fusarium* wilt incidence was noted by Martin *et al.* (1956) in wilt-susceptible variety of cotton, viz., Deltapine-15 as well as in wilt resistant variety Cooker-100, where the resistance was broken in the presence of *Meloidogyne incognita* and *M. incognita acrita*. Similarly two Tanzanian cotton varieties
e.g., UK-71 and UK-77 lose resistance against wilt fungus in the presence of *M. incognita* (Melakeberhan & Evans 1981).

Menezes & Balmer (1974) reported that a resistant variety of tomato became susceptible to *F. oxysporum* f. *vasinfectum* in the presence of root-knot nematode. Similar results were also obtained by Young (1939) and Harrison & Young (1941) in different varieties of tomato. An interesting phenomenon was noted by Goode & Mc-Guire (1967) regarding the Fusarium wilt of tomato. In greenhouse test a virulent races of *Fusarium oxysporum* f. *lycopersici* became virulent after root-knot nematode predisposed certain cultivars of tomato, thus raised the possibility that the fungus mutates within the nematode-infected host. The resistance was broken in moderately resistant tomato variety "Pearson VF-11" in the presence of *M. javanica* with *F. oxysporum* f. *lycopersici* race 1 (Pitcher, 1974). Binder & Hutchinson (1959), on the other hand, were not able to get the positive interaction between the root-knot nematode and Fusarium wilt of tomato. Johnson & Littrell (1969) also supported the above findings that the presence of *M. javanica* or *M. hapla* failed to break the resistance of chrysanthemum variety 'Iceburg' against Fusarium wilt, however, their presence enhanced wilting in the susceptible variety "Yellow-Delaware".

The soil infested with *M. javanica* increased the wilt incidence of cowpea caused by *F. oxysporum* f. *tracheiphilum*
(Thomason, 1958), however, Thomason et al. (1959) found that cowpea variety 'Grant' has not only lost resistance in the presence of *M. javanica* and *F. oxysporum f. tracheiphilum* but has also increased the severity of wilt than that in the susceptible variety "Chino-3". *M. javanica* also reduced the resistance of cowpea to *F. oxysporum f. tracheiphilum* (Swanso, 1985). The resistance was broken in chickpea variety "Avrodhi" to *Fusarium* in the presence of *M. javanica* (Upadhyay & Dwivedi, 1987); resistance of pea variety 'Alaska' to *F. oxysporum f. pisi* was broken in the presence of *M. incognita* and *M. hapla* (Davis & Jankins, 1963).

Jenkins & Coursen (1957) used two species of *Meloidogyne* and found that these affected the host in somewhat different manner, and these differences were meaningful with respect to the predisposition to *Fusarium* wilt. Both *M. incognita acrita* and *M. hapla* promoted wilt development in *Fusarium* wilt resistant tomato variety 'Chesapeake' but with different degree. When *M. incognita acrita* was combined with the fungus 100% wilting occurred as compared to only 60% when *M. hapla* was present. This suggest that their physiological effects were different because of difference in their infectivity. While Bowman & Bloom (1966) predicted that *M. incognita* probably changed the physiology of the host in such a manner that it became more susceptible to *Fusarium* wilt resulting in the breaking of resistance against the wilt fungus. Similarly three species of
Meloidogyne, viz. M. hapla, M. iavanica, and M. incognita have also shown differences in their capacity to damage alfalfa plants (McGuire et al., 1958). The extent of damage due to *F. oxysporum f. vasinfectum* increased 95, 90 and 50% when the fungus was present in combination with M. hapla, M. iavanica and M. incognita respectively. Physiological changes due to M. incognita were also noted in Fusarium-susceptible and -resistant tomato plants by Kleineke & Wyss (1981). They found that there was an enrichment of carbohydrates especially of reducing sugars, glucose and fructose, as well as of free-amino acids more in the root than shoot; the resultant effect of both the pathogens increased the amount of auxin and cytokinin contents.

There has been an assumption that wounding caused by nematodes especially root-knot nematodes increase the susceptibility of plants to invasion by wilt fungus. It was thought that root-knot larvae provide avenues for entry of *Fusarium* spp. and other fungal pathogens (Taylor, 1979). If wounding were so important, the enhanced susceptibility would be at its maximum at the time of penetration of root-knot larvae into the host roots. But this was not so. It was demonstrated that the severity of wilt diseases caused by fungi including *Fusarium* was greater when root-knot nematode were inoculated two-to-four weeks prior to the inoculation of host plants with the fungus, as compared to simultaneous
inoculation (Powell, 1971a,b; Powell, 1979). This revealed that the interactions between root-knot and *Fusarium* wilt-fungus form complexes leading to the modification of host physiology rather than just wounding. It was further supported by the fact that by the infection of root-knot nematode the root was predisposed to *Fusarium* wilt fungi which were attracted towards the infection sites. Additional information of this concept was provided by Perry (1963) from anatomical studies of roots of cotton seedlings infected with *M. incognita*. Jenkins & Coursen (1957) and Thomason et al. (1959) have shown that the mechanical injury or wounding though increased the susceptibility of the host plant to *Fusarium* wilt considerably but it was less than that caused by *Meloidogyne* spp. It shows that their relationships are biological or physiological rather than physical in nature. Porter & Powell (1967) noticed in some hosts that root-knot nematodes apparently are capable of maximum predisposition only after 3-4 weeks. This time interval would be sufficient to permit the formation of galls leading to morphological and physiological changes. The association of *M. incognita* and *F. oxysporum f. coffeae* on coffee seedlings resulting the effect in the form of chlorosis, root-necrosis, wilting and dwarfing and the reduction in these parameters were significantly greater in plants inoculated with fungus 4 weeks after nematode inoculation.
Webster (1975) and Sidhu & Webster (1977) reported greater severity when *M. incognita* predisposed tomato plants to *F. oxysporum f. lycopersici* and their complex showed chlorosis of foliage and physiological changes in the feeding sites which were mainly responsible for wilting. Wilting was more severe in the presence of *M. incognita* with *F. oxysporum f. niveum* on watermelon (Sumner & Johnson, 1973). The nematode increased the susceptibility of cucumber plants to *F. oxysporum f. cucumerinum* (Costache et al., 1978).

The soil infested with root-knot nematode play an important role to increase severity. Thomason (1958) found that wilt of cowpea caused by *F. oxysporum f. tracheiphilum* was much more severe in soil infested with *M. javanica*. Similarly severe wilting of *Mimosa* seedlings were recorded in the soil infested with *M. incognita* or *M. javanica* (Gill, 1958). Schindler et al. (1959, 1961) observed that endoparasitic nematodes like *M. hapla*, *M. arenaria thamesi*, *M. incognita acrita* and *M. javanica* increased carnation wilt caused by *F. oxysporum f. dianthi* while *Helicotylenchus nannus* and *Rotylenchulus buxophilus* did not cause significant wilting. The carnation wilt was increased when *F. oxysporum f. dianthi* was inoculated at different time intervals (1 week, 2 months, 5 months) along with root-knot nematode. The plant mortality was found greater in okra by Rankin (1957) due to combined effect of *F. oxysporum* either...
with *M. incognita* acrita or *Pratylenchus leiocephalus*. On the other hand, Menezes & Balmer (1974) noted that soybean, bean and pea plants when grown in soil infested with root-knot nematode showed susceptibility to *F. oxysporum* f. *vasinfectum*. The similar result was obtained by Lopes & Lordello (1979) with *F. solani* f. *piperi* and *M. incognita*.

Bergeson et al. (1970) noted that the rhizosphere soil of tomato plants infected with *M. javanica* had more propagules of *F. oxysporum* f. *lycopersici* as compared to the rhizosphere of non-infected plants. They also reported a significant decrease in the population density of actinomycetes in the same rhizosphere soil. They concluded that the decrease in densities of actinomycetes may be due to changes in the pH or the selective increase of competitors or antagonists of actinomycetes. Some actinomycetes are known antagonists of *Fusarium* spp. (Cook & Barker, 1983; Walter, 1965). Noguera Gonzalez (1977) noted that the intensive stem necrosis developed within 10 days of fungal infection of *F. oxysporum* f. *batatus* on tobacco before plant infected first with *M. incognita*, thus followed by death of the plants. Liburd & Mai (1976) discovered that the simultaneous inoculation of tomato with *M. incognita* and *F. oxysporum* f. *lycopersici* resulted in earlier appearance of wilt-symptom and increased incidence of the disease as compared to the plants inoculated with fungus and nematode alone. The maximum percentage of wilting occurred due to simultaneous
inoculation of *M. incognita* with *Fusarium* on Frenchbean (Singh *et al.*, 1981) and *M. incognita* with *F. oxysporum* f. *cucumerinum* on cucumber (Pelcz *et al.*, 1982). While Padil *et al.* (1980) noticed the death of pea plants after 45 days when inoculation was made simultaneously with *M. incognita* + *M. hapla* and *F. oxysporum*. However, Moorman *et al.* (1980) found severe wilt-symptoms when both pathogens were inoculated simultaneously. The wilt resistant variety of flu-cured tobacco 'Coper-298' becomes susceptible in the presence of *M. incognita*.

It is well known that temperature plays an important role in disease development caused by more than one pathogen. Morrell & Bloom (1981) found that greatest wilt occurred in tomato at 21-24°C due to combination of *M. incognita* and *Fusarium oxysporum* although *Fusarium oxysporum* alone cause significant wilt at 24°C. Optimum temperature for wilt development differ with different nematode genera, 23°C being optimum with stunt nematode, *Tylenchorhynchus capitatus*, and 29°C with root-knot nematode, *Meloidogyne incognita* (Overman & Jones, 1977) for the wilt caused by *Verticillium dahliae*.

Interesting results were obtained by Martin *et al.* (1956) while working on *Fusarium* wilt of tomatoes and cotton. They found that soil fumigation not only controlled root-knot nematode but also the wilt disease, which otherwise developed in the presence of root-knot nematode in unfumigated soil.
Supporting evidences were provided by Ross (1965) who observed the wilting of soybean cv. 'Jackson' due to *Fusarium* and root-knot only in unfumigated plots, whereas the plants were found wilt-free in fumigated plots with nematicides and thus visualised the role of nematodes in the causation of wilting of soybean.

The histopathological studies of roots infected with certain sedentary endoparasitic nematodes particularly root-knot nematode and *Fusarium* revealed their actual relationship vis-a-vis the host. Minton & Minton (1963) studied the histopathology of cotton roots jointly infected with *M. incognita acrita* and *F. oxysporum f. vasinfectum* and observed abundant fungal growth in giant cells induced by nematode as well as in the xylem, while the fungus was absent in phloem and cambium. The fungus also grew well in decaying cortical and epidermal cells, but poorly in apparently healthy tissues. The fungus entered the decaying tissue through xylem. The interaction between root-knot and *Fusarium* in tobacco also revealed a similar trend (Melendez & Powell, 1967) where the giant cells and xylem element of both wilt-resistant and susceptible plants were found to be heavily invaded by *F. oxysporum f. necotianae*. Giant cells were highly sensitive to fungal attack and became devoid of protoplasm content soon after fungal invasion. This damaging of giant cells was accompanied by gradual debilitation of
fungal hyphae occupying the tissues and ultimately the infection, also affect female nematode and adversely affect eggmass production. These workers also found that the fungus colonization was not restricted to the galled region of a nematode infected plants but they also colonized the other parts of the plants. Such fungus growth was not observed in nematode free plants. Davis (1963) also reported similar histological changes on pea; the fungus invaded the galled region, more prominently the giant cells. Giant cells and surrounding tissues were also invaded and colonised by the hyphae of *F. oxysporum f. lycopersici* on cucumber plants previously infected by *M. incognita* (Hirano & Kawamura, 1971). Rushdi *et al.* (1982) supported the above finding while studying the histological changes in broadbean and cowpea by obtaining the results in the form of multinucleate giant cells with granular cytoplasm when the plants were infected by both *M. javanica* and *Fusarium* spp. which caused much damage to entire plants.

Recently Webster (1985) has given in detail the ultrastructural response of tomato roots to infection by *F. oxysporum f. lycopersici* and *M. javanica*. The giant cells appeared normal in wilt-resistant cultivars and these cultivars exhibited no sign of fungal growth after one week of fungal inoculation. Abundant *Fusarium* hyphae were present in xylem tissues of *Fusarium*-susceptible but not in *Fusarium*-resistant cultivars at two weeks after fungal
inoculation. Giant cells exhibited degeneration which were characterised by membrane and organelle disruption. Three weeks after fungal inoculation, hyphae and conidia were visible inside xylem tissues and the giant cells in *Fusarium*-susceptible plants and also in xylem tissues of resistant plants. Nuclei of giant cells of both cultivars inoculated with *Fusarium* became spherical and dark inclusions occurred within chromatin material that condensed adjacent to the fragmented nuclear membrane. Such ultrastructural changes in giant cells were absent or not found in the root of plants inoculated with *M. incognita* alone. Since changes in the structure of giant cells were observed prior to hyphal entry, it was suggested that translocatable fungal metabolites or fungal induced plant substances are responsible for the modification and eventual death of the giant cells (Fattah & Webster, 1983).

Another genus of sedentary endoparasitic nematode, *Heterodera* has been found involved in complexes with the *Fusarium*-wilt fungi. Ross (1965) has seen such type of complex on soybean involving *H. glycines* and stated that the cyst nematode was more effective in predisposing plants to *Fusarium* wilt than *M. incognita* and visualised that this difference in the predisposing abilities between the two genera was due to penetration and migration behaviour rather than physiological difference; soybeans are generally more
tolerant to root-knot nematodes than to cyst nematodes. *Heterodera trifolii* has been found to increase wilting in the presence of *Fusarium oxysporum* and *Fusarium avanaceum* in clover plants (Sikora, 1977). In a similar report, Edward & Singh (1979) found the greater damage in pigeonpea due to association of *Heterodera cajani* with *Fusarium udum* while on the other hand, no relationship was observed by Gill & Swarup (1977) on barley plants in the form of interaction between *H. avenae*, *Fusarium moniliforme* and *Helminthosporium gramineum*. Similarly it was not found in another nematode species. The synergistic relationship between *Heterodera cajani* and *Fusarium udum* was established on pigeonpea and caused severe wilting while this relationship was not noticed between *F. udum* and three ectoparasitic nematodes, viz., *Tylenchorhynchus vulgaris*, *Helicotylenchus indicus* and *Hoplolaimus indicus* as reported by Hasan (1984). The synergistic relationship was also not found by Jorgenson (1970) who successfully controlled the sugarbeet disease caused by *Heterodera schachtii* and *F. oxysporum* by their antagonistic behaviour and realised that this interaction was disadvantage to the nematode. The fungus inhibited the nematode invasion and decreased its population resulting less damage. Another cyst nematode, *Globodera tabacum* did not develop relationship with *Fusarium* spp. on tomato and thus reduced the disease intensity and soil population of *Fusarium oxysporum* too (Miller, 1975).
Semi-endoparasitic nematode also becomes involved with the wilt-fungus, *Fusarium oxysporum*. Such type of association was seen by Neal (1954). The association of *Rotylenchulus reniformis* and *Fusarium*, developed wilt symptoms in susceptible cotton var. Half-and-Half, however, little wilt developed in resistant var. Delfos 425-920.

Nematodes other than sedentary endo and semi-endoparasites have also been found capable of forming disease complexes with *Fusarium*-wilt fungi (Powell, 1963). The sting nematode, *Belonolaimus gracilis* is as efficient as root-knot nematode, *M. incognita* which promoted wilt in the cotton caused by *F. oxysporum f. vasinfectum* as reported by Cooper & Brodie (1963). Holdeman & Graham, (1952, 1953, 1954) while working on disease complex of cotton involving *Belonolaimus longicaudatus* with *Fusarium* found that the wilt resistant variety Coker-100 and a wilt susceptible variety had 41-80% and 52-95% wilt respectively. Thus the sting nematode has broken the resistance in the cotton varieties in the presence of the fungus. The two populations (North Carolina and Georgia) of *Belonolaimus longicaudatus*, *M. incognita* and *Hoplolaimus galeatus* caused a greater amount of wilt on wilt-susceptible "Rowden Cotton" in the presence of *F. oxysporum f. vasinfectum*. However, the combination of NC populations of *R. Longicaudatus* with *Fusarium* promoted
greatest wilt development than either population of *H. galeatus* and *M. incognita* (Yang et al., 1976).

Ectoparasitic nematodes also took part in the wilt expression with *Fusarium oxysporum*, however, their association caused different symptoms than their sedentary counterparts. The association of *Hoplolaimus uniformis*, a migratory ectoparasite, and *F. oxysporum* f. *pisi* caused early yellowing and root-rot rather than wilt on peas (Labruyere et al. 1959). Similarly, another such type of nematode, the tobacco stunt nematode, *Tylenchorhynchus claytoni* was found quite capable of increasing the wilt caused by *F. oxysporum* f. *nicotianae* in the susceptible varieties of flue-cured tobacco (Holdeman, 1956). Vargas & Laughlen (1972) reported that the association of *Fusarium roseum* and *Tylenchorhynchus dubius* caused *Fusarium* blight on *Poa pratensis*.

The top growth of maize plants was reduced due to combined effect of *Hoplolaimus indicus* and *Fusarium moniliformae* as examined by Nath et al. (1974). However, on the other hand, Shanmugam et al. (1977) found suppressed root-growth of *Gossypium hirsutum* in the presence of *Hoplolaimus seinhorsti* and *F. oxysporum* f. *vasinfectum*.

Limited number of reports are also available with respect to the *Fusarium*-wilt fungi and migratory endoparasitic nematodes. Oyekan & Mitchell (1971) worked on
pea var. 'Wisconsin' and found wilt symptoms 3 days after simultaneous inoculation with *Pratylenchus penetrans* and *F. oxysporum* f. *pisi*. However, antagonistic effect of *F. solani* on *P. penetrans* population was noticed by Mouza & Webster (1982), but the combination of *F. oxysporum* f. *medicaginis* and *P. penetrans* decreased the top weight of Lucerne.

*Verticillium* spp. cause vascular wilt disease similar to that caused by *Fusarium*; since these two pathogens heavily settle in vascular system of the plants, it becomes impossible to distinguish these two diseases by symptoms in certain crops such as on cotton. The root-knot nematode, *M. incognita* also involves in disease complex with *Verticillium* spp., the incidence of disease was increased in the presence of *M. incognita*, stubby root nematode, *Trichodorus christiei* and *Verticillium albo-atrum*. However, no significant increase was observed in tomato with *M. incognita* (Conroy & Green 1974). The work of Overman & Jones (1977) also gave the similar result in tomato with inoculation of *Verticillium albo-atrum*, *M. incognita*, *Criconemoides* spp. or *B. longicaudatus*. While, Shoemaker & Barker (1979) found no synergistic effect of *M. incognita* and *Verticillium*-wilt on tomato.

The *Verticillium*-wilt also increased in the presence of *M. hapla* on potato (Jacobsen *et al.*, 1979) and *M. incognita* with *Verticillium dahliae* on cucumber plants (Costache *et
al., 1978). The resistant variety of *Solanum sisymbriifolium* lose resistance due to the combined effect of *Verticillium* and *M. incognita* as reported by Fassuliotis & Dukes (1972). *Verticillium*-wilt development is often influenced by the presence of plant-parasitic nematodes and migratory forms have been most incriminated. Simon (1957) was first to suspect that certain migratory endoparasitic nematodes promoted *Verticillium*-wilt of hops. Apart from this, the work with *Verticillium*-wilt nematode complexes involved primarily on cotton, tomato, eggplant and pepper were also reported (Mountain & Mckeen, 1962; Olthof & Reynes, 1969). An important relationship exists between *P. penetrans* and a fungus, *Verticillium* spp. in peppermint (Bergeson, 1963), eggplant (Mountain & Mckeen, 1960) and potato (Morsink & Rich, 1968). Their association caused greater damage than either pathogen alone. On the other hand, Conroy et al. (1972) used different inoculum densities of *P. penetrans* with *V. albo-atrum* in tomato which resulted in positive interaction to cause a damage even at low inoculum density. However, the additive effect was noticed by the association of *P. penetrans* and *Verticillium* spp. on *Chrysanthemum, Impatiens* and *Linum usitatissimum* (Cooseman, 1979).

A noticeable reduction in incubation period was seen by Bergeson (1963) due to combined infection of *P. penetrans* and *Verticillium albo-atrum* on peppermint, which thus
increased rapid disease development. While *Pratylenchus minyus* and *Verticillium* spp. increased the severity of wilt incidence and their association reduced the incubation period for *Verticillium*-wilt (Faulkner & Scotland, 1965).

The optimum temperature for wilt symptoms on piperment was noted by Faulkner & Bolander, (1969) where it changed due to their association of *Verticillium dahliae* and *P. minyus*. Although nematode promoted wilt incidence in all temperatures but the optimum temperature for disease development was 24°C. It has been changed to 27°C when both pathogens were present together, however, the fungus apparently changed the optimal temperature for nematode reproduction.

Muller (1977) demonstrated the interaction of five species of *Pratylenchus* with *Verticillium albo-atrum* using *Impatiens balsamina* as a host plant; only the combinations of *V. albo-atrum* with *P. penetrans* or *P. vulnus* induced the wilt symptoms, whereas the *P. crenatus*, *P. fallax* or *P. thornei* could not do so, though all the five species of *Pratylenchus* penetrated the young seedlings of *I. balsamina*. Burpee & Bloom (1978) used three potato cultivars 'Kennebec', 'Katahdin' and 'Abnaki' which did not follow the same rule by the combined infection of *P. penetrans* with *Verticillium* spp. Among 'Katahdin' plants the severity of foliar symptoms increased in the presence of both pathogens, whereas in the
susceptible cultivar 'Abnaki' there was no effect on foliar symptoms.

An other wilt causing organism was also identified which becomes destructive to plants in the presence of plant-parasitic nematodes. The black-shank of tobacco caused by *Phytophthora parasitica* var. *nicotianae* is a wilt disease, although root-decay is also an important part of the disease syndrome. The fungus is a very aggressive pathogen and causes rapid death in susceptible cultivars. Tisdale (1931) was the first to observe that black-shank resistance in certain tobacco lines was reduced in the presence of root-knot nematode. The resistance of tobacco cultivars was broken in the presence of root-knot nematode and black-shank fungus, *Phytophthora parasitica* f. *nicotianae* causing the wilt in addition to root-decay (Sasser *et al.*, 1953, 1955 and Moore *et al.*, 1956). Inspite of this Moore *et al.* (1956) found that root-knot nematode, *Meloidogyne* spp., root lesion nematode *Pratylenchus* spp. and stunt nematode, *Tylenchorhynchus claytoni* appeared to have influenced the development of black-shank symptoms. Powell & Nusbaum (1960) found that the resistance in black-shank resistant tobacco varieties 'Dixie Bright-101' and 'Coker-139' were broken down genetically with *Meloidogyne incognita incognita* and *Meloidogyne incognita acrita*. Histopathological studies revealed that hypertropic and hyperplastic regions were
formed along with gall tissues and that the giant cells seemed highly sensitive to infection.

The black-shank fungus also interact with another sedentary endoparasitic nematode and in this regard Adeniji et al. (1975) found the relationship of Heterodera glycines and Phytophthora megasperma f. sojae in soybean (Glycine max); seedling diseases were more severe in the Pms susceptible cultivars 'Corosay & Dyer' than resistant varieties to Pms. However, Phytophthora megasperma f. sojae significantly reduced the population of Heterodera glycines on roots of susceptible variety 'Corosay' (Adeniji, 1977).

The root-lesion nematode, Pratylenchus brachyurus also interact with this fungus. P. brachyurus increased the severity of black-shank in the presence of Phytophthora parasitica f. nicotianae in susceptible variety (Nicotiana tabacum) 'Hicks' when inoculated simultaneously or when nematodes were inoculated one week before the fungus inoculation (Inagaki & Powell, 1969). Graham (1958) worked with M. incognita acrita, Pratylenchus brachyurus, Pratylenchus brachyurus and Tylenchorhynchus claytoni in combination with black-shank fungus. Only the plants inoculated with M. incognita acrita and the fungus developed severe black-shank symptoms. The other nematodes do little with black-shank fungus.
2. Interaction between nematodes and root-rot fungi:

The root-rot fungi constitute another category of pathogens where considerable work has been carried out with respect to their interactions with plant-parasitic nematodes, though not to the extent of wilt fungi – nematode complexes. Steiner (1942) for the first time realised and discussed the importance of root-knot nematode with respect to plant necrosis in the presence of root-rot fungi.

The combined effect of root-knot nematode, *Meloidogyne incognita acrita* and the root-rot fungus, *Pythium graminicolum* reduced top growth of sugarcane (Apt & Koike, 1962). Littrell & Johnson (1969) noted that the association of *M. incognita*, *Belonolaimus longicaudatus* with *Pythium aphanidermatum* reduced plant growth and increased severe root-rot in *Chrysanthemum* cv. 'Iceburg'. The growth retardation or root deterioration was observed also in *Dichondra repens* by the interaction of *Meloidogyne incognita* with *Pythium ultimum* and *Rhizoctonia solani* (Radewald et al., 1974). Garcia & Mitchell (1975) reported increased severity of pod-rot of peanut when *Pythium myriotylum*, *Fusarium solani* and *M. arenaria* were present together. Several reports are also available where fungus reduced the resistance against *M. incognita* in resistant cultivars. The three cultivars of tomato infected with *Rhizoctonia solani*, *Sclerotium rolfsii* or *Verticillium rolfsii* lost the resistance to *M. incognita*
(Hasan & Khan, 1985). Another study by Hasan (1985) also found that some of the cultivars or lines of chilli which showed some resistance in the glass house condition to root-knot nematode were found to lose it under field condition. Rhizoctonia solani and Pythium aphanidermatum were responsible in the breakdown of resistance in Jawala and Longthin Faizabadi to this nematode.

Golden & Van Gundy (1972) found that M. incognita together with Rhizoctonia solani and Thielaviopsis basicola changed the permeability of tomato roots resulting increased leakage of electrolytes and organic compounds. The interesting feature was also found by Van Gundy et al. (1977) that the root-exudates and other nutrient metabolities secreted from M. incognita infected galled tissues of tomato, which caused severe root-rot in association with Rhizoctonia solani. The root-knot nematode, Meloidogyne incognita has been found capable to predispose the plants for secondary infection resulting greater damage to the plants by way of root-decay. Powell (1971) reported that Meloidogyne incognita predisposed flue-cured tabacco to Pythium ultimum when nematode preceded the fungus inoculation. Furthermore, it was also reported that the fungus colonised the galls more readily and rapidly. In this way, Melendez & Powell (1970) critically analysed the M. incognita - P. ultimum complex in tabacco in carefully controlled experiments and these tests confirmed that necrosis occurred only when the fungus
followed *M. incognita* by four weeks. Plant roots failed to develop decay in the presence of either of the pathogen alone. Similarly Nava (1970) found decay in tomato roots only when they were exposed to *M. incognita* and either of *Rhizoctonia solani* and *Pythium ultimum*. All the test pathogens failed to cause root decay when inoculated singly. *M. incognita* was found to have predisposed the tomato roots when added several weeks ahead of fungi. The resulting necrosis was extensive and rapid. Histological studies confirmed the presence of fungus mycelium in nematode galled area including giant cells and the adjacent tissues. In the roots when both *R. solani* and *P. ultimum* were present along with *M. incognita*, *R. solani* appeared to be more aggressive than *P. ultimum* and gradually became dominant in galled tissues. In a similar study, Kushner & Crittenden (1967) noted that the decay in alfalfa roots due to *Fusarium roseum* or *F. oxysporum f. batatus* became more severe in the presence of *M. incognita acrita*.

There are certain studies where reduction in plant growth was found maximum when both the pathogens were inoculated simultaneously. The association of *Rhizoctonia solani* and root-knot nematode, *M. incognita* caused maximum reduction in plant growth in okra (Chhabra *et al.*, 1977), frenchbean and okra (Reddy *et al.*, 1979), gram (Nath & Dwivedi, 1981) and potato (Sharma & Gill, 1979). Kanwar *et*
al. (1987) received the similar trend in simultaneous inoculation of *Meloidogyne javanica* with *Rhizoctonia solani* on cowpea, while Zaidi & Tiyagi (1989) found maximum plant damage in simultaneous inoculations of *M. incognita* and *F. solani* on chilli.

The root-rot lesion increased in the roots of Kenaf (*Hibiscus cannabinus*) when *M. javanica* and *Macrophomina phaseoli* were inoculated simultaneously (Tu & Chang, 1971), while Alfieri & Stokes (1971) noted leaf chlorosis and abscission, twig die back, stunting, reduction and necrosis of roots in *Legastrum japonicum* when *M. javanica* and *M. phaseolina* were inoculated simultaneously. The root-knot nematode, *M. hapla* and root-rot fungus, *Macrophomina phaseolina* together were more damaging to *Cylindrocladium crotalariae* (Dimonde & Bente, 1981). Whereas the simultaneous inoculation of *Phomopsis vexans* and root-knot nematode was reported by Khan et al. (1980) in the form of extensive root-decay, collar rot and fruit-rot in brinjal. There was significant reduction in the weight of ginger when *M. incognita* and *Pythium myriotylum* were present atogether (Lanjewar & Shukla, 1986) as compared with either of them alone.

The root-rot of soybean caused by *Phytophthora sojae* was found to be more severe in the presence of *M. hapla* rather than in its absence (Wyllie & Taylor, 1960). Book Binder & Bloom (1977) found reduced fresh weight of shoot and root of
soybean due to combined effect of M. incognita and Uromyces phaseoli. The heavy damage was noticed in the presence of M. arenaria, M. hapla and Aspergillus flavus on peanut by Minton & Jackson (1967) which increased the invasion of other soil inhabiting fungi, while on the other hand, the two fungi, Cylindrocladium crotalariae and Sclerotium rolfsii when combined together caused heavy damage to soybean in the presence of M. incognita (Hedrick & Southards, 1976).

The ability of root-knot nematodes to predispose the plant roots for fungal attack is one of important factors responsible for increasing the severity of the diseases. The maximum reduction was observed when root-knot nematode preceded the fungus 2 weeks or 4 weeks by several workers. Powell & Batten (1967) noted that the combined and individual infection of Pythium ultimum, Rhizoctonia solani and Trichoderama harzianum caused no significant damage to tobacco plants but extensive damage was observed when M. incognita was inoculated prior to these fungi. Similar results were also obtained by Batten & Powell (1971) on tobacco; root-rot was more extensive when M. incognita preceded Rhizoctonia solani by 10 days or 21 days than when simultaneous inoculation or separate or when R. solani was added after artificial wounding. Similarly in sugarbeet M. incognita, Pythium ultimum and Rhizoctonia solani were found to reduce growth of seedlings but the maximum reduction was seen where plants were inoculated with M. incognita followed
by *P. ultimum* or *R. solani* or *P. ultimum* + *R. solani* (Pandey, 1984). The significant damage in chickpea was reported by Kanwar *et al.* (1987) when nematode, *M. javanica* preceded the root-rot fungus, *Rhizoctonia solani*. Similar result was obtained by Al-Hazmi (1985) that severity of root-rot of frenchbean (*Phaseolus vulgaris*) was increased when the nematode, *M. incognita* was inoculated 2-weeks before the fungus, *Macrophomina phaseolina*. Sakhuja & Sethi (1986) reported an interaction between *M. javanica*, *F. solani* and *Rhizoctonia bataticola* on groundnut. Nevertheless, the pathogens caused significant plant damage but the maximum damage was observed when root-knot nematode preceded to either or both the fungi. Although in each case the root-knot nematode was the most sufferer as its multiplication rate was affected by the presence of the fungi.

The root-knot nematodes have the ability to predispose the plants to even non-aggressive or non-pathogenic fungi to settle or colonise. There are certain soil-borne fungi that are not regarded as pathogens of tobacco crop, e.g., *Curvularia trifolii*, *Botrytis cinerea*, *Aspergillus ochraceus*, *Penicillium martensii* and *Trichoderma harzianum*. In an experiment, Powell *et al.* (1971) noted that root-destruction by any of these fungi in the presence of *M. incognita* was as great as caused by pathogenic fungi under similar conditions. Similarly, *Trichoderma* having a very poor
"pathogenic reputation" on any host, becomes pathogenic when tobacco roots are infected first with \textit{M. incognita}. Under these conditions, the syndrome is comparable to necrosis resulting from the combination of \textit{Pythium} with \textit{M. incognita} (Melendez \& Powell, 1969).

In addition to this, Hefner (1967) reported that "soil run" nematodes, most of which were non-parasitic on cotton seedlings, increased the damage by different soil inhabiting fungi especially at low temperatures; \textit{Meloidogyne incognita acrita} predisposes cotton seedlings to several fungi including, \textit{Alternaria tenuis, F. oxysporum f. vasinfectum, R. solani} and \textit{Glomerulla gossypii} (Couquil \& Shepherd, 1970). They found that effect of each combination to be synergistic.

Another type of sedentary endoparasite similar to root-knot nematodes, the cyst nematodes which induce syncytial development also have the capability of interacting with certain fungi to increase root-decay. Roots of sugarbeet seedlings are damaged by a complex of \textit{Heterodera schachtii} and \textit{Rhizoctonia solani} (Polychronopoulos et al., 1969). The nematode induce the wounds which facilitate subsequent penetration and colonization by the fungus. Seedling symptoms characterised by softening and decay of tissues develop rapidly after infection by both the pathogens. Polychronopoulos et al. (1969) also studied histology of this interaction and found that giant cells resulting from the
infection of *H. schachtii* as well as the adjacent areas provide a highly suitable substrate for the fungal growth. Synergistic relationships on sugarbeet seedlings due to the interaction of *Rhizoctonia solani* and *Heterodera schachtii* were reported by Price & Schneider (1965) and Polychronopoulos (1970). Whitney & Doney (1973) also reported synergistic interaction between the cyst nematode, *H. schachtii* and the fungi, *Rhizoctonia solani*, *C. atramentarium* and *Aphanomyces cochlioides* in causing root-rot of sugarbeet, whereas the *Heterodera schachtii* together with *Pythium ultimum* caused severe root-rot in sugarbeet as reported by Whitney (1974).

A disease complex involving *Globodera rostochiensis* and *Rhizoctonia solani/Colletotrichum atramentarium* was noted in tomato by Dunn & Hughes (1964) and Dunn (1968). *C. atramentarium* caused brown root-rot in tomato and this reduction became maximum when *G. rostochiensis* was inoculated prior to the fungi, *Rhizoctonia solani* or *Colletotrichum atramentarium*, while James (1968) failed to observe any influence of *G. rostochiensis* on disease caused by *C. atramentarium*. The jointly infected tomato roots with *G. rostochiensis* and the grey-sterile fungus showed deformation of giant cells and nematode larvae failed to develop into adult. However, the typical giant cells were produced on plants inoculated with only nematodes (Ray 1968). In another study Dunn (1968, 1970) observed significant
reduction in tomato plants when *G. rostochiensis* was added prior to the fungi, *R. solani* and *C. atramentarium*. Similar results were obtained by Roy (1977) where *G. rostochiensis* followed by *Rhizoctonia solani* caused greater growth reduction in tomato cultivar "Ailsa Graig".

The semi-endoparasitic nematodes also took part with the root-rot fungi. Kumar & Sivakumar (1981) studied the interaction between the reniform nematode, *Rotylenchulus reniformis* and *Rhizoctonia solani* on okra. The reduction was found maximum when nematode inoculation preceded the fungus inoculation. Root-decay caused by *Fusarium solani* in lemon increased in the presence of *Tylenchulus semi-penetrans*, however, this did not occur with *Fusarium oxysporum* (O'Bonnon et al., 1967). He also studied the effect of temperature on these interactions. At certain temperature (20-25°C) growth reduction due to nematodes alone was as great as resulting from combined inoculation. However, Van Gundy & Tsao (1963) observed that the growth of citrus seedlings retarded more with the combination of *Fusarium solani* and citrus nematode, *Tylenchulus semi-penetrans* than either pathogen alone.

The migratory ectoparasitic nematodes have also been found involved in disease complexes with many rot-rotting fungi. Labruyere et al. (1959) noticed the "Early yellowing" disease and root-rot of pea in the presence of *Hoplolaimus uniformis* and *F. oxysporum f. pisi*. The earlier root-rot
symptom was developed in Chrysanthemum roots when inoculated with Belonolaimus longicaudatus and Pythium aphanidermatum as compared to the inoculation with the fungus alone as reported by Littrell & Johnson, (1969). Liu & Ayola (1970) also found a positive interaction between Trichodorus christiei and Fusarium moniliformae on sugarcane but infection by Fusarium roseum apparently was not influenced by T. christiei. In a similar study, Kisiel et al. (1969) found that T. agricola promoted the corn root-rot caused by F. roseum but not the one caused by Pythium ultimum.

Migratory endoparasitic nematodes particularly species of Pratylenchus have also been found involved in certain root-rotting complexes. In fact, some of the earliest report were those of Mountain & Benedict (1956) and Benedict & Mountain (1956) on root-rot of winter wheat in Canada, in which Pratylenchus minyus had interaction with Rhizoctonia solani causing significant reduction in wheat growth. Although Hendrix et al. (1965) found no definite interaction between Pratylenchus and Pythium associated with a large percentage of peach trees suffering from peach decline but the presence of Criconemoides spp. and Tylenchorhynchus spp. was needed for this condition. The interesting work of Edmund & Mai (1966) have shown that Pratylenchus penetrans and Trichoderma viridae caused more reduction in root and shoot growth in both alfalfa and celery than either pathogen alone,
even though Trichoderma was not recognised as an important pathogen. At certain temperatures, Pratylenchus scribneri and Fusarium moniliforme caused greater reduction of corn fresh weight than either pathogen alone (Palmer et al., 1967). Although, Olthof (1968) did not found any alteration in resistance of burley tobacco to P. penetrans, but the black root-rot caused by Thielaviopsis basicola seems to exercise some effects on root-penetration by nematodes. The combined effect of Pratylenchus hexincisus and Macrophomina phaseoli caused severe root-rot in sorghum as compared to the root-rot caused by fungus alone (Norton, 1958) while, on the other hand, Santo & Holtzmann (1970) found reduced top and root growth of sugarcane when Pratylenchus zeae and Pythium graminicola were inoculated simultaneously. Although, both were present in the same lesion but effect of each appeared independent and additive. The severe rot symptoms were developed when nematode was added seven days prior to P. graminicola. However, similar effects of Pratylenchus brachyurus and Pythium graminicola was found in the form of reduced top and root-growth of sugarcane. Miller & Anagnostakis (1977) found a significant reduction in the population of Pratylenchus penetrans and Tylenchorhynchus dubius by a weak pathogen, Trichoderma viridae because it showed antagonistic behaviour to these nematodes.

The migratory endoparasitic nematode also took part with black-shank fungus for root-rot of tobacco crops. The
synergistic relationship was observed by Inagaki & Powell (1969) on susceptible varieties of tobacco between *Pratylenchus brachyurus* and *Phytophthora parasitica f. nicotianae*. The severe black-shank symptom was noted when both the pathogens were inoculated simultaneously than nematode preceded the fungus while Mc-Intyre & Miller (1978) on the other hand, reported an antagonistic interaction between *P. parasitica f. nicotianae* and *P. penetrans* on tobacco.

Another endoparasitic nematode also involve in the disease complex with root-rot fungi. *Radopholus similis*, widely infecting banana plant, is known as burrowing nematode. A study by Stover (1966) revealed that *R. similis* was characteristically associated with *Fusarium solani* which was isolated much more frequently from deep root lesion than *Rhizoctonia*, while on the other hand, *Rhizoctonia* occurred more frequently than *F. solani* in shallow lesion caused by *Helicotylenchus* spp.

3. Interaction between nematodes and seedling diseases:

It is very difficult to differentiate between root-rot diseases from seedling diseases on the basis of symptoms and nature of infection which are quite similar in both the cases. However, the differences are based on the stage of the plant at the time of infection and disease development. In the seedling diseases, as in root-rot and wilt diseases,
nematode-fungus combination brings about more damage to the plants. Under greenhouse condition, the citrus nematode, Tylenchulus semipenetrans interact with Fusarium solani resulting greater damage of citrus seedlings than caused by either of the pathogen alone (VanGundy & Tsao, 1963). Rhizoctonia solani is responsible for damping-off of seedlings in several crops, the intensity of which is increased in the presence of nematodes. Post emergence damping-off of cotton seedlings was more severe in the combined inoculation of Meloidogyne incognita acrita and Rhizoctonia solani as reported by Reynolds & Hansen (1957). Similarly Carter (1981) noticed that the severity of cotton seedlings increased when M. incognita was inoculated simultaneously with Rhizoctonia solani and suggested that nematode provided additional penetration sites for the fungus.

Norton (1960) studied the pre-emergence damping-off of cotton caused by F. oxysporum f. vasinfectum, Pythium debaryanum and Rhizoctonia solani which showed more destruction in the presence of M. incognita acrita. The root-knot nematode, Meloidogyne incognita acrita has been found to predispose the cotton seedlings to various fungi as seen by Cauquil & Shepherd (1970), the severity of cotton seedlings increased when this nematode was inoculated simultaneously with Alternaria tenuis, F. oxysporum f. vasinfectum, Glomerella gossypii and Rhizoctonia solani. The
association of both the nematode, *M. javanica* and *M. hapla* increased the pre-emergence damping-off of soybean seedlings in the presence of *Rhizoctonia solani* (Taylor & Wyllie, 1959). While Powell & Batten (1967) observed the significant damping-off of tobacco seedlings with the inoculation of *Rhizoctonia solani* and *Pythium* spp., but their simultaneous inoculation with *M. incognita* showed greater damage. Though separate and simultaneous inoculation of *Coffea arabica* seedlings with *Meloidogyne exigua* and *R. solani* caused less root-necrosis as reported by DeSouza (1978), but more damage was reported when *M. exigua* preceded *R. solani* inoculation.

The wounds caused by different forms of nematodes plus infection by one or more fungi leads to serious damage to the plants. Cotton seedlings grown in soil infected with either of *M. arenaria*, *M. hapla*, *M. incognita*, *Rotylenchulus reniformis* and *Hoplolaimus tylenchiformis* become susceptible to *Rhizoctonia solani* for longer duration compared to those grown in the absence of nematodes. Similarly the susceptible period was prolonged by *M. incognita* or *M. hapla* for the attack of *Pythium debaryanum* (Brodie & Cooper, 1964). They also, on the other hand, found that *Tylenchorhynchus claytoni* and *Trichodorus christiei* did not lengthen the period of susceptibility to either of the fungi.

The root-knot nematodes have a wide range of host and also have capacity to interact with different fungul species on various crop plants. Synergistic effect of root-knot
nematode, *M. incognita* and *Sclerotium rolfsii* on the seedling emergence of tomato was reported by Shukla & Swarup (1971); similarly simultaneous inoculation with a fungus, *Ozonium taxanum f. parasiticum* gave synergistic effect by reducing the germination of seeds of eggplant (Nath et al., 1976). Seedling mortality in okra was observed by Chhabra et al. (1977) with simultaneous inoculation of *Rhizoctonia solani* and *Meloidogyne incognita*. The combined effect of *M. incognita* and *Rhizoctonia bataticola* inhibited the seed germination of eggplant and okra (Chhabra & Sharma, 1981). On the other hand, Agarwal & Goswami (1973) noticed that simultaneous inoculation of *M. incognita* and *Macrophomina phaseoli* as well as nematode preceding the fungus resulted in greater seedling mortality of soybean. Book Binder & Bloom (1980), however, found more growth reduction of bean's shoot and root weight with the association of *M. incognita* and *Uromyces phaseoli*.

The cyst nematode, *Heterodera* spp. also caused significant growth reduction in the presence of some fungi. The synergistic effect was seen by Whitney (1971) on sugarbeet seedling damping-off when *Heterodera schachtii* and *Pythium ultimum* were present together, similarly, Adeniji (1977) found cultivars of soybean 'Corosay' and 'Dyer' more susceptible in the presence of *Heterodera glycines* and *Phytophthora megasperma f. sojae* than with either of the pathogen alone.
Migratory endoparasitic nematodes play an important part in seedling disease complexes with many fungi and cause considerable damage to the plants. The harmful effects were observed on alfalfa by Edmund (1964, 1968) when plants were inoculated with *Pratylenchus penetrans* in the presence of *Trichoderma viride* and *Fusarium oxysporum*. Udagava & Iyatome, (1972) observed that *Pratylenchus penetrans* enhanced the penetration of *F. oxysporum* f. *cucumerinum* in cucumber seedlings roots. Whereas other forms of nematode species caused more damage to the plants in addition to migratory endoparasite with soil inhabiting fungi. Ndubizu (1977) found that association of *Pratylenchus penetrans*, *M. hapla* or *Tylenchorhynchus claytoni* with *Verticillium dahliae* resulted in greater growth reduction of cherry seedlings than that caused separately. The additive/synergistic effect was obtained by Martin et al. (1981) with *Verticillium dahliae* and *P. penetrans* in different combination. Their association accelerated the symptom expression with increased severity of *Verticillium*-wilt resulting in early dying.

The ectoparasitic nematodes also promote the seedling mortality with association of certain fungi. Wehunt & Weaver (1972) observed that *Hoplolaimus galeatus*, *Tylenchorhynchus claytoni* or *Criconemoides xenoplax* predisposed peach seedlings to *Fusarium oxysporum* resulting more growth reduction while *Sclerotium rolfsii* caused seedlings blight of
rice in the presence of *Hoplolaimus indicus* (Ramana, et al., 1974).

**NEMATODES ROOT-NODULE BACTERIA INTERACTION:**

Miller (1951) was first to observe the inhibition of nodulation on roots of pea due to root-knot infection. Since then there have been several reports about the inhibition in root-nodulation due to root-knot nematode infection, e.g., *Meloidogyne incognita* on mungbean, *Phaseolus aureus* (Hussaini & Seshadri, 1975) and soybean (Balasubramanian, 1971; Srivastava et al., 1974; Hussey & Barker 1976; Baldwin et al., 1979); *M. hapla* on hairy vetch (Malek & Jenkins, 1964) and soybean (Balasubramanian, 1971); *M. javanica* on white clover (Taha & Raski, 1969), soybean (Balasubramanian, 1971) and mungbean, *Vigna radiata* (Bopaiah et al., 1976a).

Robinson (1961) observed that the larvae of root-knot nematode, *Meloidogyne javanica* attack the root-nodule of *Vigna unguiculata* and *Steilobium* spp. at different stages of the nodular development with the preference for younger nodules. In another report, number of nodules of soybean (*Glycine max*) per plant was reduced significantly even at low inoculum level of *M. javanica* (10 larvae / kg soil); when inoculum level was increased there was a reduction in the growth (Srivastava et al., 1979). Pod formation was also affected by increasing the inoculum level.
The reduction in root-nodulation, anatomical changes in the nodules and altered physiology of mungbean caused by *M. incognita* was observed by Hussaini & Seshadri (1975). The nematode hampered nitrogen-fixation with significant decrease in weight of the plants. The symbiotic process of mungbean was adversely affected by the infection of *Meloidogyne incognita* (Singh et al., 1977). The root-galls were observed on nodules at the rate of 1000 nematode/pot. There was corresponding decreased in chlorophyll content, number of nodules and nitrogen content of grain with an increase in the inoculum level of *M. incognita* both in the presence and absence of *Rhizobium phaseoli*. Raut (1980) and Raut & Sethi (1980) found a progressive decrease in growth of mungbean and soybean respectively where inoculation level of *Meloidogyne incognita* increased. The nodule reduction took place in both the seasons in case of soybeans plants. Whereas nitrogen-fixing capacity was also affected in mungbean variety "PIMS-I". The antagonistic interaction between *Meloidogyne incognita* and *Rhizobium leguminosarum* on cowpea was observed by Ali et al. (1981). *M. incognita* reduced nodulation and inhibition of nitrogen-fixation by about 63% in the nodular tissues. Infected nodules contained different developmental stages of the nematodes but the nematode did not alter the structure of nodules. However infected nodules deteriorated earlier than the uninfected ones.
The nitrogen-fixation and nitrogen content of mung, *Vigna radiata* was reduced by the inoculation of *Meloidogyne javanica* (Bopaiah et al., 1976a). The deleterious effect of the nematode was observed when the plants were inoculated with nematode alone, simultaneously or 2-7 days preceding to *Rhizobium* inoculation. The prior inoculation of nematode to *Rhizobium* caused maximum reduction of nodules. While Taha & Kassab (1980) did not observe reduction in root-nodulation with simultaneous inoculation of *Meloidogyne javanica* and *Rotylenchulus reniformis* with *Rhizobium* on *Vigna sinensis*, however, nodule formation was found hindered only when *R. reniformis* preceded rhizobial inoculation. Nodules were also formed on *M. javanica* galls.

The reduction in nodulation was also noted by Goel & Gupta (1986) on chickpea when inoculated simultaneously with *M. javanica* and *R. bataticola*. When the three pathogens, *M. incognita*, *R. solani* and pea mosaics virus were inoculated simultaneously on pea, the nodulation was affected as reported by Hussain et al. (1985), while Mani & Sethi (1987) achieved this phenomenon on chickpea by the simultaneous inoculation of *M. incognita*, *Fusarium oxysporum f. ciceri* and *F. solani*.

The soil type also plays an important role for development of nodules in relation to nematode infection. Dhanger & Gupta (1983) observed the pathogenicity of
Meloidogyne javanica to chickpea (Cicer arietinum) in relation to soil types, Rhizobium treatment, size of pots and time intervals. Pathogenicity of this nematode reduced in sandy loam soil than other soil. The growth parameters including nodulation increased significantly in sandy loam soil. Similar results were obtained by Sasser (1954), Sleeth & Reynold (1955) and Elmiligy (1968). Kanwar et al. (1987) also studied the disease complex in relation to the soil type. Plant growth and nodules were better in loamy sand than other two types of soil, i.e., sandy soil and sandy loam soil.

The cyst nematode, Heterodera spp. is very important pathogen which has reduced nodulation or nitrogen fixation in the plants. The pea plants infected with Heterodera goettingiana possessed few nodules (Oostenbrink, 1955) but application of nitrogen fertilizers compensated for the reduced nodulation in nematode infected plants. Also, the result of Barker et al. (1971) justified the application of Na NO₃ or NH₄ to soil, which reduced nematode hatch, penetration and cyst development of Heterodera glycines on soybean. Simultaneous inoculation of nodulating and non-nodulating isogenic lines of soybean with Rhizobium and H. glycines reduced the cyst development especially on the nodulating lines. Simultaneous inoculation of Heterodera glycines and Rhizobium japonicum also showed sufficient inhibition of nodules in soybean (Barker et al., 1972).
However, 14 days delay of *H. glycines* resulted in only slight to moderate inhibition in the nodulation. Ross (1969) found that *Heterodera glycines* affected the yield of non-nodulated soybean at different nitrogen levels and stated that *H. glycines* caused reduction in yield by inciting deleterious host responses that increased with nitrogen deficiency.

Lehman et al. (1971) while working with three races of *Heterodera glycines* (1, 2 and 4 of Golden et al., 1970), found that in combination of race 1 of *H. glycines* + *Rhizobium japonicum* there were fewer nodules per gram of root tissue and N-fixing capacity was less than with *R. japonicum* alone. Similar inocula (100, 200 and 400 crushed cyst) of races 2 and 4 had no effect. Nodule number and weight were inversely proportional to the increasing densities of race 1.

Taha & Raski (1969) while working on white clover noted that the infection caused by *M. javanica* and *Heterodera trifolii* gave no harmful effect on number, size and structure of nodules formed by *Rhizobium trifolii*. Different inoculation period did not hinder nodule formation and their size did not differ in nematode-infected and nematode-free plants. Galls were also formed in the nodules but the structure of nodular tissue was not disturbed by nematode infection, even though giant cells were formed inside the vascular bundles. The nitrogen efficiency of the nematode infected nodule was not compared to nematode-free-nodes. On
the other hand, the invasion and reproduction of *Acrobeloides buetschlii*, a micro-bivorus nematode, inhibited nitrogen-fixation in nodular tissues of "Wando pea" (Westcott & Barker, 1976). Histopathological studies revealed that large number of nematodes were found in the central portion of the nodules, where they were apparently feeding and reproducing on bacteriods. Nodule structure was changed due to this invasion of the nematode, although, this had no detrimental effect on growth and on number of nodules. Nitrogen fixation was generally depressed by 80-90% compared to plants with non-infected nodules.

A semi-endoparasitic nematode, *Rotylenchulus reniformis* also reduced plant height and shoot and root weights of urd/black gram, *Vigna mungo* (Gupta & Yadav, 1979). Nodulation was also affected adversely.

Most of the workers have reported suppression or inhibition of nodulation by plant-parasitic nematodes. However, stimulation of nodulation on leguminous plants by parasitic nematodes was also reported by Hussey & Barker (1976). They studied the influence of *Meloidogyne hapla*, *Pratylenchus penetrans* and *B. longicaudatus* on nodulation of soybean. *M. hapta* and *P. penetrans* stimulated nodule formation, while the sting nematode, *Belonolaimus longicaudatus* slightly inhibited the nodulation.
PLAN OF WORK:

It is clear from the foregoing account that plant-parasitic nematodes and pathogenic fungi form specific relationships and cause greater losses to plants. Among leguminous plants, chickpea (*Cicer arietinum*) and mungbean / green gram (*Phaseolus aureus*) are grown fairly in large areas in this part of the country. These crops were found to be severely affected by *Meloidogyne incognita*, *Rotylenchulus reniformis*, *Fusarium oxysporum f. ciceri*, *Macrophomina phaseolina*, etc., however, *F. oxysporum f. ciceri* was specific to chickpea and *M. phaseolina* to mungbean. Since there is paucity of information regarding the pathogenicity, interrelationship and control of the above pathogens on these crops, it was considered worthwhile to investigate these aspects, for which following experiments were conducted:

1. Effect of different inoculum levels of the root-knot nematode, *Meloidogyne incognita* on root-knot development, plant growth and related parameters of different cultivars of chickpea, *Cicer arietinum* in the presence and absence of *Rhizobium* (Tables 1a, b).

2. Effect of different inoculum levels of the reniform nematode, *Rotylenchulus reniformis* on nematode multiplication, plant growth and related parameters of different cultivars of chickpea, *Cicer arietinum* in the presence and absence of *Rhizobium* (Tables 2a, b).

3. Effect of different inoculum levels of the wilt-fungus, *Fusarium oxysporum f. ciceri* on plant growth and related parameters of different cultivars of chickpea, *Cicer arietinum* in the presence and absence of *Rhizobium* (Tables 3a, b).

4. Effect of individual and combined inoculation of *Meloidogyne incognita*, *Rotylenchulus reniformis* and *Fusarium*
49

oxysporum f. ciceri on nematode multiplication, root-knot development, plant growth and related parameters of chickpea, Cicer arietinum cv. K-850 in the presence and absence of Rhizobium (Tables 4a, b).

5. Effect of individual and combined inoculation of Meloidogyne incognita and Fusarium oxysporum f. ciceri on nematode multiplication, root-knot development, plant growth and related parameters at different growth stages of chickpea, Cicer arietinum cv. K-850 in the presence and absence of Rhizobium (Tables 5a, b).

6. Effect of individual and combined inoculation of Rotylenchulus reniformis and Fusarium oxysporum f. ciceri on nematode multiplication, plant growth and related parameters at different growth stages of chickpea, Cicer arietinum cv. K-850 in the presence and absence of Rhizobium (Tables 6a, b).

7. Effect of individual and combined inoculation of Meloidogyne incognita and Fusarium oxysporum f. ciceri at different age of chickpea, Cicer arietinum cv. K-850 on nematode multiplication, plant growth and related parameters in the presence and absence of Rhizobium (Tables 7a, b).

8. Effect of individual and combined inoculation of Rotylenchulus reniformis and Fusarium oxysporum f. ciceri at different age of chickpea, Cicer arietinum cv. K-850 on nematode multiplication, plant growth and related parameters in the presence and absence of Rhizobium (Tables 8a, b).

9. Effect of oil-seed cakes and nematicides on root-knot development, plant growth and related parameters of chickpea, Cicer arietinum cv. K-850 inoculated with Meloidogyne incognita and/or Fusarium oxysporum f. ciceri in the presence and absence of Rhizobium (Tables 9a, b).

10. Effect of oil-seed cakes and nematicides on nematode multiplication, plant growth and related parameters of chickpea, Cicer arietinum cv. K-850 inoculated with Rotylenchulus reniformis and/or Fusarium oxysporum f. ciceri in the presence and absence of Rhizobium (Tables 10a, b).

11. Effect of oil-seed cakes and nematicides in combination with normal/deep ploughing on the population of nematodes, frequency of fungi, plant growth and related parameters of chickpea Cicer arietinum cv. K-850 in field (Tables 11a, b, c).

12. Residual effect of different treatments given to the preceding crop (chickpea, Cicer arietinum cv. K-850) on the population of nematodes, frequency of fungi, plant growth and related parameters of the following crop (mungbean/green gram, Phaseolus aureus cv. K-851) in field (Tables 11d, e, f).

14. Effect of different inoculum levels of the reniform nematode, *Rotylenchulus reniformis* on nematode multiplication, plant growth and related parameters of different cultivars of mung bean/green gram, *Phaseolus aureus* in the presence and absence of *Rhizobium* (Tables 13a, b).


18. Effect of individual and combined inoculation of *Rotylenchulus reniformis* and *Macrophomina phaseolina* on nematode multiplication, root-rot development, plant growth and related parameters at different growth stages of mungbean/green gram, *Phaseolus aureus* in the presence and absence of *Rhizobium* (Tables 17a, b).


20. Effect of individual and combined inoculation of *Rotylenchulus reniformis* and *Macrophomina phaseolina* at different age of mungbean/green gram, *Phaseolus aureus* cv. K-851 on nematode multiplication, root-rot development, plant growth and related parameters in the presence and absence of
Rhizobium (Tables 19a, b).

21. Effect of oil-seed cakes and nematicides on root-knot development, plant growth and related parameters of mungbean/green gram, Phaseolus aureus cv. K-851 inoculated with Meloidogyne incognita and/or Macrophomina phaseolina in the presence and absence of Rhizobium (Tables 20a, b).

22. Effect of oil-seed cakes and nematicides on nematode multiplication, plant growth and related parameters of mungbean/green gram, Phaseolus aureus cv. K-851 inoculated with Rotylenchulus reniformis and/or Macrophomina phaseolina in the presence and absence of Rhizobium (Tables 21a, b).

23. Effect of oil-seed cakes and nematicides in combination with normal/deep ploughing on the population of nematodes, frequency of fungi, plant growth and related parameters of mungbean/green gram Phaseolus aureus cv. K-851 in field (Tables 22a, b, c).

24. Residual effect of different treatments given to the preceding crop (mungbean/green gram, Phaseolus aureus cv. K-851) on the population of nematodes, frequency of fungi, plant growth and related parameters of the following crop (Chickpea, Cicer arietinum cv. K-850) in field (Tables 22d, e, f).