Review
Of
Literature
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2.1 *Meloidogyne* spp.

Root-knot nematodes are cosmopolitan in distribution and are an important group of plant parasitic nematodes infecting a wide range of economically important plants all over the world. Due to their small size and protective habitat root-knot nematode remained undiscovered until the 19th century even though they cause quite recognizable galls. Root knot disease was first recorded by Berkeley (1855) on glass house cucumbers in England. Since then the pathogens have been designated for a considerably long period of time with different names (Sasser and Carter, 1982; Triantaphyllou, 1973). The present day name *Meloidogyne* was given by Goeldi (1887), Chitwood (1949).

Kozhokarn (1975) reported the invasion of germinating seeds of cucurbitaceous plants by *Meloidogyne incognita* larvae in many regions of Moldavia, U.S.S.R. In the laboratory, germinating seeds in infected soil were attacked within 4 to 5 days by *M. incognita* larvae and were unable to develop further. Huang and Viana et al. (1980) observed the relationship between the levels of pre-planting inoculum of *M. incognita* and the development of cucumber in Brazil. Similarly GongHao and Monong (1981) reported the occurrence of *Meloidogyne incognita* from cucumber plants in Nanjing, Giangsu province, China.

Moussa et al. (1981) reported the species of *Meloidogyne* infecting cucurbits in northern Egypt. A survey of root samples from cantaloupe, cucumber, pumpkin, snake cucumber, squash, sweetmelon and watermelon crops from 18 sites in Northern Egypt, indicated the occurrence of 4 *Meloidogyne* species in descending order of frequency, *M. incognita* (52% of samples) *M. javanica*, *M. arenaria*, and *M. thamesi* of the 7 crop sampled. Sweetmelon and watermelon were infected by all 4 species, others were only
infected with *M. incognita* and *M. javanica*. Again Moussa *et al.* (1981) observed the reaction of certain cucurbit cultivars to nine population of *Meloidogyne incognita*. Most of 18 cultivars of 7 cucurbitaceous vegetable crops were rated as good or excellent hosts to each of nine populations of *M. incognita* from different locations in Northern Egypt.

Mukharjee and Tiyagi (1981) studied on larval invasion of root-knot nematode, *M. incognita* in *Luffa acutangula* Roxb. Infective IInd stage juveniles of *M. incognita* invaded growing roots of *L. acutangula* just behind the root tip, penetrating the epidermis and destroying cortical cells. Salim *et al.* (1981) observed the inoculum potential of the root-knot nematode, *Meloidogyne incognita* (Treub,1885) Chitwood 1949 in relation to early growth of squash *Cucurbita pepo* var. Melopepo L. In a glasshouse experiment, *Cucurbita pepo* var. Melopepo was inoculated with *M. javanica* (0, 500, 1000, 2000, 4000 and 8000 juveniles per pot). Significant damage occurred with 500 juveniles per pot. Development of four populations of *Meloidogyne hapla* on two cultivars of cucumber at different temperatures were observed by Stephan and Trudgill (1982).

Dabaj and Khan (1982) reported root-knot nematodes on indoor cucumbers in Tripoli region of Libyan Jamahiriya. A survey of indoor cucumber in the Tripoli region, Libya conducted during February-March 1980 revealed that *Meloidogyne incognita* was inflicting heavy losses in most areas. Most of the plastic tunnels were heavily infested. The disease ranged from mild to severe. In some tunnels this led to total crop failure. Narbaeu and Allamuratov (1986) noticed the distribution and biology of gall nematodes in glass houses in the Tashkent region. Gall nematodes (*M. arenaria, M. javanica, M. incognita* and *M. acrita*) was found on cucumber and their associated weeds, in 11 out of 13 glasshouses investigating in 4 district of Tashkent region, USSR. Echavez (1989) observed the performance of 3 cucumber varieties in soil infested with root-knot and reniform nematode in Puerto Rico.
Pankaj and Siyanand (1990) noticed the effect of initial inoculum levels of *Meloidogyne incognita* on bitter gourd and round melon. Significant reduction in plant growth was occurred at and above one J2/gm soil in bitter gourd and round melon. Final nematode population increase with an increase in inoculum level. Correlation of shoot weight with root galling in *Cucumis* spp. inoculated with root-knot nematode was reported by Wehner *et al.* (1991). Six genotype (*C. sativus*, cv. Sumter *C. metuliferus* accession PI 482448, PI 482450, PI 482452, PI 482454 and PI 482461) were inoculated with 4 species of root-knot nematodes (*Meloidogyne incognita* race 1, *M. hapla*, *M. arenaria* race 1 and *M. javanica*) and evaluated 8 weeks later for percentage of root galled and shoot fresh weight. Results revealed that PI 482452 had the lowest mean percentage of galled roots (35%) and the highest mean shoot and root fresh weight (514g). *M. incognita* race 1 was the most pathogenic species tested and induced the lowest shoot fresh weight of 258g in cv. Sumter. Galled root due to *M. incognita* were also reported by Salam (1991) on stem of *Luffa acutangula* from the Andaman and Nicobar Islands, India.

Walters *et al.* (1992) noticed the effect of root decay on the relationship between *Meloidogyne* species gall index and eggmass number in cucumber and horned cucumber. This study showed that root-necrosis had an adverse affect on the relationship between gall index and eggmass number in cucumber. In a survey of 26 host plants (19 vegetables and 7 legumes) from Chitwan, Nepal, *Meloidogyne incognita* and *M. javanica* were identified by Rana and Ali (1992). *M. incognita* was the most common and predominant species and 56% of crops were infested, followed by *M. arenaria* and *M. javanica* with 37% and 23% crop infestation respectively. Some crop species were infested by more than one species of *Meloidogyne*.

Bhagmati and Phukan (1993) reported the pathogenicity of root-knot nematode, *Meloidogyne incognita* on pea var. Boneville. There was a progressive decrease in all plant growth characters with increasing inoculum levels, a significant reduction occurring at or above 1000 larvae per plant. Plant
showed chlorosis, rugose leaves and shedding of a few basal leaves at the highest inoculum level. Gupta et al. (1995) observed that initial inoculum levels of hundred larvae of *Meloidogyne* spp. in bitter gourd, 1000 larvae in smooth gourd, ridge gourd and squash melon significantly reduced the growth parameters. Galling and nematode reproduction were directly related to initial inoculum levels. Creech et al. (1995) compared rates of penetration and reproduction in resistant and susceptible cotton. *M. incognita* race 3 exhibited delayed response in M-315 resistant genotype. Out of 18 cucumber varieties tested by Sharma et al. (1995) for their reaction to *M. incognita*. Hoe-707 and EC-173929 were found resistant. The resistant line of *Gossypium hirsutum* against *M. incognita* exhibited necrosis around nematode head.

Zarina and Abida (1995) recorded the new host of root-knot nematodes (*Meloidogyne* species) in Pakistan. They reported *M. javanica* on black night shade and snake melon (*Cucumis melo* var. Flexuous) and rose and *M. incognita* on snake melon as new host record in Pakistan. Bahar and Phukan (1996) observed the reaction of certain cucumber cultivars to root-knot nematode, *M. incognita*. Most of them were susceptible (Khira-90), or highly susceptible (CEC 173934, Priya, 20-3-2-1 and Pusa Sanyog). Bhat et al. studied the morphological and biochemical responses of pigeonpea cultivars to *M. incognita* race-1 and *Rotylenchulus reniformis*. Pedrosa et al. (1996) found all the cultivars susceptible towards *M. incognita* race 1. Eight genera of leguminaceae were evaluated against *M. chitwoodi* and *M. hapla* Pedrosa et al. (1996) inoculated *M. arenaria* race 1 and 2 to know resistance and susceptibility of three genotype of soyabean. Fazal et al. (1996) determined threshold levels of *M. incognita* and *R. reniformis* on black gram. The threshold limits of *M. incognita* and *R. reniformis* were 1000 J2 and 1000 immature females, respectively. Sivakumar et al. (1996) noticed the association of Northern root-knot nematode, *Meloidogyne hapla* Chitwood, 1949 on temperate vegetables in the Nilgiris. The soil and root population of *M. javanica* were highest in carrot and beetroot
and lowest (<200 nematodes / 200 cm$^3$ soil) in cabbage, cauliflower and radish in the Udhagamandalam cooner and kotagiri areas of Tamilnadu, India. The root-knot indices and percent density were highest for carrot, beetroot and broad beans and lowest for cabbage. Cauliflower, radish, potato, bush bean, Kohlrabi, turnip and peas were also examined.

Eddaoudi et al. (1997) identify the resistance breaking population of *Meloidogyne* on tomatoes in Morocco and their effect on new sources of resistance. 25 isolates of *Meloidogyne* collected in Moroccan vegetables growing areas. Nejad and Khan (1997) studied the influence of initial inoculum levels of root-knot nematode, *Meloidogyne incognita* (race-1) on growth of some chickpea cultivars Pusa-209, Pusa-212, Pusa-244, Pusa- 256, Pusa- 267 and Pusa-436 with inoculum levels of 0.10, 100, 1000 and 10,000 J$_2$/pot under artificial inoculations. There was a progressive decrease in plant growth as the inoculum levels of the nematode increases. An inoculum level of 1000 J$_2$/pot was found to be a damaging threshold level for Pusa-212 and Pusa- 267 whereas 10,000 J$_2$/pot caused significant reduction in growth parameters of all cultivars. Rhizobial nodulation was adversely affected at all inoculum levels and this effect was significant at 1000 J$_2$ and above.

Anver et al. (1997) noticed the reaction of pigeon pea accessions to root-knot nematode, *Meloidogyne incognita*. Thirteen *Cajanus cajan* accessions were screened in pots infested with 5000 freshly hatched second stage juveniles of *M. incognita*. Three months after inoculation, the accession KMG and AF293 were noted resistant and moderately resistant respectively. The intensity of nematode infestation was positively correlated with a reduction in plant mass, pod number, nodules number, leaf chlorophyll content and bulk density of stems.

Hokoma (1998) studied the influence of soil types on the susceptibility of okra and damage caused by *Meloidogyne incognita* (Kofoid and White) Chitwood. The pathogenecity of *Meloidogyne incognita* race-3 to turmeric (*Curcuma longa*) cv. BSR-1 and PTS-10 was studied by Poornima et al.
(1998). The nematode was pathogenic to both the cultivars. The leaves of inoculated plants were pale in colour and shoot weight was reduced by 6-10% in both varieties, level of protein, carbohydrate, chlorophyll contents, total chlorophyll, rhizom curcumin level were lower in plants inoculated with 10,000 juveniles when compared to healthy ones. It was concluded that the nematode caused loss in yield as well as quality of the produce in turmeric.

The penetration and post penetration development of *M. incognita* juvenile stage (J2) was observed by Rao et al. (1998) in tomato hybrid FM-2, lines (BN-10 and IIHR-550) and variety Pusa Ruby, before and after transplanting of the crop. The degree of penetration was significantly less in the 3 resistant hybrid/ lines as compared to Pusa Ruby, where it was 30% and 35% before and after transplanting respectively. In Papaya the pathogenicity of *M. incognita* was studied by Aparajita et al. (1998) with 5 inoculum levels: 100, 1000, 3000, 5000 and 10000 juveniles / 3 kg soil. There was also a progressive decrease in growth of the plant with an increase in inoculum level. Haseeb et al. (1998) recorded the relationship between *M. incognita* and growth physiology and oil yield of *Ocimum kilimandscharicum*. The greatest reduction in all growth parameters occurred in plants inoculated with the highest inoculum density of *M. incognita* (16000 J2/7.5 kg soil). The highest reproduction factor (45.85) occurred in plants inoculated with 5000 J2/7.5 kg soil.

Pathogenic action of *Meloidogyne incognita* race-2 and *Meloidogyne javanica* to two winter rapeseed (*Brassica napus* var. oleifera) cv. Hyola 401 and Iciola 41 was evaluated under greenhouse condition by Ferraz et al. (1999). After 40 days plant growth showed the significant difference between inoculated and uninoculated plants. At highest inoculum level both the nematode species caused a severe reduction in root system and plant becomes clearly stunted. Mahapatra et al. (1999) tested the pathogenicity of root-knot nematode (*Meloidogyne incognita*) in pointed gourd (*Trichosanthes dioica*). A significant reduction in shoot and root weight of *T. dioica* was observed at an
initial inoculum density of 1000 J2 of *M. incognita* per kg soil. This was considered as the damaging threshold level. Rate of nematode reproduction was density dependent.

Host parasite interaction of *M. incognita* and *Vitis vinifera* under greenhouse conditions was reported by Hafez *et al.* (2000). Shoot fresh weight showed a different response at different inoculum levels (100, 1000, 10,000 juveniles per pot). Effect of *Meloidogyne incognita* on growth and storage root formation of cassava (*Manihot esculenta*) was reported by Makumbi-kidza *et al.* (2000). Two node cutting of cassava cultivars SS4 were inoculated with 1000 infective juveniles of (*Meloidogyne incognita*) at 1, 14, 40, 70, 88 and 127 days after planting (DAP). Plant growth and root damage was assessed at 150 DAP. *M. incognita* significantly reduced the number of storage root formed in plants inoculated at 14, 40, 70 and 88 DAP and the total weight of storage roots in plants inoculated at 1, 14, 40, 70 and 88 DAP, compared to uninoculated plants. Experiment indicated that young cassava plants are most prone to root-knot nematode damage in terms of storage root formation. The production loss caused by *M. incognita* to young SS4 plants was due to a reduction of storage-root number rather than a reduction in individual storage-root weight.

Thirteen indigenous and exotic Acacia grown in Saudi Arabia were evaluated by Ibrahim *et al.* (2000) for their host status for *M. javanica* in pot tests both in the growth chamber and under outdoor conditions. Results of both the growth chamber and the outdoor test were similar. *Acacia farnsian*a, *A. gerrardii* subsp. *negevensis* var. and *najdensis* and *A. saligna* were excellent host and highly susceptible. This is the first report on the susceptibility of *Acacia* spp. to *M. javanica* in Saudi Arabia.

### 2.2 Pythium spp.

Krober *et al.* (1975) reported that *Pythium* and *Rhizoctonia solani* as pathogens of Gerbera. Stunted and dying plants of *G. jamesonii* in some commercial nurseries had symptoms of root-rot and occasionally rot of the stem base. *R. solani* and *P. irregularare* were identify as the casual organisms.
Inoculation tests showed that *P. ultimum* and *P. splendens* were also pathogenic. *R. solani* caused more damage than *Pythium* spp and attacked more mature plants, whereas damage by *Pythium* was restricted to younger plants. Hoch *et. al.* (1975) observed *Pythium* spp. as incitants of bean root and hypocotyls rot in Wisconsin. Studies were made of diseased plants and infested soil from over 100 Phaseolus bean fields. *Pythium* spp. including *P. splendens*, *P. ultimum* and *p. aphanidermatum*, were commonly isolated, as along with *Rhizoctonia solani* and *Fusarium solani*. Kuhnel (1978) collected soil and plant samples from different part of East Germany and examined for fungi causing beet damping off and black leg. *Pythium* occurred in 89%, *R. solani* in 50% and *Aphanomyces cochlioides* in 18% of 61 soil samples.

Ogundane *et. al.* (1976) discovered basal rot of cowpea a new disease caused by *P. aphanidermatum* and *Sclerotium rolfsii* singly or together occurs at any time in the field after first weeding till shortly before maturity. The optimum temperature for root-rot development was 30°C. Suzuki *et. al.* (1978) reported that zoospores of *P. aphanidermatum* were strongly attracted by crude exudates from cucumber roots. Singh *et. al.* (1978) observed the incidence of *P. butleri*, on the fruits of bottle gourd (*Lagenaria lucantha*), melon, watermelon and all isolates resembled one another morphologically and pathogenically.

Wahab *et. al.* (1978) reported the growth requirements of *Pythium aphanidermatum*, cause of “cottony leak” in *Luffia cylindrical* fruits. Mitchell (1978) studied on relationship of inoculum levels of several soil borne species of *Phytophthora* and *Pythium* to infection of several hosts. Between 15 and 43 zoospores/ gm soil were required for 50% infection of groundnuts, rye or soyabean by *Pythium myriotylum*; Amaranthus, cotton and tomato by *P. aphanidermatum* or of cabbage by *P. polymastum*. Petrov (1979) observed the role of *Pythium* spp. on the development of some diseases of vegetable crops in Murmansk region. *P aphanidermatum* spp. are also responsible for damping-off...
and death of seedlings of lettuce, radish, cucumber, tomato, turnip, cabbage, carrot, beet and swede.

Johnson (1979) noticed the susceptibility of cotton seedlings to _P. ultimum_ and other pathogens. Hypocotyls of 27 cotton cvs. were inoculated with _P. ultimum_. Disease severity was rated after 7 days at 18°C. There was a small but measurable difference in susceptibility. 8 cultivars were significantly more resistant, and 2 were more susceptible, than Stoneville 603. Delcot 277 was more susceptible than Stoneville 603 at 18 or 20°C. Tarabein et al. (1979) reported the damping-off and fruit rot of certain cucurbitaceous plants in Iraq. _Pythium aphanidermatium_ and _Fusarium solani_ caused the disease of squash and cucumber. These were newly reported disease. Similarly Liu (1980) observed the _Pythium_ root-rot of sugarcane in Puerto Rico. _P. aphanidermatum_ and _P. deliense_ were frequently isolated from fields on the south coast where ratoon stunting was also observed. _P. acanthicum, P. butleri, P. echinocarpum, P. graminicola, P. oligandrum_ and _P. perioplasm_ were also isolated and all were pathogenic to cv. PR1152 in lab and glasshouse test. only _P. aphanidermatum_ significantly reduced dry weight of top and root growth of PR1085. Rahimian et al. (1979) observed the biology of _P. aphanidermatum_; the intact of cucurbit root-rot and damping-off in Fars province of Iran.

Kageyama et al. (1982) observed the survival structure of _Pythium_ spp. in the soil of bean fields. The propagules of _P. acanthoporon, P. paroecandrum, P. spinosum_ and _Pythium_ spp. which survived in organic matter and/or soils zoospores or Zoosporangia. Sida et al. (1983) observed the influences of soil moisture on the incidence of damping-off of cucumber. Seedling growth was considerably affected by infections at 55% moisture. In contrast damping-off caused by _P. aphanidermatum_ was more severe and high population of the fungus was maintained in soil at 95% moisture. The effect of the soil moisture on disease incidence caused by _P. aphanidermatum_ was evident only in the early stages of growth.
Watanabe (1983) studied the distribution of Pythium aphanidermatum and its significance in Japan. He isolated fungus from the roots of 11 plants samples including cucumber, eggplant, tomato, spinach, Brassica spp. and Chinese cabbage using cucumber and lupin seeds as bait let to its detection in 52.4% of 21 samples from the Rukyn Islands in 48% of 25 from Kyushu and in 14.8% of 27 from Tohaku. The pathogeneity of 10 isolates to cucumber and bean seedlings was demonstrated at 28-33°C and also at 18-23°C. Thus this fungus may be more widely distributed than was previously believed.

Stanghellini (1983) observed the distribution of Pythium aphanidermatum in rhizosphere soil. P. debaryanm is reported causing wilt of watermelon grafted on bottle guard (Legenaria sicerania) by Tominaga et. al. (1983). Watermelon grafted, on squash plants were not infected. Sumner et. al. (1983) reported the rot diseases of cucumber in irrigated multiple cropping systems with pest management. Cucumber was planted in each of 6 years in a 2 year of multiple cropping sequences of turnip-groundnut cucumber-turnip-cucumber-soybean with 4 types of soil pest management. Root disease and post emergence damping off were caused primarily by P. aphanidermatum, P. irregulare and Rhizoctonia solani AG-4.

Hall (1983) observed the Pythium root-rot of white bean in Ontario. Pythium spp. were isolated from 35% of stem and 15% of root lesion on bean (Phaseolus vulgaris), plants. Other spp. commonly isolated were P. spherical (stem 69%, 50% root), P. paroecandrum (stem 5%, root 32%), P. selpingophorom (23%, 12%) and P. rostratum (2%, 4%), P. ultimum, P. oligaudrum and P. arrhenomanes were rare (1% or less of isolates). In pathogeneity tests, all tested isolates of the common spp. caused rotting of fine roots similar to that observed in the field, but few caused stem rotting.

Alvarez et. al. (1984) identified the fungi causing the root-rot on chickpea (Cicer arictinum L.) Of 32 isolates from 180 samples collected in various region in Chile, 70 were Fusarium, 15 Rhizoctonia, 10 Pythium, 5 Botrytis and 5 Sclerotinia. In pathogeneity tests, Fusarium caused wilt, leaf
chlorosis and root-rot, *Pythium spp.* pre-emergence damping-off and root-rot, chlorosis and wilt in seedlings and *R. solani* pre and post emergence damping-off and severe root-rot with foliar symptoms, followed by death of seedlings.

Bakhariev (1984) introduce a new disease of cucumber, caused by *Pythium cucumerinum*, isolated from glass house cucumber in Bulgaria in 1983. Infected leaves showed round pale green spots, 4-5 cm diam. The leaf tissue became soft and the leaves died. The fungus grew well at 20°C. Kusunoki *et. al.* (1984) observed the relationship between density of *Pythium butleri* zoospores and infection of cucumber seedlings.

*P. aphanidermatum* was isolated from mature plants of cucumber in glasshouse as reported by Nowsicki (1985). The fungus has described for the first time in Poland. Inoculation was successful on plants from the seedling stage until the beginning of harvesting; at temperature less than 30°C all 17 cultivars tested were susceptibl. Abdel latif *et. al.* (1985) studied on soft-rot of cucumber fruits caused by *Phytophthora drechsleri* and *Pythium butleri* and were highly pathogenic to fruits of cucumber, honey dew melon, marrow sweet melon, and watermelon. Both pathogens caused pre and post emergence damping-off of the cucurbitaceous plants and *P. butleri* was pathogenic on all post emergence seedling tested. Naiki *et. al.* (1986) noticed the *Pythium* spp. causing damping-off of spinach seedlings under plastic house cropping. Both species *P. aphanidermatum* and *P. paroecandrum* caused severe pre and post emergence damping-off of spinach in pathogenecity tests, and both were pathogenic to cucumber, pumpkins, watermelon, kidney bean (*Phaseolus vulgaris*) and soybean. Lourd *et. al.* (1986) studied the qualitative and quantitative test of pathogenic *Pythium* spp. in soils of Manaus region using a biological test. *Pythium* spp. were detected in soils not affected by flooding, cultivated soils and primary forests and infectivity being always higher in cultivated soils because of the presence of *P. aphanidermatum* which was highly pathogenic to cucumber used in the biological test.
Lourd et al. (1987) again did the qualitative and quantitative analysis of pathogenic *Pythium* spp. in soils of Manaus region II, Varzea soils. All 41 sample examined were infested by *Pythium* (85%). Stanghellini et al. (1988) reported *P. intermedium* for the first time as a root pathogen of hydroponically grown cucumbers. Favria et al. (1988) observed *Pythium* spp. associated with crown rot of cucumber in British Columbia. *P. aphanidermatum*, *P. irregulare* and *Pythium* spp. regularly isolated from infected root crown tissues. Isolates were tested for pathogenicity to cucumber in greenhouse and growth chamber studies. All 4 species were pathogenic. *Pythium aphanidermatum* caused much damage in the form of death of the plant followed by *P. irregulare* and other *Pythium* spp.

Saeed (1990) observed the population dynamics of the fungal incitants of root-rot and wilt disease complex of sunflower. *Macrophomina phaseolina* (*M. phaseolina*), *Fusarium oxysporum*. *F. solani*, *Pythium ultimum* and *R. solani* were isolated from diseased sunflower roots in Etmimia, Assiut and Sohag in upper Egypt. The number of isolated varied between localities and depended on the stage of plant growth.

Studies on the effects of different plants raising and growing conditions on severity of *Pythium* infection in artificially inoculated glasshouse cucumber on rockwool showed, plants raised at 25°C and at low frequency of watering to become more seriously infected than those raised at 19°C and watered frequently as observed by Paternotte (1992). After planting out, infection severity increased with increasing temperature (19 to 25°C), but frequency of watering had no effects on disease development. Disease severity was higher when *Pythium* inoculum was applied on new rockwool slabs than on reused infested slabs. Bhatti et al. (1992) noticed effects of inoculum density and temperature on root-rot and wilt of chickpea.

Kratka (1993) reported the effect of *Pythium oligandrum* and *P. ultimum* on IAA content and growth of cucumber. Roots of cucumber seedlings were treated with mycelium and spore suspension of *P. ultimum* and *P. oligandrum,*
and changes in the roots were studied over a period of 10 days. Second treatment was then applied and changes in the plants were studied during the next 14 days. *P. ultimum* inhibited plant growth and decreased IAA content and after the second treatment all plants died. *P. oligandrum* stimulated plant growth and increased IAA content, especially after second treatment.

Chang (1993) investigated and tested the pathogenicity of *Pythium* spp. From rhizosphere of *Cinnamomum osmophlocum*, eight *Pythium* spp. (*P. deliense*, *P. oligandrum*, *P. plerioticum* *P. spinosum*, *P. splendens*, *P. ultimum* var. *ultimum*, *P. vexans* and *Pythium* spp.) were isolated from the roots of *C. osmophlocum* in Taiwan. The pathogenicity tests in the greenhouse recorded that *P. splendense* and *P. vexans* exhibited 100% infection rate and 15-30% mortality rate to *C. osmophlocum*, *P. deliense* had a 40% infection while the other species had a low rate of infection (15-35%) and nil mortality rate. Wolk *et. al.* (1994) tested the pathogenicity of *Pythium aphanidermatum* on cucumber. When the inoculum quality was $5 \times 10^5$ oospores/pot, root weight was reduced from 5.27 gm to 2.07 g. Sprout weight from 21.37 gm to 16.72 g and sprout length from 26.70 cm to 19.90 cm. Although root weight showed the greatest damage caused by *P. aphanidermatum*. Moulin *et. al.* (1994) also tested the pathogenicity of *Pythium* spp. on cucumber in peat sand rockwool and hydroponics. Thirty nine isolates of *Pythium* obtained from discoloured roots of cucumber and tomato plants in soil less culture were assayed for their ability to cause damping-off in cucumber seedlings in sand peat and for their pathogenicity in soil less cultures of cucumber rockwool hydroponic solution. Isolates of *P. aphanidermatum*, *P. irregulare*, *P. sylvaticum* and *P. ultimum* were highly pathogenic is sand peat, but only *P. aphanidermatum* strains were pathogenic in soil less condition leading to root-decay.

In Japan browning root-rot of barley caused by *Pythium spinosum*, *P. sylvaticum* and *P. ultimum* var. *ultimum* was reported by Kusunoki *et. al.* (1994). From isolation and pathogeneicty test, *P. spinosum* was the most important pathogen followed by *P. ultimum* var. *ultimum* and *P. sylvaticum*. 
Larkin et al. (1995) identified the *Pythium* spp. associated with alfalfa seedlings and studied its distribution and comparative pathogenicity. Root system colonization of Lucerne seedlings by *Pythium* spp. was investigated during the first four weeks after seedling emergence at Cooks and New Franklin Missouri, USA. *P. sylvaticum*, *P. irregulare* and *P. ultimum* caused severe pre and post-emergence damping-off. Necrosis and stunting of root and shoot growth in greenhouse pathogenicity tests were observed.

The effect of different inoculum densities of *P. aphanidermatum* on disease development in long English cucumber plants grown in recirculating hydroponic culture were examined by Menzies et al. (1996). Cucumber plants in small recirculating culture systems were inoculated with *P. aphanidermatum* at levels ranging from 0.22 to $2 \times 10^6$ c.f.u./ 100 litre of nutrient solution. *Pythium aphanidermatum* spread through the nutrient solution and caused browning of roots at all inoculum levels. At $2 \times 10^6$ C.F.U/ 100 litres all plants died between 7 and 28 days after inoculation. Plants inoculated at low levels showed reduced growth and yield.

Different species of *Pythium* associated with root-rot of 5 vegetables (Peas, lettuces, cucumbers, *Phaseolus vulgaris* and cabbages) were recorded by Botha et al. (1996) as new records from South Africa. Eight species of *Pythium*, namely *P. dissotocum*, *P. sylvaticum*, *P. spinosum* *P. irregulare*, *P. aphanidermatum*, *P. polymastum*, *P. miyriotylum*, *P. mamillatum* and 2 heterothallic groups (T. groups and F. groups) were isolated from rotted roots. In 1994 and 1995 in Iowa, USA, *P. torulosum*, was isolated by Zhang et al. (1996) from soil and diseased soyabeans. All of the 9 isolates caused preemergence damping-off in soyabeans and maize and *P. torulosum* was reisolated from diseased tissues. It caused seed-rot and death, root-tip discolouration and yellow lesions on the root and hypocotyls bases of 2-week-old soybean. Mukharjee et al. (1996) reported the *Pythium* leaf blight of groundnut. Symptoms of leaf blight were observed in groundnut fields in Trambay, Mumbai, Maharashtra, India in 1994 and 1995. *P. aphanidermatum*
was isolated from infected leaves and it was thought that it was the first record of this pathogen. Kim Jin Won et al. (1998) isolated a *Pythium* spp. from roots of lisianthus (*Eustoma grandiflorum*) showing wilt symptoms and reduced growth in a greenhouse at Ichon, Kyonge C-do Korea republic in 1997. The isolate was strongly pathogenic when inoculated to roots of lisianthus plants in pots. The diseased plants showed typical symptoms of root and crown rot, resulting in reduced root and shoot growth wilting of above ground plant parts.

Wulf et al. (1998) observed that when hydroponically grown cucumber (Cucumis sativus cv. corona) seedlings were inoculated zoosporangia of 1 mycoparasitic (*Pythium oligandrum*) and 2 pathogenic (*P. aphanidermatum* and *Pythium group F*) *Pythium* spp. caused reduction in root length. However, roots treated with *P. oligandrum* quickly reached the length of the control, *P. oligandrum* was not pathogenic on cucumber. *Pythium group F* and *P. aphanidermatum* were pathogenic to cucumber seedlings. *Pythium 'group F'* had a constant negative influence on root length and plant growth, measured as fresh weight. *P. aphanidermatum* caused generally necrosis of the root system, inhibiting consistently root elongation and plant growth and finally causing plant death. *Pythium 'group F'* and *Pythium aphanidermatum* were better root colonizers than *P. oligandrum*.

The occurrence of fungi associated with root-rot and vine decline of melon in commercial fields in California, USA was surveyed by Aegerter et al. (2000) over three years. The fungi most frequently isolated from discoloured vascular tissue or root-rot were *Acremonium cucurbitacearum, Rhizopyenis vagum, Monosporascus Cannaballus, Fusarium solani, Maacrophomina phaseolina, Verticillium dehliae* and *Pythium* spp were frequently associated with a wet and brownish root-rot.

### 2.3 *Rhizoctonia* spp.

Ibrahim et al. (1977) reported from Egypt that the fungi associated with seedlings and podrot of peanut in inoculation tests of *Rhizoctonia solani* and *Sclerotium rolfsi*, which were highly pathogenic to seedlings and plants at
fruting stages. Kannaiyan et. al. (1978) studied the reaction of certain cereal crop plants to sheath blight disease of rice. The effect of artificially inoculating 18 graminaceous crops with Rhizoctonia solani was tabulated. The results indicated that the pathogen perpetuate in any of these hosts which may serve as inoculum sources. Rakvidhyasastra (1978) reported the host range of R. solani pathogenic to the leaves of all the test plants i.e. Eichornia crazies, Hibiscus sabdariffa, rice, maize, sorghum, Phaseolus aureus (Vigna radiata), groundnut, soybean, cotton and tobacco and also caused post emergence damping-off all except Graminae at the seedling stage. Naiki et. al. (1978) reported grouping of R. solani Kuhn causing root disease of spinach in plastic houses cropping from June-September. The pathogen occurred most frequently during the earlier growth stages of the plant.

Lakshmanan et. al. (1979) reported the color-rot and web-blight of cowpea caused by R. solani in Kerala. This new disease of cowpea was noted when cowpea was cultivated as a fallow crop in rice fields in summer. Perrin (1979) reported the rot of beechnuts caused by R. solani Kuhn. The fungus caused decay of the cotyledons, resulting in failure to sprout or death after emergence in November and December throughout France. Fukutomi et. al. (1979) again processed the ultrastructure of infection of R. solani kuhn in cucumber hypocotyls. Attachment of the hyphae on the epidermal surface was clearly observed 12 h after inoculation of an isolate of type III: A in cucumber seedlings. Gudmestad et. al. (1979) observed the effect of harvest date and tuber borne sclerotia on the severity of Rhizoctonia disease of potato.

Takade et. al. (1980) observed the yearly range on the development of sheath blight of rice plant caused by R. solani. Bose et. al. (1982) studied the effect of Aspergillus ochraceous and R. solani on Physicochemical properties of sunflower and sesame oil. Deteriorated oil samples showed change in colour, iodine value and saponification with prolonged incubation depending on the fungus and substrate.
Murray et. al. (1982) studied the penetration of barley root and coleoptile surface by *R. solani*. Ruppel et. al. (1982) observed *Rhizoctonia* root-rot of sugarbeet was remain unaffected by herbicides. Vanzainum et. al. (1982) studied *Rhizoctonia solani* kuhn on mung bean. Isolation from infected roots and leaves caused severe pre and post emenrgence damping-off and pod-rot; a seed isolate was less virulent, though dry weight of all inoculated plants differed from the control. Venkatasubbaiah et. al. (1983) observed the importance of inoculum density of *R. solani* in collar-rot disease of coffee. A linear relationship was found between inoculum density or disease expression upto densities of 25% above this there was a gradual decline in infection in both sterilized and unsterilized soils. Maximum infection (100%) was apparent at inoculum densities of 5-25% in sterilized and 25-50% in unsterilized soil.

Abawi et. al. (1985) reported the *Rhizoctonia* foliar blight of cabbage in New York state. Bittencourt also in 1985 reported that the most important diseases on pea in Federal district was stem and root-rot caused by *Rhizoctonia solani*, which was detected in 54% of the isolations. Plants stands were reduced by 13-24%. Sippel et. al. (1985) noticed the *Rhizoctonia* root-rot of rapeseed in the Peace River region of Alberta. Alam et. al. (1985) reported the disease of *Vigna radiata* caused by *Rhizoctonia solani* for the first time in Pakistan. Kinsbursky et. al. (1988) noticed the influence of different soils on inoculum density, disease incidence relationships of *Rhizoctonia solani*. Estimating radish seedlings after 3d in soil artificially infested with *R. solani* assessed these relationships.

Hossain et. al. (1989) reported *Rhizoctonia* leaf spot on two new hosts radish and groundnut. Saeed et. al. (1990) studied on population dynamics of the fungal incitants of root-rot and wilt disease complex of sunflower *Macrophomina phaseolina, Fusarium oxysporum, F. solani, Pythium ultimum* and *Rhizoctonia solani* were isolated from diseased sunflower roots in El-minia, Assiut, sohag and upper Egypt. Nishimura et. al. (1991) noticed the susceptibility of corn to *Rhizoctonia* root-rot and different varieties, 66 foreign
varieties and 27 inborn lines of maize tested were susceptible to *R. solani*. Sugar beet and maize strains were equally pathogenic to maize and sugar beet, but sugar beet strains were more pathogenic to *Rhizoctonia*. A severe fungal infection causing stem and fruit-rot, was recorded in melon cv. Soleado in central Italy by Corazza *et al.* (1992). Naresh Mehta *et al.* (1992) observed the influence of culture media on the pathogenic behaviour of *R. solani* and *R. bataticola* on various host plants. Virulent isolates of *R. solani* and *R. bataticola* (*Macrophomina phaseolina*) from cowpea roots were entered in various media and used to inoculate tomato, cowpea and *Lagenaria siceraria* plants grown in sterilized soil in pots.

*R. solani* caused 100% seedling mortality in cowpea, 78.12% in *L. siceraria* and 69.25% in tomato. *M. phaseolina* caused 92.18% disease in cowpea, 71.87% in tomato and 62.3% in *L. siceraria*. Severe attacks by *R. solani* on Kohlrabi were observed by Stranato *et al.* (1994) in province of Latina, Italy during the spring of 1992-93. The fungus caused root and stem rot and caused loses upto 20% of the crop. This was the first report of *R. solani* on Kohlrabi in Italy. Isolates of the fungus were pathogenic to Kohlrabi when inoculated artificially. Kamlesh Mathur *et al.* (1995) reported *Rhizoctonia solani*, a new pathogen in chilli in Rajasthan, India. They noticed that 80% *Capsicum* plants were affected by *Rhizoctonia solani* during March-April for the first time.

Factors affecting the viability of sclerotia and mycelia of *R. solani* on rice were studied by Basu *et al.* (1995) and Channa *et al.* (1995) studied on *R. solani* kuhn causing root-rot of lentil. *R. solani* was isolated from infected lentil roots and in vitro pathogenicity tests, 100% infection was recorded. Sunder *et al.* (1996) observed the effect of age and quality of inoculum, temperature and pH of substrate on the pathogenic behaviour of *R. solani* on cowpea and cotton. It was noted that *R. solani* was more pathogenic to cowpea than cotton. Increase in inoculum from 50 to 200 mg/pot resulted in an increase in seedling mortality. Pathogenecity of the isolates with an increase in the age of inoculum
at 25-30°C temperatures and 6.5-7.5 pH produced maximum disease on cowpea and cotton.

Maize yield losses caused by sheath-blight (*R. solani*) was determined in 20 varieties or combination in various parts of Jiangsu, China by Lianji Narg *et. al.* (1997). Result showed that yield losses ranged from 5.62-59.62%, were significant and linearly correlated with the severity of the disease. Yield losses increased as disease severity increased. Fungal pathogens were isolated from plants and seeds of chickpea cultivar Aziziye-94 (developed for possible large scale production in Eastern Anatolia in Turkey) and their pathogenicity was tested individually or in combinations in pot trails under controlled environmental conditions by Demirci-E et. al. (1999). *Fusarium solani* f.sp. pisi and *R. solani* were the most pathogenic species when inoculated alone or in combination with other species. They caused substantial reductions in seedlings emergence, plant dry weight and height.

### 2.4 Interaction of root-rot fungus and Nematode

Plant pathogens and environment form the disease triangle and the outbreak and intensity of disease depends upon the mutual interaction of these components. This is true with mono pathogenic condition, which is very rare in nature. Disease complexes involving nematodes and other microorganisms are common in nature. In the complex, biotic environment of soil, the pathogens always influenced by associated microorganisms. Root system irrespective of the nature of plant species, is constantly exposed to abiotic and biotic factors including soil-inhibiting micro-organisms which develop several kinds of inter relationships among themselves. Such association may be beneficial/deleterious to plants. Disease syndromes resulting from root diseases are often caused by microbial interactions. The fact that plant parasitic nematodes interact with other pathogens has been observed as early as in 1892. While working on cotton, Atkinson reported that there was greater damage as a result of interaction of root-knot nematodes *Meloidogyne* spp. and wilt fungus.
Considerable studies have been made on the interaction of nematodes with fungal pathogens and the literature has been reviewed from time to time (Miller 1965, Pitcher, 1965, Powell et al. 1971a, Pitcher 1978, Sikora 1987, Webster, 1985, Swarup, 1990). However Pitcher (1965) classified the interaction between nematodes and other fungi as:

- Vectors of pathogens capable of self-establishment once in contact with the host.
- Vectors of pathogens incapable of self-establishment unless introduced below the host epidermis.
- Mechanical wound agents.
- Providers of necrotic infection courts
- Modifier of substrates.
- Breaker of disease resistance.
- Deterrents of plant diseases.

Plant parasitic nematodes have principal role in many interactions, often making plant roots more susceptible to invasions and parasitism by other soil inhibiting micro-organisms (Hussey and McGuire 1987). Several possibilities have been suggested by different workers by which plant parasitic nematodes interact with other microorganisms. The literature on this subject has been extensively reviewed by several authors (Bergeson, 1972; Hirano, 1975; Powell, 1979; Taylor, 1990, Khan, 1993; and Ghoneim et al. 1997), which firmly establish the involvement and role of plant parasitic nematodes in interactions with other microorganisms.

Interaction between fungi and nematode have been recognized since 1892, when Atkinson reported that Fusarium wilt [Fusarium oxysporum f.sp. vasinfectum (Atk.) Synder and Hansen were more severe in presence of root-knot nematodes (Meloidogyne spp.) than in their absence. Several workers have reviewed the work on interaction of plant parasitic nematodes with fung on
various crops (pitcher, 1978; Powell, 1971 a, 1979; Bergeson 1972; Riedel, 1988; Hasan, 1993, Francl and Wheeler, 1993; Evans and Haydock; 1993; and Ghonein et. al.1997). Nematode-fungus interaction has been classified in number of ways and the roles played by nematodes in such interactions have been examined thoroughly. Powell (1971a) classified the nematode-fungus interaction on the basis of symptomatology of the disease caused by fungi into following three types.

1. **Nematode-fungus wilt disease interactions.**

2. **Nematode-fungus root-rot disease interaction.**

3. **Nematode-fungus seedling disease interactions.**

Although the involvement of nematode-fungus disease complex situation is widespread and literature is quite extensive, in the present study the review of literature is confirmed to the interactions involving nematodes and root-rot fungi, and is further categorized on the basis of nematode parasitism (i.e. with endo, semi endo and ecto-parasitic nematodes).

The root-rot fungi constitute a category of pathogens where considerable work has been carried out with respect to their interaction with nematode though not to the extent of wilt fungi-nematode complex. Prominent amongst the root-rot fungi are species of *Rhizoctonia* [*R. solani* (kuhn), *R. bataticola* (Taub) Butler, *Pythium* (*P. aphanidermatum* (Eds.) Fitz, *P ultimum* Trow, *Fusarium* [*F. solani* (Mast) App. Wollen]), *Phytophthora parasitica* Dastur, *Sclerotium rolfsii* (Sacc). and *Colletotrichum coccades* (Wallr.) Hughes that are known to interact with different plant parasitic nematodes. The role of nematodes in root-rot disease, in general is assisting the fungus pathogen in pathogenesis and increasing host susceptibility.

The frequency of involvement of nematodes and fungi in disease complexes is reflected in number of crops from which such complexes are recorded. Amongst the different plant parasitic nematodes of economic importance the root-knot nematodes (*Meloidogyne* spp.) have been thoroughly
studied and commonly found involved in synergistic interactions with root-rot fungi. Sterner (1942) for the first time realized and discussed the importance of root-knot nematode with respect of plant necrosis in presence of root-knot nematode and root-rot fungi on different crops.

A number of such studies underline the significance of nematode infected tissues in which the fungi pathogen derives aggressiveness and becomes more pronounced. The root-knot nematode, _M. incognita_ have been found to predispose the plant roots for secondary infection (fungal attack) resulting in the greater damage of plants by way of root decay and the disease caused by fungal pathogens become more pronounced and may appear earlier when plants are infected with nematodes.


Powel and Batten (1967) observed that _R. solani_ increased the severity of disease in tobacco when present in combination with _M. incognita_, though fungus alone is not an important pathogen especially after plants have crossed Juvenile stage. In galled roots, necrosis due to fungus was extensive, resulting in yellowing and stunting of above ground plant parts.

Nava et. al. (1970) found decay in tomato roots only when _M. incognita_ was added several weeks ahead to either of fungus _R. solani_ or _P. ultimum_. In the roots both _R. solani_ and _P. ultimum_ were present along with _M. incognita_. The _R. solani_ appeared to be more aggressive than _P. ultimum_. Cauquil and Shepherd (1970) reported that concomitant inoculation of root-knot nematode
(M. incognita) with Alternaria tenuis Nees, Fusarium oxysporum f.sp. vasinfectum, Glomorela gossypii, and Rhizoctonia solani kuhn synergistically increased the severity of the disease of cotton seedlings. Batten and Powell (1971) reported that when M. incognita inoculation preceded R. solani inoculation by at least 10 days, the M. incognita susceptible tobacco cultivars Dixie Bright 101 and Coker 316 exhibited more severe root-rot than when nematode and fungus were inoculated simultaneously.

Golden and Vangundy (1972) studied the interaction of M. incognita with R. solani and Thielaviopsis basicola Zopp on tomato and reported that M. incognita induced changes in the permeability of infected tomato roots resulting in increased leakage of electrolytes and organic compounds which consequently increased growth of both the fungi. Radewald et al. (1974) observed that root retardation and root deterioration was more when M. incognita was present with Pythium ultimum or R. solani on Dichondra repens. Hazarika and Roy (1974) studied the effect of R. solani on the reproduction of M. incognita on eggplant and reported that the two pathogens acted synergistically in causing plant damage but in the presence of fungus nematode reproduction was enhanced. Similar results were also obtained by Varshney (1982) on cowpea, when inoculated with M. incognita and R. solani Azam (1975) reported that Colletotrichum atramentarium (Break and Br.) Taub; a week pathogen, greatly damaged eggplant roots and reduced plant growth when inoculated simultaneously with root-knot nematode.

Few studies have attempted to elucidate the physiological basis of nematode-fungus interaction. It has been shown, however, that exudates from nematode infected roots accounted for an interaction between M. incognita and R. solani which produced a disease complex on tomato and okra (Golden and Vangundy, 1975). Galled roots of field grown tomato and okra infected with M. incognita were more susceptible to infection by R. solani than non galled roots on the same plant. Fungal sclerotia developed only on the surface of the galls and the first symptom of root decay appeared four weeks after initial gall
formation. Roots decayed only when the fungus and nematode were present together. The fungus initially colonized the giant cells, which were destroyed in two, or three days before invading other root tissues. In the same study Golden and Vangundy (1975) reported that *R. solani* responded to stimuli, which originated from nematode infected roots and passed through semipermeable cellophane membrane, by producing sclerotia on the membranes just opposite the galls. The leakage of nutrients from the roots attracted the fungus to the galls and initiated sclerotial development.

The role of exudates emanating from galls in this interaction was confirmed when it was shown that no decays occurred if roots inoculated with *R. solani* resulted in severe necrosis. Exudates increased between 3 to 14 days after nematode infection with carbohydrates being the principal constituents whereas after 28 days, nitrogenous compounds increased in the exudates of infected plants. The change in the carbon/nitrogen ratio of gall exudates after 28 days, favoured parasitic rather than saprophytic development of the fungus. This work illustrated the role of primary nematode pathogen in altering root exudates to favour the parasitic development of the fungus. Azam *et. al.* (1977) reported that extracts of root-knot nematode infected roots when incorporated into agar medium resulted in significant increase in radial growth of *R. solani*, *Pythium* spp. and *Colletotrichum atramentarium* in comparison to extracts of healthy roots. The radial growth of all the three fungi was highest in a medium having extracts obtained from roots inoculated with 5000 larvae. Chabra *et. al.* (1977) reported that association of *M. incognita* with *R. solani* caused highest reduction in root and shoot growth of okra, when the plants were simultaneously inoculated with both the pathogens.

Vangundy *et. al.* (1977) observed that root exudates and other nutrient metabolites, secreted from galled tissues of tomato which were infected by *M. incognita*, caused severe root-rot in association but when used alone no root-rot occurred. Root exudates contain increased amount of carbohydrates in comparison with those from uninfected roots. Galled roots also contained
increased quantities of protein and amino acids. These changes in concentration
and composition of organic substances in the soil doubtlessly influenced the
attraction and growth of the fungus and enhanced its ability to penetrate into
roots. When root leachates from infected roots were removed by trickle
irrigation, root-rot did not develop.

Chabra et al. (1978) reported that combined inoculation of *R. solani*
and *M. incognita* on okra plants grown in sandy loam and or sandy clay loam
soil caused heavy reduction in plant growth than either the pathogen alone. In
french beans simultaneous inoculation of *M. incognita* and *R. solani* caused
maximum reduction in plant growth. Sharma et al. (1980) reported that
*M. incognita* and *R. bataticola*, when inoculated simultaneously, had
synergistic effect on root-rotting of okra plants. They further reported that
biochemical analysis of okra roots revealed large accumulation of total
phenols, proteins and proline in the roots infected with *M. incognita* alone and
in combination with *R. bataticola* over the healthy roots. A pronounced
increase in proline contents was observed in *M. incognita* and *R. bataticola*
infected roots than in roots infected with *M. incognita* alone.

Carter (1975) reported that concomitant inoculation of *M. incognita*
with *R. solani* caused more damage than caused by either pathogen alone. They
further suggested that the nematode provided additional penetration sites for
the fungus since the two organisms attack spatially separate tissues. Hypocotyls
wounding and infection by *M. incognita* were independent in enhancing the
seedlings disease of cotton caused by *R. solani*, as localized effect was
produced by hypocotyls wounding, but the systemic effect was induced due to
infection of *M. incognita*. Chabra and Sharma (1981) studied the effect of
*M. incognita* and *Rhizoctonia bataticola* on germination of eggplant and okra
seeds and reported greater reduction in seed germination when both
*M. incognita* and *R. bataticola* were present together than in case of either
pathogen alone.
Raut (1983) reported that prior establishment of *M. incognita* to *R. bataticola* had a synergistic effect on the growth. However, adverse effect of the nematode was mitigated to a great extent by establishment of either of the fungus, but establishment of nematode prior to *R. bataticola* had synergistic effect on reducing top growth. Inoculation of *M. incognita* three weeks prior to *R. solani* significantly reduced the plant growth of tomato in comparison to its reverse condition (Chahal and Chhabra, 1984). This was attributed to the predisposition of seedling roots by nematode for subsequent damage caused by *R. solani*. Similarly in sugrabeet, *M. incognita*, *P. ultimum* and *R. solani* were found to reduce the growth of seedlings but maximum reduction was seen when plants were inoculated with *M. incognita* followed by *P. ultimum* or *R. solani* or *P. ultimum + R. solani* (Pandey 1984).

Husain (1985) reported loss of resistance to *M. incognita* in two chilly cultivars, Jowala (resistant) and longthin Faizabadi (moderately resistant) infected with *R. solani* or *P. aphanidermatum*. Similarly in other greenhouse study it was found that tomato cultivars could lose resistance to *M. incognita* in presence of *R. solani* and *Sclerotium rolfsii* (Hasan and Khan, 1985). Lanjewar and Shukla (1985) reported that rotting of ginger roots by *P. myriotylum* Drechsleri was equally severe in presence or absence of *M. incognita* but the presence of fungus decreased nematode reproduction. Al-Hazmi (1985) found increased severity of root-rot in two french bean cultivars when *M. incognita* was introduced prior to *Macrophomina phaseolina* (Maub 1) Ashby, but nematode reproduction was adversely affected when fungus was introduced first.

On cowpea, *M. incognita* interacted with *R. solani* and reduced plant weight and greater damage occurred if the nematode infection was established before inoculation of the fungus (Varshney et. al. 1987). Similarly on white jute plants combined inoculation of *M. incognita* and *R. bataticola* markedly increased the incidence of root-rot as compared to either organism alone (Mishra et. al. 1988).
Khan and Hussain (1988a) reported that individually *R. solani* was the most aggressive pathogen of cowpea followed by *M. incognita*, but the association of *R. solani* caused greater reduction in plant growth of bacterized plants when inoculated simultaneously with nematode and fungus. On the other hand there was significantly less reduction when fungus preceded nematode inoculation *R. solani* reduced the rate of nematode multiplication in all combinations as compared to nematode alone. Inoculation of cowpea with *M. incognita* and *R. solani* led to breakdown of resistance to both the organisms (Khan and Hussain 1989a) and a higher decrease in plant dry weight occurred when the lower inoculum levels of *M. incognita* were used with higher inoculum levels of *R. solani*. However, *R. solani* irrespective of inoculum level inhibited the multiplication of nematode (Khan and Hussain 1990a) and restricted its penetration in roots (Khan et al. 1992).

Pandey and Singh (1990) reported that *R. bataaticola* and *M. incognita* inoculated on chickpea (*Cicer arietinum*) either singly or concomitantly showed significant reduction of plant growth in pots. Tomato (Srivastava and Singh, 1991) and chilli (Kumar et al. 1992) have also been found to suffer by the effects of disease complexes involving *M. incognita* and *R. solani*, with great damage occurring when both the pathogens were inoculated simultaneously. Ali and Venugopal (1992) together studied the interaction between *M. incognita* and *R. solani* on damping-off or rhizome rot disease of cardamom seedlings in India. Plants were killed when both the pathogens were present together but not by either pathogen alone. Effect of individual and concomitant inoculation of *Rotylenchulus reniformis, M. incognita* and *R. solani* on the nematode penetration in cowpea roots was noted by Khan et al. (1992). The presence of *R. solani* adversely affected penetration of both the nematode species.

A greenhouse trial was conducted by Anwer et al. (1994) to determine the basis for antagonistic interaction between *Rhizoctonia* and *Meloidogyne incognita* on soyabean (*Glycine max*) cv.Clark-63. Greater inhibition in root
penetration by \textit{M. incognita}, development of females, galling and nodulation occurred with simultaneous inoculation of \textit{R. solani} and \textit{M. incognita} than prior and later inoculation of nematode. Physiological studies also showed the significant alteration in chlorophyll a and b, protein, oil and nitrate reductase enzyme of soyabean. Similarly Walia et. al. (1994) observed the interaction of \textit{R. solani} and \textit{M. javanica} on tomato. Shahzad & Ghaaffar (1995) studied the effect of \textit{M. incognita} on colonization of \textit{R. solani} on mung bean roots in Pot experiment and found that the colonization of mung bean roots (\textit{Vigna radiata}) by \textit{R. solani} increased in presence of \textit{M. incognita} in soil. Root colonization by \textit{R. solani} was related with the population of the fungus in the soil.

Interaction between root-knot and root-rot on olive trees was reported by Ghoneim et. al.(1996). Olive trees and seedlings grown at Islamia, Nairobi, Giza, and Fayoum, Egypt, showed a highest rate of infection with root-rot, while root-knot infection was abundant at Nairobi, Fayoum, and Ismailia. Among the nematodes isolated from olive roots, \textit{M.incognita} was more prevalent on diseased roots and increased the severity of fungal root-rot. Kumar et. al. (1997) recorded the effect of \textit{M.incognita}, \textit{Rotylenchulus reniformis} and \textit{Rhizoctonia solani} on brinjal. The growth characters were adversely affected by all the three pathogens when inoculated alone or in combination. The greatest loss was when all the three pathogens were combined, followed by a combination of both the nematodes.

Charu et. al. (1998) observed the effect of interaction between \textit{M.incognita},\textit{F.oxysporum} and \textit{R. bataticola} on chickpea. The combination of nematode and fungi caused more severe disease and yield loss. Reduction in plant growth, the severity of root-knot and wilt incidence were greater in combined treatments as compared to the pathogen alone. Similar influence of certain rhizosphere fungi together with \textit{R. solani} and \textit{M. incognita} on germination of (Pusa Ruby) tomato seeds was observed by Rekha & Saxena (1999). All the test fungi adversely affected the seed germination of tomato in
combination with *R. solani* and *M. incognita* in the order (least severe first) *A. flavus*< *P. vrmiiculatum*< *E. purpurascens*< *Rhizopus stolonifer*.

### 2.5 Seedling-rot fungus and Nematode

Pathogenicity of *Pythium aphanidermatum* to chrysanthemum in combined inoculation with *Belonolaimus longicaudatus* or *Meloidogyne incognita* was studied by Litterel *et al.* (1969). Iceberg chrysanthemum plants inoculated with *Pythium aphanidermatum* and *Belonolaimus longicaudatus* or *Meloidogyne incognita* showed *Pythium* disease symptoms earlier and were more severe, when plants were inoculated with the fungus alone. A significant reduction in plant weight and higher disease ratings were recorded for plants inoculated with *P. aphanidermatum* and *B. longicaudatus* than in plants inoculated with the fungus and *M. incognita*. Similar results were obtained when fungus were delayed 7 days after nematode inoculation.

Whitney (1974) used factorial glasshouse experiments to investigate the effect of *Pythium ultimum* and *P. aphanidermatum* with and without *Heterodera schachtii* on root-rot of sugarbeet. One in 4 yield tests, revealed a significant synergistic interaction between *P. ultimum* and *H. schachtii* on yield. Synergistic interactions of *P. myriotylum* with *Fusarium solani* and *Meloidogyne arenaria* on pod-rot of peanut was observed by Gracia *et al.* (1975). Peanut pod-rot was more severe when pods were exposed to soil containing combinations of *Pythium myriotylum* and *Fusarium solani* or *M. arenaria* than when pods were exposed to *P. myriotylum* alone. Only *P. myriotylum* alone caused significantly more pod-rot than that observed in controls.

Valle Lamboy *et al.* (1980) tested the pathogenecity of *M. incognita* and *Pratylenchus zea* and their association with *Pythium graminicola* on roots of sugarcane in Puerto Rico. Combined action of both the nematodes on cv. PR 890 was less severe than when only one nematode was present, but both reduced the number of internodes significantly. *P. graminicola* alone reduced
the height of primary shoots but had a greater effect with each nematode separately.

An interaction between *Pythium myriotylum* and *Meloidogyne incognita* on ginger was observed by Lanjewar *et al.* (1985) and resulted in fungal antagonism against the nematode in the rhizosphere, though the infection by fungus and infestation by nematode existing concomitantly did not affect the disease syndrome. The role of the *R. solani* and *Pythium aphanidermatum* was investigated by Hasan (1985) in the breakdown of resistance to *M. incognita* in *Capsicum annum* cultivar Jowala and Longthin Faizabadi respectively as resistant and moderately resistance to this nematode, when either of the fungi were inoculated simultaneously or later than the nematode, there was a breakdown of resistance of Jowala and Longthin Faizabad to *M. incognita*.

On chilli, *Meloidogyne incognita* interacted with *Fusarium solani*, *Pythium aphanidermatum* and *Rhizoctonia solani* to reduce plant weight. (Mani and Sethi, 1987). Although ginger was susceptible to root rotting caused by *P. aphanidermatum* or *F. solani*, prior infection with *M. incognita* appeared to prevent rotting caused by *P. aphanidermatum*, whereas, the rotting caused by *F. solani* become more severe (Doshi and Mathur 1987).

Vadhera *et al.* (1992) observed the inter-relationship between *Pythium aphanidermatum* causing soft rot and *Meloidogyne javanica* causing root–knot. There was a progressive cessation of plant growth with the increase of the inoculum level of root-knot nematode. Synergistic action due to combined effect of *Pythium aphanidermatum* and the initial level (1000 J2) of nematode was seen when the fungus was inoculated after seven days of nematode inoculation, but a higher inoculum level more than 1000J2 delayed the disease by five days. Intensity of soft -rot and root-knot complex was closely interdependent on inoculum levels of the nematode and fungus separately and simultaneous inoculation of fungal and nematode pathogen.

Ramana *et. al.* (1998) reported the effect of *Meloidogyne incognita*, *Pythium aphanidermatum* and *Ralstonia solanacearum*, alone and in
combination in ginger. *M. incognita* caused 29.6% to 33.35% yield loss at $\pi = 0.2$ to 2.0/100 c.c. soil. It had synergistic effect in rhizome rot/soft rot of ginger particularly when nematode was inoculated to the plants prior to fungal inoculation. The damage to the crop was greater, and the onset of the disease was early when *M. incognita* was inoculated 40 days prior to fungal inoculation.

Influence of *Meloidogyne incognita* infection on incidence of *Pythium aphanidermatum* in tomato cv. Pusa Ruby was observed by Ali-Anwar *et al.* (1998). Disease incidence caused by *P. aphanidermatum* in tomato cultivar Pusa Ruby was much greater in plants inoculated with root knot nematode + fungus than inoculated with the fungus alone. Fungal infection at various inoculum levels caused greater reduction in the length and weight of shoots and roots than to the nematode alone. Sequential inoculation of both pathogens irrespective of time interval, caused greatest reduction in plant growth. The maximum reduction in plant length and weight was recorded when *M. incognita*+ *P. aphanidermatum* were inoculated simultaneously. The results also showed that the decrease in nematode multiplication were proportional to the fungal inoculum.

Interaction between *Pythium aphanidermatum* and *M. incognita* in chilli and brinjal was reported by Karthikeyan *et al.* (1999). *Capsicum annum* and aubergine plants were inoculated with *P. aphanidermatum* and *M. incognita* in field experiment in Tamil Nadu. Both the pathogens were inoculated separately and in combination. The number of normal seedlings was counted weekly and the nematode gall index was determined. Damping off of chilli and aubergine seedlings was highest when the fungus and the nematode were inoculated in combination. Pre-emergence damping–off was 32.7 and 47.66% and post emergence damping off was 38.9 and 53.1% in chilli and aubergine respectively. The dry shoot weight was greatly reduced in both fungus and nematode inoculated plants. A drastic reduction of plant stand was caused by the interaction of the fungus and the nematode. The highest gall index was
observed in plant beds inoculated with *M. incognita* alone, followed by those treated with simultaneous inoculation of *M. incognita* and *P. aphanidermatum*.

### 2.6 Particulate air Pollutant and their effect on plants

In India there are 83 coal fired thermal power plants. The coal used in India is of mostly sub-bituminous type, followed by bituminous and lignite (brown coal), which contain high amount of ash content along with sulphur. Burning of large quantity of coal in thermal power plant release huge amount of fly ash, gases and volatile minerals into the atmosphere, while non combustible mineral matter retained in the bottom ash. Ash contents in coal consumed in the thermal power station is responsible for the emission of 2-3 thousand tons of fly ash per day and about 0.8 million tons suspended particulate matter per year.

The pollutants called particulate matter are conglomerate of chemically heterogeneous substances. The major air pollutants in developing countries is particulate matter which include coal dust, fly ash, lime dust, cement dust, soil dust and matter from various types of metal processing etc. They are the products of coal, cement, combustion of coal, gasoline and fuel oil, lime kiln operation, incineration, wrong agricultural practices, volcanic eruption transportation and construction etc. In developing countries particulate air pollutants are the major problem. In India 40-44% air pollutants are of particulate type (Das 1986).

During the burning of coal, oxides of carbon, sulphur and nitrogen and particulate matter are formed. Among particulate air pollutants, fly ash is most important with regard to its amount of production. Formation of fly ash depends primarily on the ash content of coal. Pulverized bituminous or sub-bituminous coal used in India, contain 25-40% ash, leading to formation of about 60 millions tons fly ash annually. Fly ash is grayish, powder waste and its ecofriendly disposal and gainful utilization is one of the most serious issues for the environmentalists and planners do face today, because in India around 4000 hectare precious land is needed annually to dispose of fly ash (Lal, 1994).
In view of presence of numerous vital plant nutrients, agronomic use of fly ash being explored. Some toxic elements are also present in fly ash, which may influence microbial activity in soil. A few formations are available on this aspect, which reveal both favorable and adverse effects of fly ash.

Constituents of Fly ash

Fly ash comprises finely divided particles of ash on entrained in fuel gases arising from combustion of coal. The size of particles may vary from 0.02\( \mu \) to over 300\( \mu \). It contains incompletely burned coal and the carbon contents of fly ash, may vary from 5-20\%. Although some samples may contain as higher as 50\%. A large number of minerals such as SiO\(_2\), Al\(_2\)O\(_3\), Fe\(_2\)O\(_3\), CaO, MgO, SO\(_3\), K\(_2\)O+N\(_2\)O, P\(_2\)O\(_5\), SnO\(_2\) and traces of Ni, Be, V, Hg, Se, Mn may occur in fly ash (Bhatia et al. 1978). Kamath (1979) by using instrumental neutron activation analysis determined the concentration of 17 elements in coal and corresponding fly ash (Na, K, La, Ce, Hg, Tb, Th, Cr, Hf) collected from stack precipitators of power plants.

X-ray studies show that fly ash obtained from the Thermal power plant station of Harduaganj (near Aligarh U.P. India) is basic in nature. It consist predominantly quartz, alumina, silica and traces of chromium, cupper, maganese, nickel and zinc (Majumdar and Mukharjee, 1983; Flukegel et al. 1983). Analysis of fly ash from thermal power plant, Kasimpur (now known as Harduaganj) was done by Pasha et al. (1991). Total organic carbon and total nitrogen were 0.07% and 0.05% respectively. Total metal analysed were Pb (27.56ppm), Ni (6.90ppm), Mn (22.8ppm), Co (3.82ppm), B (21.71ppm), Cu (1.52ppm), Cr (13.91ppm), Cd (0.24ppm), K (722.20ppm), Zn (3.04ppm), Fe (2.43ppm) respectively. The concentration of K, Pb, Mn, and B were higher than other metal elements. According to Sawell et al. (1989) fly ash contains relatively moderate concentration of cadmium and copper and much higher concentration of aluminium, lead and zinc. In another estimation, fly ash samples contained greater amount of various trace elements, including Cd, and Pb and other metals such as Co, Ca, Fe, Mn, Mo, Ni, and zinc (Wong and
Several nutrients essential for plant growth were present in fly ash in appreciable amount (Negi and Meenakshi, 1991). Khan & Khan (1996) found higher concentration of boron, calcium, copper, magnesium, manganese, phosphorus, potassium, etc., in fly ash collected from a coal-fired thermal power plant. Fly ash application in soil may increase pH, electrical conductivity, and cation exchange capacity and concentration of boron, selenium, sodium, and sulphate (Shane et al. 1988; Khan et al. 1997). Fly ash contains certain heavy metals and other compounds such as nickel, arsenic, cadmium, chromium, lead, zinc, copper, etc. (Wadge and Hutton 1987; Onliveers et al. 1990) and complex compounds such as dibenzofuran and dibenzo-p-dioxine mixtures (Helder et al. 1982; Sawyer et al. 1983). These chemicals may prove toxic to plants and soil microbes.

**Mineral uptake by Plants**

Plants growing in fly ash amended soil absorb elements present in ash. Lisk et al. (1979) reported enhanced absorption of B, Cu, Co, Fe, Mg, Mn, Mo, Se, and Zn by plants grown on ash amended soil. Lettuce, spinach, wheat, tomato, and perennial rye and gram absorbed selenium in proportion to percentage of ash in the growth media (Littman et al. 1988).

Fly ash application was considered to increase yield by increasing the pH of soil and the content of moisture in the soil. Although fly ash has been used successfully to improve the yield of certain crops (Adriano et al. 1980; Tolle et al. 1982) particularly when fly ash corrected a macro and micro nutrient deficiency. However, higher amendment rates produced a significant decline in test crops due to toxic effects. Fly ash usually contain high concentration of essential plant nutrients except nitrogen (Adriano et al. 1980; Mishra and Shukla, 1986). Moliner and Street (1982) found calcium carbonate and fly ash to be equally effective as limiting material for all three acid soil of Florida tested. Elseewi and Page (1984) found a small application of fly ash to improve molybdenum deficiency. However, for a safe land application of fly
ash, it is essential to evaluate its potential effect microbe mediated ecological process, which maintain the fertility and productivity of biosphere.

Effect of coal fly ash application on the elemental composition and yield of some crops and on the properties of calcareous soil was observed by Khandkar et al. (1996). The application of fly ash increase the proportion of silt size (0.02, 0.002 mm diameter) particles, the water holding capacity, the electrical conductivity and the extractable amounts of Mg, Ca, S, Fe, Mn, Zn, B, Na and Al from the soil. Particle density, pH and extractable N were decreased. Biofuel ash use in salix plantation, Biomass production nutrient uptake and heavy metal circulation was studied by Sander (1997).

Khan et al. (1997) reported 62 and 113% increase in root and shoot boron of tomato plants grown in 10% ash amended soil. The boron contents gradually increased with the increase in ash concentration leading to a maximum of 5092 and 3944% in root and shoot of tomato in 100% ash respectively compared to the plants grown in soil without ash. Physico-chemical analysis revealed exceedingly higher concentration of important plant nutrients like P, K, Ca, Mg., Mn, Si, Se, B etc. in the ash collected from a field near by a power plant (Khan and Khan, 1998).

Effect of fly ash application on physico chemical properties of soil was noted by Kuchnawar et al. (1997). Fly ash application decreased maximum water holding capacity and increased available N, P, K and exchangeable Ca$^{2+}$, Mg$^{2+}$ and trace elements such as Zn$^{2+}$, Fe$^{2+}$, and Mn$^{2+}$. The study showed that 10t fly ash/ha was the best rate for improving soil properties.

Soil metabolic activities and yield in groundnut, ladiesfinger and radish in fly ash amended soil were reported by Sarangi et al. (1998). The fly ash amended soil showed increase in pH, soil conductivity, available phosphorus, organic carbon, organic matter and C/N ratio in amended soil over control. The yield per plant and total leaf area/plant increased by 4%, 57% and 77% for groundnut, ladies finger and radish respectively in fly ash amended soil.
Burman et al. (1998) reported the accumulation of heavy metals in vegetables, pulse and wheat grown in fly ash amended soil. Heavy metals in soil and in 12 plants species (turnip, cabbage, carrot, radish, spinach, pea, coriander, lettuce, tomato, brinjal, gram and wheat were determined in fields receiving fly ash from a thermal power plant. The metal contents (Cd, Cu, Zn, Fe, Ni, Cr. and Pb) in soil samples were higher than in the control soil. In the edible parts of the plant Cu, Zn and Pb concentration were in the recommended permissible limits, whereas Cd, Cr. and Ni concentrations were sometimes higher.

Root growth of wheat seedling and trace element levels in ryegrass (Lolium multiflorum) were determined by Wright et. al. (1998) in acid soils treated with 1.25 to 80 gm/kg of eight coal combustion byproducts: fly ash (FA), bed ash (BA), Cyclone ash (CA), Limestone Injection residue (LIMB), spray drier residue (SD), scrubber sludge (LS), stabilized scrubber sludge (SS) and gypsum like material (G). B, Se, As and Mo were increased in ryegrass grown in treated soil, but Se from FA treatments was the only potential food chain risk from a single application of these materials. It is suggested that the G material is the most beneficial for land application because it improved root growth without producing elevated trace element levels in plant material or soil solution.

Influence of fly ash with and without FYM (Farm yard manure) and fertilizer on physico chemical properties of sunflower and cotton growing soil was observed by Malewar et al. (2000). The result showed that the application of 10t FYM/ha + recommended doses of NPK were beneficial for soil improvement and nutrient availability. Further uses of fly ash decreased the bulk density and increased porosity, infiltration rate and available boron in sunflower and cotton growing soils. Fertilizer, FYM and fly ash in interactions improved soil physical properties.

Effect of fly ash on physico chemical properties of the soil and seed germination, metal uptake of barley and wheat plants was noted by Khan et. al.
Beneficial effect on physiological development was noted at lower doses.

**Plant growth and yield**

Effect of various particulate matters on vegetation has been documented by many workers (Thomas *et al.* 1952; Middleton *et al.* 1958; Pack *et al.* 1959; Schuck and Locke, 1970; Shimshon *et al.* 1975). Heavy deposition of particulate matter can cause severe damage. They cause chlorosis, necrosis and death of tissues. Many particles are by product of agricultural practices and are usually inert. Most of the reports concerning harmful effects viz; cement kiln dust on plant stress, the fact that the leaves, twigs and flowers.

Peirce (1910) and Parish (1910) noted in California that settled dust in combination with mist or light rain formed a relatively thick crust on upper leaf surfaces of affected plants. Peirce (1910) demonstrated that incrustation of cement kiln dust on citrus leaves interfered with light required for photosynthesis and reduces starch formation. This was later confirmed by Czaja (1962) and Bohne (1963) in a variety of plants. Czaja (1966) has presented histological evidences that stomata of conifers may be plugged by dust, preventing normal gas exchange by the leaf tissues. Darley (1966) demonstrated that kiln dust deposited on beam leaves in presence of free moisture interfered with the rate of CO$_2$ exchange but no measurement of starch were made. They also reported that cement dust is alkaline in nature and produce injury to the plants in the close vicinity to cement factory.

Mc Cune *et al.* (1965) reported an increase of 4-mm. Tip burn on gladiolus exposed to cryolite (Sodium aluminum fluoride dust). Coolwill *et al.* (1979) noticed the deposition of dust on leaves of plants grown along the road side with highly busy traffic. Such plant showed poor growth. Satyanarayan *et al.* (1988) observed the effect of fly ash pollution on *Datura inoxia*. The dustfall on the leaves was high and the concentration of photosynthetic pigments were low for leaves of plants growing near the power station; these
leaves showing high levels of sugars, total phenol and free proline and high activity of oxidative enzymes.

The effect of dust fall studied in leaves in high pollution and low pollution areas of Ahmedabad (India) by Vora and Bhatnagar (1987) showed that the percentage of foliar injury was much more in high pollution in comparison to low pollution areas. There have been numerous reports that dust of varying origin interfere with stomata functioning mostly by filling and blocking of stomata aperture (Ricks and Williams, 1974; Fluckiger et al. 1978, 79); increase leaf temperature (Eller, 1977; Fluckiger et al., 1978) and transpiration (Beasley, 1942; Eveling, 1969); reduce photosynthesis (Darley, 1966) and increase the uptake of gaseous air pollutants (Ricks and Williams, 1974). All these effects eventually resulted in poor growth of suffering plants.

Fly ash is of the important particulate air pollutants contains macro and micro nutrients which enhance plant growth in nutrient deficient soils (Martens and Beahm, 1978). Scanlon and Duggan (1979) reported that tree and shrub seedlings grew well in fly ash amended soil. Sopper and Mcmohan (1987) observed the application of industrial fly ash and municipal sludge mixture successfully establish vegetation on area designed as “Superfund” site.

Wong and Wong (1989) studied germination and early seedling growth of Brassica parachensis and B. chienis in two types of soil (Sandy soil and Sandy loam) to which fly ash was added. Low fly ash amendment at 3% improved young seedling growth of both crops, but high ash amendment (12-30%) produced adverse effects or growth. Application of 70 MT/ha fly ash in strip mine plot increased the biomass production of two grasses (Agrostis tenuis and Lespedeza cuneata) and one legume (Festuca amendinacea) by 5 to 30 times in comparison to the plants grown in untreated soil under field condition (Fall Jr. 1987).

Germination behaviour of some important crops species in fly ash incorporated soils was observed by Pawar and Dubey (1988). Seed germination of maize, Sorghum, wheat and gram was tested in two soil types, treated with
0-100% fly ash on w/w basis. Plant growth and yield of chickpea and lentil increased gradually with the increasing level of fly ash from 10% to 50% (60% in case of lentil). Percent germination in most crops increased in soils treated up to 10% fly ash and decreased with higher fly ash rates except in gram, which tolerated 30% fly ash.

Fly ash is the waste product of thermal power plant. An attempt was made to biologically reclaim the fly ash disposal area near Chachai, Madhya Pradesh by Mishra et al. (1995,1997). Out of 12 species planted as 2 month old seedling in pits at 2 x 2 m spacing, with four treatments (various combination of soil, fly ash, sand and compost), only Eucalyptus hybrid (E.tereticornis) and Acacia auriculiformis survived after 6 years. These two species grew best in treatment receiving soil, sand, fly ash and compost at a 1:1:1:1 ratio. Performance was poorest in fly ash alone. In second experiment seedling of 4 species were planted in pits in an area with a 2.54 cm. layer of soil spread over the fly ash dyke. All 4 species survived with E. tereticorhis performing best, A. auriculiformis and Peltophorum ferigineum intermediate and Pongamia pinnata most poorly. After 6 years of plantation growth, natural vegetation had become established and will ultimately stabilize the fly ash and reduce the environmental pollution it causes. Similarly Srivastava et al. (1995) introduce biological method of fly ash stabilization through afforestation an ash dump yards near thermal power station, Panki (Kanpur) by sowing the sapling of different trees. Trials were carried out of 10 multipurpose tree species (6 nitrogen fixing and 4 non-nitrogen).

Matte and Kene (1995) observed the effect of fly ash application on yield performance of Kharif and rabi crops in Nagpur, Maharashtra. Application of 10t fly ash /ha gave the best results, increasing seed/grain yields by 7-30%. Yields were generally highest with the recommendation NPK rates. Effect of fly ash on soil crust strength and crop yield was observed by Patil et al. (1996). Application of fly ash, FYM, sand and rice husks either alone or in
combination with fly ash generally reduced the crust strength of soil. The effect was in the order of rice > husks fly ash > sand = control.

A pot experiment was conducted by Tripathi and Sahu (1997) to study the effect of fly ash on growth and yield of wheat. Data showed that 50% fly ash applied to soil increased seedling height, plant height, girth, leaf number, leaf area, spike length, dry weight etc. The values of the effect of soil + fly ash on growth and yield are comparable with those of soil +10% compost and soil + 0.6% NPK treatments.

Kuchnawar and Matte (1997) studied the graded doses of fly ash and fertilizers an growth and yield of groundnut. The study showed that 10+ fly ash / ha and 25; 50: O N: P: K kg / ha were optimum levels for groundnut cultivation. Su Dechun (1997) reported the growth of Agropyron elongatum in an artificial soil mix with coal fly ash and sewage sludge. Addition of the ash sludge mixture significantly improved the seedling emergence and dry weight yields of Agropyron. Pots with 10% fly ash sludge mixture at 1:5: psi soil mixing ratio had the highest yield, while those with 10 and 35% ash sludge amendment at 1:1: psi soil mixing ratio had lower dry weight yield but were still higher than that of the control with fertilizer treatment.

Kalra et al. (1998) reported the fly ash as soil conditioner and fertilizer. The grain yield of maize increased in fly ash treated plots with the addition of ash up to a maximum addition of 10t /ha. The yield of wheat increased up to an addition of 20t/ha and declined thereafter. Fly ash treated pots had a marginally higher uptake of Zn, Cu, Fe, Mn and Cd. The addition of fly ash also reduced the hydraulic conductivity and improved moisture retention at field capacity and wilting point. These changes in soil properties might have been due to modification in macro, micro pore size, which may also have contributed to the increased crop yields in light and medium textured soils.

Tripathi et al. (1998) observed the impact of fly ash, light and shade environment on growth and chemical response of Albizia procera and Acacia nilotica. On the basis of storage substances, ascorbic acid, proline, phenol and
amino acids in both the species, it was concluded that *Acacia neolotica* could survive in shade as well as in light. Similarly Malewar *et al.* (1998) noticed the effect of different combinations of fly ash and soil on growth attributes of forest and dryland fruits such as nilgiri (*Eucalyptus globules*), neem (*Azadirachta indica*), custard apple (*Annona squamosa*) and Jamun (*Syzygium cumini*) at Marathwada Agricultural university, Parbhani, Maharashtra (India) during 1995-96. Malewar *et al.* again in 1999. Studied the impact of different levels of fly ash on growth attributes and dry matter yield of various crops. Plant dry weight of wheat and sunflower was highest in 1:3 fly ash: soil mixtures, while in sorghum the 3:1 fly ash: soil plants gave the greatest weight.

Khan and Ghadirpour (1999) examined relative efficacy of broadcast, raw and spot treatments of fly ash on the growth and yield of chilli, eggplant and tomato. Fly ash was applied @ 6 qt /ha in fields through the above mentioned mode of treatment. Row application of fly ash @3Qt/ha significantly increased the plant growth and yield of tomato cultivars (Khan and Singh 2001). Masilamani and Dharmalingam (1999) observed the germination behaviour of teak (*Tectona grandis* Linn. *F*) drupes in fly ash incorporated medicine. The best germination, seedling growth and vigour were in sand only medium followed by the fly ash + red earth + FYM mixture.

Bhaisare *et al.* (2000) observed the effect of fly ash on yields, uptake of nutrients and quality of green gram grown on vertisol. Result showed that the highest yield of grain and straw along with highest content and uptake of nutrients were recorded with the increasing levels of fly ash up to 10t/ha. The same level of fly ash recorded the highest content of crude protein and test weights. Amongst the fertilizers green gram responded well to higher doses of N and P fertilizers for yield, quality and nutrient uptake and content. The combined effect of fly ash and fertilizers has not significant. Khan *et al.* 2001 reported that Raw application of fly ash @ 3 qt / ha significantly increased the plant growth and yield of tomato cultivars.
Sharma et al. (2001) observed the fly ash incorporation effect on soil health and yield of maize and rice. Results obtained from experiments indicate that grain yield of maize increased in fly ash added plots (up to 10t/ha), where rice yield was similar to fly ash treated plots. Fly ash added plots marginally higher uptake of Zn, Cu, Mn and Cd. Similarly effect on plant height and flowering of winter ornamental plants was observed by Khan and Abdussalam (2002).

**Pesticidal effect of fly ash**

Addition of fly ash in soil does alter physico chemical characters of soil that may directly influence activity of soil microorganism including pathogens. Effect of soil applications of fly ash on a few soil-borne pathogens have been examined. Fly ash incorporation in soil (20-100%) adversely affected the root invasion by the larval, disease intensity (number of galls / root system) and reproduction (number of eggmases/root system) of root-knot nematodes, *Meloidogyne* species on cowpea and tomato (Khan et al., 1993, 1977). Mature females of the nematode excised from root of pea plants grown in 50 or 75% fly ash developed abnormality and irregularity (Singh et al., 1994) field application of fly ash especially spots and row treatments greatly decreased the intensity of root-knot disease and reproduction of the nematode on chilli, eggplant and tomato (Khan and Ghandirpour 1999). In a recent study, Khan and Singh (2001) noted the fungicidal effect of 3-6 Qt / ha fly ash on the soil population of *Fusarium oxysporum f.sp.* Lycopersici on tomato. Wilt severity was also decreased. Similarly root-rot caused by *Rhizoctonia solani* was also inhibited in some winter ornamental plants when grown in flyash amended soil.

### 2.7 Effect of Photosynthetic Pigments

Chlorophylls, the green pigments of plants are the most important pigments responsible for the conservation of light energy into chemical energy and are thus active in process of photosynthesis. Chlorophyll a and b are the most abundant pigments in the plants. Nematodes and fungi are known to interact with the metabolisms of photosynthetic pigments in plants. However,
the information about their influences on the photosynthetic pigments and photosynthesis is limited.

**Effect of Nematodes**

When nematodes infect one part of the host plant eg. roots, they rapidly disrupt the physiological process in one way or the other. Loveys and Bird (1973) reported that *M. javanica* infection caused the reduction in net photosynthetic rate and chlorophyll contents of tomato. Nematode invasion is also known to bring a change in the concentration of nutrient elements such as Fe, Zn, Mn, K. etc. which play an important role for the constituents of plants eg Fe and Mn in photosynthetic pigments. Change in the concentration of these elements in plants even to a small extent, appears to have a profound impact on host physiology which in turns appear to have a major cause in limiting the growth of host plant and cause imbalance in translocation process (Bird and Loveys, 1975; McClure, 1977).

Singh *et al.* (1977) observed a gradual decrease in the chlorophyll contents of mung bean with the increase in the inoculum level of *M. javanica*. The bacterized plants had higher concentration of chlorophyll than the unbacterized ones. The reduction in chlorophyll contents was attributed to the alteration of host nutrition and physiology, as reported earlier (Bergeson, 1966; Doney *et al.* 1970). Melakeberhan *et al.* (1985 a) found significant decrease in the chlorophyll content of French bean, within two weeks after infection with different inoculum levels of *M. javanica*. In another study chlorophyll content at the end of the experiment was markedly lowered in the French bean inoculated plants with *M. incognita* (single generation), at the bud stage than at either of earlier stages (BPLE, TRIF). While chlorophyll b content in all plants did not change significantly with increasing inoculum level, the total chlorophyll (a + b) in the TRIF and BDS plants and chlorophyll a content in all plants was significantly lowered and become increasing so with increasing inoculum levels (Melakeberhan *et al.* 1986).
Upadhyay and Banerjee (1986) reported that decrease in the chlorophyll content of chickpea due to *M. javanica* infection was because of proportional increase in the concentration of Pheophytin. The imbalance in chloroplast pigments may be correlated with the general chlorosis dieback caused by the infection of nematodes.

The increased number of nematodes (*M. incognita*) caused significant reduction in the chlorophyll content (a, b) of mungbean leaves which ultimately lead to the reduced production and supply of carbohydrates to nodules for carrying out nitrogen fixation (Chahal and Chahal, 1987). Quantitative changes in the chlorophyll content of root-knot infected plants have also been reported on pigeonpea (Anwar and Alam, 1989) and chickpea (Ahmad and Kumar, 1990) Tiyagi and Alam, (1990). Sharma and Trivedi (1992) observed a decrease in photosynthetic efficiency and reduced chlorophyll content in the brinjal plants 90 days after treatment with *M. incognita*. Chandel *et al.* (1993) found a higher reduction in the chlorophyll content of susceptible pigeonpea cultivar when inoculated with *M. incognita* whereas Vashisth *et al.* (1994) observed similar effect of root-knot nematode on the chlorophyll content of some black gram cultivars.

In pot experiment conducted by Haseeb *et al.* (1998) a negative correlation was observed between various initial inoculum densities of *M. incognita* on *Ocimum kilimandscharicum*. The greatest reduction in chlorophyll a, chlorophyll b and total chlorophyll occurred in plants inoculated with the highest inoculum density of *M. incognita* (16000 J2 / 7.5 kg. Soil). Pathogenecity of *M. incognita* to turmeric (*Curcuma longa*) cv. BSR-1 and PTS-10 was studied by Poornima *et al.* (1998). In both the varieties chlorophyll a, chlorophyll b and total chlorophyll were lower in plants inoculated with 10,000 juveniles when compared to healthy one.

**Effect of fungi**

Fungus also has an adverse effect on the photosynthetic pigments. *Taphrina macularis* Butler, infected leaves of turmeric (*Curcuma longa L.*)
possessed lower contents of chlorophyll than the healthy ones (Agarwal et al. 1982), an effect also noted by Srinivasan (1982) on arecanut infected with yellow leaf disease. Parmar et al. (1983) observed 98% reduction in the pigments of Cichorium intybus L. leaves infected with Alternaria cichorii Nattras. Murumkar and Chavan (1985) reported that wilt fungus, F. oxyporum f.sp. ciceri caused marked reduction in chlorophyll content of chickpea, while Singh et al. (1986) found reduced chlorophyll and carotenoid content in downy mildew, Pernospora arborescens (Berk) de Bary infected leaves of opium. Reductions in chlorophyll (a, b and total), carotenoides and xanthophylls contents were also recorded in the leaves of coriander infected with Protomyces macrosporus (Prasad et al. 1989). Similar marked decrease in chlorophyll content also occurred in Taphrina deformis infected peach leaves (Sharma and Sharma, 1990). Buonaurio (1991) determined the chlorophyll content of chloroplasts from fababean leaves infected with Uromyces viciae (Pers.) schroet, and observed decreased chlorophyll contents from the beginning of uredospore differentiation to pustule eruption 8-14 days after inoculation. In addition there was a significant reduction in chlorophyll a/b ratio. Similarly in onion leaves infected with Pernospore destructor (Berk.) Casp., a significant gradual loss in the contents of chlorophyll with an increase in the infection of foliage was observed by Sugha et al. (1992).

Effect of Fungi and nematode on Photosynthetic Pigments

Fungi are also associated with legumes and they reduce the photosynthetic pigments of plants. Reduction in chlorophyll contents of chickpea was reported due to wilt fungus, Fusarium oxysporum f.sp. ciceri infection (Murumkar and Chavan, 1985). Tiyagi (1990) reported the effect of M. incognita and Macrophomina phaseolina alone and in combination on the chlorophyll contents (chl. a, b and total chl. a+b) in concomitant inoculations than in either of them alone. Shah (1993) reported the similar effect in photosynthetic pigments (chl. and carotenoids) in simultaneous inoculations of M. incognita and R. solani on the potted french bean plants.
Effect of fly ash

Dubey et al. (1982) observed the effect of fly ash deposition on photosynthetic pigments and dry matter production of wheat and gram. Wheat cv. N-4 and chickpea cv. H-355, grown in pots in the field and were dusted daily with 2.4, or 6 gm. fly ash / m² for 45 days. Fly ash increased plant weight, chlorophyll content, and carotenoid of both the spp. Singh et al. (1988) observed the reduction in chlorophyll and energy contents in plants as indicator of atmospheric pollution. Plants growing on 5 km line transect from a power station at Panki, kanpur were sampled and foliar damage, leaf chlorophyll and energy content were determined. Chlorophyll a and energy contents were reduced in the areas near the power station (particularly upto a distance of 0.5 km) in Achyranthes aspera, Ageratum conyzoides, Amaranthus spinosus, Cassia obtusifolia, Croton bonplandianum, Cynodon dactylon, Dichanthium annulatum, Justicia simplex, Tephrosia hamiltonii and Xanthium strumarium whereas, Blumea aromaticum, Calotropis procera, Lantana camara and saccharum munja were unaffected.

Kashyap et al. (2000) studied the chlorophyll contents of Acacia nilotica grown in fly ash obtained from the coal fired thermal power plant at korba, Madhya Pradesh (India), They mixed fly ash with sand, N (200 ppm N as urea) and P (25 ppm P as SSP {Single superphosphate}) in different combinations. The chlorophyll content differed significantly in the treatment at 1, 3 and 5 months old plants. The amount of chlorophyll a, chlorophyll b and total chlorophyll decreased gradually during the study period for all the treatments. The chlorotic nature of nutrient deficient plants was attributed to impaired photosynthesis resulting from the direct effect of the fly ash medium on the protein level and the chlorophyll content of the chloroplast. The best treatment for increasing the chlorophyll content of the leaves of Acacia was fly ash + sand + N (2000 ppm) + P (25 ppm).

Merakchiska et al. (1995) observed changes in the pigment content, fluorescence ad photosynthetic activity of the leaves of bean plant (Phaseolus
vulgaris L.) as a result of the direct and residual effects of fly ash added to soils. Chlorophyll a and b contents were not greatly affected by fly ash application but there was a considerable increase in carotenoid content in plants grown immediately after fly ash application. Srivastava et al. (1995) reported that chlorophyll a and b contents were increased in the Lactuca sativa plants leaves grown in 10% fly ash amended soil.

**Effect of nematode fungus disease complex**

Only few reports are available on the combined effect of nematode and fungus disease complexes on the chlorophyll contents of plants. Tiyagi (1990) while studying the effect of *M. incognita* and *Macrophomina phaseolina* alone and in combination on the chlorophyll contents of mung bean observed significant higher reduction in chlorophyll contents (a, b and total) in concomitant inoculation than in either of them alone. Similar effect in photosynthetic pigments (chlorophyll and carotenoids) was also noticed in simultaneous inoculation of *M. incognita* and *R. solani* on the potted french bean plants (Shah, 1993). Siddiqui and Mahmood (1994) examined the effect of *Heterodera cajani, Fusarium udum* Butler, and *Bradyrhizobium Japonicum* on the chlorophyll contents in the disease complexes of pigeonpea. Individually each pathogen reduced the chlorophyll contents but simultaneous inoculation had a synergistic effect on it.