Review of Literature
REVIEW OF LITERATURE

The earliest known report of the observation of plant parasitic nematode was made in 1743, when Needham in England observed thousands of nematodes in wheat cockles (Jenkins and Taylor, 1967). The second plant parasitic nematode, recorded by Berkely in 1855 was the root-knot nematode (Meloidogyne sp.) that caused damage to cucumber in an English green house.

Generally, root damage caused by parasitic nematodes is reflected on the above ground portion of the plants as poor shoot growth, leaf chlorosis and even death of plants resulting in low yield and poor quality of marketable produce. The stresses inflicted upon by the nematodes on the plant are manifested in the form of lesser tillering, yellowing and stunting of plants, which result in low productivity. The above ground symptoms are similar to those associated with any root injury that result in reduced amount of water uptake by plants. Flowering is scanty and fruits are either lacking or are of poor quality (Jenkins and Taylor; 1967).

Root-knot nematodes, Meloidogyne spp. are the most important and the best understood plant parasitic nematodes. They parasitize more than 2,000 species of herbaceous and woody plants belonging to monocotyledons and dicotyledons including both wild and cultivated varieties (Webster, 1969, 1975; Taylor and Sasser 1978; Hussey, 1985). Meloidogyne sp. has evolved a very complex host parasite relationship that leads to
the formation of familiar knots or galls on the roots of susceptible host plants resulting in severe growth retardation.

In sweet potato the second-stage juveniles of *M. incognita* entered the primary roots and the lateral roots through the ruptured surfaces or the cracks. They were also found to enter the roots anywhere from the root caps to the region of root hair formation (Krusberg and Nielsen, 1958). In wheat, *M. naasi* penetrated in the zone of differentiation and elongation (Siddiqui and Taylor, 1970). The juveniles entered into the inner tissues of the root by thrusting stylet and simultaneously using cellulolytic and pectolytic enzymes (Linford, 1942; Bird and Loveys, 1980).

The penetration of juveniles was followed by intra-and intercellular migration in the cortex and the stele. Intercellular migration involved separation of cells by dissolving middle lamella. The pectic compounds of middle lamella were dissolved by pectolytic enzymes secreted by the juveniles. Intercellular migration has been advocated by Nemec, 1910; Godfrey and Oliveira, 1932; Linford, 1937; 1942; Endo and Wergin, 1973; Jones and Payne, 1978). Migration of juveniles, intercellularly and intracellularly has been observed by several workers (Christie, 1936; Krusberg and Nielsen, 1958; Bird, 1959, 1960, 1962; Siddiqui and Taylor 1970; Siddiqui, 1971a, b; Ismail et al., 2004; Youssef and El-Nagdi, 2004). Formation of galleries and furrows due to separation and breakdown of the cells indicated inter-and intracellular migration (Roman, 1961). Hisamuddin (1992) observed that the juveniles migrated in two distinct manners. Firstly, the juveniles that entered through the
The root-knot nematodes are obligate plant parasites. They alter the pattern of cell division and cell differentiation. In the vicinity of the nematode, the plant cells respond differently. Some cells divide repeatedly (hyperplasia) and some cells enlarge enormously (hypertrophy). In response to feeding activity of the nematode larvae, some cells become large and conspicuous. These cells become multinucleate and contain very dense cytoplasm, thus exhibiting immense metabolic activity. These specialized cells are called "giant cells" (Christie, 1936; Mountain, 1960; Jones and Northcote 1972; Huang, 1986; Doyle et al., 2003).

The giant cells are highly specialized transfer cells induced and maintained by the feeding of *Meloidogyne* spp. in susceptible host plants. Bird (1962) demonstrated that induction and development of the giant cells in tomato roots depended on the presence of the nematode. He further showed that the functional giant cells were essential for the development and
the survival of the nematode. Hussey and Sasser (1973) detected
the enzyme peroxidase in the stylet exudates of *M. incognita*
females and suggested that this enzyme was involved in giant
cell induction and its maintenance. The giant cells are the
specialized transfer cells towards which the metabolites are
translocated by the host plant and from where the developing
nematode gets its nutrition. There are ample evidences
indicating that transfer cells are metabolically hyperactive cells
and essential for the development of the nematode (Bird, 1961;
Littrel, 1966; Endo and Veech, 1969; Veech and Endo, 1969;
Webster, 1969; Endo, 1971; Dropkin, 1972; Gommers and
phloem and the adjacent parenchyma are the highly preferred
tissues for the induction of giant cells (Christie, 1936; Krusberg
and Nielsen, 1958; Byrne *et al.*, 1977).

Beille (1898) was the first who proposed that the giant
cells were formed by the disintegration of cell walls and
coalescence of neighbouring cells in papaya roots. Formation of
giant cells through cell wall breakdown and subsequent
cytoplasmic fusion was not proved convincingly although it
was supported by several other workers (Kostoff and Kendall,
1930; Christie, 1936; Krusberg and Nielsen, 1958; Dropkin and
Nelson, 1960; Bird, 1961; 1972; Owens and Specht, 1964; Smith
and Mai, 1965 and Littrell, 1966;).

In 1902, Tischler proposed that the giant cells became
multinucleate due to mitotic divisions in the nuclei. Nemec
(1910) found that when the head region of the juveniles reached
the plerome, then the host cells became enlarged. The plasma
contents of these cells increased and their nuclei divided without the formation of cell wall and thus the giant cells became multinucleate.

In 1969(a), Huang and Maggenti demonstrated that metaphase chromosome numbers of giant cells in *Vicia faba* infected with *M. javanica* followed the geometric progression 2n, 4n, 8n, 16n, 32n (24, 48, 96, 192, 384, respectively). Multinucleate giant cells, according to them, were most likely formed through repeated endomitosis without cytokinesis. They hypothesized that involvement of cytoplasmic coalescence in the formation of giant cells was unlikely, otherwise increase in chromosome number would follow arithmetic progression. Bird (1973), who worked on *Vicia faba* to ascertain the chromosome number and the ploidy sequence, as given by Huang and Maggenti (1969a), could not find true ploidy sequence and argued that wall breakdown was also involved in multinucleation.

Jones and Payne (1978) critically studied giant cell formation immediately after infection on *Impatiens balsamina* roots by *Meloidogyne* spp. In the tissues examined, 24h after infection, cell wall breakdown was not observed while mitotic events were frequently seen. After 48 hours, 2, 4 and 8 nuclei were observed in the cell near the nematode head. There was no sign of cell wall breakdown in early stages of giant cell formation. This view of repeated endomitoses without cytokinases in giant cell formation after infection of *Meloidogyne* spp. has been supported by Endo, 1987; Pasha, 1987; Hisamuddin, 1992.
In the giant cells of root-knot nematode infected sweet potato roots, the nuclei varied in size, shape and other characteristics. Some nuclei in the giant cells were much larger than the nuclei of neighbouring unaffected cells. The shapes of the nuclei were non-uniform like spherical, pyriform, elongated, dumb-bell shaped and sometimes lobed that possessed projections (Krusberg and Nielsen, 1958). The nuclear enlargement was due to swelling or due to fusion (Owens and Specht, 1964; Rubinstein and Owens, 1964). About 10 to 12 fold increase in nuclear volume in the giant cells of tomato (Rubinstein and Owens, 1964) and extremely lobed in *Vicia faba* (Huang and Maggenti, 1969a) were reported. Highly enlarged nuclei and nucleoli having irregular shapes in many host plants were reported by a number of workers (Tischler, 1902; Nemec, 1910; Kostoff and Kendall, 1930; Christie, 1936; Krusberg and Nielsen, 1958; Davis and Jenkins, 1960; Dropkin and Nelson, 1960; Paulson and Webster, 1970; Siddiqui and Taylor, 1970; Siddiqui, 1971a; Jones and Payne, 1978). In Okra, the nuclei in the giant cells were very large (El-Nagdi and Youssef 2004).

The giant cells induced by the root-knot nematode varied considerably in size, shape and cytology. Smaller giant cells, in a giant cell complex, are usually more vacuolated than larger giant cells. Christie (1936) observed highly vacuolated smaller giant cells containing a little homogeneously dispersed cytoplasmic contents. In general, the giant cells contain dense and granular cytoplasm as has been observed in many plants (Christie, 1936; Owens and Specht, 1964; Heald, 1969; Riffle, 1973). In *Luffa cylindrica* at the time of induction of giant cell,
the size of the cell increased enormously. The rate of synthesis of cytoplasmic contents lagged behind the rate of expansion of giant cell. After one week of giant cell induction, the cytoplasmic contents became very dense and granular. After two weeks of induction, some smaller giant cells became vacuolated. After three weeks vacuolation was also observed in larger giant cells (Hisamuddin, 1992).

Christie (1936) found infection in vascular elements and reported disruption in vascular strands and formation of abnormal xylem. In the roots of sweet potato, Krusberg and Nielsen (1958), noticed abnormal xylem at the site of infection. Abnormal vessel elements of various shapes depending upon the shape of parenchyma cells were found. The parenchyma cells adjacent to the giant cell complex changed into vessel-like elements by the deposition of secondary cell wall material in the form of annular and spiral thickenings. Some of the transforming parenchyma cells also enclosed nuclei (Hisamuddin, 1992).

In Gardenia roots, infected with M. incognita, the vascular strands were found disrupted due to developing nematode and formation of giant cells. The vascular strands occurred as irregular patches at infection site (Davis and Jenkins, 1960). Disruption of vascular tissues in balsam (Odihirin and Jenkins, 1965); in Zingiber (Huang, 1966); in peony roots (Eversmeyer and Dickerson, 1966), in basella (Swamy and Krishnamurthy, 1971), in tomato (Farooq, 1973) have been reported.
In *Meloidogyne incognita* infected roots of *Lagenaria leucantha* Siddiqui and Ghouse, 1975, observed that primary phloem was destroyed at infected part and new but abnormal phloem comprising mainly of parenchyma, and few sieve tube elements was formed. In the primary roots of *Glycine max*, nearly all the second-stage juveniles of *M. incognita* selected primary phloem or adjacent stelar parenchyma as feeding sites (Byrne *et al.*, 1977). The second–stage juveniles of *M. chitwoodi* were found embedded in the phloem of sweet potato (Finley, 1981). Abnormal xylem in the form of scattered patches was observed in *M. incognita* infected roots of *Solanum melongena* (Pasha *et al.*, 1987). Disruption of vascular elements as a result of root–knot nematode infection has been reported by Fawole (1988) in white yam; Kim and Ohh (1990) in tomato; Sharma and Tiabi (1989) in pea; Patel and Patel (1991) in wheat; Salawu (1991) in *Celosia argentia*; Datta *et al.*, (1991) in *Vigna cymopsis*; Hussain *et al.* (1992) in tomato and brinjal.

Hisamuddin and Siddiqui (1992) observed intercellular migration of *M. incognita* larvae and emphasized that the feeding site was the protophloem originating from procambium. They did not find any disruption in the vascular strands. Vovlas and Sasnelli (1993) reported cambium as the feeding site of *Meloidogyne* juveniles in the roots of *Helianthus*.

Metabolic processes like uptake of water and minerals, translocation of water and solutes, photosynthesis, respiration and cell division of the host plant are altered by the root–knot nematodes which are manifested in the form of stunting,
chlorosis and galling. Some of the common responses of the affected plant to nematode infestation are enhanced rate of respiration, reduced rate of photosynthesis, excessive protein and nucleic acid synthesis, accumulation of metabolites at the site of infestation, enhanced enzyme activity and hyperauxinity.

Biochemical alterations, induced by *M. incognita* in brinjal (Singh *et al.*, 1978), comprised of increase in protein, aminoacids, proline and phenol content in infected roots over that of healthy roots. Severity in disease symptoms, anatomical anomalies and in chemical imbalances were found to be influenced by the amount of inoculum. Vaishnav and Sethi (1978) found significant reduction in plant growth parameters at and above 1,000 larvae per plant. Pant and Sethi (1980) reported a progressive decrease in the growth of soybean plant when the inoculum level of *M. incognita* increased. A comprehensive study was carried out in order to determine the pathogenicity of *M. incognita* on six cultivars of Japanese mint and was found that initial damage occurred at one juvenile per gram of soil with marked reduction in chlorophyll content, rate of photosynthesis and oil yield. The rate of nematode reproduction appeared to be density dependent (Pandey, 1988; Pandey *et al.*, 1992). Verma and Ali (1993) worked out the damaging threshold of *M. incognita* on parwal and revealed that progressive decrease in plant growth occurred with increase in nematode inoculum level. Vashisht *et al.*, (1994) studied the morphological and biochemical responses of blackgram cultivars to *M. incognita*. Maximum increase in peroxidase activity was stimulated by *M. incognita* in T-7 followed by B-6
varieties of black gram. Significant reductions in protein and chlorophyll contents, except in cultivars T-9 and B-6 were also observed.

In 1995, Gupta et al., observed that initial inoculum of 100 larvae of *Meloidogyne* sp. in bitter gourd, 1,000 larvae in smooth gourd, ridge gourd and squash melon significantly reduced the growth parameters. Galling and nematode reproduction was directly related to initial inoculum level. Haseeb et al. (1996) observed decrease in root and shoot growth, fresh weight and dry weight, chlorophyll content, total sugar, phenol content in leaves, and oil yield of *Ocimum canum* plants as the inoculum levels increased. Furthermore, root gall index was directly proportional to the population density. Fazal et al. (1996) determined threshold levels of *M. incognita* and *R. reniformis* on black gram as 1,000J$_2$ and 1,000 immature females, respectively. Nagesh (1996) reported significant reduction in plant growth and yield characteristics of potato as a result of root-knot infection. Samathanam and Sethi (1996) observed 0.5 larvae per gram soil as minimum threshold of *M. incognita* for mungbean.

Increase in initial inoculum level of plant parasitic nematodes caused higher reduction in fresh and dry weights of the plants, oil yield, chlorophyll, total sugar and phenol contents in *Mentha citrata* (Shukla and Haseeb, 1998). Ramakrishnan and Rajendran (1998) observed highest percent reduction in root length, root weight and shoot weight of papaya (*Carica papaya* L.) plants at 1,000J$_2$ of *M. incognita*. Perveen et al. (1998) reported significant reductions in root and shoot length, root and shoot fresh and dry weights of pigeonpea
at minimum initial inoculum level (50 J2 per pot) and the reduction in growth parameters increased with increase in initial inoculum level. Significant reduction in height, weight of roots, rhizome and total biomass of ginger, variety “Himachal”, occurred at different inoculum levels. The yield of rhizomes significantly reduced even at lowest nematode inoculum level of Pi=0.2 J2 per 100 cc soil (Ramana et al., 1998). Poornima and Vadivelu (1998) reported stunted growth and reduced shoot weight in turmeric (Curcuma longa L.) cvs. BSR-1 and PTS-10 at 5,000 and 10,000 J2 of M. incognita (Race-3) per plant. Reduction in levels of protein, carbohydrate, chlorophyll a,b and total chlorophyll and rhizome curcumin level in plants inoculated with 10,000 juveniles was also reported by these workers. Sharma et al. (1999) observed significant reductions in growth of groundnut at 1,000 and 10,000 nematodes per plant. Higher inoculum levels of M. incognita produced maximum number of galls and resulted in significant reduction in growth of Allium porrum L. (Rombati and Dhanachand, 2000). A negative correlation between nematode multiplication and inoculum level was also observed by these workers. Singh and Goswami (2000) reported significant growth reduction over control in cowpea with an initial population of 1,000 nematode per 500g soil. Pathak et al. (2000) reported that plant growth characters in cauliflower were adversely affected with an increase in the level of inoculum from 50 to 10,000 juveniles/kg soil. The significant reductions in growth characters were noticed at and above the level of 500 nematodes/kg soil by these workers. Jonathan and Rajendran (2000) carried out pathogenicity test of root-knot
nematode on banana in greenhouse conditions and reported that significant reduction in plant growth parameters occurred at 1,000 and 10,000 juveniles per kg of soil. Reduction in multiplication of the nematode with increase in inoculum level was also reported by these workers. Significant yield losses in cotton (*Gossypium hirsutum*) were reported by Jain *et al.* (2000). Kumar (2000) reported significant reduction in plant growth of *Polyanthus tuberosa* inoculated at 10J_{2}/g soil and 1 J_{2}/g soil. The number of storage roots in cassava decreased when plants were inoculated with *M. incognita* even 88 days after plantation (Makumbi-Kidza *et al.*, 2000). Ploeg and Phillips (2001) observed decreased melon fruit yields with increasing pre-plant nematode levels. Maximum reduction in plant height, root length and root weight of sunflower plants was recorded at 2,500J_{2} (Bhatt *et al.*, 2001).

The root-knot nematode *Meloidogyne incognita* correspondingly decreased the photosynthetic leaf area, petal area, fresh as well as dry weight of flowers and oil contents of rose with increase in inoculum levels (Tiyagi *et al.*, 2001). Reduction in growth and bulb weight of Yellow Granex onion infected with rice root-knot nematode has been reported by Gergon *et al.* (2002). Nehra and Trivedi (2002) carried out pathogenicity test of *M. incognita* on ginger and found a gradual decrease in root shoot length, root, shoot and rhizome weight with increase in nematode inoculum levels. The highest reduction in rhizome yield was caused at highest inoculum level (10,000 larvae per pot). In Balsam (*Impatiens balsamina* L.), significant reduction in plant growth at 1,000J_{2}/1,000cc soil has
been reported by Khan (2003). Haider et al. (2003), while carrying out comparative pathogenicity tests of root-knot nematode *M. incognita* on different pulse crops viz. mung bean, urd, lentil, *Lathyrus*, French bean and pea reported that an initial inoculum level of 100 juveniles of *M. incognita* per plant caused significant reduction in growth characters of pulse crops and proved to be pathogenic. Maximum decrease occurred in *Lathyrus* while minimum in French bean at 10,000*J₂* level. The multiplication rate of nematode was maximum at 10 *J₂* inoculum level and minimum at the highest level. Significant reductions in root and shoot length, fresh weight and dry weight of tomato (*Lycopersicon esculentum* var Shiva-2) plants with the increased inoculation level were observed by Satyandra et al. (2003). Sheela et al. (2003) reported 50 to 75 percent reduction in leaf yield of coriander (*Eryngium foetidum* L.) at an initial population of 200 to 300 larvae of *M. incognita* per 250g soil sample. Reduction in leaf size of plants was also reported by these workers. Drastic reduction in yield and characteristic gall formation in Gherkin (*Cucumis anguira* L.) has been reported by Gowda et al. (2003). Khan (2003) reported significant reduction in weight of onion bulbs at 1 to 10 juveniles/500cc soil. Significant reduction in length, fresh as well as dry weight and yield of *Papaver rhoaes* and *Eclipta alba* plants as a result of *M. incognita* infection has been reported by Hisamuddin et al. (2003, 2004). Youssef and El-Nagdi (2004) observed significant reduction in plant growth and yield of faba bean (*Vicia faba* L.) under the highest inoculum level i.e., 10,000 larvae of *M. incognita*. Reduction in plant growth of tomato
cultivars (Peshwari and Roma) has been reported by Pathan et al. (2004). Khan et al. (2004) while observing the pathogenic effect of *M. javanica* on cucurbits suggested that an increase in the level of inoculum showed a progressive increase in host infestation as indicated by number of galls as well as nematode multiplication. Maximum nematode population in all the tested plants was observed at the lowest inoculum density and *vice-versa*. Reduction in growth of bottle gourd and red gourd was recorded at an initial inoculum level of 1,000J₂/kg of soil of *M. javanica* which was the damaging threshold level. Similarly, the damaging threshold levels of *M. javanica* on sponge gourd and bitter gourd were recorded at the inoculum level of 500 and 2,000J₂/kg soil. Kumar and Pathak (2004) while working on spinach, beet (*Beta vulgaris bengalensis*) and fenugreek (*Trigonella foenum-graecum*) observed significant reduction in plant growth characters of both plants at 500J₂/kg soil and above levels. Increase in number of galls and total nematode population with increase in inoculum level from 50 to 5,000 nematodes/kg soil was also observed by these workers. Kheir et al. (2004) found significant reduction in the growth parameters of certain banana cultivars, especially at the level of 1,000 juveniles per plant and up. Hisamuddin et al. (2005) reported significant reduction in dry weight and chlorophyll content of *Phaseolus mungo* inoculated with 1,000J₂ of *M. incognita*. A progressive increase in plant growth reduction of lettuce (*Lactuca sativa*) with an increase in inoculum level of *M. incognita* from 250 to 8,000J₂ per plant was reported by Khan and Ashraf (2005).
Fly Ash:

The presence of extraneous materials in an environment in concentrations that become harmful to living organisms cause pollution. According to Odum (1996) the pollution is defined as an undesirable change in the physical, chemical or biological characteristics of our air, land and water that may or will harmfully affect human life or that of a desirable species, our industrial processes, living conditions and cultural assets; or that may or will deteriorate our raw material resources.

The agent or the material that causes pollution is termed as pollutant. A pollutant can be any chemical or geochemical substance, biological organism or its product, released advertently or inadvertently by man into the environment with actual or potential adverse, harmful or unpleasant and inconvenient effects.

Air pollution is increasing tremendously due to industrial and other activities including power generation plants and transportation. The major particulate air pollutants are coal dust, fly ash, lime dust, cement dust and/or particulate matter released from various metal processing units. The concentration of particulate air pollutants ranges from 40 to 44% in India (Das, 1986). The particulate matters are settled down on aerial parts of plants and cause damage to them. Chlorosis, necrosis and death of the affected tissues are the consequences of heavy depositions of particulate air pollutants. Increase in leaf temperature, rate of transpiration and decrease in rate of photosynthesis are caused by the deposition of particulate
matters (Darley, 1966; Fluckiger et al., 1978; Vora and Bhatnagar, 1997). Heck et al. (1970) noticed that emission of particulate materials at higher level from different sources caused reduction in the quality of the vegetables and the fruits growing in close proximity of the source. A linear relationship between the doses of cement dust pollutants and transpiration rates, chlorophyll contents and productivity of crop plants, has been advocated by Singh and Rao (1981). The percentage of occluded stomata of conifers increased with a decrease in the distance from the source of particulate emission (Durasovic and Tatjana, 1997). The deposition of fly ash on leaves retarded the rates of transpiration and photosynthesis (Gupta et al., 2002).

Fly ash, emanating from the thermal power plants, where coal is used as the source of fuel, is a major cause of ambient pollution, and such a pollution is one of the great concerns in developing countries (Das, 1986). Increased use of coal as a primary source of energy especially in the countries like India, which have sufficient coal reserves are expected to release more quantities of fly ash as a waste product.

The fly ash emitted from coal based thermal power plants is conveyed to large pits, specially prepared for this purpose, or stacked in the form of mounds. From these dumping places it is spread by the wind into surrounding areas where it alters the physico-chemical characteristics of the soil. It also affects vegetation depending upon the extent of deposition. Due to increasing costs of disposing off of the fly ash there is an urgent need to find out its potential uses, one of the such uses is land application with an aim to improve physical or chemical
properties of soil. Various researches have been carried out on the presence of essential plant nutrient in fly ash taking into account that fly ash amended soils improved the plant growth, yield and leaf pigments of pulse and vegetable crops (Das et al., 1990; Rodgers and Anderson, 1995 and Khan et al., 1997).

Scanlon and Duggan (1979) showed that the seedlings of some tree and shrub grew well in fly ash amended soil. The addition of fly ash improved the nutrient status of soil and neutralized soil acidity to a level suitable for agriculture, depending upon the initial pH of the soil (Moliner and Street, 1982). The low rates of fly ash dusting increased plant height, dry weight, metabolic rate and amount of photosynthetic pigments of Zea mays L. and Glycine max L. (Mishra and Shukla, 1986). Wong and Wong (1989) found that seed germination and growth of Brassica parachinensis was enhanced in sandy soil amended with 3 to 6% fly ash. But at higher concentrations of fly ash i.e. 12 to 30%, seed germination was reduced. Khan and Khan (1996) reported growth promoting effects of fly ash on tomato plants. They observed that soil application of fly ash (40% v/v) enhanced the yield and market value of tomato by 81 and 30%, respectively.) In Agropyron elongatum, improvement in seedling emergence and dry weight was observed due to addition of fly ash in the soil (Wong and Su, 1997). Karpate and Choudhary (1997) reported that plants irrigated with fly ash water or grown in fly ash amended soil, showed improved growth at lower concentrations (25 and 50% of fly ash water and fly ash). The higher concentrations (75 and 100%) showed
deleterious effects. Kumar et al. (1998) suggested that 4% addition of fly ash resulted in higher grain yields of rice.

Germination of fresh and one year old teak drupes was studied in fly ash incorporated nursery mixtures by Masilamani and Dharmalingam (1999). The mixed sand and fly ash nursery medium increased rate of the germination and boosted seedling vigour, whereas fly ash alone proved to be inhibitory to seed germination and seedling vigour. A mixture of paper factory sludge and fly ash when incorporated at transplanting time was found to be more effective in increasing yield (79%) of rice rather than applying it 30 days before transplanting the seedlings (Karmakar et al., 2001). The application of fly ash at 40t/ha in conjunction with phosphate solubilising bacteria *Pseudomonas striata* improved the yield of soyean (Gaidn and Gaur, 2002). Enhancement in plant biomass, photosynthetic pigments, protein content and *in vivo* nitrate reductase activity of *Prosopis juliflora* L. plants, grown on ameliorated fly ash occurred, in comparison to unamended or garden soil (Rai et al., 2004). Singh and Lone (2004) reported enhanced chlorophyll harvest, specific leaf weight, plant fresh and dry weight of two mustard cultivars Pusa Bihar and Varuna under irrigated and drought conditions by applying 20% fly ash to the soil. In most countries, application of fly ash in agriculture land is not common because high ash concentration causes deterioration in soil properties and depression in plant growth (Hodgson and Holliday, 1966; Adriano et al., 1980).

There are several reports that the dust from various origins interferes in stomatal functioning (i) by filling and
clogging the stomatal aperture (Ricks and Williams, 1974; Fluckiger et al., 1978); (ii) increasing leaf temperature and the rate of transpiration (Beasley, 1942; Eveling, 1969; Eller, 1977; Fluckiger et al., 1978); (iii) reducing rate of photosynthesis (Darley, 1966); (iv) and increasing rate of uptake of gaseous air pollutants (Ricks and Williams, 1974). All these factors are responsible in deteriorating the growth of the plants as has been mentioned by many workers like Thomas et al. (1952); Middleton et al. (1958); Pack et al. (1959); Schuck and Locke (1970); Shimshon et al. (1975). Harmful effects of saline aerosal deposition in the fields of maize and soybean have been encountered reported by Mulchi and Armbruster (1981).

Amendment of soil with fly ash reduced the microbial respiration (Wong and Wong, 1986); inhibited seed germination and increased post-emergence mortality in chickpea and lentil seedlings (Singh, 1989). Pasha et al. (1990) observed that 10% and 25% fly ash enhanced growth of cucumber plants but higher levels (50–100%) proved to be toxic to plants which suppressed plant growth and decreased chlorophyll content of the leaves. Pandey et al. (1994) observed improved growth in sunflower (Helianthus annus L.) plants grown in the soil treated with 1,1.5 and 2 kg fly ash m⁻². The leaf area of the treated plants was increased and at low fly ash application, 20% increase in Relative Growth Rate (RGR) and Net Assimilation Rate (NAR) was also noticed. The feasibility of the application of fly ash compost mixture to soils for the availability and uptake of various elements by corn (Zea mays L.) was studied by Ghuman et al. (1994). The plants were grown in soil alone, soil
amended with 15% compost, and amended with 2, 5, 10, 15, 20 and 25% of fly ash. It was observed that 20–25% fly ash and compost soil ratio treatments generally increased plant growth and yield. The fly ash amended soil raised the growth response in Beta vulgaris (Singh et al., 1994). The application of fly ash, particularly in higher amounts (4 and 8% w/w), increased the pH and conductivity of the soils to undesirable levels, whereas in low amount it favoured the plant growth and improved the yield. The effect of fly ash amended soil on the growth and photosynthetic pigments of Lactuca sativa L. was studied by Srivastava et al. (1995) and a marked increase in plant growth and pigment formation was observed at 10% fly ash level. On the contrary 20% and 30% fly ash level caused reduction in plant growth as well as pigment formation.

Increase in seedling height, plant height, girth, leaf number, leaf area, spike length, dry weight etc. in wheat plants at 50% fly ash level was reported by Tripathi and Sahu (1997). Tripathi and Tripathi (1998) examined the impacts of fly ash, light, and shade environments on growth and chemical response of Albizia procera and Acacia nilotica, and revealed that lower concentration of fly ash (i.e. 10%) favoured the growth of both plants whereas higher concentrations (30%) showed adverse effects. Fly ash amended soil mixtures contributed in enhancement in growth, dry matter production and photosynthetic pigments in Phaseolus aureus cultivars (Kumar et al., 1998). Hammermeister et al. (1998) have shown significant increase in the yield of barley silage at intermediate rates (50 to
100t ha\(^{-1}\)) of fly ash application and significant reduction at the rate of 400t ha\(^{-1}\).

Gupta et al. (2000) revealed that amending fly ash with press mud enhanced growth as well as other physiological responses chlorophyll, protein; \textit{in vivo} nitrate reductase activity in \textit{Leucaena leucocephala} compared to 100% fly ash treated plants. Pathan et al. (2003) reported 1.2 to 1.5 fold increase in root mass of \textit{Cynodon dactylon} L(Pers) cv. 'Winter green' or left bare in fly ash amended soil compared to non-amended soil.

Fly ash neutralizes the pH of acidic soil upto some extent and increases ion exchange capacity, water holding capacity and porosity (Jones and Straughan 1978; Adriano \textit{et al}., 1980; Elseewi \textit{et al}., 1981). Utilizable plant nutrients have been found in fly ash, which enrich the soil with macro- and micronutrients (Druzina \textit{et al}., 1983). Hammermeister \textit{et al}. (1998) tested the potential of fly ash as an agent of soil amendment and discovered that it emerged as a source of trace elements which are beneficial to the plants. The massive fly ash materials have been a potential resource for agricultural activities that affect the physicochemical characteristics of soil as it is generally very basic, rich in various essential and non-essential elements, but poor in both nitrogen and available phosphorus (Gupta \textit{et al}., 2002). Increase in soil salinity and elevation in the soil pH to as high as 6.45 of an acidic soil has been reported by Adriano \textit{et al}. (2002). Siddiqui \textit{et al}. (2004) revealed fly ash addition into the soil increased its porosity, water holding capacity, pH, E.C.,
C.E.C. and the contents of sulphate, carbonate, phosphorus, potassium, calcium and various trace elements.

The adverse effects on plants at higher concentrations of fly ash were attributed to dibenzofuran and dibenzo-p-dioxin mixture and heavy metals detected in fly ash that appeared toxic to the plants (Kamath, 1979; Helder et al., 1982; Mishra and Shukla, 1986; Wong and Wong, 1986). Significant improvement in plant growth, yield, leaf pigment and oil content of soybean plants has been reported at 25% and 50% fly ash. Further increase in fly ash level caused suppression of these parameters (Singh, 1993; Singh et al., 1994). Srivastava et al. (2002), reported that fly ash amendment upto 50% enhanced fresh weight and dry weight of methi (Trigonella foenum-graecum) plants whereas higher levels, caused reduction in the same parameters. Aziz and Parveen (2003) reported retardation of plant growth characters of Solanum nigrum irrigated with concentrated water extracts of fly ash. Suppression in plant growth and yield of Pisum sativum plants at higher concentration of fly ash has been reported by Singh et al. (2005).

Kalra et al. (1998) reported fly ash as a soil conditioner and fertilizer. In order to evaluate the effects of fly ash incorporation (upto 50t ha\(^{-1}\)) on soil properties and the growth and yield of wheat, mustard, rice and maize, different experiments were carried out and it was found that the grain yield of maize increased in fly ash treated plots with the addition of ash upto a maximum of 10t ha\(^{-1}\); the yield of wheat grain increased with the addition of ash at 20t ha\(^{-1}\) but declined thereafter; with the addition 10t ha\(^{-1}\) of ash, the rice yield
remained unaffected whereas improvement in seed yield of mustard was observed with fly ash addition at 10 t ha\textsuperscript{-1}. Bharti \textit{et al.} (2000) studied the effect of fly ash on yield, uptake of nutrient and quality of green gram on vertisol and observed highest yield of grain and straw along with highest content and uptake of nutrients with the increasing levels of fly ash upto 10 t ha\textsuperscript{-1}. The results also showed highest content of crude protein and test weights at the same level of fly ash. The application of fly ash-filtered mud mixture in proportion 1:1 (w/w) along with small amount of inorganic fertilizer promoted radish growth, development and metabolism and increased reducing sugar and vitamin C (Xing shihe \textit{et al.}, 2001). Parveen \textit{et al.} (2003) reported increased germination rate, shoot length, leaf area and total green area of \textit{Ocimum sanctum} at lower levels of fly ash whereas adverse effects pertaining to same parameters were observed at higher levels of fly ash. In \textit{Mentha citrata}, increase in plant length, weight, leaf area, chlorophyll content and oil yield of leaves was observed at lower levels of fly ash (10-30\%) whereas adverse effects regarding the same parameters were observed at higher (40-50\%) levels (Parveen \textit{et al.}, 2006).

In the polluted atmosphere, plants may be exposed to the pollutants as well as attacked by the pathogens. In such conditions the pollution injury or microbial infection may be enhanced or suppressed. A clear picture about the nature of pathogen pollutant interactions does not exist, and the available information suggests the occurrence of synergistic, additive and antagonistic relationships (Khan and Khan, 1993). Despite many
effects of land application of fly ash, little information is available on the effects of fly ash on soil microbial activity (Adriano et al., 1980). Certain elements such as potassium, phosphorus and boron play important roles in the defense mechanism of plants against nematodes (Kirkpatrick et al., 1964; Francois, 1984). All these elements are amply present in fly ash (Elseewi et al., 1981; Druzina et al., 1983; Wong and Wong, 1989). Khan (1989) found that fly ash at the concentrations 10-40%, increased root penetration of the juveniles and root-knot disease intensity on tomato, whereas from 40% onwards, root penetration and reproduction of M. incognita race was gradually inhibited and disease intensity was also reduced. Singh (1989) observed the responses of fly ash on galling and egg mass production by M. incognita and M. javanica on chickpea and lentil. Suppressed growth and yield in presence of nematode and fly ash treated plants was shown by both crops in comparison to uninoculated and fly ash treated plants. Decrease in soil population of M. javanica at 10-100% fly ash was reported by Pasha et al. (1990). Higher concentration of fly ash suppressed the growth and development of root nodule bacteria (Bradyrhizobium japonicum) and root-knot nematode (Meloidogyne javanica) (Singh, 1993). Suppression in morphometrics of M. javanica females and egg mass production was observed by Singh (1993) and Singh et al. (1994). The egg mass production and fecundity gradually decreased with the increase in fly ash level. The effects of different concentration of fly ash (0, 10, 20, 30-100% v/v in soil) on plant growth and yield of root-knot infected and non-infected tomato plants were investigated by
Khan et al. (1997). Enhancement in plant growth, leaf pigment concentrations, fruit production, weight of fruit per plant and mean fruit weight occurred in both nematode infected and non-infected tomato plants, being maximum in the soil containing 50 or 60% fly ash. The root invasion by juveniles, disease intensity and reproduction of the nematode was adversely affected by fly ash treatments. Linear regression suggested 40% fly ash as the most economic level, enhancing yield of infected plants by 96% and suppressing the nematode disease and reproduction by 63 and 76% respectively. Hisamuddin et al. (2003) reported enhancement in growth, yield and chlorophyll contents of M.incognita inoculated Cicer arietinum plants grown in 30% fly ash in comparison to M. incognita inoculated plants grown in unamended soil. Khan and Ghadipur (2004) tested the feasibility of fly ash as non-conventional nematidice-cum-fertilizer through broadcast, row and spot application @ 0.6 kg/m² in order to obtain high productivity of vegetables in the fields infested with root-knot nematode Meloidogyne incognita. Row or broadcast treatment enhanced growth and yield of brinjal, tomato and chilli whereas spot application was ineffective in promoting the plant growth and yield. All the three treatments of fly ash protected the vegetables from nematode attack. Ash treatments also suppressed the disease intensity and inhibited the reproduction of M. incognita. The egg masses excised from the fly ash grown plants contained fever eggs. Row application of fly ash greatly enhanced the yield (weight of fruits per plant) of inoculated and uninoculated brinjal, tomato and chilli plants by 27.7% and 115%, 90.4% and
108% and 21.3% respectively, compared to uninoculated and inoculated plants grown in the plots without fly ash. The fly ash application also increased the carotenoid and chlorophyll content of leaves. Hisamuddin et al. (2005) reported minimum reduction in growth parameters and chlorophyll contents of *M. incognita* inoculated *Pisum sativum* plants grown at 30% fly ash level.