INTRODUCTION

Air pollution has become a serious environmental problem in different parts of the world. Air pollutants originating from various kinds of industries fall into two categories i.e., gaseous and particulate. The important gaseous air pollutants are sulphur dioxide (SO$_2$), oxides of nitrogen (NO$_x$), carbon monoxide (CO), ammonia (NH$_3$), chlorine (Cl$_2$), ethylene (C$_2$H$_4$), hydrogen fluoride (HF), ozone (O$_3$) and peroxyacetyl nitrate (PAN). Some air pollutants such as SO$_2$, CO, NO$_x$, NH$_3$, HF are called primary air pollutants and some such as O$_3$ and PAN as secondary air pollutants depending upon their origin (Wood, 1968). Primary air pollutants directly originate from their source while secondary air pollutants are formed by reaction of primary air pollutants with other environmental factors.

Certain ranges of environmental factors and air quality are necessary for the proper growth and plant health, as over 90% biomass of green plants is derived from atmosphere. Plant growth and yield are adversely affected, directly or indirectly by air pollution (Mudd and Kozlowski, 1975, Heck et al., 1982). Air pollutants induce injuries of various kinds in a number of agricultural and horticultural crops. Adverse effects of air pollution on agricultural crops are being assessed in different parts of the world. The Environmental Protection Agency (EPA), in U.S.A. estimated that in 1976 annual losses to agriculture production caused by poor air quality was around 2.9 billion dollars. Yield losses have been found to be caused by air pollution in a large number of crop plants including soybean, peanut, cotton, tobacco, vegetable crops, ornamentals etc.

Direct injury to leaf tissue or interference in biochemical reactions in leaves are main effects of gaseous air pollutants after their entry through stomata (Pell, 1979). Particulate air pollutants fall and deposit on the leaf surface forming a thin encrustation on the leaf surface which affects transpiration and transmission of solar radiation (Darley, 1966). Sulphuric acid or nitric acid formed by gaseous air pollutants SO$_2$ and NO$_2$ respectively by reaction with water, either directly injure the plant parts or indirectly through soil harm the root system. Air pollutants affecting physiology and biochemistry of the plant, induce visible symptoms like chlorosis, necrosis, early senescence, stunting etc. (Heagle, 1973, 1982; Agrios, 1988).
Mycorrhiza is a term which designates a symbiotic relationship between fungi and plant roots. There are two main types of Mycorrhizae viz., ectomycorrhizae and endomycorrhizae. Ectomycorrhizae belongs to the other Agaricales of the class Basidiomycetes. They modify the plant roots and absorbent hairs of roots are lost. The ectomycorrhizal fungus surrounds the roots and forms a mantle of mycelium. The external hyphae originating from the mantle explore the soil and help in absorption of nutrients and water, while the internal hyphae make a close contact with the roots.

Endomycorrhizae belong to the order Endogonales of class Zygomycetes. Endomycorrhizae are characterized by intercellular infection within the root and absence of any organized fungal growth on the root surface. They may be formed by non-septate fungi referred to as vesicular-arbuscular mycorrhizae.

Vesicular-arbuscular mycorrhizal fungi which have attracted greater attention of agricultural scientists are intercellular within the roots and form vesicles and arbuscules of the endophytic phase. Inside the root hyphae are limited to only root cortex and grow usually intracellularly where thick-walled hyphae with angular projections give rise to fine, thin-walled, irregular branches, the arbuscules in inner cortex and thick-walled spores and the vesicles in the outer cortex.

VA mycorrhizae are agriculturally more important than other mycorrhizae. The most important role of VAM fungus is to absorb nutrients from the soil and transfer them to their hosts. The exchange of nutrients between host cells and fungus occurs through arbuscules whose function is like that of haustoria. Mycorrhizal fungi in symbiotic relationship with plant roots help plants in acquiring mineral nutrients from the soil, especially immobile elements such as P, Zn and Cu but also more mobile ions such as S, Ca, K, Fe, Mg, Mn, Cl, Br and N (Cooper and Tinker, 1978; Tinker, 1984). Mycorrhizae improve the phosphorus nutrition of a host particularly in low fertility soil through exploration of the soil by the external hyphae beyond the root hairs and phosphorus depletion zone (Gray and Gerdemann, 1969). Increased P uptake in mycorrhizal legumes stimulates nitrogen fixation by Rhizobium, thus indirectly causing an increase of nitrogen concentration in the host (Carling et al., 1978; Schenk and Hinson, 1973). Mycorrhizal fungi have been shown to tap organic and inorganic phosphorus sources in soil which are normally unavailable to non-mycorrhizal plants (Powell, 1979).
Plant growth is enhanced by the mycorrhizal fungi due to increase in the efficiency of mineral uptake. Increased water uptake by mycorrhizal fungi alter the plant physiology to reduce stress response to soil drought (Parke et al., 1983, Safir and Nelson, 1985). Mycorrhizal fungi also reduce plant response to other soil stresses such as high salt levels, toxicities associated with mine spoils or land fills and heavy metals (Tinker, 1984). Disease response to plant pathogens causing morphological or physiological changes in the plants is reduced by mycorrhizae (Dehne, 1982). VAM infection counteracts adverse soil factors. They alleviate heavy metal toxicity (Dueck et al., 1986) and increase the tolerance of crops to high acidity and temperature (Poss et al., 1985; Pond et al., 1984). Mycorrhizal fungi are known to alter soil texture by increasing the extent of soil particle aggregation (Sutton and Sheppard, 1976). One of the major changes in mycorrhizal plants is reduced membrane permeability primarily due to increased P nutrition (Graham et al., 1981; Ratnayake et al., 1978). The decreased membrane permeability affects the quality and quantity of root exudation (Schwab et al., 1983) which in turn induce a significant response in the rhizosphere microflora and microfauna.

VAM fungi may serve as a tool for improving the growth of agricultural and horticultural plants (Tinker, 1978; Gianinazzi et al., 1989; 1990a, b). The symbiotic systems of these fungi can also be exploited to save the costly phosphatic fertilizers (Abott and Robson, 1982a, b). Their importance in natural ecosystem (Koske, 1981) and in revegetation of the disturbed lands has also been recognized (Reeves et al., 1979).

Legumes can form two types of symbiotic relationship with microorganisms: one with nitrogen-fixing species of Rhizobium and Bradyrhizobium, the other with vesicular-arbuscular mycorrhizal (VAM) fungi, concerned mainly with the uptake of phosphorus by the plants. Glasshouse experiments have demonstrated that legumes inoculated with both types of microorganisms grow and nodulate better and have higher nitrogenase activity and phosphorus content than plants that are uninoculated or inoculated with either root nodule bacteria or mycorrhizal fungi separately (Crush, 1974, Powell, 1976). Seed yield, shoot weight and percentage of P and N of nodulated soybean plants grown in P deficient field soil were increased by inoculation with Glomus fasciculatus (Bagyaraj et al., 1979a). Similar effects on growth of soybean, bean, alfalfa and peanut under glasshouse conditions have been reported (Daft and El-Giahmi, 1975).
VAM fungi may be influenced by a wide range of environmental and edaphic factors. Greater plant growth enhancement due to mycorrhiza occur in sterile soil than in non-sterile soil (Gerdemann, 1968). Mycorrhizal development and plant growth response decreases with an increase in soil fertility (Hayman and Mosse, 1972; Khan, 1975). The nutrient (N or P) rich soils contain fewer spores of VAM fungi, which can be recovered from field soil of several agricultural crops than soils which are nutrient deficient (Hayman, 1970; Hayman and Mosse, 1972).

Effect of air pollution on roots and mycorrhizaes has only recently received some attention of researchers. The ectomycorrhizaes have been shown to alter some of the effects of air pollutants through promotion of shoot and root growth (Carney et al., 1978; Garrett et al., 1982; Mahoney et al., 1985). Interactions between O3 and simulated acid rain and ectomycorrhizal treatment and soil regime had significant effects (Keane and Manning, 1988). Reich et al.,(1985) observed the adverse effect of O3, SO2 and acid precipitation on mycorrhizaes of red oak (Quercus rubra L.). VAM fungi have gained very little attention in relation to gaseous and particulate air pollutants.

Microorganisms, parasitic or non-parasitic associated with plants growing under air pollution stress are likely to be affected directly or indirectly. Symbiotic nitrogen fixation by root nodule bacteria in leguminous crops is a very significant natural biological process and important for nitrogen economy of soil. Air pollutants affect nitrogen fixation and root nodulation (Tigney and Blum, 1973; Shriner, 1978). It has been suggested that inhibition of N2-fixation results from reduction in the nodulation and suppression in bacterial population. These effects are caused through the impact of air pollutants on plants. Ozone (O3), SO2 and particulate matters are reported to suppress N2-fixation by the species of Rhizobium (Tigney and Blum, 1973; Shriner and Johnston, 1981). Some workers have observed reduced root nodulation, nitrogen fixation, and or leghaemoglobin content of leguminous plants following 1 or 2 acute O3 exposures in greenhouse or controlled environment chambers (Blum and Heck, 1980; Blum and Tigney, 1977). Root nodulation by Rhizobium in kidney beans grown in greenhouse or outdoor plots and soybeans grown in greenhouse (Shriner, 1978; Waldron, 1978) was reduced by sulphuric acid rain of pH 3.2. Root nodulation was inhibited by SO2 and O3 exposures at 0.1 ppm and 0.2 ppm in soybean (Singh, 1993), mungbean and chickpea (Jahan, 1983) and chickpea (Abbas, 1994).
Determining the response of vesicular-arbuscular mycorrhizal fungi (VAM) and root-nodule bacteria on leguminous plants growing under specific pollution stresses is the theme of the present work. Black gram (Vigna mungo) a pulse crop was selected as test crop in the present study because it is one of the important pulse crops grown in India, which are sources of protein to vast vegetarian population of the country; can be sown in two season i.e., June-July (rainy season) and October-November (Autumn); and most importantly the crop develops symbiotic relationships with root nodule bacteria and VAM fungi.

The system with components-host (Vigna mungo), symbionts-VAM fungus, (Glomus caledonicum) and nodule forming bacterium (Rhizobium sp.) has been used as a model to ascertain the impact of air pollution stress on the various components. Three major air pollutants SO₂, O₃ and fly ash were used to assess the impact. Thesis is divided into introduction, literature review, materials and methods, results, discussion and summary. References cited in the different sections are listed at the end.