REVIEW AND LITERATURE

Ahmedabad is a fast-growing industrial city and has high rates of SPM and gaseous pollutants emitted from different industries and vehicles. It comes under arid and semi-arid zones of India and experiences moderate climatic variations with a maximum of 45°C in summer and minimum of 14°C in winter. Average wind velocity is between 8-10 km/hr, blowing predominantly from South-West to North-West (Ganapathy and Padmanabhan, 1985).

NEERI (1981) studied the air pollution status in Ahmedabad's industrial, commercial, and residential areas and gave the SO\textsubscript{2} concentration in the atmosphere as 31, 13 and 11 \(\mu g/m^3\) respectively. NIOH (1983) conducted a long-term study of SO\textsubscript{2}, NO\textsubscript{2}, and SPM from 1979-1983 in Ahmedabad industrial and non-industrial areas. In non-industrial areas, SO\textsubscript{2}, NO\textsubscript{2}, and SPM concentrations ranged between 10.6 to 12.9, 10.8 to 17.6, and 228 to 342 \(\mu g/m^3\) respectively, whereas in industrial areas, they were 22.2 to 29.6, 17.2 to 30.2 and 407 to 608 \(\mu g/m^3\).

INFLUENCE OF METEOROLOGICAL AND SEASONAL CHANGES ON AIR POLLUTION DAMAGE TO VEGETATION

Pollutant accumulation by tree foliage and damage are
strongly dependent on physico-chemical properties of the pollutant and on the meteorological conditions prevailing in the atmosphere (Coenen, et al., 1987). It has been shown that light and temperature (Jones and Mansfield, 1982), relative humidity (McLaughlin and Taylor, 1980), soil moisture, mineral nutrition (Guderian, 1977) and wind speed (Ashenden and Mansfield, 1977) modify the response of plants to pollutants.

Generally plants appear to be particularly sensitive during winter conditions (Davies, 1980; Baker et al., 1982; Colvill et al., 1983). Anlauf et al. (1986) found large seasonal differences between winter and summer concentrations of $SO_2$, $NO_2$ and $O_3$. These concentrations were found much larger in winter. Materna (1974) demonstrated that Picea trees absorb $SO_2$ during winter and that this exerts its effect later on under more favourable external condition.

Wesely and Hick (1977) stated that the deposition of $SO_2$ on vegetation is affected by several environmental factors, many of which undergo diurnal, seasonal and spatial variations. According to Heck and Dunning (1978), low temperature during the growth period increased $SO_2$ resistance of the plants. This resistance was further increased by low humidity and decreased by high humidity at the time of exposure. Rist and Davis (1979) investigated the influence of three different temperatures (13°C, 21°C and 32°C) and three different relative humidities (40%, 60% and 80%) on leaves
of *Phaseolus vulgaris* treated with SO$_2$. Injury induced by SO$_2$ was generally greatest at RH 80% and temperature 32°C. This may be because of increased stomatal conductance with increased temperature and relative humidity (Jager and Klein, 1980). Barton *et al.* (1980) and McLaughlin and Taylor (1980) also emphasized the effect of RH on the foliar uptake of SO$_2$ by *Phaseolus vulgaris*.

Agrawal *et al.* (1986) indicated that transport and recycling of heavy metals are a function of several environmental factors viz. topography, micro-meteorological conditions, physico-chemical characteristics of soil and vegetation cover. They further observed that heavy metals attached to small size particles is likely to be transported to distant places in prevailing wind direction.

**POLLUTANTS OF MAJOR CONCERN DISCUSSED IN THE PRESENT WORK**

**Coal Dust**

Coal is formed from partly decayed vegetable matter in earth and is mainly composed of carbon. It is the main source of energy in many factories and power houses. Accumulation of coal dust on vegetation leads to unfavourable changes in growth behaviour and causes injury to different organs (Rao, 1971 and 1972).

**Fly Ash**

Increasing use of coal as fuel for thermal power stations
has increased the fly ash in the surrounding environments. Fly ash comprises of finely divided particles of ash entrained in flue gases arising from combustion of coal. The size of particles may vary from 0.02 μ to over 300 μ and its carbon content may vary from 5-20%. Also, a large number of minerals like Na, K, Ca, Hg, Th, Cr, Mn, Ni, etc., originally present in coal may occur in fly ash. Kamath (1979) determined the concentrations of 17 elements in coal and corresponding fly ash.

Fly ash may affect vegetation directly through deposition on leaf surfaces and indirectly through accumulating in soil medium. By depositing on leaves it brings about changes in cuticular and epidermal traits of leaves (Sharma, 1977). Its deposition in soil medium enhances plant growth and yields various positive results, but will have phytotoxic effect if deposited in high concentrations (Dubey et al., 1982; Pawar and Dubey, 1982; Pawar et al., 1983; Shukla and Mishra, 1986). Krajickova and Mejstrik (1984) described that fly ash particles are relatively inert and harmless but may become harmful, if their concentration was high enough to plug the stomata or smother the leaf.

Automobile Exhaust

Major pollutants emitted by automobiles are CO₂, CO, oxides of nitrogen, SO₂, hydrocarbons, unburnt petrol and
carbon particles. Both gaseous and particulate pollutants from exhaust are extremely toxic and cause damage to roadside vegetation and soil. Many of these emissions contribute to the oily depositions on the foliar surfaces.

Many studies were made to prove that vegetation and soil are contaminated by these pollutants (Lagerwerff and Specht, 1970; Burges et al., 1973; Solomon and Hartford, 1976; Mankovska, 1977; Wheeler and Rolfe, 1979). The physiological and biochemical effects of long term exposure of plants to automobile exhaust were widely studied (Keller, 1974; Fluckiger et al., 1978; Eckert and Houston, 1982; Sarkar et al., 1986).

Gaseous Pollutants

Gaseous pollutants of prime concern are \( \text{SO}_2 \) and oxides of nitrogen (\( \text{NO}_x \)).

\( \text{SO}_2 \) has been found to be major gaseous pollutant in the vicinities of thermal power plants, smelters and major industrial units using coal. The impact of \( \text{SO}_2 \) in the vicinity of several thermal power plants has been studied (Pandey, 1983; Rao et al., 1987; Agrawal and Agrawal, 1988). Nitrogen oxides, like \( \text{SO}_2 \), are formed mainly as a result of burning of fossil fuel. With the heat of combustion nitric oxide is formed: \( \text{N}_2 + \text{O}_2 \rightarrow 2 \text{NO} \), and then a spontaneous reaction between NO and \( \text{O}_2 \) occurs: \( 2\text{NO} + \text{O}_2 \rightarrow 2\text{NO}_2 \). These \( \text{NO}_2 \) gases occur near industrial units and busy roads.
(Law and Mansfield, 1982). The ambient environment of an urban industrial area may be contaminated with several pollutants and plants growing there would be exposed to many pollutants and their mixtures. Air pollutants in mixtures and in different environmental conditions may modify plant responses (Agrawal, 1985). Prasad (1980) noted an adverse additive effect of \( \text{SO}_2 \) and \( \text{NO}_2 \).

Phytotoxicity and mode of action of these pollutants individually and in mixtures, and a detailed review about them is written in the later parts of this chapter.

**ALTERATIONS IN PHYSICO-CHEMICAL CHARACTERS OF SOIL.**

Soil is an natural sink for particulate and gaseous pollutants (Smith, 1984). The pollutants absorbed by the soil change its physicochemical characters and ultimately affects the soil and plant interaction.

Pandey (1983) studying the soil factors reported that the changes including \( \text{pH} \), organic matter and \( \text{N}, \text{P}, \text{K}, \text{S} \) content of soil, seems to be the function of pollution in the area. They observed foliar injury symptoms in vegetation growing in the soil due to the mineral imbalance in the soil. Agrawal (1985) reported that major effects of \( \text{SO}_2 \) on soil system include increases in content of \( \text{S} \), organic carbon and exchangeable \( \text{Al} \), lowering of \( \text{pH} \) and decrease in the contents of \( \text{N}, \text{P} \) and exchangeable \( \text{K} \) and \( \text{Ca} \). Farberby (1981)
also reported the effects of cement dust on soil. They observed higher carbon and pH of soil. Due to higher pH microbial activity was lowered causing low decomposition of organic matter.

Soils have high affinity for heavy metals (Lagerwerff, 1967). Agrawal et al. (1988) observed accumulation of Fe and Cd in the soil.

Trace Metal Study

Most of the trace metals exist in the atmosphere in particulate form and are mainly associated as metal oxides, though a few are present in gaseous form. These trace metals are phytotoxic air pollutants and stems particularly from densely industrialized areas, smelters of metals and heavy road traffic. Further trace metals create a major ecological crisis as these are non degradable and are often accumulated by plant parts (Veer and Latha, 1989).

Reports are available of aerosols containing trace metals arising predominantly from industrial activities, coal and petroleum combustion etc. (Lee et al., 1972; Pierson et al., 1973). Bowen (1977) analysed the industrial smokes and stated that they are potential sources of atmospheric contamination by As, Cu, Fe, Pb, Mn and Ni. Wagen and Turner (1980) observed that emissions from coal fired power plants contribute to the trace metal content of vegetation in the vicinity. Earlier Burton and John (1977) also reported
contamination of vegetation by Pb, Zn, Cu and Ni, through aerial deposition because of motor vehicle pollution.

Dispersion and deposition patterns of trace metals are influenced by factors like stack height, wind velocity, rain fall, meteorological stability and the terrain (Evans et al., 1960) and the uptake capacity of plants largely depend upon cuticular morphology, trichome density and other morphological features (Yunus et al., 1985). Flanagan et al. (1980) in their study on leaves and twigs of Bramble and Rhododendron besides a major road, found that large amounts of Zn and Pb had accumulated on Bramble leaves, which are pubescent than Rhododendron leaves. According to Ormrod (1984), if trace metals are deposited in a soluble form, or are rendered soluble after the impact, they are probably taken into plants through stomata and other openings. He further observed that many aerosol particles of industrial origin are less than 1 μm in diameter, where as stomatal openings ranges from 5-30 μm, so that entry through them is possible.

Nag et al. (1981) found that toxicity imposed by the trace metals involves an overall disruption in the synchronization of different metabolic processes occurring in the cells, the resultant effect being manifest in the inhibition of cell division and consequent retardation of growth. Extensive work had been carried out on the damaging effects of various trace metals on the growth and metabolism of plants (Dutta and Mukherjee, 1980; Singh and
Pandey, 1981; Rauser and Dumbroff, 1981; Mukherji and Sharma, 1987; Baldi, 1988 and Sela et al., 1989). Shukla and Mishra (1986) reported inhibited growth and development due to trace metals in the fly ash. The inhibitory action of Zn on photosynthesis and growth are reported by Nriagu (1980); Latha (1983); Sathyra and Balakrishnan (1988) and Veer and Latha (1989). Same damaging effects were reported by Burton et al. (1986) in the case of cadmium. But experiments of Jana (1988) with Cr and Hg revealed that chlorophyll synthesizing system, chlorophyllase activity, protein synthesis and other enzymatic activities were not impaired by these metals. He concluded that these plant species have tolerance capacity to the metals tested.

DUST FALL, EFFICIENCY OF PLANTS IN UPTAKE OF PARTICULATE AND GASEOUS POLLUTANTS AND THE RESULTANT FOLIAR INJURY TO PLANTS:

Dust Fall

Pollutants do not remain in atmosphere for long times. They may be removed from the atmosphere through both dry and wet deposition processes (Rasmussen et al., 1974). Dry deposition includes absorption of air pollutants by water bodies, vegetation and soil surfaces. If reaction with surface is the major sink for particulate and gaseous pollutants, vegetation can be considered as the major available surface as it covers major part of the land (Hill, 1971; Keller, 1978).
Dust pollution in relation to vegetation in India has been widely studied (Chaphekar et al., 1980a; Shetye and Chaphekar 1980; Das and Bhaumik, 1980). From the ambient air quality data published by NEERI (1980) and Dave (1986), it is apparent that SO₂ and SPM are major pollutants in India, especially in Ahmedabad and Calcutta. Das et al. (1986) also reported that in India, the amount of particulate pollutants in air is very high as compared to other countries and comprises of 40-44% of the total pollutants of air. The leaves of the perennial plants are usually covered with a thick layer of dust particles during most part of the year.

Sudhakar and Agarwal (1978) studying the particulate pollution load in Kanpur textile factories observed maximum concentration of 70 mg/m³. Bose et al. (1983) measured the seasonal values of SPM and settled dust in Jharia coal field complex and highlighted the seriousness of dust problem. Rao et al. (1987) observed a thick and hard encrustation of cement dust on the leaf surfaces around a cement factory. From his study it is clear that soil and vegetation in the vicinity of a source can be variously affected, depending on the dust emitted from the source.

Efficiency of plants in uptake of particulate and gaseous pollutants

The use of vegetation in filtering out dust, soot and particulates from the atmosphere has long been accepted
(Meetham, 1964). Das et al. (1981) studied the dust collecting capacities of different trees and recorded 0.15 mg/sq.cm. to 1.4 mg/sq.cm. of dust deposition on the leaves of various tree species. Dochinger (1980), who examined the ability of plants to abate particulate pollution, reported a reduction of upto 42% of overall dustfall, by a canopy of plants in urban areas of Ohio, USA. Similar studies have been conducted in India by Das (1981).

Yunus et al. (1985) showed a convincing relationship between inherited morphological traits of the leaves and the amount of dust captured. Various morphological features i.e. orientation of the leaf on main axis, size and shape, surface nature, the presence and absence of trichomes and wax deposition etc. play a role in efficient interception of air particulates. In the study conducted by Yunus et al. (1985), Calotropis procera, with it's large leaf size, collected maximum amount of dust (8.81 mg/cm²), where as Eucalyptus globulus and Acacia melanoxylon, both with oblong to lanceolate shape, collected the minimum amount of dust (0.54 and 0.53 mg/cm²). Flanagan et al. (1980) in their study on two plants besides a major road found large amounts of 2n and Pb accumulated on Bambie leaves, which are pubescent, than Rhododendron leaves. Das et al. (1981) indicated that evergreen trees with smooth or hairy leaf surfaces are better dust collectors than deciduous trees with compound leaves. Microscopic observations of leaves in
their study revealed a dense accumulation of dust particles on
the surface of hairs and they have also observed dust
particles heavily concentrated on the stomatal pores.

Evidence is available to support the potential of plants
to function as sinks for gaseous pollutants (Rasmussen et al.,
1975; Bennett and Hill, 1975). Wind velocity, light
intensity, soil moisture etc. which play a role in stomatal
mechanism, exert great influence in foliar removal of
pollutants (Smith, 1984), since stomata are the main organs,
through which gaseous pollutant enter leaf.

Studies by Bennett and Hill (1975) indicated the ability
of Alfalfa canopy in removing the gaseous pollutants from
the atmosphere. Roberts (1974) measured $SO_4^-$ sorption by woody
species and all the species examined were capable of reducing
the high ambient levels within the test chambers. Robert and
Krause (1976) monitored $SO_2$ uptake of Rhododendrons and Fire
throns and suggested that the more uptake of Fire thron may
have been due to it's abundant trichomes. Garland and Branson
(1977) observed that number of stomata and wet surface of the
leaves enhances the uptake of gaseous pollutants. Heath
(1980) indicated the importance of solubility of gases in the
uptake. $NO_2$ dissolves in water and yields nitrite and nitrate
ions and the later can be taken up by leaves (Bennett and
Hill, 1975). Rogers et al. (1979) have provided nitrogen
uptake rates for loblolly pine and white oak.
Foliar Injury

Agrawal and Agrawal (1986) noted high level of foliar injury in plants near the emission source and they noticed a direct relationship between the concentration of SPM in air and amount of dust deposited on the leaf surfaces. Prasad and Rao (1981) studied the foliar injury of *Phaseolus aureus* induced by petro coke particles.

Heath (1980) in his review described different symptoms like flecking, bronzing and necrosis caused by different pollutants. NO₂ injury to leaf appears as silvering and affects the adaxial surface of intra costal regions. Damage caused by SO₂ and HF is often restricted to leaf margins and tips. Flecking and bronzing are recognizable generally as small patches of brown and tan discoloration, which turn into necrotic regions after a few days. These are the results of localized death of previously living tissues.

The effect of pollutant combinations, which generally occurs in the atmosphere can be less than additive, synergistic or equal to additive effect of the individual pollutants (Sharma and Rao, 1983 and 1985). Sharma (1986) reported permanent leaf damage in wheat and *Phaseolus* due to SO₂ + HF. Elkiey and Ormrod (1987) studied the responses of *Casuarina* and *Eucalyptus* to single and multiple gaseous pollutants. In *Eucalyptus* initial symptoms of SO₂ + NO₂ foliar injury usually appeared as tip and marginal necrosis or irregular flecks of necrotic tissue on middle and lower
leaves. They reported ozone injury as irregular bleached areas. Elkiyey and Ormrod, further observed that *Casuarina* plants were insensitive to both NO₂ and SO₂ and only at high concentrations of these pollutants, apical necrosis appeared with some chlorosis and the injury level was 8% of the total leaf surface. Leaf injury, when exposed to combinations of O₃ + SO₂, O₃ + NO₂, SO₂ + NO₂ and O₃ + NO₂ + SO₂, ranged between 10-30%. Armentano and Menges (1987) observed air pollution induced foliar injury in jack and white pine needles. Tip necrosis and chlorotic mottles were observed throughout all populations.

Linzone (1986) described the foliar injury symptoms of forest trees due to SO₂. According to him, the first visible evidence of SO₂ injury is discernible in the foliage. Acute injury on broad leaves takes the form of bifacial lesions, which usually occur between veins. In some cases injury occurred on the margin of the leaves. Linzone also explained that young leaves rarely displayed necrotic markings, whereas fully expanded leaves are most susceptible to SO₂ injury.

Heath (1980) gave generalized indication that foliar injury is associated with cell death leading to a decrease in total photosynthetic area of the plant, and hence the reduced plant productivity.

CHANGES IN STOMATAL AND LEAF EPIDERMAL TRAITS

Gozdik and Sassen (1979); Debnath (1980); Garg and
Varshney (1980); Nicholas and Quinn (1980); Yunus and Ahmad (1980), Ahmad and Yunus (1981); Chakraborty and Gupta (1981) and Yunus et al. (1981) studied the effects of environmental pollution on leaf surface, epidermal trait changes and stomata through scanning electron microscopic studies.

Sharma and Butler (1973) observed stomatal frequency to be decreasing with increasing amounts of pollution. Leaves from urban environment have high trichome density, which may act as insulators in polluted environment. Gupta and Ghouse (1987) from their study of coal smoke pollutants on leaf epidermal features of Abelmoschus esculentus, observed significant decrease in the density of stomata and epidermal cells as well as stomatal index in polluted leaves. The low density of epidermal cells was coupled with increase in their dimensions and the length of the stomatal aperture was decreased in polluted leaves. Similar results of low stomatal frequency were observed in Kudzu (Pueraria lobata) population growing in polluted area by Sharma et al. (1980) and they further observed that length and breadth of leaf blades and petiole size were less in polluted leaves. Sharma et al. (1980) felt that high trichome density and low frequency of stomata is an adaptation in regulating limited and controlled entry of pollutants.

The SEM study results of Sharma and Butler (1975); Garg and Varshney (1980); Chakraborty and Gupta (1981); Agrawal and Kasat (1982); Mishra (1982) and Choudhari et al. (1984)
revealed marked difference in morphology of leaf cuticular features. They observed high trichome density, stomatal frequency and stomatal index in polluted leaves. Garg and Varshney (1980) and Mishra (1982) observed increased frequency of epidermal cells and less size, whereas Chakraborty and Gupta (1981) and Chaudhari et al. (1984) reported less frequency of epidermal cells, since their size was larger in polluted area. They further observed that in polluted leaves stomatal aperture was almost closed, and leaf surfaces showed cuticular ridges.

Pande (1985) working on SO$_2$ resistance of barley cultivars stated that stomatal diffusive resistance seemed to play a role in sensitivity. He found highest stomatal resistance in most tolerant cultivars. Karhu and Huttunen (1986) reported the erosion of cuticular wax in needle surface due to SO$_2$, NO$_2$, O$_3$ and dust. On exposure to SO$_2$ and NO$_2$ pollution the SEM analysis of Commelina communis by Pande and Oates (1986) showed that control plants had evenly distributed surface waxes, while fumigated plants had wax accumulated in small heaps with large denuded areas.

Ricks and Williams (1974) studied the interference of particulate matter with stomatal behaviour and stated that it seems to be mechanical obstruction of pore preventing normal closure. Borka (1980) reported that in Helianthus annus growing in cement dust pollution the moist stomata were partially closed by cement plugs and this hindered the out
flow of water vapour. While working on effect of coal dust on plants Periasamy and Vivekanandan (1982) found that Croton plants showed increased stomatal index, out of the six plants studied and Sankhla et al. (1982) observed that dust deposited leaves had wider stomatal opening as compared to control plants. Krajickova and Mejstrik (1984) worked on effects of fly ash particles on stomata and indicated that stomata of dusted plants did not become plugged by particles, but the dust particles accumulated on the surface of guard cells stimulated the mechanism regulating opening and closure of stomata and thus blocked the closure of stomata. Yunus et al. (1979) observed decreased size of stomatal and epidermal cells and also high percentage of abnormal stomata in plants growing in polluted areas.

The SEM study of leaf surfaces by Krizek et al. (1985) revealed a direct relationship between stomatal density of leaf and $SO_2$ sensitivity for all four cultivars of Poinsettia studied. The cultivars most tolerant to $SO_2$ had lowest stomatal density, highest trichome density and low stomatal conductance and transpiration rates. From these findings Krizek et al. (1985) suggested that measurements of leaf surface properties such as stomatal conductance, transpiration rate, stomatal density and trichome density may provide useful criteria in selecting and breeding pollution tolerant cultivars of plants.
PHOTOSYNTHETIC PIGMENTS

Photosynthesis is intimately linked with plant productivity and takes place primarily within the mesophyll cells, which are the first exposed cells to pollutants. Hence, photosynthesis is crucial to any discussion of air pollution effects on plants.

Literature regarding the effects of gaseous pollutants like \( \text{SO}_2 \) (Horsman and Wellburn, 1975; Ashenden and Mansfield, 1977; Black and Unsworth, 1979 'a' and 'b'), \( \text{NO}_2 \) (Hill and Bennett, 1970; Srivastava et al., 1975; Capron and Mansfield, 1976) and gaseous mixtures like \( \text{SO}_2 \) and \( \text{NO}_2 \) (Bull and Mansfield, 1974; White et al., 1974; Hou et al., 1977) on photosynthesis is available. Photosynthesis and productivity of a large number of plant species have been widely studied with reference to several particulate matters of different origins. Studies in this regard were made of, fluoride dust (Leblanc et al., 1972); cement dust (Darley, 1966; Parthasarathy et al., 1975; Singh and Rao, 1978), coal dust (Rao, 1971) and fly ash (Sobotaka and Materna, 1959; Pawar and Dubey, 1986).

Chlorophyll content, an index of photosynthetic potential of plants is highly susceptible to pollutant action. Pigment interaction with pollutants leads to the destruction of photosynthetic leaf areas and development of foliar symptoms (Singh et al., 1982). Majority of
investigations by Black and Unsworth (1979b) and others indicates that SO$_2$ exposure results in depressed photosynthetic rates, although small number of workers report temporary enhancement in photosynthesis (Horsman and Wellburn 1975). Black and Unsworth (1979b) had given the evidence that many factors such as light, relative humidity, temperature and CO$_2$ concentration may influence photosynthetic response to pollutant gases. Malhotra (1977) and Malhotra and Khan (1984) indicated that SO$_2$ interacts with chlorophyll molecules forming phaeophytins and Mg$^{2+}$. Malhotra and Khan (1984) also reported that SO$_2$ fumigation of leaves increased the formation of O$_2^-$ (Super oxides) in chloroplasts, that in turn destroy chlorophylls. Super oxide radicles have been shown to influence chlorophylls at very low concentrations. According to Rao (1985) the effect of SO$_2$ on chlorophyll may be considered under two cellular pH conditions i.e. pH values above and below 3.5. At pH 2.2, to 3.5 the free H$^+$ ions generated in cell from the splitting of H$_2$SO$_4$ into SO$_3^{-2}$ and H$,^+$ displace the Mg$^{2+}$ from chlorophyll molecule to degrade them into phaeophytin molecules. At pH above 3.5, SO$_2$ may affect the thylakoid membrane of chloroplast by causing oxidation of carotenoids through generation of O$_2^-$ radicles. Malhotra (1976) reported a sharp decrease in total chlorophyll content due to aqueous SO$_2$ and he also noted that chlorophyll 'a' was more sensitive than chlorophyll 'b'. Singh and Rao (1988) observed similar
results induced by SO$_2$. McLaughlin et al. (1979) observed that depression in photosynthesis was probably due to biochemical basis rather than stomatal or any other factor.

Sabaratnam et al. (1986) explained the reduction of photosynthesis in plants due to NO$_2$ as competition for NADPH between the process of nitrite reduction and carbon assimilation in chloroplast. In contrast Sandhu and Gupta (1989) proved NO$_2$ stimulated photosynthetic activity in Black turtle bean. They observed significant increase in chlorophyll 'a', 'b' and total chlorophyll in 0.1 $\mu$ liter$^{-1}$ NO$_2$ treated plants.

Mixture of pollutants usually have either antagonistic, synergistic or additive effects on photosynthesis. Under field conditions, where emissions of gaseous pollutants are usually accompanied by high levels of CO$_2$, the effect of pollutant mixtures on photosynthesis could be influenced by CO$_2$ concentration in the atmosphere (Hou et al., 1977; Malhotra and Khan, 1984). Carlson (1983) observed decreased photosynthesis with increased SO$_2$ concentration at 300, 450 and 600 ppm, with larger reductions occurring at low CO$_2$ concentration. Vij et al. (1981) observed chlorophyll reduction in five species of plants growing upto 3 k.m of distance from a thermal power plant. Dubey et al. (1982) showed a direct relationship between percentage loss of chlorophyll and ambient concentrations of pollutants. Automobile exhaust is also known to effect photosynthetic
ability of plants (Fenelly, 1975; Thompson et al., 1984).

Deleterious effect of cement dust on chlorophyll pigments of plants was reported by Singh and Rao (1960). Prasad and Rao (1981) studied the responses of Phaseolus aureus, sprayed with petrocoke and reported that total chlorophyll increased initially but decreased later on at higher cumulative doses. Pawar et al. (1983) and Pawar and Dubey (1983) observed similar results with fly ash dusting on bean plants. Mishra and Shukla (1986) explained that reduction in chlorophyll at higher dusting rate may be due to the alkalinity caused by excessive soluble salts on the leaf surface. Besides these, trace metals emitted from various sources are also known to inhibit photosynthesis and affect pigments (Hampp et al., 1976; Nag et al. 1981; Veer and Latha, 1989).

BIOCHEMICAL PARAMETERS

There are several reports suggesting that injury in plants is primarily caused at biological level, often termed as 'hidden injury' or 'invisible injury', subsequently ultra structural and cellular changes takes place, leading to a development of visible injury (Farooq et al., 1988). Pierre and Queiroz (1981) stated that biochemical changes occur in leaves during long term pollution and these metabolic effects can be observed at concentrations of pollutant
required to produce ultra structural changes. They, therefore concluded that the primary site for the pollutant effect is at the metabolic level. Pierre and Queiroz (1981) hypothesized that pollutant can modify the metabolism by diverting the metabolic operation towards a kind of pathological pattern and accumulation or consumption of a specific metabolite.

Some authors reported that continuous exposure to pollution triggers a generalized quantitative readjustment of intermediary metabolism like changes in synthesis of sugars (Kozioł and Jordan, 1978), in photosynthesis (Cowling et al., 1973), respiration and growth etc. This generalized but temporary readjustment in metabolic capability will enable the cell to achieve an efficient metabolism of the pollutant and a mechanism of stabilization of cellular pH. (Kozioł and Jordan, 1978; Pierre and Queiroz, 1981).

Carbohydrate Metabolism

Evidences are available in literature proving that pollutants interfere with photosynthate production and utilization.

Prasad and Rao (1981) studied the phytotoxicity of pet coke particles on Phaseolus aureus and reported a decrease in carbohydrate values. Reduction in carbohydrates due to SO₂ has been reported by Constantinidou and Kozlowski (1979) and Prasad and Rao (1982). Vijayan and Bedi (1988)
explained that this decrease may result from reduced CO₂ fixation and increased respiration. Beg and Farooq (1986) exposed three plants to varying concentrations of SO₂ and studied the changes in carbohydrate levels at 'No injury', 'Mild injury' and 'Severe injury' concentrations. At former two stages starch content, total soluble sugars and reducing sugars increased, while at severe injury concentration both starch content, total soluble and reducing sugar levels decreased. Reduced sugar content, sucrose concentration and starch content due to O₃ fumigation was reported by Jensen (1981). Prasad (1960) exposed wheat plants to SO₂, NO₂ and SO₂ + NO₂ and observed that cumulative doses of these pollutants promoted the carbohydrate levels, however, reduction occurred at higher pollutant doses.

Khan and Malhotra (1977) reported increased amounts of soluble sugars in plants exposed to SO₂. Malhotra and Sarkar (1979) observed increased content of reducing sugars and reduced content of non-reducing sugars in Pinus banksiana exposed to SO₂. It was suggested that the increase was due to a breakdown of polysaccharides rich in reducing sugars. Koziol and Jordan (1978) observed free sugar levels in the plants exposed to as high as 3.06 parts 10⁻⁶ SO₂. Even in the leaves exhibiting visible damage to 60% of total leaf area, the free sugar level fell to equal or below to sugar levels in control plants. Koziol and Jordan interpreted this trend that, in response to SO₂ exposure, chemical energy
would be made available for repairs or replacement of damaged plant tissue by keeping the products of photosynthesis within leaves or translocating them from stem and roots. This use of energy would be reflected in increased respiration. Farooq et al. (1985) also reported that acute doses of $SO_2$ led to significant increase in total free sugar content of *Holoptelea integrifolia*. The increase was much more pronounced if the reducing sugars were observed separately. It was suggested that accumulation of sugars was due to breakdown of starch rather than its reduced biosynthesis. Free sugars have been allotted an important role in providing resistance towards oxidant gases (Dugger and Ting, 1970). Asada (1980) explained that increase in the level of sugars can partly overcome the phytotoxic effects of free radicals produced by gaseous pollutants, as sugars also act as scavengers of free radicals.

**Protein Metabolism**

Many workers have studied the alterations in protein metabolism induced by air pollutants and reported in different ways. Rabe and Kreeb (1979), Bolsinger and Fluckinger (1989) and others reported a decrease in protein content due to air pollution, while Ballantyne and Glover (1981) and some others reported an increase in protein content. However, Bolsinger and Fluckinger (1989) revealed an increase in all most all the detected amino acids in plants exposed to
polluted motor way air. It was explained that the plants were stressed by the air pollutants, resulting in a premature physiological senescence with an increased degradation of protein, remobilization of organic nitrogen and hence, increased content of free amino acids and decreased protein content of the plants.

Many workers studied the effects of SO₂ pollution on the changes in protein and amino acid contents. Constantinidou and Kozlowski (1979); Sardi (1981); Farooq et al. (1985) and Vijayan and Bedi (1986) in their fumigation experiments observed decrease in protein content of plants and increase in amino acids content. Most of these authors felt that this decrease in protein content could be attributed to enhanced break down of existing proteins and to the reduced de novo synthesis (Singh et al., 1985). Sardi (1981), however, found increased soluble protein content of plants at low SO₂ and soot pollution, which was inhibited at high levels.

Priebe et al. (1978) observed a marked increase in free and bound polyamines such as putrescine and spermidine in Pisum sativum subjected to SO₂ fumigations. Polyamines which are metabolic products derived from amino acids play a role in nucleic acids metabolism and in regulation of cellular pH. The accumulation of these metabolic products led Priebe et al. to suggest that polyamines, whose basicity in comparable to NaOH, could form polyvalent cations by binding H⁺ that was
produced in tissues as a result of $SO_2$ absorption) and thus act as buffering compound in the cell. Malhotra and Sarkar (1979) observed an increase in contents of glycine, alanine, thionine, lysine and methionine in needles of Pinus barksiana treated with $SO_2$ concentration, but were inhibited at high concentrations.


$NO_2$ and NO affects the nitrogen metabolizing enzymes. Wellburn et al. (1980) showed that NO stimulated nitrite reductase and other related enzymes. Fumigation of a tomato cultivar, that is sensitive to NO resulted in a significant increase in the activities of glutamate dehydrogenase, glutamate pyruvate transaminase and glutamate oxaloacetate transaminase. Plants have the ability to metabolize the dissolved $NO_3^-$ through their $NO_3^-$ assimilation pathway:

$NO_3^- \rightarrow NO_2^- \rightarrow NH_4^+ \rightarrow$ Amino acids $\rightarrow$ Proteins (Srivastava and Ormrod, 1984). According to Yoneyama and Sasakiwa (1979) and Kaji et al. (1980), plants exposed to gaseous $NO_2$ can accumulate and metabolize various products of the above pathway. Sabaratnam and Gupta

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(1988) indicated that reduction of NO$_3^-$ and NO$_2^-$ to NH$_4^+$ is greatly stimulated in light and this NH$_4^+$ can be subsequently utilized in amino acid synthesis. Using labelled NO$_2$ ($^{15}$NO$_2$), Yoneyama and Sasakawa (1979) and Kaji et al. (1980) showed that incorporation of $^{15}$N was predominantly in the amide nitrogen of glutamine, followed by glutamate, asparate, alanine and aminobutyric acid. Sabaratnam and Gupta (1988) suggested that NO$_2$ acts as a source of nitrogen and this results in increased cellular protein. They also described that normal scavenging mechanism for NO$_2$ is reduction by nitrate reductase (in cytoplasm) and nitrite reductase (in chloroplast) to form ammonia and amino acids.

**RNA Metabolism**

A loss in total nucleic acid content due to stress imposed by salt was reported long ago (Nieman, 1965; Rauser and Hanson, 1966). Sheoran and Garg (1978) reported inhibited RNase activity due to salt stress. On the contrary Gabr (1978) reported an increased RNase activity and build up of RNA content.

Decreased levels of RNA due to the influence of fluoride pollution has been reported by Chang (1970) and Pilet (1970). However, Ballantyne et al. (1981) reported fluoride induced increases in RNA levels in pea leaves.

Bisht and Agrawal (1980), while working on the effects of certain heavy metals on RNase activity in corn leaves found
an increased enzyme activity due to excess of metal supply. Nag et al. (1984) reported distinct inhibition in RNAse activity of Zn treated *Oryza sativa* seedlings. On the otherhand Singh and Shrotria (1989) found that Zn was advantageous upto some extent but Cd caused decrease in RNA levels of plants tested. Jana (1988) working on Hg and Cr reported that no significant changes occurred in RNA. Sharma and Chawla (1989) described increase in RNAse activity as an indicator of susceptibility, while, Satakopan and Rajendran (1989) described the increase in RNA level in Cd treated plants as the decrease in RNA degradation due to Cd interaction with RNA.

**Proline**

Soluble Proline accumulates within leaves when subjected to environmental stresses as low temperature, enhanced salinity, water stress and air pollution, as reviewed by Dashek and Erickson (1981). The diversity of these stresses suggest that Proline accumulation may be a general response to stress. Proline is known to act as storage compound for carbon and nitrogen during drought, when both starch and protein synthesis are impaired due to adverse conditions (Vora and Bhnagar 1986). Patel and Vora (1985) reported that drought resistant plants synthesize more proline than less resistant plants.

Jager and Mayer (1978) suggested that proline could
serve as precursor for chlorophyll synthesis immediately following the alleviation of stress. Godzik and Linskens (1974) and Jager (1975) reported increased foliar soluble proline in Phaseolus vulgaris and Pisum sativum upon exposure to SO₂. Erickson and Dashek (1982) studied the accumulation of proline in SO₂ stressed seedlings. They observed proline accumulation occurring prior to the appearance of visible injury and explained that proline may confer resistance to the plants.

Phenols

Many workers had observed the accumulation of phenols in the plants influenced by air pollution, (Howell et al., 1971; Howell, 1974; Agrawal et al., 1982).

Keen and Taylor (1975) found an accumulation of isoflavonoids in O₃ treated plants and suggested that plants under stress can trigger such metabolic responses. Enzymes involved in phenol metabolism such as phenylalanine ammonia lipase, polyphenol oxidase and peroxidase, are known to be influenced by pollutants (Tingey et al., 1978). Agrawal (1982) studied the effect of SO₂, O₃ and the mixture of SO₂ + O₃ on Vicia faba and Panicum melisaeicum and reported higher levels of phenols in comparison to control plants. Rao et al. (1987) found increased phenol content in the plants growing in the cement dust pollution area.
OXIDATIVE ENZYME

Peroxidase

Total peroxidase activity and altered peroxidase isoenzyme patterns are known to result from stress conditions and elevated peroxidase levels induced by pollutants have been described as an indicator of physiological stress by Horsman and Wellburn (1975). Hydrogen peroxide, a toxic chemical, is produced by different metabolic activities within the plant system and its removal is essential to prevent the destructive oxidation of important metabolites. Peroxidase enzyme is known to be capable of performing this function. Varshney and Varshney (1985) suggested that an increase in peroxidase activity after SO$_2$ fumigation promotes oxidative processes and thus indicates the plant's potential for response to a stressful situation. According to them peroxidase acts as a scavenging molecule for superoxide radicals and protect the plant from serious cellular damage. On the contrary Patton and Garraway (1986) felt that a normally high level of peroxidase activity or pollutant induced increases in activity may speed up the accumulation of toxic polymers that lead to lesion development. In their study with popular leaves, they showed correlation between O$_3$ induced necrosis of leaves and increase in peroxidase activity.

Endress et al. (1980) observed elevated peroxidase
activities in pintobean and tomato plants exposed to pollutants and stated that peroxidase activity appears to be extremely sensitive to the internal physiological conditions of the plants. Keller (1981) described these patterns in peroxidase activity as indicator of plant stress imposed by air pollution. Sarkar et al. (1986) working on automobile exhaust pollution observed stimulated peroxidase activity in plants growing in the area nearest to the road. Increased levels of activity in response to automobile exhaust has been reported by Flueckiger et al. (1978) and Eckert and Houston (1982). Peters et al., (1989) observed stimulated activity upon exposure to $O_3$ and $SO_2$, when the dose does not cause obvious necrosis or chlorosis of the leaves. Murray (1984) and Nandi et al. (1984) also reported increased activity due to $SO_2$.

Trace metal pollution is also known to induce changes in peroxidase enzyme activity. Studies of Nag et al. (1981) with Hg and Cu, Roy and Mukherji (1982) with Cr, Nag et al. (1984) with Zn and Assche et al. (1988) with Zn and Cd, proved that these metals induce increase in the peroxidase activity of plants.

USE OF VEGETATION AS BIO-INDICATORS OF ENVIRONMENTAL POLLUTION AND FOR ABATEMENT AND THEIR RELATIVE TOLERANCE Indicators

Some plant species are relatively sensitive to certain
air pollutants. It is therefore possible to monitor the level of air pollution through proper quantification and standardization of responses of sensitive species. Varshney (1985) defined indicator plant, as the one which exhibits injury or stress symptoms when exposed to phytotoxic concentrations of pollutants.

Efforts were made to use plants for detecting air pollutants, particularly, $\text{SO}_2$, $\text{NO}_x$, HF, $\text{O}_3$, $\text{F}$ etc. (Manning and Feder, 1980). Field studies by Rao (1972) revealed the relative high sensitivity of Mango trees to air pollutants and thus it has been suggested as an indicator species of air pollution. Pandey (1983) worked on natural vegetation around a thermal power plant and showed the importance of plants as indicators.

Leaf epidermal features, most documented aspect in the field of air pollution, have proved quite effective in assessing air pollution (Garg and Varshney, 1980; Yunus and Ahmad, 1981; Yunus et al., 1982; Bhairav Murthy and Kumar, 1983). The invisible changes caused by non necrotic $\text{SO}_2$ exposure can be detected at metabolic level by examining certain biochemical parameters as chlorophyll, protein content, specific metabolites and enzymes (Nandi et al., 1980; Varshney and Varshney, 1984).

Among the important plant parameters that have been used for monitoring air pollution level are: changes in chlorophyll (Agrawal, 1985), ascorbic acid content (Rao,
1981), enzyme activities such as peroxidase (Nandi et al., 1984), catalase (Nandi et al., 1980) super oxide dismutase (Agrawal et al., 1986), metabolites (Agrawal, 1985) and growth behaviour (Rao, 1980; Agawal, 1985).

Abatement

Plants can be used for reducing the quantum of pollution through process of absorption, detoxification and accumulation or metabolism (Rao, 1985). It has been long believed that vegetation can filter out dust, soot, smoke and other pollutants from the air. Meetham (1964) reported that Hyde park, a green area of about 1.5 km$^2$ in the centre of London, reduced smoke concentration by 27%. Bach (1972) reported in Soviet Union that Lilac, Maple, Lindon and Poplar trees can filter up to 2.33 mg dust/m$^2$ leaf surface.

Giridhar and Chaphekar (1983) have studied $SO_2$ absorption and removal capacity of Solanum melongena and Cyamopsis tetragonoloba and found that rate of pollutant removal was related to leaf area. Studies carried out by Varshney (1985) have showed the role of tree bark in promoting surface deposition of sulphur. Leaf analysis of Nerium indicum plants along the roads have demonstrated the scavenging properties of this plant.

Rao (1980) proposed that pollution tolerant species of herbs, shrubs and trees in urban and industrial areas help in reducing air pollution and in improving air quality. The study of Das et al. (1981) also indicated that species of
advanced plant families like Gramineae, Orchidaceae etc. during the course of evolution, have evolved a built-in mechanism for absorbing chemicals from airborne particulate pollutants to their advantage.

Tolerance

For the toxicant to be removed by plant the later has to be tolerant enough to detoxify and metabolize the toxicants.

Singh and Rao (1983) screened the plant populations and gave the "air pollution tolerance index" of different plants, on the basis of leaf extract pH, ascorbic acid, total chlorophyll and relative water content. According to Singh and Rao (1983) air pollution tolerance index of Ficus glomerata, Azadirachta indica and Nerium odorum (which are the plants discussed in this thesis) are 32, 23.5 and 15 respectively in decreasing order. Farooq et al. (1988) also indicated the usefulness of planting Azadirachta and Ficus species around industries to lower the burden of SO₂ impact to environment, since they are SO₂ tolerant.

Krizek et al. (1985) and Pande and Oates (1986) indicated that certain morphological and physiological properties of leaf may be important in explaining SO₂ and NO₂ tolerance. These properties include low stomatal density, high trichome density, low stomatal conductance and low transpiration rate. Pande (1985) observed that stomatal resistance was highest
in tolerant species and lowest in sensitive species. He also stated that a cultivar with high metabolic efficiency would be under less stress from the accumulation of pollutants. On the other hand Beg and Farooq (1988) indicated that on exposure to pollutants, in the most susceptible plants the process of metabolism is activated towards synthesis and most of the biochemical constituents are accumulated in higher amounts. While in tolerant species, showing visible injury only at higher levels of pollution, most of the biochemical constituents existed at low levels indicating a low metabolic profile. Armentano and Menges (1987) interpreted lower visible injury range in Jack pine than White pine as a genetic selection tolerance towards low air quality.

Plant species differ in the degree of injury which they sustain at the same level of exposure. So many works have been done to identify species and cultivars of plants which have greater degree of tolerance to pollutants. From these studied it is possible to breed desirable resistant strains for their utility in abatement measures, (Khoshoo 1981).