RESPONSES OF CROP PLANTS TO AIR POLLUTION

DISSERTATION FOR
Master of Philosophy
IN
BOTANY

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بسم الله الرحمن الرحيم

علم الانسان ما لم يعلم

He (Allah) taught man that
which he knew not
(The Quran 96:5)

TO
MY PARENTS
WITH RESPECTS

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C E R T I F I C A T E

It is my plesure to certify that the dissertation entitled "RESPONSES OF CROP PLANTS TO AIR POLLUTION" has come to shape due to the genuine and sincere efforts made by Mr. Farooq Ahmad Lone under my supervision. This may be submitted to the Aligarh Muslim University in candidacy for the award of M.Phil. degree in Botany.

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Farooq. Ahmad. Lone.
(FAROOQ AHMAD LONE)

CONTENTS

INTRODUCTION

Human survival depends upon the life activities of thousands of species of plants, animals and various micro-organisms. No organism is independent of its environment, every living thing constantly influences and is influenced by its inorganic and organic surrounds. All components of the universe influence life, and all are parts of the environment. Environment for living being includes all factors and forces prevailing internally and externally on, around, and in the organism.

The deteriorating quality of the environment is causing world wide concern and mankind is faced with newer and unimaginable kinds of environmental problems. Protecting the environment while making efficient use of natural resources is the most pressing demand in the present stage of social development. Developmental activities all over the world have widely altered the environmental quality at micro, macro and global levels. Development is accompanied by some form of pollution which threatens not only animal and plant life but the very existence of the human race. There have been disasters of great dimensions such as leakage of lethal gases, poisoning of water by toxic chemicals, droughts, erosion, land-slides, rapid silting of dams, mass scale death of trees, wild life, fishes, etc. through ecological back-lashes due to unplanned developmental activities.

A good environment means not only conditions that are favourable to the maintenance of physical health, but also certain emotional and aesthetic qualities of the surroundings. These criteria which are very different from those that governed industrial growth in the past, should generate new forms of growth in which quality of life will take precedence over the quality of goods produced. Economic affluence has its draw-backs. It spoils human relationships and creates forms of environmental degradation that increasingly damage the physical and biological quality of the globe as a whole, for the simple reasons that most pollutants spread far beyond their points of emission. Radiation from the Chernobyl disaster was first noticed in Sweden, It was only after the first alarm was raised in Sweden that the tragedy was traced to the U.S.S.R. At home the proposed fourth "accord" refinery at Numaligarh (Assam) could be a major environmental risk for the Brahmputra and the Kaziranga National Park. The mass death of pigeons in Bhopal due to the presence of carbon-monoxide in the atmosphere, suspected to have been caused by electrographite unit is another instance of environmental pollution. Yet there are innumerable permenant sources delibrately releasing various toxic substances into the air in sub-lethal to lethal quantities round the clock. Thermal Power Plants are also included among the major sources of air pollution due to coal burning that gives rise to various noxious gases and particulate matters. One such plant is located at Kasimpur, about 16 kms. north-east of Aligarh City.

Pollution means the presence of extraneous materials in a particular environment in concentrations that are harmful to living organisms. In 1966, the committee on pollution, National Academy of Sciences, U.S.A. defined the pollution 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 desirable species, our industrial processes, living conditions and cultural assets, or that may or will waste our raw material resources (Anonymous, 1966). In other words, any undesirable change in the physio-chemical and biological properties of air, water and soil which may cause harm to man, other organisms, or to cultural and natural elements of man's environment, is pollution (Gopal & Bhardwaj, 1979). Pollution may also mean "direct or indirect changes (usually, but not always created by man) in one or more components of the ecosystems, which are harmful to the system or at least undesirable to man" (Ambasht, 1984). According to Odum (1971) pollution is the undesirable change in physical, chemical and biological characteristics of our air, soil and water that may show direct or indirect effect on the ecosystems. To ecologists, pollution means environmental degradation and toxicity to life supporting systems comprising air, water and soil. Thus the pollution involves alteration of the atmosphere by the introduction of natural and man-made contaminants.

Environmental pollution has assumed alarming magnitude and its frontiers are no longer confined to any particular region of the world. It is a growing threat to the whole planet (Hobb _et al_., 1975), endangering the ultimate future of living organisms on the earth. Steve Van Matre (1984), a Professor at George William College, Chicago, estimates that in the present world only 20% of the air is breathable, only 10% of the land is capable of being exploited for producing food, and just 1% of the earth's water is portable. It is estimated that hundreds of million tonnes of harmful gases and dust are emitted into the earth's atmosphere every year (Astanin & Blagosklonov, 1983). In 1969, merely smoke concentration was estimated to be 35 mg/m^3 in Stockholm. It was 25 folds this figure in Mexico, 10 folds in Osaka, 7 folds in Bombay, 5 folds in Prague and 4 folds in Tokyo (Kochhar, 1982). According to Sharma (1981), the amounts of pollutants such as hydrocarbons, nitrogen oxides, carbon monoxide, sulphur dioxide and dust entering the air of calcutta and Howrah cities is as much as

1299 tonnes per day. Rai (1984) has quoted that some 1,400 tonnes of hydrocarbons, Co, NO_x and SO_2 are emitted in the air of Delhi every day by power plants, automobiles, industries and chullas. Some 60,000 tonnes of Co, 24,000 tonnes of hydrocarbon and 2000 tonnes of NO_x are released annually in Delhi by the petrol using vehicles alone. Another report (Agarwal *et al.*, 1982 a) has revealed that over 70% of the available water in India is polluted, 60% of Calcutta's residents suffer from respiratory diseases because of air pollution, and the incident of blood cancer has increased five times in Lucknow during the last decade. Pollution increases not only because as people multiply the space available to each person becomes smaller, but also the demands per person are continually increasing, so that each throws away large quantities of harmful substances year by year. As the earth becomes more crowded, there is no longer an "away". One person's trash basket is another's living space.

Pollution is a man-made problem and at present it is a problem of affluent countries. The developing countries with approximately 70% of the human populations are economically hard pressed. Some of these try to meet the situation by inflation which causes economic disaster at national level, while the advanced and heavily industrialised countries with 30 percent populations are in a mad rush to exploit every bit of the natural resources and manufacture them into finished goods for their comforts and to earn currency from the needy countries. In doing so, the industrialised countries are dumping lots of materials and waste in their immediate environment which is now becoming a big source of pollution. They are disturbing the economy of nature and creating international problems. In some of the big cities deaths have been reported not because of famine or epidemic but due to lack of healthy air for breathing purpose. Man-made pollutants not only damage environment, health, vegetation and materials, but also interfere with climate. Thus, step by step, the precious gifts of Nature are being destroyed and the human life is being shortened by the polluted air we breath and the unhealthy water we drink. Every parameter of our biosphere is getting increasingly polluted day and night due to the rapid industrialization, urbanization, advancement of technology and production of nuclear energy.

Air pollution is the product of the activities of man. As man started manufacturing chemicals and processing metals, generating electric power, developing faster means of transportation and crowding in overpopulated cities, the problem of air became inevitable. The air environment began to lose its earlier purity due to the concentration of smoke and other pollutants. Burning of coal gives off both soot and sulphur dioxide. Chemical industries release HCl, H_2SO_4,

SO_x, NO_x and other gases to the atmosphere. The petroleum industry contributes hydrocarbons from refinery stacks, besides emitting SO_2, NO_2, particulate matter, etc. The metallurgical industry adds quantities of Pb, As, Zn, Cu and Cd into the air. The automobile pumps pollutants into air in the form of hydrocarbons, Co, NO_x soot, lead and several other noxious compounds. Air pollutants not only remain confined or limited in the vicinity of industrial establishments or emission sources, but depending on the topography and meteorology of the area, these may spread into far off places of the natural landscape, affecting growth, development and productivity of plants and animals present there (Rao, 1980).

The air pollutants contaminate air, water and soil, corrode materials, destroy buildings and clothing, harm plants and wild life and affect human health. Innumerable air pollutants have toxic effects on vegetation. Although the relative importance of phytotoxicants varies from location to location, international estimates of the economic damage in forest and natural tree plantings indicate that primary offenders are sulphur dioxide, fluorides and ozone. Additional aerial phytotoxicants are of minor consequences. These toxicants could become more destructive if their emissions are more widely distributed.

Atmospheric pollution with gases such as SO_2, O_3, HF, PAN (per oxyacetyl nitrate), and NO_x (oxides of nitrogen) can have dramatic effects on plant growth and community structure (Grace et al., 1981; Koziol & Whatley, 1984). For example, along a 60 km. transect downwind from a smelter in Ontario, Canada, there were no trees or shrubs at all in the first 8 kms., and there was high mortality of mature trees as far as 25 km. The species richness of the ground flora was reduced up to 35 km. downwind (Gordan & Gorham, 1963). Ozone, alone or in combination with SO_2 and/or NO_2, is responsible for upto 90% of the crop losses caused in the United States (Heck et al., 1982; Miller et al., 1982) and has been recognised as a factor in crop production for over two decades. Estimates of crop losses, using limited available dose-response and assuming that all areas of the United States meet the current O_3 standard of 0.12 parts per million (ppm) for one hour, are one to two billion dollars annually (Cure, 1982; Heagle, 1982; Heck et al., 1982; Miller et al., 1982; Olson, 1982; Shriner, 1982). Ozone has been found to cause a crop loss in 80 sites in the National Aremetric Data Bank (Larson et al., 1988). Loss to crop production due to ozone has been noted in soybean, corn, wheat and cotton (Heggested, 1988).

The air pollutants affect plants both directly and indirectly. The direct, phytotoxic effects influence net photosynthesis, stomatal resistance, and metabolic and reproductive activity (Treshow, 1984; Salgare & Chakraborty, 1988; Takemoto et al., 1989). For example, 8 hours of exposure to SO_2 at 785 $\mu g/m^3$ produces symptoms such as chlorosis and bleached spotting of leaves, and 4 hours of exposure to O_3 at 59 $\mu g/m^3$ causes flecking of leaves and necrosis of canifer-needle tips. Exposure to HF at concentrations of only 0.08 $\mu g/m^3$ for five weeks causes tip and margin burn to leaves, dwarfing and leaf abscission (Stern et al., 1984). Amer et al. (1989) reported in *Vicia faba* fumigation with SO_2 (5 ppm for 5 hrs.), a significant percentage of abnormal pollen mother cells, abnormalities in different meitoic stages and a large number of non-viable pollen grains. Rabe (1981) reported that activities of enzymes (Glucose-6 phosphate dehydrogenase; Isocitrate dehydrogenase; Glutamate dehydrogenase; aspartate amino transferase and alanine amino transferase decreased at higher SO_2 concentrations associated with a decrease in chlorophyll and protein contents.

The indirect effects of air pollutants act via the alterations in plant biochemistry which they induce. One interesting side effect involves the plant's invertebrate herbivores. It has been known for some time that plants which are exposed to extreme conditions (eg; drought, pollutants, physical disturbance exhibit altered nitrogen metabolism;

they tend to show increased tissue concentrations of nitrogen and altered patterns of amino acid composition (White, 1974; Jager & Grill, 1975). It now appears that these increased levels of amino acid availability can represent substantial improvements in food quality for the insects feeding on these plants, with the result that air pollution may even lead to insect outbreaks (Port & Thompson, 1980; Edmunds & Alstad, 1982). In a detailed study of blackfly (Aphis fabae) on broad beans (Vicia faba), Dohmen et al. (1984) suggested that increased pest-status of blackfly in Essex, downwind from London, is due to alteration in the concentration and composition of amino acids in the bean plant, induced by SO_2 and NO_2 in the London air. Experiments with these gases, and with filtered London air, show that the gases have no effect on the insects directly and that the increase in aphid growth which they observe in polluted air is mediated entirely through induced changes in host plant chemistry.

Environmental problems do not recognise national borders. This has been accepted world-wide for some years now, specially in the light of the growing evidence of the 'green house effect' caused by global warming. The unfettered use of technology, which is the hallmark of our era, has led to profoundly ambiguous results. On the one hand, technology has given, who have mastered it, unprecedented economic growth and on the other, the same mastery has brought us the threat of disaster, in the short term from nuclear war, and in the long term irrevocable damage to the global environment.

Our well being is irrevocably interwined with the long-range ecological security. Most of us are undermining ecology all the time, in fact, the enemy is within each of us and we are at war with our precious environmental assets.

ENVIRONMENT AND POLLUTION OF THE ATMOSPHERE

The Earth's atmosphere is a tenuous envelop of a mixture of gases that not only sustains all life on this planet but also plays a vital protective role. Our atmosphere is predominantly a mixture of life-giving oxygen and nitrogen which together make up almost 99 percent of its volume. The rest is accounted for by carbon dioxide, water vapour and several other gases in trace amounts. Surprisingly, it is not the oxygen but two of the minor constituents of our atmosphere, carbon dioxide and ozone that hold the key to human survival. There is evidence to show that even small changes in the level of these two gases may have far reaching impact on the global climate and human well-being. Nowadays, change in the global constituents due to certain anthropogenic activities ultimately lead to imbalance of the atmosphere.

Rapid urban and industrial growth has resulted in vast quantities of potentially harmful waste products being released into the atmosphere. Societies have been reluctant to accept, or have simply failed to recognize, the limitations of the cleansing properties of the atmosphere. The result has been that air pollution has affected the health and well being of people, caused wide-spread damage to vegetation, crops, wildlife, materials, buildings and climate, and resulted in depletion of the scarce natural resources needed for long term economic development.

The worst air pollution has occurred in and around urban-industrial areas. The seriousness of atmospheric pollution for urban communities, as shown by the effects of short-term pollution episodes or accidental releases of large quantities of pollutants, has led to the introduction of national pollution-control policies which have largely been aimed at tackling the local pollution problems. Initially, these national policies gave little or no consideration to the phenomenon of exported or imported pollution. Inevitably, the transport of pollutants over long distances has created international and global pollution threats, and problems such as acid rain, ozone episodes and accidental releases of toxic chemicals and ionizing radiation have emerged. Areas distant from sources of pollution, once perceived as being too remote to be affected, now experience acid rain which threatens irreversible damage to sensitive aquatic and terrestrial ecosystems. Global-scale problems include increasing the atmospheric concentration of carbon dioxide which might be causing a change in the world's climate, and chloroflurocarbons (CFCs) that would be depleting the stratospheric ozone.

There are many different views as to what constitutes pollution of the atmosphere. To some people, pollution implies the increase, or even decrease of any atmospheric constituent from the value that would have existed without human activity. Given that our planet's atmosphere has undergone profound changes in its constitution, and that volcanic eruptions, forest fires and sand storms cause marked local and regional variations in atmospheric constituent values, then such a definition is of limited use. The atmospheric pollution is also defined as 'The presence of substances in the ambient atmosphere, resulting from the activity of man or from natural processes, causing adverse effects to man and environment' (Weber, 1982). An expanded version of this definition will be, that air pollution is defined as 'the presence in the atmosphere of substances or energy in such quantities and of such duration liable to cause harm to human, plant, or animal life, or damage to human-made materials and structures, or changes in the weather and climate, or interference with the comfortable enjoyment of life or property or other human activities'.

Clean air, essential for all living beings has the following composition in general :

Nitrogen = 78.09% Oxygen = 20.94%
Inert gases = 00.93% CO_2 = 00.03%
(Natural pollutants) N_2O & NO_2 = 00.52%

Any variation in this normal composition of air is indicative of a polluted atmosphere.

Until well into this century, air pollution was for most people synonymous with suspended particulate matter (soot, smoke and sulphur dioxide). These are waste products produced mainly by domestic heating equipment, a wide range of industrial plants and power plants. As the twentieth century has progressed, concern for pollution of the atmosphere has ranged across a large number of pollutants. The tremendous increase in the use of petroleum products, particularly in petrol-powered motor vehicles, introduced several new pollutants (World Health Organisation, 1972), Exhaust emissions of nitrogen oxides, carbon monoxide, hydrocarbons and lead added greatly to the pollution of urban areas. From the emissions of oxides of nitrogen and hydrocarbons are also produced the secondary pollutants of photo chemical oxidants. The development of new industries introduced the problem of toxic chemicals, while nuclear power production and atomic-weapons testing high lighted ionizing radiation as a pollutant. Some of the contaminants which cause the pollution of the air are listed below :

S.No.	Group	Specific Examples
1.	Fine Solids (Less than 100 μ in diameter)	Carbon, flyash, $CaSiO_3$, ZnO, $PbCl_2$
2.	Coarse particulates (greater than 100 μ in diameter)	
3.	Sulphur compounds	SO_2, SO_3, H_2S, merceptons
4.	Organic compounds	Aldehydes, hydrocarbons, tars
5.	Nitrogen compounds	NO, NO_2, NH_3
6.	Oxygen compounds	O_3, CO, CO_2
7.	Halogen compounds	HF, HCl
8.	Radioactive compounds	Radioactive gases, aerosols

Apart from these pollutants natural contaminants from sea, forest, desert, valcano, and field have long been with us. Fog containing droplets of air contaminants have , however, been included as our more prevalent and unwelcome natural pollutant.

Pollen dust form another natural pollutant. The total ragweed-pollen emission weighs far less than the natural dust. Yet, because of its peculiarly irritating properties, about four million North Americans suffer each year from varying degrees of hay-fever discomfort.

Natural dust appears to be present in far greater weight than industrial smoke and dust combined. Astanin and Blagosklonov (1983) have given a chart for maximum permissible concentration of harmful substances in the air over polluted areas (Table I).

The pollutants of current local or regional concern, such as anthropogenic heat and toxic chemicals, have been projected to become global pollution problems of the future. The heating effect exerted by the atmosphere upon the earth, by absorbing and re-emitting long wave radiation from the earth, will disturb the earth climate. This inturn will aggravate the existing problems such as drought, desertification and soil erosion in some regions. This effect on earth has to be checked by reducing the amount of fossil fuel burnt, by filtering CO_2 from the emissions of power stations and by disposing off the green house gases. The "Green House Effect", once a subject of purely scientific enquiry, is rapidly emerging as an important public policy issue. A precise definition of green house effect is difficult but in simple terms, it is the heating effect exerted by the atmosphere upon the earth by virtue of the fact that the atmosphere absorbs and re-emits long wave radiation from the earth which becomes warmer or cooler mainly because of the effect of sunlight (Arjunan, 1989).

Among the various 'green house gases' the best known is CO_2 with a concentration of about 344 parts per million by volume (0.034%) and the concentration of which is increasing at an annual rate of 0.4%. It is now well proved that CO_2 is responsible for half of the green house effect. The important green house gases, their concentration and annual rate of increase are given below.

S.No.	Green House Gases	Atmospheric Conc. (PPb. V/V)	Annual rate of increase (%)
1.	Carbon dioxide	344,000	0.4
2.	Methane	1,650	1.0
3.	Nitrous oxide	304	0.25
4.	Methyl chloroform	0.13	7.0
5.	Ozone	Variable	-
6.	CFc 11	0.23	5.0
7.	CFc 12	0.4	5.0
8.	Carbon tetrachloride	1.25	1.0
9.	Carbon monoxide	Variable	0.2

These gases trap the long wave low energy radiations emitted from the earth's surface and raise the temperature globally, leading to the possibility of a climate change of geological proportions occurring over time span as short as a single human life time. Thus, the future of the earth's climate depends on how much the concentrations of CO_2 and other trace gases are likely to increase in future. It is said that the concentration of CO_2 has increased nearly 25% since industrialization and they are expected to increase by a further 30% in the next 50 years. Hence the green-house effect will disturb the climate of the planet, changing such critical variables as rain-fall, wind, cloud cover, ocean currents and the extend of the polar ice caps.

Another crucial atmospheric phenomenon caused by air pollution is the depletion of ozone in the stratosphere. Ozone is produced in the stratosphere by the action of high energy ultraviolet radiation on oxygen, and being a good absorber of ultraviolet radiation its presence there effectively blocks out the Sun's ultraviolet radiation. The ultraviolet radiation is dangerous to any life form because it is known to destroy living organisms and cause skin cancer in humans. The stratospheric ozone layer thus plays an important protective role for life on earth and its disruption is obviously fraught with dangerous consequences. It has been estimated that a one percent drop in ozone level in the stratosphere could lead to as many as 10,000 more cases of skin cancer a year in the United States alone.

Man has now realised that the pollution damage is obvious, severe and inescapable unless the violation of the environmental safety is not checked.

Table I. Maximum permissible concentrations of harmful substances in the air over polluted areas (After Astanin & Blagosklonov, 1983).

Pollutant	Maximum permissible concentrations (mg/m^3)	
	Short-term*	Daily**
1. Ammonia	0.20	0.20
2. Arsenic	-	0.003
3. Benzine	5.00	1.50
4. Benzol	1.50	0.80
5. Carbon disulphide	0.03	0.01
6. Carbon monoxide	3.00	1.00
7. Carbophos	3.00	-
8. Fluorine	0.10	0.03
9. Florine compounds	0.03	0.01
10. Formaldehyde	0.035	0.012
11. Hydrogen sulphide	0.008	0.008
12. Lead	-	0.0007
13. Mercury	-	0.0003
14. Nitrogen dioxide	0.085	0.085
15. Non-toxic dust	0.50	0.15
16. Phenol	0.01	0.01
17. Phosphoric anhydride	0.15	0.05
18. Soot	0.15	0.05
19. Sulphur dioxide	0.50	0.05
20. Sulphuric acid	0.30	0.10

*Short-term = Emissions mostly for 20-30 minutes.

**Daily = Average daily emission over a long period.

SOURCES AND GENESIS OF AIR POLLUTION

Pollution travelled with man and his civilization from the time of cave dwelling scattered families to the time of urban skyscrapers, metropolis communities. It has grown manifolds with the population and industrial out break, and now has reached every nook and cranny of the earth. The increasing tilt towards urbanization and industrial concentration has led, among other things, to congestion in residential areas and heavier use of city highways. Today, industrial enterprises and automobiles are considered to be the primary sources of severe atmospheric pollution. The major emission sources however include : (a) Transportation (b) Electric Power Generation (c) Industrial processes. (d) Industrial and domestic fuel burning.

Air pollution involves enrichment of our atmosphere with noxious gases, and other undesirable substances like smoke, dust etc. caused largely as a result of burning of fuels and the consequent release of gases in various factories and industries, automobiles and house holds. Another important source of artificial contamination is certain fluorocarbon compounds (gases) used widely as refregerants, as propellants for aerosol products and for other applications. Thermal Power

Plants are also included among the major sources of air pollution due to coal burning.

Varshney and Garg (1978) identified some major sources of pollution and their magnitude in an industrialized country like India (Fig. 1 and 2). These figures show relative importance of pollutants and source because the absolute amount increases by the year.

The relience of modern technology on combustion of fossil fuels has brought a 10% increase in the atmospheric CO_2 over the past century and this could rise to 25% after the current century. At present the concentration of carbon-dioxide in the atmosphere is 340 ppm as compared to 315 ppm in 1958. Scientists now predict that the atmospheric level of CO_2 will nearly double to 650 ppm by the year 2050.

Among the various gaseous pollutants, oxides of sulphur produced by sulphur containing coal and petroleum constitute the most common pollutants. The quantity of sulphur emitted into the atmosphere is in the order of more than a hundred thousand tonnes each day. SO_2 forms some 60% of the total air pollution (Rohrman & Ludwig, 1965). Burning of sulphur forms SO_2 which may react with oxygen (O_2) forming sulphur trioxide (SO_3), which in turn combines with H_2O to form H_2SO_4 (Sulphuric acid).

$$S + O_2 \xrightarrow{\hspace{2cm}} SO_2 \text{ (Pry. pollutant)}$$

$$2\ SO_2 + O_2 \xrightarrow{\text{Sunlight}} 2\ SO_3 \text{ (Sec. pollutant)}$$

$$SO_3 + H_2O \xrightarrow{\hspace{2cm}} H_2\ SO_4 \text{ (Sec. pollutant)}$$

Acid rain which contains about 65% H_2SO_4, 30% HNO_3, 5% HCl, is caused by pollutants which the fossil fuel based industries emit. It destroys the vegetation considerably.

Oxides of nitrogen released to the atmosphere originate from the combustion of fuels, motor-vehicle exhaust, petroleum refining and burning of the organic wastes. Nitrogen oxides in turn produce other pollutants such as Ozone (O_3); Peroxyacetyl nitrate (PAN) and nitric acid (HNO_3) Cox et al. (1975).

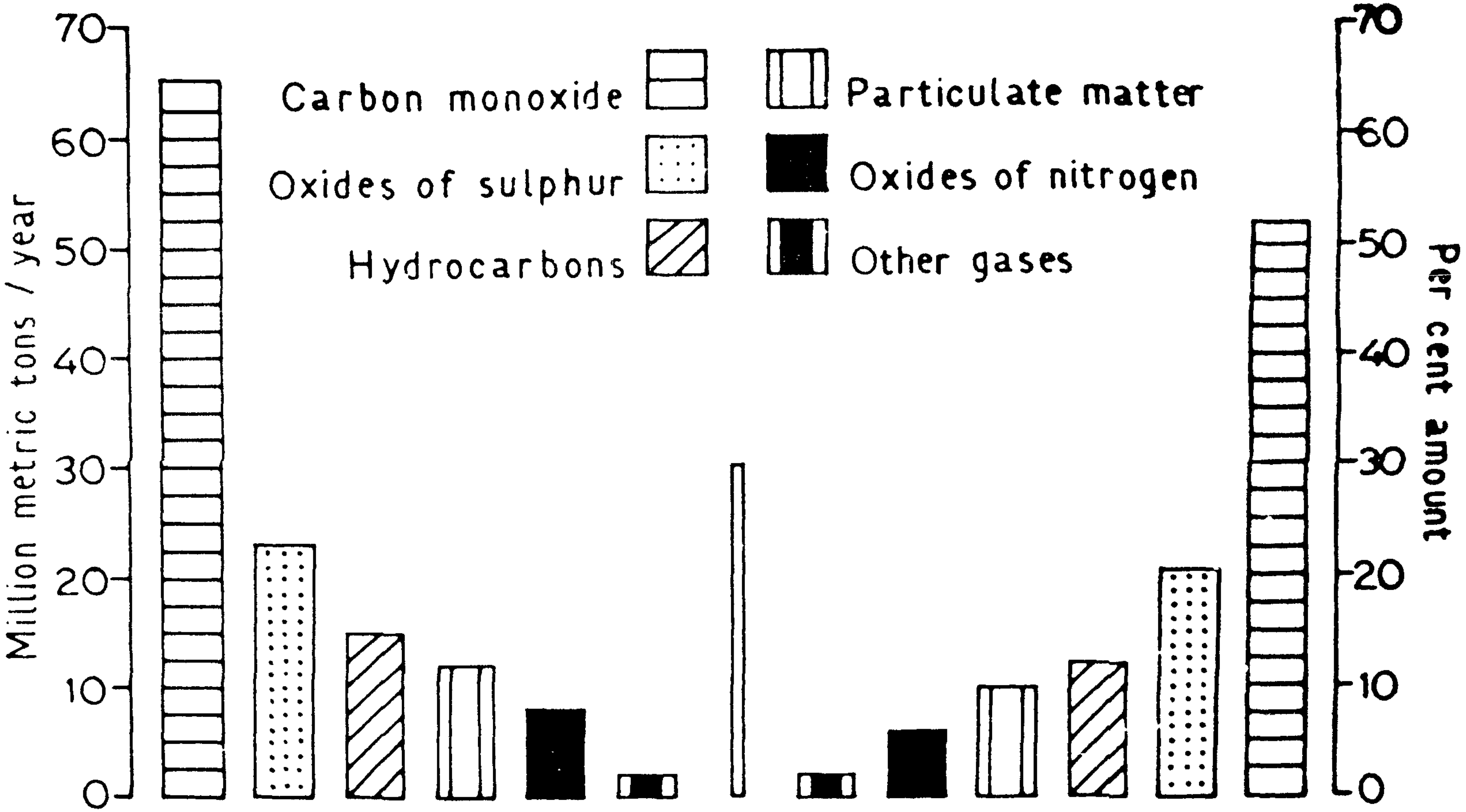
$$\text{Nitrogen oxide} + \text{Hydrocarbons} \xrightarrow[\text{sunlight}]{\text{Ultra violet radiations in}} \text{PAN} + O_3$$

PAN is the major harmful nitrogenous compound , but quantitatively less important than ozone. Ozone increases respiration of leaves killing the plant by decreasing its food, while PAN blocks the Hill reaction in photosynthesis. Photochemical smog containing ozone and NO_2/NO constitutes another source of air pollution.

Apart from these gaseous pollutants, particulate pollutants which include particles of dust, fumes, soot and droplets are also emitted from various industries. Particulates of the smallest size (.01 µm) are known as aerosols. They form 'mist' with liquid particles and 'dust' with solid particles regardless of the particle size (Corn, 1968). Smoke is the bye-product of combustion and produces an unusual type of damage (phytotoxic effect) which has been variously described as silvering, bronzing or glazing. Silvering usually appears on the underside of leaves. This type of damage causes a severe economic loss.

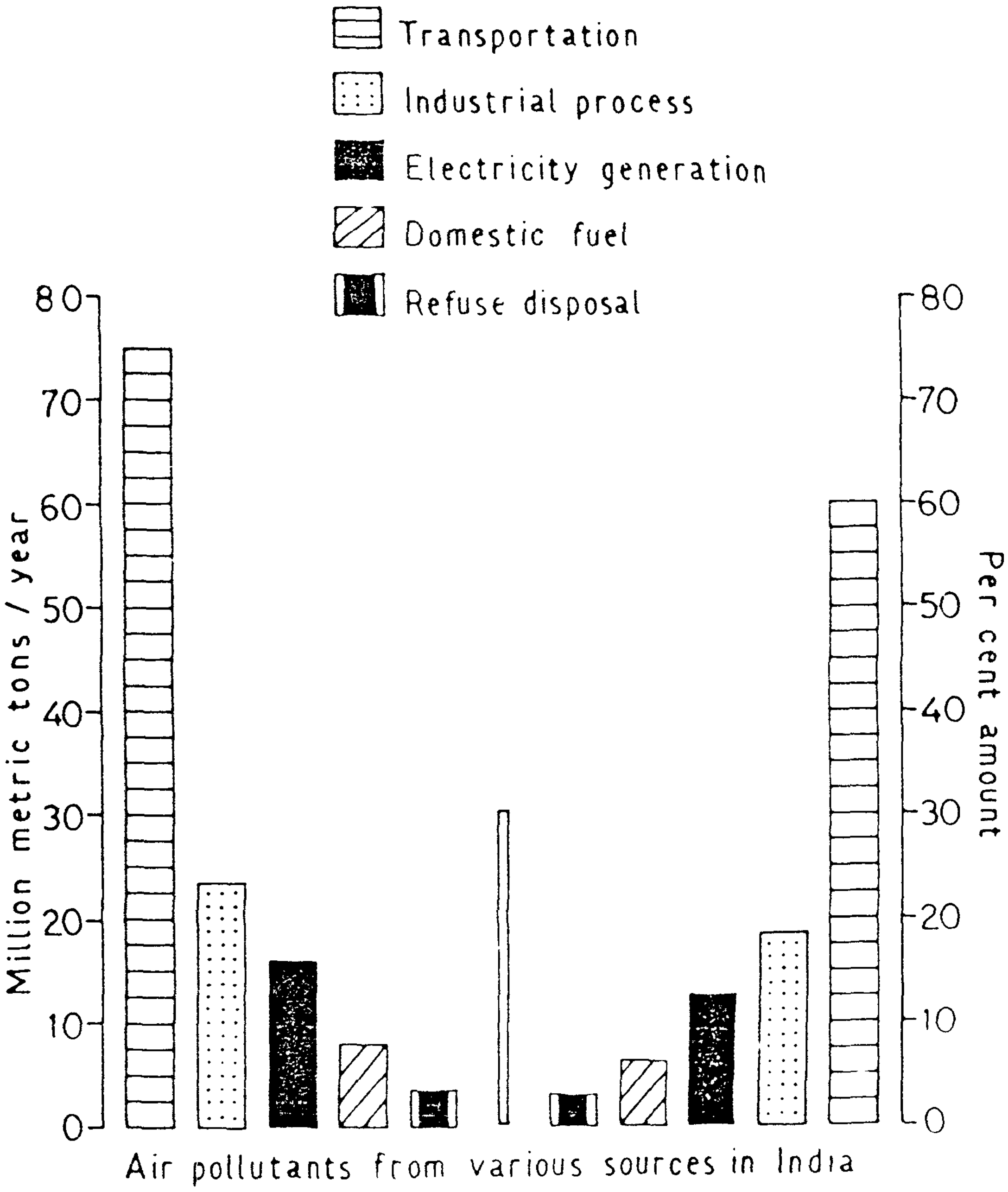
Flyash is the common product of coal combustion. Besides having large amounts of carbon, silica, alumina and iron oxides it contains certain other metals such as arsenic, cadmium, berrylium, selenuim etc. It contaminants soil, water and air around the industrial enterprises (Astanin & Blagosklonov, 1983).

Rossana (1966) however, provided a chart of various categories of air pollutants and their emission source (Table II).



Relative magnitude of air pollutants in India
(after Varshney & Garg,1978)

Fig. 1



Air pollutants from various sources in India
(after Varshney & Garg, 1978)

Fig. 2

Table II. Classification and emission sources of air pollutants (after Rossana, 1966)

Activity	Major Operation	Emission Sources	Important pollutants
Combustion	Fuel burning	Domestic burning, Thermal Power Plants	Sulphur and nitrogen oxides
	Transportation	Cars, trucks, aeroplane and railways	Carbon monoxide, nitrogen oxides, lead, smoke, odours and organic vapours
	Refuse burning	Open burning	Flyash, Particulates
Manufacturing Processes	Chemical Plants	Petroleum refineries, fertilizers, Cement and paper mills, Ceramic clay products and glass manufacture	Hydrogen sulphide, Sulphur-dioxide, Fluorides, Odours and Organic vapours.
	Metallurgical Operations	Aluminium refineries, Steel Plants	Metal fumes (Pb & Zn), fluorides and particulates
	Waste recovery	Scrap metal yards, rendering plants	Smoke, Soot, Odours Organic vapours, metal fumes

Contd....

Table II Cont....

Activity	Major Operation	Emission Sources	Important Pollutants
Agriculture	Crop spraying	Pest and weed control methods	Organic phosphates, chlorinated hydrocarbons, Pb, As, etc.
	Field burning	Burning of refuse, fire wood and dry cattle dung	Smoke, flyash, soot, sulphur-oxides, particulates and organic vapours.
Solvent usage	Spray painting, Solvent extraction, inks.	Furniture and appliances finishing dying, printing and chemical seperation.	Hydrocarbons and other organic vapours
	Solvent cleaning	Dry cleaning, degreasing etc.	Petroleum vapours, dust etc.
Nuclear energy operations	Fuel fabricating	Gaseous diffusion	Fluorides
	Spent fuel processing	Chemical separations	Argon-41, Iodine-131
	Nuclear device testing	Bomb explosions	Radio active fall out, Sr-90, Cs-137, C-14

THERMAL POWER PLANT AS A SOURCE OF ENVIRONMENTAL POLLUTION

The main causes of the environmental deterioration include the increase in number of industries and power stations. The natural rocky hills are disappearing due to heavy quarrying. Tall chimneys and gigantic machines emit a cloud of dust with flyash and smoke containing high level of acid forming oxides of sulphur and toxic fluorides and huge quantity of highly toxic cement particles which find easy foothold on plant leaves and human lungs. In fact the clean air, clean water, abundent fuel wood, fruit and timber trees, grazing lands have been deteriorated and the process of desertification has set in.

The organic fuel burnt at Thermal Power Stations contains harmful impurities which are injected into the environment as gaseous and solid components of combustion products and thus adversely affect the atmosphere, water and the whole biosphere. The Thermal Power Stations use thousands of tonnes of low quality (high ash content) coal per day. In India, by the turn of the century, about 70,000 MW of thermal power will be generated using coal with high ash content.

In thermal power plants, the products of complete burning of fuel mainly consist of carbon dioxide, water molecules, nitrogen, sulphur dioxide and SO_3 anhydride (sulphur trioxide) and ash. At high temperatures existing in the flame core of high power boilers, the nitrogen of fuel and air may partially be oxidized to form nitrogen oxides that dissociate in the presence of sunlight to nitric oxide and atomic oxygen. The latter combines with moleculer oxygen to reform ozone (O_3). The concentration of ozone in polluted atmosphere often goes up 10 to 20 times the natural ozone level (0.02-0.03 ppm).

With incomplete combustion of fuel in furnaces, carbon-monoxide, hydro-carbons (CH_4, C_2H_4) etc. and some carcinogenic substances are additionally formed. Among many carcinogenic substances of highest importance, as regards their intensity of action, are polycyclic aromatic hydrocarbons, in particular, benzapyrene. The highest quantity of benzapyrene is formed under the conditions when air is deficient and complete combustion can not occur.

Pollutants in the effluents of thermal power and natural admixtures undergo complex processes of transformations and reactions. Deposited on the ground, they are washed down by the atmospheric precipitates and reach the soil and water basins. Hot fuel gases get removed in a powerful upward flow through high stacks and ejected into the atmosphere at a substantial height where they will be mixed with higher layers of the atmosphere.

Thermal power stations and other industries are also great sources of waste water which affects the biocenosis (the community of living organisms) of complex natural ecological system of water basins. Waste waters of water treatment plants contain various neutral salts, acids and alkalies which change the pH index. The waste water also carries unburned fuel, slime, coarse - disperse particles, organic substances, iron and aluminium compounds, $Mg(OH)_2$ and $CaCO_3$ which raise the BOD (biochemical oxygen demand) and affect the pH index of the basin. This has serious consequences for the biocenosis due to accumulation and rotting of organic substances (anaerobic respiration) and for the quality of water.

In India, about 80 million tonnes of coal is burnt annually. According to the recent studies, deforestation adds 1-2.6 billion tonnes of carbon annually or between 20-50% as much as the burning of fossil fuels. The world watch institute reported that fossil fuel combustion has contributed 150-190 billion tonnes from forest clearing. According to Kumar and Prakash (1977) after the consumption of 80 million tonnes of coal, 1.35 million tonnes of SO_2 is let into the environment.

Astanin and Blagosklonov (1983) reported that the main sources of air pollution are the electric power plants which burn 2000 tonnes of low grade coal a day and emit about 400 tonnes ashes and 120 tonnes of sulphurous gas every day. Data show (Amani, 1982 a) that a 8.75 MW power plant burning 1 % sulphur fuel oil would emit about 55,000,000 pounds of sulphur dioxide, 19,000,000 pounds of NO_2 and 900,000 pounds of particulate per year. It has been estimated that a power plant burning 5000 tonnes of coal per day may discharge nearly 500 tonnes of SO_2 (Jhonstone, 1952).

One such plant is situated at Kasimpur about 16 kms. north-east of Aligarh City. The plant has been in existence now for about 40 years and generates electricity from combustion of sulphur rich bituminous coal containing 2.93% moisture, 2.17% ash, 31.86% volatile substances (S = 0.48%; H = 5.61%; N = 5.23%; O = 20.3%) and 42.47% fixed carbon. The plant includes three units for power generation with a total capacity of 700 MW. The present generation of power is however, 350-400 MW. The annual consumption of coal in the plant is about 1165069 tonnes. The plant emits a number of noxious gases such as carbon dioxide, carbon monoxide, oxides of nitrogen, sulphur dioxide, hydrocarbons (CH_4, C_2H_4) etc and many other additional carcinogenic substances. Certain other substances like flyash, particulate matter and traces of heavy metals are also emitted from the plant. It has been reported that the annual concentration of SO_2 released from the plant comes to range from 0.10-0.016 ppm/hr; about 1.804-2.664 ppm/hr of CO_2; and about 0.177-0.294 ppm/hr of NO_2 (Amani, 1982 b). However, recent reports of coal consumption in the power plant and gases released are shown in the table III & IV. These emissions are likely to contaminate the local environment, polluting soil, water and air and have adverse effects on the surrounding vegetation.

Table III. Coal Consumption figure in the Thermal Power Plant Complex of Kasimpur in Metric Tonnes (An Average of the three years data, 1986-1988)

		Power Stations			Total Monthly Consumption
		A	B	C	
Summer	April	14338	52810	72844	139992
	May	12665	53252	67929	133846
	June	08627	38382	58957	105966
Monsoon	July	07920	26623	56011	090554
	August	07322	38403	63050	108775
	September	08899	42852	66602	118353
	October	08240	44974	67110	120324
Winter	November	08530	42650	72059	123239
	December	09240	53153	83674	146067
	January	10992	48070	93579	152641
	February	12830	38128	78697	129655
	March	18941	56674	85688	161303
	Annual Consumption	128544	535971	866200	1530715
	Average Monthly Consumption	010712	44664	72183	127560
	Average daily Consumption	357	1489	2406	4252

Table IV. Amount of gases released from the chimneys of the Thermal Power Plant Complex in different months (Average of three years 1986-1988)

Months	Amount of SO_2 kg/hour	Amount of SO_2 ppm/hour	Amount of NO_x kg/hour	Amount of NO_x ppm/hour	Amount of CO_2 kg/hour	Amount of CO_2 ppm/hour
April	18675	0.019	334590	0.335	1819826	1.820
May	17278	0.017	309442	0.309	2801652	2.802
June	14129	0.014	253152	0.253	2292021	2.300
July	11684	0.012	209354	0.209	1895479	1.900
August	14503	0.015	259862	0.260	2352779	2.353
September	15271	0.015	273623	0.274	2477369	2.447
October	15533	0.016	278180	0.278	2519855	2.520
November	16437	0.016	294416	0.294	7784993	7.785
December	18848	0.019	337696	0.338	11294414	11.294
January	19695	0.020	352894	0.353	14647129	14.647
February	18523	0.019	331869	0.332	14550399	14.550
March	20814	0.021	372920	0.373	17809853	17.810
Average kg/hour	16782.5	0.0169	300666.5	0.300	6853814.1	6.854

KASIMPUR THERMAL POWER PLANT

POWER STATIONS A.B. & C.

Fig① - A, Fig 2, B.C.

AIR POLLUTION VERSUS PLANTS

Unlike the industrialized nations, in India air pollution problems are still localized in certain pockets, but exert a potential threat to plant and animal lives. India has vast reserves of coal and therefore, thermal power stations spread all over the country are a major source of atmospheric pollution. According to 1980 estimates, 13 million tonnes of flyash, 4,80,000 tonnes of SO_2, 280,000 tonnes of NO_x, 16,000 tonnes of CO and 5000 tonnes of hydrocarbons are released in the atmosphere each year by our thermal power stations (Sharma, 1986).

Injury to vegetation caused by air pollution from cities and factories has been well recognised because of many botanical and chemical investigations during the past hundred years. The injuries are caused by a small number of contaminants present in the air in relatively low concentrations of which the principle ones are (i) SO_2 (ii) hydrogen halides and halogens, particularly hydrogen fluoride though hydrogen chloride and chlorine may be occasional toxic agents (iii) Smog gases containing certain organic compounds, particularly the olefines together with oxidising agents such as Ozone and nitrogen oxides to make them highly reactive.

The damaging effects of air pollution on vegetation have long been recognised. Some earlier reports (Haselhaff & Lindau, 1903; Hedgecock, 1912; NRC, 1939; Middleton *et al.*, 1950; Adams *et al.*, 1952; Thomas & Hendricks, 1956; Das & Gupta, 1957; Middleton, 1961; Stern. 1968; Brandt & Heck, 1968; Heck, 1968 a, b; Woodwell, 1970; Mudd & Kozlowski, 1975; Treshow, 1984) have revealed the devastating effects of SO_2, fluoride, hydrogen chloride and other pollutants on plant population. Temmerman (1982) described the effect of ammonia on vegetation following an accidental release of gas. Several other harmfull effects of ammonia on plant growth have also been reported (See Raza & Bano, 1981; Woo & Canvin, 1980; Woodstock *et al.*, 1986; Raza & Rao, 1988).

Air pollution affects leaf tissue and various physiological, morphological and anatomical features of the plants. Astanin and Blagosklonov (1983) concluded that various afflictions of plant leaves appear under the influence of air pollutants and the plant growth is stunted. Leaves are probably the most sensitive plant pasts to air pollution. They first develop certain protective adaptations and ultimately fall prey to the harsh atmosphere. Stomata and trichomes usually undergo changes pertaining to the size, frequency and density. Under atmospheric pollution stress, stomatal frequency was found to decrease in *Pueraria lobata* (Sharma *et al.*, 1980); *Commelina benghalensis* (Mishra, 1982); *Annona squamosa* .

Bougainvillea spectabilis, *Mangifera indica* and *Mimusops hexandra* (Patel & Devi, 1958); *Lycopersicon lycopersicum* var. *angulata* (Chaudhari *et al.*, 1984); *Catharanthus roseus* and *Lantana camera* (Salgare & Chakraborty, 1988); *Tridex procumbens* (Gupta & Ghouse, 1988); *Amaranthus spinosa*, *Altermanthera sessilis*, *Aegerantum conyzoides*, *Blumea eriantha*, *Cassia tora*, *Euphorbia hirta*, *Eclipta erecta*, *Heliotropium indicum* and *Malachra capitata* (Salgare & Acharekar, 1988). In contrast, an increase in the stomatal frequencies due to air pollution was reported in *Calotropis procera* (Yunus & Ahmad, 1981); *Artocarpus integrifolia*, *Ficus benghalensis*, *Mangifera indica*, *Psidium guajava* (Debnath & Nayar, 1983).

That the air pollution caused a decrease in the stomatal density was reported in *Tridex procumbens* (Gupta & Ghouse, 1988); *Solanum melangena* var. Pusa (Gupta & Ghouse, 1986); *Abelmoschus esculentus*, *Euphorbia hirta*, *Ficus benghalensis* (Gupta & Ghouse, 1987) and *Croton bonplandianum* (Zaidi *et al.*, 1979). However an increase in the stomatal density was noted in *Peristrophe bicalyculata* (Inamdar & Chaudhari, 1984).

Since most air pollutants find their entry in leaves through stomata, the stomatal apertures undergo size variation. Air pollution brings about a decrease in the stomatal pore size in *Brassica oleracea*, *Chenopodium album*, *Cicer arietenium*, *Dolichos lablab*, *Lantana camara*, *Sonchus* *asper* and *Withania seminifera* (Garg & Varshney, 1981) and (See Gupta & Ghouse, 1987, 1988). Whereas an increase in the pore size and gaurd cells in *Mangifera indica*, *Artocarpus integrifolia*, *Ficus benghelensis*, *Psidium guajava* (Debnath & Nayar, 1983). Yunus and Ahmad (1981) demonstrated in *Calotropis procera* that the *stomatal* size remained unaffected to air pollution. Similarly, there was no remarkable change in the frequency or size of stomata in case of *Syzygium jambos*, *Ficus religiosa*, *Mimusops elangi*, *Alistonia scholaris* and *Polyalthia longifolia* (Debnath & Nayar, 1983). Other epidermal components such as trichomes also show variations under air pollution stress. An increase in the length and density of trichome was reported in *Croton bonplandianum* (Zaidi *et al*., 1979 and Amani *et al*., 1979); *Brassica olearacea*, *Chenopodium album* (Garg & Varshney, 1981), *Commelina benghalensis* (Mishra, 1982). *Peristrophe bicalyculata*(Inamdar & Chaudhari, 1984), *Pueraria lobata* (Sharma *et al*., 1980), *Bougainvillea spectabilis*, *Lantana camara* var. aculeata (Patel & Devi, 1985).

The degree of injury or damage caused by a pollutant or its combination differs for different or even for the same plant species. The quality to perceive or to withstand the effects of pollutant or its combination by the plants depends on several factors such as nature, concentration and the time factors of the pollutants, and the genetic, environmental and growth factors of the plant. Air pollution released from various sources affects the vegetation chiefly in two ways (a) By causing visible symptoms in case of a high incidence of air pollution (b) by disturbing the over all physiology of plants and thereby affecting the growth, productivity and quality of vegetation without producing any visible symptoms thus causing what is known as "hidden" or "invisible" injury.

VISIBLE INJURY :

Most studies on the effect of air pollutants on plants have been related to the appearance of visible symptoms. Visible foliar symptoms may be read as chlorotic and necrotic patches. The pattern of injury like spotted markings between the veins of dicot leaf and necrotic streaks between the parallel veins in monocot leaf may be commonly produced by a variety of pollutants and may also be a result of certain plant diseases. Brandt and Heck (1968) described in detail the leaf markings caused by air borne pollutants and similar markings due to infection and physical injuries. The visible symptoms are characteristic in nature but in no way specific because they are indistinguishable from other conditions (Beg, 1980). Visible injury refers to the immediate adverse and apparant effects of air pollutants on foliar or other parts of the plant.

Spectacular examples of such effects on vegetation were recorded around the smelters in North America and Europe where entire ecosystems were destroyed over thousands of hectares (Unsworth, 1981). Brandt and Heck (1968) categorised the visible injuries into three types (a) leaf tissue collapse with necrotic patterns (b) chlorosis or other colour changes and (c) growth alterations.

(a) Leaf tissue Collapse with necrotic patterns :-

Necrosis means death or mortification. It may be death of isolated cells, tissues, or organs, or death of entire plant. Necrosis occurs whenever cells are killed by any component of the biotic or physical environment. The exact colour or expression of necrosis ranges from pale yellow or white to dark brown. The leaf cells get plasmolysed and finally the tissue is collapsed (Thomson et al., 1965). The initial plasmolysis resulting first into changes in water relations and finally into changes in structural integrity, may occur in spongy cells, as in the case of peroxy acetyl nitrate (PAN) injury (Glater et al., 1962), in palisade cells as under the effect of ozone (Bobrov, 1952) or throughout the mesophyll as with fluorides and sulphur dioxide (Thomas, 1951). In most cases the first visible symptom on leaf occurs in the form of slightly water soaked or bruised looking areas

(Bobrov, 1952) which generally dry out, leaving necrotic pattern characteristic of the toxicant.

(b) Chlorosis or other colour changes :-

Chlorosis, the loss or reduction of chlorophyll is a common and non specific symptom. The loss of chlorophyll usually leads to a pale green or yellow colouration. Sometimes new pigments, already present in the leaf or developed due to the upset of chlorophyll content, partially mask or completely overcome the green colour. The specific expression and distribution of chlorosis can vary considerably. The mildest form of chlorosis involves simply a slight loss of the green colour in local areas of the leaf, a faint mottling, or a rather uniform pale green discolouration. General yellowing develops as chlorosis becomes more severe, and with extreme chlorosis the entire leaf becomes pale yellow and even bleached. Gupta and Ghouse (1987) reported, in *Ficus benghalensis*, foliar injury in the form of interveinal necrosis and chlorosis and decrease in the dry weight and pigment content of the leaves, when plants were subjected to air pollution stress. Tip and marginal burnings and less specific leaf weights were found in *Butea monosperma* (Singh, 1982). Keul *et al*., (1984) demonstrated in *Carpinus belulus*, *Fagus sylvatica*, *Quercus* spp.and *Robinia pseudoaccacia* that air pollution caused leaf necrosis, increase of dry mass, an inhibition of the growth of annual shoots and premature ageing of trees. Foliar injury with chlorotic mottle and tip necrosis was also found in *Oryza sativa* plants (Sun & Su, 1985) and *Pinus strobus* and *Pinus blanksiana* (Armentano & Menges, 1987). Air pollution also caused a decrease in the level of foliar tennin in case of *Cryptomeria japanica* (Terutake *et al.*, 1989).

(c) Growth alterations :-

Some distinctive growth anomalies such as twisting and/or elongation of leaves and stems, epinasty or drooping of leaves as well as abscission are attributed to air pollutants. There may be lack of normal vigrous growth which may cause early leaf fall, reductions in the size of fruits and leaves, and a poor growth of plant (Amani, 1982 b; Ghouse & Khan, 1983, 1984; Khan & Khair 1984 a, b). Some of the adverse effects such as changes in water relations, increased respiration and subnormal growth with early leaf fall have been experimentally alleviated (Koritz & Went, 1953; Menser *et al.*, 1986; Taylor & Eaton, 1966; Rao, 1972; Lal & Ambasht, 1980). A decreased respiration rate and enzyme catalase activity of leaves have been reported by Bokra (1980).

INVISIBLE INJURY :

Several studies have indicated that growth and yield of plants may be affected by air pollutants with out the expression of any visual symptoms possibly due to several pre-visual disturbances in the metabolism (Malhotra & Sarkar, 1979; Ayazloo *et al*., 1980). The controversies regarding visible and invisible injury symptoms have been dealt with critically by Mudd and Kozlowski (1975). The use of the term "physiological injury" in place of invisible injury (Thomas & Handricks, 1956) is also in vogue.

Thomas (1951) categorized the SO_2 injury into (i) Chronic injury (ii) acute injury which can be applied to other pollutants as well. This categorization is based on the degree of injury (visible or invisible) sustained by leaves or plants in response to the nature, time of exposure, and concentration of the pollutants or its combinations.

Chronic injury :-

This applies where only a limited number of cells are killed so that no microscopic collapse occurs. Decolourization of leaf tissue may progress slowly until most of the chlorophyll and carotenoids are destroyed rendering the interveinal areas pale or white. The leaves are generally abscised. This injury may be caused by the absorption of a sublethal amount of gas with multiple exposure for a longer duration (Thomas & Hendricks, 1958; Black & Unsworth, 1979 b). In other words, it is caused by a "Chronic exposure" i.e. low concentration and longer period exposure of gas (Heck, 1982). This is a slow process generally accompanied by partially destroyed chlorophyll and protoplast; the cells remain partially functional unless the injury turns more chronic with time and destroys the leaf completely. Thomas (1951) fixed nearly 0.10-0.30 ppm concentration of SO_2 as a chronic dose.

Acute injury :-

It occurs at higher concentrations of pollutants and causes injury to the test plant in a relatively short time. The injury extends to the adjacent cells at a fast rate killing them in a limited or extensive area. At this concentration of gas the time of exposure which leads to acute injury is known as "acute exposure" (Heck, 1982). The cells here lose their water, the cell sap diffuses through intercellular spaces giving the area first a water soaked, dull grey green appearance. The flaccid area dries out leaving bleached, light tan to ivory, necrotic zones extending through the leaf. Brandt and Heck (1968) suggested the concentration above 0.25 ppm - 0.30 ppm as acute dose.

Based on experimental facts, a third type of injury can be identified as transient injury. In this case the exposure to air pollutant is relatively light the chloroplasts remain intact, the injured cells may recover and the evidence of injury may disappear.

Air pollution affects many plant parts, causing a significant damage to the overall growth and productivity of plants. A considerable reduction in leaf area of plants due to air pollution was noted in *Cicer arietinium*, *Dolichos lablab*, *Lens culnaris*, *Phaseolus aureus*, *Vigna sinensis* (Varshney & Garg, 1980); *Desmodium trifolium* and *Polygonum glabrum* (Khan & Khair, 1984; 85); *Euphorbia hirta* (Gupta & Ghouse, 1987). Also, the air pollution caused a significant reduction in the development of leaves in *Melilotus indica* (Ghouse & Khan, 1983); *Anagallis arvensis* and *Melilotus indica* (Ghouse & Saquib, 1986). Defoliation, early leaf fall and abscission were noted in *Pinus nigra* (Gabor, 1987); *Dactylis glomerata* and *Lolium perenne* (Ashenden, 1987); *Glycine max* CV. Davis (Norbey *et al.*, 1985) and *Euphorbia hirta* (Gupta & Ghouse, 1987). Similarly there was a considerable reduction in root and shoot lengths under heavy atmospheric pollution in *Polygonum glabrum* (Khan & Khair, 1984); *Phaseolus aureus* (Prasad & Rao, 1981); *Commelina benghalensis* (Mishra, 1982);

Euphorbia hirta and *Abelmoschus esculentus* (Gupta & Ghouse, 1987); *Melilotus indica* (Ghouse & Khan, 1983). That the air pollution caused a reduction in number and size of nodules, flowers, fruits and pods was noted in *Phaseolus aureus* (Prasad & Rao, 1981); *Pueraria lobata* wild (Sharma *et al*., 1980); *Commelina benghalensis* (Mishra, 1982). Significant reductions in total biomass of plants were also demonstrated (See Varshney & Garg, 1980; Ghouse & Khan, 1983; Khan & Khair, 1984, 1985; Ghouse & Saquib, 1986). Salgare and Chakraborty (1988) reported that under the industrial pollution, plants like *Acalypha hispida*; *Ceratophyllum hortaenge*; *Malva viscus*; *Nerium indica*; *Pathos scandens*; *Quisquatis indica* and *Tabernae* monotana showed a reduction in the following growth parameters: Length of shoot (from apex of 3rd internode), area of internode, number of flowers, dry matter of shoot, number of leaves, length of petiole (of 3rd leaf), Length of lamina (of 3rd leaf), breath of lamina, l/b ratio, calculated area, graph area, moisture content, dry matter (of 3rd leaf) and dust fall.

In contrast, an increase in the size and weight of plant, shoots, roots, fruits and leaves was noted in *Cassia occidentalis* by Amani *et al*. (1979). Panda (1989) also demonstrated an increase in the dry matter accumulation in the polluted plants.

Air pollution interferes with various physiological functions of plants such as photosynthesis, respiration, transpiration and enzyme activity etc. Daly *et al.* (1988) noted a rapid inhibition of photosynthesis in *Phaseolus vulgaris* plants growing around an Oil Spill Chemical Industry. Pollution also caused a severe drop in CO_2 assimilation in case of Six year old Norway spruce (Kammerbever *et al.*, 1987). Since various photosynthetic pigments like carotenoides, chlorophyll etc. are directly involved in the food production process, therefore the concentration of these pigments plays a vital role in the growth and survival of the plants. Pollution also alters the various pigment concentrations in plants. For example, air pollution caused a decrease in the contents of photosynthetic pigments (Chlorophyll/Xanthophyll + Carotenoid) in case of *Posidonia oceanica* (Augier & Maudinas, 1979). Similarly, air pollution caused a decrease in the chlorophyll content in *Triticum aestivum* (Singh & Rao, 1980); *Cicer arietenium*, *Dolichos lablab*, *Lens culnaris*, *Phaseolus aureus* and *Vigna sinensis* (Varshney & Garg, 1980); alfalfa barley and young spruce plants (Rabe & Kreeb, 1980); Wheat (Singh & Rao, 1981); *Phaseolus aureus* (Prasad & Rao, 1981); *Butea monosperma* (Singh, 1982); a few dicotyledons (Benerjee *et al.*, 1983), *Glycine max* (Norby *et al.*, 1985); barley (Bokra, 1986); *Cistus salvifolius*, *C. tauricus*, *Nerium oleander* and *Olea europea* (Asadov & Mekhtier, 1986); maize and soybean (Mishra & Shukla, 1986); *Euphorbia hirta*, *Ficus benghalensis* (Gupta & Ghouse, 1987); *Cassia siamea*, *Melia azadirachta* (Kumarvat & Dubey, 1988); *Butea monosperma*, *Ficus benghalensis*, *Mangifera indica* (Reddy & Dubey, 1988); *Aegerantum conyzoides*, *Altermanthra sessilis*, *Amaranthus spinosus*, *Blumea eriantha*, *Cassia tora*, *Eclipta erecta*, *Euphorbia hirta*, *Heliotropium indicum* and *Malchea capitata* (Salgare & Acharekar, 1988) and in *Croton bonplandianum* (Panda, 1989). However, the amounts of chlorophyll contents were unaltered in *Ficus benghalensis* (Ahmad, 1987). Air pollution also caused an increase in the chlorophyll contents in case of maize (Bokra, 1981) and *Azadirachta indica*, *Pitheclobium dulce* (Trees); *Bougainvilla spectabilis*, *Ipomoea aquatica* (Shrubs); *Parthenium hysterophorus*, *Tridex procumbens* (Herb) Raza & Ahmad, 1988). An increase in ascorbic acid content, relative water content and leaf extract pH was also noted in the above cases.

That the air pollution caused a decrease in transpiration was demonstrated by Singh and Rao, (1981) in wheat plants. Kumarvat and Dubey, (1988) reported in case of *Cassia samiea* and *Melia azadirachta* a reduced transpiration rate and stomatal conductance but a steady increase in leaf temperature and leaf extract pH. An initial increase but ultimate decrease in transpiration was also noted by prasad and Rao

(1981) in *Phaseolus aureus*. They also noted reductions in ascorbic acid, Carbohydrate contents and in accumulation of N, P, S, K and Ca. Lower contents of mineral elements like Ca, Mg, Mn and Zn were also reported in Norway Spruce (Nebe *et al*., 1988). Air pollution does not only have a negative impact on transpiration but it sometimes also proves advantageous for plants. Reddy and Dubey (1988) reported an increase in the transpiration rate and stomatal conductance in *Butea monosperma*, *Ficus benghalensis* and *Mangifera indica*.

Air pollution also altered the protein, carbohydrate and fat contents in plants. A change in pollen wall proteins was reported in *Festuca elatior*, *Pinus taeda*, *Quercus rubra* and *Ulmus puinila* growing in polluted atmosphere (Ruffin *et al*., 1983). Decreased protein contents were found in *Phaseolus aureus* (Prasad & Rao, 1981) and in few dicotyledons (Benerjee *et al*., 1983). An initial increase but a final decrease in the protein content and nitrate reductase activity was demonstrated in *Cassia samiea* and *Melia azadirachta* (Kumarvat & Dubey, 1988). Braun *et al*. (1980) found in *Betula pendula* and *Cernus sanguina* a decreased content of proteins and RNA. Maize plants affected by dust pollution also showed a decrease in protein contents, moisture, total ash, fat and crude fibre but an increased total carbohydrate content (Pandey & Simbu, 1988). Higher levels of sugars but lower levels of starch, leaf protein, DNA and ascrobic acid were reported in *Bauhinia tomentosa*,*Eucalyptus longifolia* and *Peltophorum fèrugineum* (Krishnamurthy *et al.*, 1986). Higher levels of sugars, total phenols and activity of oxidative enzyme were reported in *Datura innoxima* (Satyanarayana, 1988). However, a decreased total sugar content due to air pollution was noted in *Carpinus betulus*, *Fagus sylvatica*, *Quercus* spp. and *Robinia pseudoaccia*. Besides, air pollution caused an increase in the free proline contents in *Datura innoxima* (Satayanarayana, 1988) and *Butea monosperma*, *Ficus benghalensis* and *Mangifera indica* (Reddy & Dubey, 1988).

Bokra (1981) found in maize growing in a polluted atmosphere a decreased catalase activity and intensity of respiration. However it increased in Barley (Bokra, 1986). Similarly Panda (1989) found an increased catalase activity and sulphate content in the polluted leaves of *Croton bonplandianum*.

The chloroplasts are specialized pigmented organelles in plant cells, which at the expense of environment provide carbohydrate to plants. Solar energy is trapped to generate chemical energy and reducing equivalents needed for the reduction of CO_2 to carbohydrate. Exposure of plants to SO_2 prior to the development of visible injury symptoms induces swelling of thylakoids in chloroplast as the primary ultrastructural change (Wellburn et al., 1972). Different shapes of chloroplasts and starch grains were observed in the polluted leaves of Streblus asper (Patel & Devi, 1984). The same authors in 1986 noted in the leaf mesophyll cells of Syzygium cumini and Tamarindus indica that chloroplasts showed in the polluted atmosphere (i) varied size & shape (ii) wide loculi of granular thylakoids (iii) long and narrow protubrences of plastids (iv) loss of outer envelop of chloroplasts (v) vacuolation in stroma, and (vi) emergence of lipid bodies out of the chloroplast of stroma as free bodies in cytoplasm.

Air pollution has a devastating effect on the pollen viability, pollen germination, germination rate, fertilization and other aspects of reproductive parts, besides on yield.

The cytogenetic effect of fumigation of Vicia faba plants, with different concentrations of SO_2 (5-10 ppm) for 5 hours and 5 ppm SO_2 for one, two and four successive days in the pollen mother cells (PMCs), tetrads and pollen grains (PGc) has been investigated by Amer et al., (1989). SO_2 was effective in inducing abnormalities in the different meiotic stages but the highest percentage of abnormalities was observed in the anaphase stages. The common type of irregularities observed in the PMCs were : Stickiness, lagging and disturbance of the chromosomes, sticky bridges, fragments, bridges with fragments and multipolar ana and telophases. PMCs with more than one types of anomaly were frequently observed. More than four spores were the dominant type of abnormalities observed in the quartet stage. A statistically significant percentage of nonviable pollen grain was observed in addition to the small and deformed pollen. Salgare and Sebstian (1988) demonstrated in case of *Hamelia patens* an inhibition in the pollen viability, pollen productivity, pollen size and frequency. An inhibition in the pollen germination and tube growth was reported in *Allamanda cathartica*, *Cassia siamea*, *Catharanthus roseus* (Salgare & Sebstian, 1988); and *Gliricidia sepium* (Salgare & Rane, 1988). Palowski (1986) reported in *Pinus sylvestris* a decreased germination power but higher accumulation of metals like Pb, Zn, Cd, Cu, Fe, Ca etc. A decrease in the percentage of pollen germination and seed viability occurred in *Cassia tora* and *Cassia occidentalis* (Krishnayya & Bedi, 1986). Fertilisation and ear production was adversely affected due to air pollution in maize (Bokra, 1981). Deterioration in fertilization was also noted in winter barley (Bokra, 1986) and maize (Anda, 1986). An inhibition in the organic content of seeds due to air pollution was reported in *Acacia auriculiformis*, *Cassia siamea*, *Ceiba pentendra*, *Delonix regia*, *Erythrina indica*, *Glyceridia sepium*, *Leuaenea* leucocephala, Polyalthia longifolia, Spathodea companulata and Thesperia populnea (Salgare & Anis, 1988).

That the air pollution caused reductions in yield was noted in Dactylis glomerata and Lolium perenne (Ashenden, 1987); wheat (Singh & Rao, 1981); Corn, Soybean and Wheat (Miller, 1983); leaf lettuce, green onion, turnip and beet (McCool et al., 1987); Abelmoschus esculentus (Gupta & Ghouse, 1986).

Anatomical features of plants also show responses to air pollution. For eg; a decrease in the length of vessels was noted in Polygonum glabrum (Khan et al., 1984); Chenopodium album (Ghouse et al., 1985); Datura inoxia (Iqbal et al., 1986); Sida spinosa (Mahmooduzaffar et al., 1986); Cassia occidentalis (Iqbal et al., 1987); Achyranthus aspera (Mahmooduzaffar et al., 1987) and Cajanus cajan (Ghouse et al., 1989). In contrast an increase in the length of vessels was shown in Lantana Camara (Iqbal et al., 1987).

Width of vessels also show remarkable correlation with air pollution. Decreased width of vessels was pointed out in Polygonum glabrum (Khan et al., 1984); Chenopodium album (Ghouse et al., 1985); Datura inoxia (Iqbal et al., 1986); Lantana camara and Cassia occidentalis (Iqbal et al., 1987). However an increase in the width of vessel elements was reported in *Sida spinosa* and *Achyranthus aspera* (Mahmooduzuffar *et al.*, 1987); *Cassia tora* (Iqbal, 1987) and *Cajanus cajan* (Ghouse *et al.*, 1989).

A greater vessel frequency was found in *Cajanus cajan* (Ghouse *et al.*, 1989), *Achyranthus aspera* (Mahmooduzaffar *et al.*, 1987); *Calotropis gigentea* and *Datura inoxia* (Iqbal *et al.* 1986).

That the air pollution caused a decrease in the length of fibres was reported in *Sida spinosa* (Mahmooduzaffar *et al.*, 1987); *Cassia occidentalis* (Iqbal, 1987), *Datura inoxia* (Iqbal *et al.*, 1986); and *Chenopodium album* (Ghouse *et al.*, 1985). However an increase in the fibre length was reported in *Cajanus cajan* (Ghouse *et al.*, 1989); *Lantana camara* (Iqbal *et al.*, 1987); *Achyranthus aspera* (Mahmooduzaffar *et al.*, 1987) and *Calotropis gigentea* (Iqbal *et al.*, 1986).

Stem circumference and proportion of cortex and xylem was increased in many plants (See Mahmooduzaffar *et al.*, 1987; Iqbal *et al.*, 1987), whereas a decreased value for these parameters was reported in others (See Ghouse *et al.*, 1989; Iqbal *et al.*, 1987; Ghouse *et al.*, 1985; Khan *et al.*, 1984).

Loss of wood due to air pollution was demonstrated in *Tectona grandis* (about 26%/year),(Ghouse *et al.*, 1984); *Chenopodium album* (Saquib *et al.*, 1986); *Dalbergia sissoo*

(Ghouse *et al*., 1984).

Kalimullah *et al*. (1987) reported in *Mangifera indica*, that air pollution caused an increase in the area, length and width of ray across the radial system of bark, but ray frequency decreased significantly. Further, the air pollution caused a significant reduction in the conducting region of phloem while there was a gain in the non conducting phloem and periderm regions (Ahmad & Kalimullah, 1986). Salgare and Acharekar (1988) showed that *Aegerantum conyzoides*, *Altermenthera sessilis*, *Amaranthus spinosus*, *Blumea eriantha*, *Cassia tora*, *Ectipta erecta*, *Euphorbia hirta*, *Heliotropium indicum* and *Malachea capitata* affected by pollution show inhibition in the following parameters : number of parenchyma cells in cortex and pith in L.S. of 4th internode, number of parenchyma cells in cortex and pith in T.S. of 4th internode and thickness of cortex, pith and stele (Um) in T.S. of 4th internode.

HAZARDS OF MAJOR AIR POLLUTANTS

Pollutants in the atmosphere are generated by anthropogenic (man made) and biogenic (natural) processes. Their individual contributions vary in time and space, with anthropogenic processes predominating in the industrialized areas. Air pollutants exist in gas (eg; SO_2, NO_x, CO_2, O_3); vapour(eg; nitric acid, sulphuric acid), and particle (eg; sulphate - SO_4) phases. These pollutants are deposited to the ground by dry and wet fall processes. The industrial contribution and importance of these mechanisms vary in time and space.

The following review elucidates the sources and properties of different air pollutants, the mechanism and mode of their action and their effects on plant morphology, growth, biomass and productivity.

OXIDES OF SULPHUR :

Sulphur dioxide constitutes the largest fraction of sulphur compounds emitted into the atmosphere during coal combustion. Once emitted into air, depending upon the source length, meteorological conditions, topography, etc. SO_2 is transported from the source to different distances. During transport, predominately during the day light hours, the SO_2 in the plume is transformed to fine particulate sulphuric acid (H_2SO_4). These particles have a mean size of less than 0.5 μm. In coal-fined power plant plumes, the conversion of SO_2 to H_2SO_4 is known to proceed at a rate of roughly 0-5% per hour. Depending upon the plume and the ambient air composition, pollutant residence time in the air, geographic path of pollutant transport, etc; the H_2SO_4 molecule can react with other atmospheric constituents and beneutralized to varying degrees. The neutralized sulphate particles are known to have their mean size greater than o.50 Um.

Sulphur dioxide is formed during the combustion of all sulphur containing fuels, such as coal and oil and from the heating of sulphide ores during smelting. It is also released into the atmosphere during the production and use of sulphur, sulphuric acid, petroleum and natural gas. The combustion of sulphur containing compounds releases vast amounts of sulphur dioxide and some sulphur trioxide into the atmosphere. Industries also emit some hydrogen sulphides in their processing operations. The burning of coal and other fuels in stationary installations produces the largest quantity of SO_2, some 26.5 million tonnes in 1970 in the United States (Dochinger & Calvert, 1978). Natural processes also release sulphur in the form of hydrogen sulphide and sulphur dioxide from biological decomposition and sulfates from the oceans and volcanic eruptions.

Among the various pollutants emitting as a result of combustion processes etc; SO_2 alone is responsible for some 60% of the air pollution (Rohrman & Ludwig, 1965). It has been estimated that a power plant burning 5,000 tonnes of coal per day may discharge nearly 500 tonnes of SO_2 (Johnstone, 1952). Katz (1961) estimated SO_2 emission, on world wide basis, to be about 11-12 million tonnes per day from copper smelters and 3-5 million tonnes per day from the lead and Zinc smelters.

The concentration of SO_2 ranges from short term speaks of a few ppb near point sources to average concentration of 70 ppb in industrial areas, and a back ground of 10 ppb in many rural areas of Great Britain (Fowler & Cape, 1982) The mean annual concentrations may vary considerably in different cities generally ranging from 0.035 ppm to 0.070 ppm, the highest daily means being three to four folds higher (Jakes, 1983). The annual concentration of SO_2 released from the Kasimpur Thermal Power Station has been estimated to range from 0.010-0.016 ppm/hr (Amani, 1982 b).

EFFECTS OF SO_2 ON PLANTS :

Studies on the injurious effects of SO_2 on plants have been conducted for more than hundred years. Enough information has been accumulated on symptomology (Jacobsen & Hill, 1970; Van Haut & Stratman, 1970; Malhotra & Blanel, 1980; Yu & Wang, 1981) and effects on growth and various biochemical and physiological processes (Naegele, 1973; Ziegler, 1973 a, b, 1975; Dugger, 1974; Mudd & Kozlowski, 1975; Malhotra & Hocking, 1976; Mansfield, 1976; Hallgren, 1978; Koziol & Whatley, 1984; Malhotra & Khan, 1984). In early German publications, Schroeder and Reuss (1883) and Haselhoff and Lindau, (1903) reported acute and chronic damage to numerous conifers and deciduous trees. Detailed reviews of the literature on vegetation injury from the oxides of sulphur have been published by Thomas (1951, 1956); Katz and McCallum (1952); Thomas et al. (1952); Scheffer and Hedgcock (1955); Thomas and Hendricks (1956); Wentzel (1956); Scurfield (1960); Dassler (1963); Knabe (1966); Brandt and Heck (1968) and Danies (1968).

The numerous stomata present on the epidermal surface of green parts of the plants, particularly leaves, form the principal entrance for the pollutants. Their frequency may vary with species as well as due to pollution as reported in *Trifolium* spp. (Sharma & Butler, 1973; 1975); *Liquidamber styraciflua* (Sharma & Tyree, 1973); *Psidium guajava* (Ghouse & Khan, 1978); *Croton bonplandianum* (Zaidi *et al*., 1978); *Ricinus communis* (Yunus *et al*., 1979); *Callistemon citrinus* (Ghouse *et al*., 1980); *Calotropis procera* (Yunus & Ahmad, 1981) and *Ipomea fistulosa* (Yunus *et al*., 1982). The stomatal aperture is the main route by which the gas exchange between plants and environment takes place. It has long been known that plants sustain less injury at night. Later it was found that plants with higher resistance in the dark close their stomata at night. Potato plants still open their stomata during the night time, so they are vulnerable to air pollutants at both day and night, indicating that the stomatal closure is the major cause of higher resistance at night. Mansfield and Freer - Smith (1981) have shown that there is linear relationship between stomatal conductance and net sulphur flux into leaves. Winner and Mooney (1980) have also demonstrated that the difference in leaf resistance to pollutant uptake has been associated with difference in SO_2 resistance.

The principal avenue of SO_2 gas in leaves is stomata (Majernik & Mansfield, 1970; Biscoe *et al*., 1973; Black & Black, 1979; Black & Unsworth, 1979 a, b; Black, 1982) because in the presence of SO_2 the stomata stop their closing mechanism and allow the gas to enter the leaves. However, it has been seen that the stomatal response to SO_2 varies with plant. In broad bean, it induces stomatal opening wider than the normal size (Majernik & Mansfield, 1970, 1971), whereas it causes closure in other plants such as peanut and tomato (Kondo & Sugahara, 1978). when plants are exposed to the same SO_2 concentration, different species may respond differently (Biggs & Davis, 1980). Differential destruction of guard cells and their neighbours, subsidiary and epidermal cells, may be likely due to the differential effects of SO_2. Gaurd cells are less susceptible to SO_2 than the subsidiary or epidermal cells. As SO_2 enters the substomatal cavity, the latter loses turgor while guard cells retain it, then the stomatal opening occurs as a result of the release of surrounding pressure. If SO_2 causes a loss of turgor only in guard cells, then stomata close (Mansfield & Freer-Smith, 1984). In addition, inhibition of photosynthesis by SO_2 may cause a build-up of intercellular CO_2 concentration in the leaf, which may inturn induce stomatal closure.

As a consequence of enhanced stomatal opening, SO_2 will diffuse into leaves increasingly. It also stimulates the loss of water which is a secondary injurious effect of SO_2. On the contrary, there will be an increased diffusive resistance to SO_2 as a result of reduced stomatal opening. It may be argued that this event can not be regarded as a desirable way to avoid SO_2 stress, for a true avoidance mechanism involves stomatal closure in advance of stress, rather than as an event secondary to stress. However, Mansfield and Freer - Smith (1984) have found that stomatal closure in silver birch in the presence of SO_2 operates as an effective avoidance mechanism. They showed that 0.07 ppm SO_2 caused a depression of about 19% in net photosynthesis and a loss of 46% in transpiration. The main influence of 0.07 ppm SO_2 was on the stomatal movement with little effect on the internal resistance to CO_2 intake. So they suggested that stomatal closure induced by SO_2 might represent a mechanism for avoiding SO_2 stress without any major interference with photosynthesis.

MECHANISM OF INJURY :

SO_2 enters leaves through stomata and dissolves in water contained in the cell wall and generates bisulphite and sulphite ions as well as hydrogen ions :

$$SO_2 \longrightarrow H_2SO_3 \overset{--}{\rightleftharpoons} H\,SO_3 + H^+$$

$$H\,SO_3 \rightleftharpoons SO_3^{.2-} + H^+$$

Therefore, the toxic effects of SO_2 are likely to be related to these three kinds of ions. After the observation through stomata, SO_2 accumulates into inter cellular spaces. A large amount of SO_2 can be absorbed by the cells of the leaf without any injury if the absorption is slow and the concentration of the gas is low. However, SO_2 accumulates faster than it can be oxidised and assimilated, thus exceeding the threshhold level, and a phytotoxic concentration presumably develops in the intercellular spaces of the leaf, causing injury (Ketz, 1952; Thomas, 1961). The excess SO_2, accumulated in the intercellular spaces, comes in contact with waterbathed cell walls of the surrounding tissue to form sulphurous acid and sulphates, leading to plasmolysis and collapse of the cell (Brandt & Heck, 1968).

Various speculations have been made regarding the mechanism of injury. Haselhoff and Lindau (1903) believed that the gas reacts with aldehydes and sugars to form secondary products which slowly release sulphurous or sulphuric acid causing injury to the cell. However, the idea could not last long, since the leaves were found to be more sensitive to SO_2 in the morning when the sugar content is low (Treshow, 1970). In 1929, Noack suggested that the SO_2 inactivates iron in the chloroplast causing interference with its catalytic properties in assimilation. This promotes secondary processes and breaks down the chlorophyll, ultimately killing the cells. Dorries (1932) noted that the absorbed acidity could decompose chlorophyll, liberating megnessium and forming pheophytin, which may lead to chlorosis and reduced photosynthesis. According to Thomas et al. (1943) the toxicity of sulphurous acid is related primarily to its reducing properties rather than to its acidity because it is thirty-fold more toxic than sulphuric acid. Excess of sulphate may interfere with ion absorption, leading to disruption in nutrient balance. Bleasdale (1952) found that normally an equillibrium is maintained between sulphydryl group and more oxidised sulphur compounds such as sulphites. Any imbalance in this equillibrium, as might be caused by an excess of oxidized sulphur compounds, would upset sulphur utilization and protein synthesis. Sulphur dioxide would reduce the sulphites to sulphydryl, causing an accumulation of the latter and disturbing the ratio between sulphydrill and oxidised sulphur compounds. The sulphydrill compounds thus becomes a product of disturbed sulphur metabolism, and the tolerance of plants to SO_2 may be a function of the stability of sulphydrill (Dekok et al. 1982).

The plants with lower pH value (3-4) are more susceptible to excess SO_2, while those with pH values around 7 are resistant (Yu et al., 1982 a). These authors suggest that Permeability of plasmamembrane was closely related to the SO_2 injury. The higher the concentration, the higher the leakage of K^+ ions that cause serious visible injury to mesophyll cells. The rate of uptake of gaseous pollutants into a leaf also depends on several physical factors (Bennett et al., 1973). Before being capable to cause injury within the plant cells, the pollutant has first to enter the solution in the extracellular water contained in the cell wall. The simple solubility in water is therefore likely to assume importance while considering two pollutants which differ markedly in solubility and are taken up at different rates by the plants (Law & Mansfield, 1982).

MacCormick (1968) concludes that the effect of SO_2 in "daily cycle" is more in the morning (7-10 A.M.) and in theevening (7-10 P.M.). This diurnal change in sensitivity compounds to the diurnal changes of stomatal aperture in a number of plants. During the "seasonal cycle" the effect of SO_2 is more during winter than in summer (MacCormick, 1968). Experiments under two light regimes depicting winter and summer have proved that 50% reduction in shoot dry weight was obvious when SO_2 fumigation accompanied winter light (Davis, 1980).

SYMPTOMS DUE TO SULPHUR DIOXIDE EFFECT :

Broad-leaved Trees :-

Sulphur dioxide injury on deciduous trees can be either acute or chronic. Acute markings may occur after the rapid intake of toxic concentrations of sulphur dioxide. Shortly after exposure, tissues become dull and hydrotic and then collapse, usually assuming a grey green colour. These affected areas later dry and bleach to a light tan or ivory colour in many species, but occasionally the lesions may be brown or reddish brown. The final pattern of acute injury is either marginal or intercostal with minimum effect across the veins of broad-leaved trees unless injury is quite severe.

Linzon (1969) observed that acute injury on deciduous trees may occur as bifacial lesions between veins. Developing leaves rarely exhibited necrosis and oldest leaves were moderately susceptible; but newly expanded leaves were most sensitive, especially towards the petiole.

Chronic or chlorotic markings are caused by the absorption of an amount of gas somewhat less than that necessary to cause acute injury, or they may be caused by the slow, long and continued absorption of sublethal amounts of gas which accumulate until the buffer capacity of the leaf is exceeded or a salt effect is produced. The leaf does not collapse because of this type of injury, but histological examination (Thomas & Hendricks, 1944) reveals that some of the mesophyll and palisade cells may be shattered or the chloroplasts in some otherwise intact cells may be ruptured, allowing the grana to fill the cell. Photosynthesis measurements (Thomas *et al*, 1944) of cotton leaves indicate that the chronically injured areas are about one half as active as normal areas.

Leaves may remain turgid and appear to function at a rate of efficiency proportional to the amount of chlorophyll remaining. Chronic symptoms can be localized into a few flecks of injury varying in colour from yellow, ivory or bronze to black. Some hard wood species have diffuse mottling on their leaves. Both chronic and acute symptoms may be present on either one or both surfaces of leaves.

Conifers :-

Foliar markings indicative of exposure to high concentration of SO_2 begin near the apex of a needle and progress down-ward. In trees exposed to high concentrations of SO_2, needles develop distinctive bands, their terminals apear to be water soaked, and tissues turn raddish brown.

With repeated exposures, needles may drop prematurely. Sensitive conifers grow slowly and may die prematurely.

In conifers symptoms of exposure to low levels of SO_2 develop over an extended period. Needles become chlorotic, often discoloured over this entire length. Pigmented necrotic lesions are occasionally scattered along the yellow-flecked needles. Senescence of older needles on sensitive trees causes early needle loss, and these trees appear sparse and unthrifty (Dochinger, 1968).

Whitby (1939) and Thomas et al., (1950) found large amounts of sulphate on analysis of leaves with chronic symptoms. Actually injured leaves had only slightly higher sulphate content. Higher quantities of sulphate did occur in leaf tissues without injury. However, if excessive amounts were absorbed quickly, acute injury resulted.

Foliar injury symptoms are direct manifestations of phytotoxic nature of SO_2 (Jacobson & Hill, 1970; Hill et al., 1974). The macroscopic observation revealed that Calendula officinalis and Dhalia rosea plants started developing sporadic foliar injury symptoms of chlorosis and necrosis after 20 days of fumigation. Interestingly, blooming and senescence set in 10 days earlier in the treated Calendula plants than in their controls. Besides, flower size was reduced in both Calendula and Dhalia plants (Singh et al., 1985).

Norby and Kozolowski (1983) reported in leaves of *Betula nigra* and *B. papyrifera* SO_2 caused injuries. Higher degree of leaf damage was noted in *Festula rubra* and *Dactylus glomerata* (Wilson & Bell, 1986). Visible leaf injury in the form of interveinal chlorosis and necrotic patches was found in *Avena sativa* (Chand & Kumar, 1989). SO_2 developed chlorotic lesions, in four agriculturally important grasses, *Lolium perenne*, *Lolium multiflorus*, *Dactylis glomerata* and *Phleum pratense* (Lockyer, 1985); wheat (Thompson, 1985). Necrotic lessions were also found in *Arabidospsis thaliana*, *Mentha piperata* (DeSanto *et al.*, 1979); *Arachis hypogea* (Mishra, 1980); apple, chestnut, grape, pear and peech (Hesebe *et al.*, 1986). Leaf tip burning was noted in *Hordeum vulgare* to be associated with higher soluble sugar in its seedlings(Farooq & Beg, 1982). Kim (1981) reported that SO_2 caused an increased injury which brought about plasmolysis in spongy and epidermal cells leading to shrinkage and destruction. Visible foliar injury due to SO_2 was also noted in *Lolium perenne* (Cowling, 1978); 46 varieties of crops (Chukawar *et al.* 1980); *Opuntia basilaris* (David *et al.*, 1987); Spruce needles (Piene & Queriroz, 1988) and several other plants (See Agarwal *et al.*, 1987). However, Marehwinska and Kucharski (1987) found in carrot that a long term exposure to low levels of SO_2, even without visible plant injuries, resulted in more significant crop losses than short term high concentrations.

The pernitious effects of SO_2 are well documented (Mudd, 1975). *Impatiens balsamina* and *Tageter tenuifolia* on fumigation with SO_2 exhibited a wide range of damage. In general their growth pattern was altered and the foliage exhibited chlorosis, curling and necrosis. Both plants responded more or less similarly to 2 and 5 ppm SO_2. In *T. tenuifolia*, moreover, flowering was delayed and the number of flowers was reduced considerably. The plants died after 15 days of exposure to 5 ppm SO_2. The exposed plants of *Amaranthus graecizans*, on the other hand, showed no visible injury symptoms and were identical to the control plants in growth and vigour. Likewise, no adverse effects on the general growth of plants were apparent even at higher concentration of SO_2 (Yunus *et al.*, 1981).

The effect of SO_2 may be both direct and indirect. Direct injury is caused by the absorption of pollutant particles on the surface of leaves, flowers or other parts of the plants. SO_2 might be expected to impair ~~p~~ reproduction in many plant species by direct injury to reproductive structures damaging pollens, seeds and seedlings or reducing the viability of seeds (Katz, 1939).

Discussing the cause of the poor growth of pollen grains, Ma et al. (1973) showed that the chromosomes of vegetative and reproductive nuclei breakdown due to SO_2 in Tradescantia paludosa. Ma and Khan (1976) reported a fall in the pollen mitotic index (number of metaphase / 100 nuclei under observation) by SO_2 from 38.7% to 24.3% for exposure at 0.076 ppm and to 3.8% for exposure at 50 ppm. More recently Amer et al. (1989) demonstrated in Vicia faba fumigated with 5 ppm SO_2 for a period of 5 hours, a significant percentage of abnormal pollen mother cells. Sulphur dioxide was effective in inducing abnormalities in the different meiotic stages but the highest percentage of abnormalities was observed in the anaphase stages. Pollen germination in Cicer arietienum, Nasturtium ludicum, Petunia alba and Tradescantia axillaris was less sensitive than the pollen tube growth (Varshney & Varshney, 1981). Fedotor et al. (1983) also reported that male reproductive organs in case of pine are more sensitive to SO_2. Masaru et al. (1976) reported that SO_2 at 0.81 ppm concentration markedly inhibited pollen germination and pollen tube growth in gymnosperms. Khan, (1982) observed a 10% reduction of seed germination and a highly significant loss (63-65%) in the reproductive capacity of Dalbergia sissoo plantation near a thermal power plant complex. Germination of red pine seeds was noted to get decreased after seeds were exposed to 1.0 ppm of SO_2 (Ridding & Boyer, 1983). However SO_2 caused a significant increase in the seed germination percentage of many plants . SO_2 caused a decrease in the germination rate of fern spores of *Adiantum capillusveneris* and greatly influenced the rhizoid development causing apical swelling (Wada *et al.*, 1987). Sprugel *et al.* (1981) reported in the field grown soybeans (*Glycine max*) fumigated with SO_2, yield reductions (50-48%) due to decrease in both mean weight per seed and number of seeds per plant. Harvested ratio was also reduced in more heavily fumigated plots. SO_2 also affected seed germination in *Brassica juncea*, *Medicago sativa*, *Pennisetum typhoedeum* and *Raphanus sativa* (Benerjee & Chaphekar, 1980).

Majstrik (1980) reported that SO_2 causes significant reductions in fresh weight of green leaves, shoots & roots, in the root/shoot ratio, leaf area and dry weight in *Nicotiana tobacum*, and *Cucumis sativus*. By using different concentrations of SO_2 in open top chambers, a decreased shoot & root weight was found in *Medicago sativa* (Navari-Izzo, 1989). A significant reduction was also found in shoot and root length, shoot & root biomass, leaf area and leaf number in *Melitotus indica* and *Solanum nigra* (Ghouse & Khan 1983, 1984), and in *Polygonum glabrum* and *Desmodium triflorum*. (Khan & Khair, 1984 a, b). Norby and Kozlowski (1981) noted a reduced growth of shoots and roots in five woody plants exposed to SO_2. Exposure to SO_2 also caused a reduction in the length of roots and shoots, number of leaves, nodules and pods, in Vicia faba (Agarwal et al., 1985); Vigna mungo (Lalman & Singh, 1988); Raphanus sativus (Tomer et al., 1987); Phaseolus vulgaris (Temple et al., 1985); Hybrid popular (Biggs & Davis, 198). Reductions in shoot and root length and number of roots was also observed in Avena sativa (Chand & Kumar, 1989).

There are evidences that SO_2 also influences the growth of plants. Singh et al., (1987) reported that higher cumulative dosages of SO_2 immediately resulted in an appreciable reduction in plant growth and ultimately in the production level of plants. Similarly, SO_2 inhibited seedling growth in Betula platyphella as determined by leaf injury (Tsukahara et al., 1987); reduced annual shoot increament and total above ground biomass in pine stands (Fedotor et al., 1983); mean relative growth rates in case of Betula nigra and B. papyrifera (Norby & Kozolowski, 1983) and seedling growth, especially shoot growth in case of Raphanus sativus; Brassica juncea; Medicago sativa; and Pennistum typhoedeum (Banerjee & Chaphekar, 1980). Growth reduction were also noted in case of Medicago sativa (Singh et al., 1985); Lollium perenne (Kozoil et al., 1986). However an increase in the seedling growth was reported in Zea mays (Chand & Yadav, 1989).

Of the twelve tree species studied by Dubey et al. (1982) and Trivedi and Dubey (1983), nine showed significant reductions in stem perimeter, dry weight and chlorophyll content. Reduction in stem perimeter was maximum (37.93%) in Bridala resula and minimum (4.54%) in Aegle marmelos. The dry weight pattern in polluted area confirms the damage due to air pollution. The maximum reduction was in B. retusa followed by Mangifera indica, Tectona grandis, Cassia fistula and Adina cordifolia respectively. Navari-Izzo (1989) reported a reduced plant height and dry matter of root and shoot in Hordeum vulgaris, while reductions in dry weight of Lolium perenne was reported by Crittenden and Read (1978). Saxe (1983) reported in Phaseolus vulgaris that SO_2 inhibited fresh weight in mature and old leaves, root and stem. Satyanarayana et al. (1985) in Cajanus cajan reported that SO_2 affected the root growth and nodulation and also decreased dry matter accumulation in all parts of seedlings.

The yield of plants suffers a great loss due to SO_2 pollution. Reductions in yield has been noted in barley, grape vine, peas rye, and wheat (Catanescu et al., 1987); and Vigna mungo (Lalman, 1988). Raynolds et al. (1987) found in Phaseolus vulgaris a reduction in the yield of non-infected plants, however there was no apparant reduction in the yield of infected plants. Exposure to SO_2 effectively inhibited disease development but also reduced yield. Prasad and Rao (1981) reported that carbohydrate contents, calorific values, phytomass accumulation and net primary productivity were increased initially after exposure to SO_2 but with a later decrease in all above parameters in case of wheat.

Reductions in fruit size of Mangifera indica, together with necrosis of stigmatic surfaces and fruit tips have been reported by Rao (1972). Heggestad et al.(1986) found that the effect of increasing doses of SO_2 reduced fruit yield by 18%. With increase in doses of SO_2 the S quantity of leaves increases. The leaves of Mangifera indica and alfalfa analysed for sulphur indicated a high sulphur content (Rao, 1972; Singh & Rao, 1980). Plants of Arachis hypogea showed an increase in the accumulation of Sulphur and a decrease in N and P concentrations (Mishra; 1980). In white pine (Cortonis, 1971; Roberts, 1976) and spruce (Jaeger, 1976), the tip injury of needles by sulphur dioxide exposure was recognised as necrosis due to the accumulation of appreciable amount of sulphur content. Injury was also noted in young leaves of Mirabilis polygonum and Crossandra species when fumigated with SO_2 (Chaphekar & Karabhari, 1974). DeSanto et al (1979) found leaf necrosis, chlorophyll destruction and sulphur accumulation fumigating *Mentha piperata* and *Arabidospsis thaliana* with SO_2. Elevated SO_2 concentration decreased the buffering capacity and increased the total sulphur content as well as injury of wheat leaves (Bytenerowicz *et al.*, 1987). Sulphur level increased significantly in wheat grass (Milchunas *et al.*, 1981). Soybean showed greater response to SO_2 than wheat, with lower leaf extracts pH, having higher accumulation of sulphur on SO_2 treatment and lower content of chlorophyll, ascorbic acid and total carbohydrate (Prasad & Rao, 1982). The cited authors also concluded that the leguminous crops are more sensitive to SO_2 than cereal crops. Cowling (1978) reported in *Lolium perenne* exposed to high concentration of SO_2, an increased sulphur content in the shoots which increased with increasing concentration of SO_2. An increase in the total leaf sulphur was found in wheat, whereas lettuce remained unaffected by SO_2 exposure (Thompson, 1985). Similarly, sulphur content increased in *Abies balsamea*, *Acer balsamea*, *Betula papyrifera* and *Picea mariana* to the tune of about 48-157% over those growing in the SO_2 free environment (Sidhu & Singh, 1977). Pollutants may react directly with leaf cuticle (Fowler & Cape , 1982; Huttenum & Laine, 1983). A loss of epicuticular wax due to SO_2 occurred in *Lolium perenne* (Kozoil & Cowling, 1981).

Unsworth (1981) and Black (1982) have suggested a direct and preferential uptake of SO_2 by subsidiary and epidermal cells, when the gas enters the stomatal complex.

Indirect injury by SO_2 is caused due to absorption of the pollutant by mesophyll cells (Unsworth et al., 1972). When stomata are open the absorption of gas is maximum leading to a higher degree of injury (Ketz & Ledgham, 1939). There exists a highly significant correlation between the foliar injury and the amount of SO_2 absorbed (Furukwa et al., 1980).

It has been observed that a treatment with low concentration of SO_2 leads to stomatal opening (Mansfield & Majernik, 1970) due to increase in turgor pressure of the guard cells subsequently caused from the changes in water relationship or destruction of the epidermal cells adjacent to stomata (Ashenden, 1978; Black & Unsworth, 1979 a, Black, 1982). At higher concentration of SO_2 or longer exposure time, stomata are closed (Sij & Swanson, 1974; Bonte et al., 1977; Noland & Kozlowski, 1979) possibly due to damage to chloroplast in the guard cell (Black & Black, 1979) which first causes a reversible swelling of grana thylakoides (Wellburn, et al., 1972; Fisher et al., 1973; Black, 1982) and after a long exposure the plasmolysis. Thomas (1951) noted that SO_2 affected chloroplast and ruptured its walls allowing the grana to fill the cell, which tended to decrease the photosynthesis rate by 50%. The same was noted in chronically injured cotton leaves and pine needles (Thomas, 1956; Malhotra 1976). Nyomarkay _et al_. (1986) noted a damaging effect of SO_2 concentrations on the development of both thylakoides and the whole inner membrane of chloroplasts in _Zea mays_ seedlings. Another report from Hiroshi-Miyake _et al_. (1989) on spinach leaf cells showed that SO_2 injury appeared first as swelling of the stroma and deformation of the chloroplast and later as the swelling of the thylakoid. The uptake of significant amounts of SO_2 is known to lower intracellular pH values of leaf cells and tree bark (Skye, 1968; Johnson & Sochting, 1973; Turk _et al_., 1974). Significant alteration in intercellular pH is inhibitory or detrimental to plants. For example, a decrease in pH may cause transformation of chlorophyll to phaeophytin. But this phenomenon has been observed only in plants exposed to high concentration of SO_2. At low levels of SO_2, only chlorophyllide has been detected. Rabe and Kreeb (1980) have shown that isocitrate dehydrogenase activity in leaves of alfalfa and pansy is also reduced by SO_2. Several enzymes involved in aminoacid metabolism are affected by SO_2 with consequent increase in free amino acid content in general (Malhotra & Sarkar 1979; Heath 1984). When plants are injured by SO_2, ethane is released (Boessen _et al_., 1979; Peiser & Yang, 1979; Li _et al_., 1980). The amount of ethane increases with the degree of injury. Khan and Malhotra (1978) showed a loss of glycolipids after treatment of the sections of Pine needles to SO_2. Grunwald (1981) found that the amounts of free fatty acids were lowered by 75-85% by the exposure of soybeans to 0.8 ppm of SO_2 for 20 days. Also the polar lipids were reduced by 25-35%. Cai (1985) also observed that the contents of myritic acid, Oleic acid, linoleic acid and linolenic acid of lipid in the wheat leaves declined following the exposure to SO_2.

Vijayan and Bedi (1988) reported in *Syzygium cumini* a reduced chlorophyll a, b; carotenoid, protein, ascorbic acid and carbohydrate. Reductions in photosynthetic pigments (Chlorophyll a, b; carotenoides) has been reported in wheat (Pandey & Rao, 1978); western wheat grass (Lauenroth & Dodd, 1981); *Oryza sativa* (Agarwal *et al*., 1982 b); Lady's finger (at 0.5 to 2.0 ppm of SO_2) (Shringi, 1982); *Trigolum subterraneum* (Murray & Frank, 1985); *Solonum tuberosum* (Kumar *et al*., 1986) *Raphanus sativus* (Tomar *et al*., 1987); *Vigna radiata* (Singh & Rao, 1988). Also see BoKza (1981); Dubey *et al*. (1982); Pawar (1982); Pawar and Dubey (1983); Trivedi and Dubey (1983); Agarwal *et al*. (1987). Singh *et al*. (1985) reported in case of *Calendula officinalis* exposed to long term fumigation in pre-flowering, flowering and post-flowering stages that photosynthetic pigments were degraded and leaf extract pH and protein content declined. Protein content decreased also in case of soybean and wheat (Sardi, 1981); wheat (Pawar, 1982); Lolium perenne (Murray, 1984). Nandi et al. (1986) found that exposure of Oryza sativa plants to SO_2 during tillering and flowering decreased the concentration of photosynthetic pigments, starch, increased peroxidase activity and amounts of reducing sugar. DeSanto et al. (1979) found destruction in chlorophyll and sulphur accumulation in Mentha piperata and Arabidopsis thaliana; there was also a decrease in cell sap pH in both species. Reductions was noted in both chlorophyll a & b in mature and old leaves and in starch in Phaseolus vulgaris (Saxe, 1983). Reduced levels of protein and RNA, but an increase in the contents of chlorophyll a and b was reported by Backerson and Hofstra (1979). Chand and Yadav (1989) in Zea mays reported a significant increase in seedling growth, dry weight fractions and chlorophyll content.

Photosynthesis and transpiration were also noted to be adversely affected by SO_2 fumigation in Phelum pratense (Terese & Mansfield, 1982) and Glycine max (Takemoto & Mansfield, 1982; See Lore & Andreas, 1987). SO_2 significantly affected the transpiration coefficients of Dactylis glomerata and Phleum pratense (Lockyr, 1985). Reductions in net photosynthesis and in translocation was found in Phaseolus *vulgaris* (Noyes, 1980). Inhibition of photosynthesis due to SO_2 was also reported in *Marchantia polymorpha* and and *M. tinctorum* (Takaoki *et al*., 1986); spruce (Saxe & Murali, 1989); rye grass, *Lolium perenne*, *Vicia faba*, *barley* (Darall, 1986). L'Hirondelles *et al*. (1986) found a significant decrease in the biomass of SO_2 fumigated *Pinus blanksiana* seedlings and *Populus tremuloides* and also a transient decrease in the net assimilation rate. Katainen (1987) found that moderate concentration of SO_2 caused a decrease in the photosynthetic rate and the lowest concentration had the smallest effect on dark respiration. *Phaseolus vulgaris* was exposed to SO_2 with contineous monitoring of photosynthetic and respiratory activity. In all tissue samples the levels of total sugars were increased by exposure to the low concentrations of SO_2, but decreased by the higher concentrations. Starch levels in leaves followed a similar trend. Increase in the sugar and starch levels preceded symptoms of visible injury (Koziol & Jordan, 1979). Gould *et al*. (1988) by using C^{11}-labelled photosynthate revealed that there is a change in the paterns of tracer profiles when cereal leaves (*Triticum aestivum*, *Zea mays*) are exposed to SO_2. The change after exposure to SO_2 was interpretted interms of a decrease in lateral water flow into the sieve tubes brought about by reduced phloem loading along the length of a leaf. It also reveals that the speed of translocation was reduced as expected by the Munch model of phloem transport.

Ultracytopathological observations of Pinus ponderosa var. Scopulorum needles after long term fumigation with SO_2 showed such symptoms as lack of starch grains,vacuoles with darkely stained deposits, occurrence of large droplets of lipid like material and the rounded chloroplasts (Karenlampi & Honpis, 1986). Effect of SO_2 on microorganisms in spruce raw humus causes the extinction of spruce raw humus ecosystem (Hildemera & Fieldler, 1989). Leaf conductance, xylem tension and fructose level decreased, and sulphur level increased as SO_2 concentration and duration increased in case of ten-week-old Pinus blanksiana (L'Hirondelle & Addison, 1985). Black and Black (1979) found that stomatal conductance of the adaxial as well as abaxial leaf surface was increased by exposure to SO_2 in field bean (Vicia faba). However a decrease in stomatal conductance was reported in Phaseolus vulbaris (Temple et al. 1985).

As to the effect of SO_2 on the diameter increment of trees, Lathe and MacCallum (1939) noted markedly reduced growth in yellow pine and Douglas fir growing in areas where leaf burning and defoliation occurred. Katz (1952) confirmed that SO_2 did not affect the growth of conifers in the absence of necrosis. He also noted that transient injuries on trees were gradually recovered. However, a reduction in the growth rate of eastern white pine was observed without any apparant injury to foliage near a coal burning power plant in Pennsylvania (Wood, 1967). The same held for scots pine (Garsed *et al*., 1981). In a similar study annual increament of wood was found severely retarted in certain timber trees such as *Dalbergia sissoo* and *Tectona grandis* in the vicinity of a thermal power plant (See Khan, 1982; Ghouse et al., 1984 a, b). Gilbert (1983) also reported reduction in the width of annual rings in *Pinus nigra* due to SO_2 pollution. Pawar and Dubey (1983) reported as much as 93.65% reduction in flowers as compared to unpolluted areas in *Mangifera indica*. Similar effect was observed in *Acacia arabica* and *Delonix regia* (Pawar, 1982) and there was a marked reduction in fruit number also. Rao (1972) also reported reduction in size of fruit and yield in *Mangifera indica* growing in polluted areas.

Effects of SO_2 on fungal spore germination studied by Dubey (1983) revealed that while the spores of common pathogenic fungi (*Alternaria tenuis* & *Fusarium moniliformae*) were tolerant, *Rhizopus nigricans* and *Penicillium nigricans* were comparatively more succeptible. The tolerance expressed by the spores of pathogenic fungi is significant as the vegetation will be susceptible to both fungi and SO_2.

NITROGEN OXIDES (NO_x) :

Anthropogenic activities, especially since the dawn of the industrial revolution have transfered large amounts of matter and energy from lithosphere to the atmosphere and hydrosphere. Matter is energy but matter in a harmful state of oxidation is a pollutant. Oxides of nitrogen exemplify this notion. Nitrate and ammonia are life sustaining nutrients of plants. But nitric oxide (NO) and nitrogen dioxide (NO_2) are toxic, directly in their gaseous forms and indirectly in the form of acid precipitation. The nitrate component resulting from No emissions is believed to account for more than 90% of the acid precipitation in the U.S.A. and Ca. 35% in western Europe (Chadwick, 1983).

Oxides of nitrogen, consisting principally of NO and NO_2 are collectively refferred to as NO_x species because their relative ratios in the atmosphere are constantly changing, spatially and temporally. There oxides result from biological as well as abiological processes. NO produced biologically, mostly by bacterial action in the soil, is believed to be ten times as much as that produced by human activities, yet is nontoxic since it is distributed all over the globe. Nitric oxide and nitrogen dioxide, the most important pollutants among the oxides of nitrogen, are the bye-products of the chemical industry engaged in the production of nitric acid, sulphuric acid and nylon intermediates, in the nitration of organic compounds, and in many high temperature processes (Katz, 1956). They are also important constituents of vehicle exhaust gases, and over 70% of NO_2 in the atmosphere originates mainly from automobile exhausts (Treshow, 1970). Transportation alone is estimated to contribute about 30% of NO_x emission in the UK and West Germany, 40% in Japan and 45% in the U.S.A. Fuel combustion in a wide variety of equipments is estimated to contribute about 99% of the technology associated NO_x emissions. Morrison (1980) reported that coal burning alone is believed to account for 80% of NO in the atmosphere. About 95% of NO_x is estimated as NO and the remaining 5% as NO_2 (Kumar, 1977). NO and NO_2 produced naturally (by bacteria) and artificially (by man made sources) constitute about 50×10^7 and 5×10^7 tonnes per year respectively (Robinson & Robinson, 1970). The annual emission of NO_x in North America and West Europe collectively amounts nearly to 80×10^6 tonnes per year, whereas the concentration of NO_2 in agricultural areas of the U.S.A. alone is 25×10^6 tonnes per year (Fowler & Cape, 1982).

Nitrogen dioxide, a brown gas with pungent smell, and nitric oxide a colourless gas contribute to many other secondary pollutants such as ozone (O_3), peroxyacetyle nitrate (PAN) and nitric acid (HNO_3). The reactions which generate O_3 and PAN are explicitly described in a report by NAS (1977).

In the presence of radient energy NO_2 quickly splits back into NO and atomic oxygen, which combines with the molecular oxygen of the atmosphere to form ozone (Cox et al., 1975).

$$NO_2 \xrightarrow{hv} NO + O; \quad O_2 \xrightarrow{m} O_3$$

hv = light energy m = any inert molecule

The net reaction is $NO_2 + O_2 \rightleftharpoons NO + O_3$

Here the back reaction theoretically proceeds faster than the initial reaction so that the ozone gets removed from the atmosphere. However, hydrocarbons present in the urban atmosphere react with and remove NO, stopping the back reaction so that O_3 accumulates. In the dark, the net reaction is reversed, and NO_2 accumulates at the expense of ozone. In the atmosphere NO_x react photochemically with unburnt hydrocarbons and SO_x to form other undesirable secondary compounds like peroxy-acetyle nitrate (PAN)(Stephans et al., 1956; Cox & Penkett, 1971) as shown below:

$$\text{Hydrocarbons} + NO \text{ or } NO_2 + SO_2 \text{ or } SO_3 \frac{uv}{hv} \text{PAN} + O_3$$

Oxides of nitrogen are also harmful to plants in local situations and many a times are considered to be more important contaminants than O_3 and PAN which are simply their derivatives (Taylor & Eaton, 1966). The threat of these pollutants has assumed alarming dimensions today because not only coal burning but any combustion process which creates high temperature in the presence of atmospheric nitrogen and oxygen, yields oxides of nitrogen (NO & NO_2) as combustion products (Wellburn et al., 1976; Ashenden, 1979; Law & Mansfield, 1982). The hotter the flame, the greater the production of these oxides. The combustion dilutes the gases present in the immediate atmosphere and part of NO, perhaps as much as 10% (1 % of the total NO_x formed) is oxidized to NO_2. once the NO has been diluted to about one part per million (1 ppm) of the air, it no longer reacts readily with oxygen to produce NO_2 (Taylor et al., 1975).

Potentially damaging concentration of NO_x occur only in sporadic episodes especially in rural areas. Urban areas, can have highly polluted atmospheres, depending upon the density of road traffic. In Genoa (Italy), for example, valves as high as 2 ppm NO_x have been measured, and even 24 h average values were often found to exceed 0.5 ppm (Capanelli et al., 1977). Even in a relatively small town like Oslo (Norway), NO_2 concentration during traffic rush hour in winter could be as high as 1.6 ppm though the monthly average is around 0.4 ppm (Larson & Friberg, 1980). In general, NO_x distribution is quite uneven in space and time. While an annual cyclic variation is not so apparent for NO_x as for SO_2 and O_3, maximum NO_x concentrations occur during the winter (Fowler & Cape, 1982; Pfeffer et al., 1982; Ferm et al., 1984, Martin & Baber, 1984).

Ambient air measurement by Schuck et al. (1966) have shown the average monthly concentration in Los Angeles to be 20 to 30 ppm during the winter and about 10 ppm in the summer, Concentrations in smoggy days may be much higher, sometimes exceeding the 'Alert' level of 3.0 ppm (Bush et al., 1962). The highest values occurred at night, since the day time concentrations were reduced by participation of nitrogen oxides in photochemical reaction. Substantial amounts are also utilized by plants during the day when stomata are open (Treshow, 1970). The annual concentration of NO_2 released from the Kasimpur Thermal Power Plant, Aligarh, ranger from 0.177 - 0.294 ppm/hour (Amani, 1982 b).

The term nitrogen oxides (NO_x) is often used collecting to describe their mixture, but in practice, NO_2 alone has been preferred for studying the phytotoxicity of these oxides (Bennet & Hill, 1973). Capron & Mansfield (1976, 1977) demonstrated that NO_2 is more harmful than NO and the uptake of NO_2 per unit area of leaf is almost three times that of NO.

EFFECT OF NITROGEN OXIDES ON PLANTS :

Like other gaseous pollutants NO_x (NO and NO_2) make their way into leaf through stomata (Bull & Mansfield, 1974), increasing the stomatal conductance (Ashenden, 1979), where they dissolve in the extracellular water of the stomatal complex to form a stoichiometric mixture of nitrate and nitrite ions. Maintenance of a concentration gradient between the atmosphere and the substomatal cavities through metabolism, translocation or chemical reaction, is necessary for continued uptake of pollutant gases. The similarity of the uptake rate Constant in several plants like maize, soybean and loblolly pine has promoted the suggestion that NO_x uptake is primarily governed by physical exchange process and not metabolic ones (Rogers *et al.*, 1979). Interactingly, uptake of NO_2 by sweet pepper leaves is three times that of NC despite the fact that the two gases were present at equal concentrations in the ambient air (Law & Mansfield, 1982). This differential uptake was shown not be due to variation in stomatal resistance and so is believed to be due to residual internal resistance i.e., the capacity of the cells inside the leaves to absorb and metabolise NO, NO_2 and their products in solution, Law & Mansfield (1982) argue that the difference in solubility of the two gases is reflected in their uptake.

, Oxides of nitrogen alone are unlikely to inhibit plant growth except when present in very high concentrations or on chronic exposure. On the contrary, they may prove beneficial when the growth medium is deficient in nitrogen (Bennett et al., 1974). It has been established that NO_x is absorbed and assimilated in plants (Durmishidze & Nutsubidge, 1976; Roger et al., 1979; Yoneyama et al., 1980) through nitrate ⟶ nitrite ⟶ ammonia ⟶ amino acid (Zeavaart, 1974; 1976; Kaji et al., 1980, Wellburn et al. 1981; Ito et al , 1984) and transported to other parts of the plant (Rogers et al., 1979; Okano et al., 1984). At subthreshhold concentrations, NO_2 alone promotes cyclic electron flow and makes available through additional photophosphorylation extra ATP (Wellburn et al., 1981) and also increase the activities of enzymes involved in N-assimilation (Wellburn et al., 1980; Srivastava & Ormrod, 1984). Such assimilation besides nourishing the plant, also detoxifies NO_x and their products.

Nitrogen level in plants increase due to foliar absorption when exposed to NO_2 (Hill, 1971). Similar increase in total N content was also observed in tomato plants (4 weeks old) exposed to NO_2 by Troiano & Leone (1977), in Phaseolus vulgaris (10 day old seedling)(Ito et al., 1985). It was coupled with reduced translocation of sugars from leaves to roots, root respiration significantly reduced after 5 days. An increased content of N after exposure to NO_2 was reported in Potato (Sinn et al., 1984) and soybean

(Sabaratanan *et al.*, 1988). However significant decreases in nitrogen accumulation occurred in leaves exposed to 80 ppm NO_2 for 4 hour daily for 4 day in 6 week old plants of *Petunia hybrida* (Elkiey & Ormrod, 1981 b). It has been demonstrated that after fumigation with NO_2, pea plants show a higher content of nitrate and nitrite ions with an associated increase in the rate of protein synthesis (Zeevart, 1976). Protein content increased in wheat after exposure to NO_2 (Prasad & Rao, 1980). Rowland *et al.* (1989) found an inhibition of nitrate reductase activity after exposure to NO_2 in the mutants of *Hordeum vulgare*. After fumigation with NO_2 nitrate content increased in spruce seedlings and so did the metabolic activities of nitrate assimilating enzyme and glutemic synthetase in shoots. In case of roots, however, nitrate reductase activity reduced while glutemic synthetase activity remained unchanged. Murray and Wellburn (1985) reported no effect on nitrate reductase activity of either of the two gases (NO_2, NO/ in pepper, although an increase occurred in Nitrite reductase activity in the presence of NO_2 in one tomato cultivar, Moreover, after three hours exposure to 400 ppb NO, tomato plants showed a significant reduction in the levels of nitrate reductase and a significant increase in those of nitrite reductase (Wellburn *et al.*, 1980).

That the NO_2 caused the transpiration rate in plants to decline was reported in bean plants (Srivastava *et al.* 1975 a), wheat (Sing & Rao, 1981); spruce tree (Kammerbauver *et al.*, 1987). However, Furukawa *et al.* (1984) found the transpiration of sunflowers to be unaffected by even 4 ppm NO_2 for 2 h, also Amundson & Weinstein (1981) reported no effect of 0.46 ppm NO_2 on the transpiration in soybean leaves.

Srivastava *et al.* (1975 a) demonstrated an inhibition of Photosynthesis and dark respiration in bean, treated with 1-7 ppm NO_2. Similarly, reduction in photosynthesis was found in alfalfa and Oat plants (at 0 - 10 ppm NO or NO_2 for 2 h) (Hill and Bennett (1970); sunflower (at 2 and 4 ppm NO_2 for 2 h) (Furukawa *et al.*, 1984); soybean (Sabaratnam *et al.* 1988) and *Picea abies* (Saxe, 1989). Whereas Carlson (1983) reported that 4-5 week soybean plants exposed to 0-0.06 or 4 ppm for 2 h showed no change in photosynthesis, but reductions in stomatal conductance, dark respiration and photorespiration. It was shown by Capron and Mansfield (1976) that 500 ppb of NO or NO_2 reduced the net photosynthetic rate by about 30 percent in detached tomato leaves. The effect, equal in extent for both the pollutants, was additive rather than synergistic. Reduced photosynthesis in grasses has been reported by Witemore and Mansfield (1983), Prasad & Rao (1979) noted in Triticum aestivum, that lower doses of NO_2 increased chlorophyll content while higher doses decreased chlorophyll and primary productivity. Decreased chlorophyll content was also found in soybean by Sabaratnam et al. (1988). However, chlorophyll and carotenoid content increased in 7 day old seedlings of Phaseolus vulgaris (with no external N nutrition) (Srivastava & Ormrod, 1984).

Hill and Bennet (1970) reported reductions in the CO_2 assimilation in Oat and alfalfa fumigated with 0.6 ppm of NO_2. Okano and Totsuka (1985) reported that the net assimilation rate of both species Helianthus annuus, and Zea mays was reduced after exposure to NO_2. A reversible swelling of thylakoids in the chloroplasts, without any extra chloroplast damage, was observed by Wellburn et al.(1972) in bean (Phaseolus vulgaris) under fumigation with 1, 2 or 3 ppm NO_2 for one hour. A physical disruption such as this may be partly responsible for the reduced photosynthetic activity.

It is not clear whether the induced stomatal closure is a direct or indirect effect. The indirect effect may be due to an inhibition of photosynthesis (Sometimes coupled with an effect on dark respiration) leading to high CO_2 concentrations in the substomatal cavities resulting in reduced stomatal opening (Hill & Bennet, 1970). In general NO_x, alone and in lower concentrations cause no or only a small reduction in the stomatal conductance (Amundson & Weinstein, 1981). NO in particular, affects CO_2-uptake rates, the least. A 10% inhibition of CO_2-uptake rate needs approximately a 2 h fumigation with 1.5 ppm NO_2 or 2,5 ppm NO (Bennet & Hill, 1973). There is no evidence of stomatal closure with NO_x fumigation Until after an appreciable reduction in CO_2 uptake has been measured (Hill & Bennet, 1970). NO_x affects transpiration much less than photosynthesis (Furukawa _et al._, 1984). According to Srivastava _et al._ (1975 a, b) and Furukawa _et al._ (1984) the major effect of NO_2 (above 2 ppm) is that it increases mesophyll resistance to CO_2-exchange, but Carlson (1983) found no reduction in the residual resistance including carboxylation resistance due to 0.6 ppm NO_2 above for 2 h. The higher concentrations of NO_2 used by Srivastava _et al._ (1975 a, b) and Furukawa _et al._ (1984) probably account for the varying results.

Visible injury symptoms depend on the concentration of the pollutant, duration of exposure, plant species and its stage of development, environmental factors comprising temperature, light, humidity, soil moisture, time of the day when the pollutant episode occurs and nutrient availability. In most studies, in NO_x injury to plants, summarized by Taylor _et al._ (1975), the concentration of the gas used, mostly NO_2, was quite high (2 to 50 ppm) and without relevance to existing ambient concentrations. Where leaf injury was apparant, it generally took two forms, a discolouration of the leaf associated with collapsed, necrotic lesions and a waxy water soaked appearance. In almost all species studied, young leaves were most resistant while older leaves most susceptible. Moist exposure conditions and fumigation during night were more detrimental. In general, acute leaf-injury symptoms following exposure to 2 to 10 ppm of NO_x were similar to those caused by exposure to SO_2. Foliar lesions appear first on the abxial surface and tend to be near the apex or along the margins. The severity of injury in response to NO_2 is much increased by misting with deionized water for 5 min. twice daily (Elkiey & Ormrod, 1981 c).

Chronic injury resulting from long term exposure to concentrations less than 1 ppm of NO_2 alone are uncommon (Tingey et al., 1971), but a few plants show an enhanced green colour which is later followed by chlorosis and abscission of the leaves (Taylor et al., 1975; Ashenden & Williams, 1980; Elkiey & Ormrod, 1980; Reinerts & Saunders, 1982; Whitmore & Freer-Smith, 1982).

Two kinds of necrotic damage were distinguished by Zeevart (1976). One kind correlated well with nitrite accumulated in the leaves and is believed to be the result of acidification (NO_2 in water produces a mixture of nitrous and nitric acids : $2\ NO_2 + H_2O \rightarrow HNO_3 + HNO_2$), since it would be antagonized by ammonia (base effect) or light. In light, nitrite is rapidly converted to ammonia, a process consuming a large amount of acidity.

$$NO_2^- + 3NADPH + 5H^+ \rightarrow NH_4^+ + 3NADP^+ + 2\ H_2O$$

Lack of reducing power in darkness probably leads to nitrite accumulation, acidification, protein denaturation and necrosis even with a relatively low NO_2 concentration. Leaf injury in believed to occur when a certain threshhold pH is reduced, leading to an altered calcium balance of the cells (Heath, 1980).

The second type of necrosis caused by low NO_2 in light was found only in Nicotiana glutinosa, without simultaneous nitrite accumulation or acidification and could not be corrected by ammonia. Since this type of injury is reduced by pretreatment with - SHcompound mercaptoethanol, and since light apparantly is essential for it to appear, the involvement of an unknown photo-oxidativeprocess is suspected (Zeevart, 1976).

There are several reports of NO_2 fumigation promoting plant responses eg; increases in chlorophyll and darker green leaves (Singh, 1980; Elkiey & Ormrod, 1980), leaf number and leaf area in Dactylis glomerata (Ashenden, 1979 b), dry weight of roots of Lolium multiflorum and leaf area in Poa pratensis (Ashenden & Williams, 1980), . leaf area and dry weight of Cucumber, kidney bean & Sunflower (Yoneyama et al., 1980), total shoot dry weight in Poa (Whitmore & Freer-Smith, 1982; Lane & Bell, 1984) and dry weight of Tilia cordata and Betula pendula (Whitmore & Free-Smith, 1982).

A decrease in productivity following exposure to NO_2 alone was noted in two cultivars of potato (Sinn & Pell, 1984), in wheat (Singh, 1980) and in Dactylis glomerata and Poa pretensis (Ashenden & Mansfield, 1978). Marigold and redish plants appear to be relatively resistant to NO_2, the later needing exposure to more than 2 ppm to suffer injury (Reinert et al., 1982). Radish biomass production was unaffected by 0.3 ppm NO_2 fumigation over a three weeks period (Reinert & Saunders, 1982).

The response of grasses to NO_2 fumigation is somewhat complex and peculiar. Depending upon the species and the environmental conditions, they show promotion, inhibition or no effect. (See Ashenden & Mansfied, 1978; Ashenden, 1979, b; Ashenden & Williams, 1980; Elkiey & Ormrod 1980; Mansfield et al., 1985). Similarly as response of tree species to chronic NO_2 exposure is also quite variable (See Kress & Skelly, 1982; Feer-Smith, 1984).

Visible injury from nitric acid fumes was described by Haselhoff et al. (1932). Leaf tips of grains and conifer needles turned bright yellow, margins of broad-leaved species became brown, and dark spots appeared on the affected leaves. Age of the leaf is more important than the age of the plant since injury occurs primarily in leaves. Newly matured leaves are more sensitive than older leaves (Setterstrom & Zimmerman, 1939; Benedict & Breen, 1955).

In field conditions NO_2 was reported by Janone (1954) to cause necrotic stem lesions, defoliation, dieback and death of peech and black locust trees. Benedict & Breen (1955) found that NO_x first caused white to tan coloured irregular shaped, small necrotic lesions in between the large secondary veins near the leaf margin. Later, a waxy shiny green coating appeared on the leaves of certain species. The glossy sheen developed on both upper and lower leaf surfaces in pig-weed, on the upper surface in mustard, and on the lower surface in kentucky blue grass. Plasmolysis of palisade tissue cells, disappearance of starch granules and browing of cell walls were described by Berge (1963).

OXIDES OF CARBON

The oxides of carbon include carbon dioxide and carbon monoxide which are the bye products of fuel combustion (along with water vapour).

Carbon monokide (CO) is a colourless, odourless gas produced by the incomplete combustion of carbon containing fuel and by some biological and industrial processes. Every year human activities put some 1500 teragrams (1 Tg = 10^{12}g) of carbon monoxide into the Earth's atmosphere compared with the 1200 Tg/yer from natural sources (US National Research Council 1977 a).

The major source of CO emissions is the exhaust of petrol-powered motor vehicles; the diesel engine (compression ignition), when properly adjusted, emits little carbon monoxide. Locally, high concentrations of CO may occur near industrial plants such as power stations, petroleum refineries, iron foundries and steel mills, as well as in the vicinity of refuse burning. CO levels show a distinct diurnal pattern with peaks corresponding to the morning and evening traffic rush hours. Levels of this pollutant decrease very rapidly with distance from emission source. Data from the united states and Japn show that 8-h mean concentrations of CO are generally less than 20 mg/m^3 (17 ppm) although maximum 8-h mean concentration of upto 60 mg/m^3 (53 ppm) have occasionally been recorded.

Short-term concentration of even higher concentrations have been observed in confined spaces such as tunnels, garages, loading bays, underpases, underground car parks and in narrow congested road ways (Bodkin, 1974; World Health Organisation, 1979 C; Wright et al., 1975).

Carbon monoxides are normally converted into carbon dioxide in presence of ultraviolet hight, thus reducing the rate of accumulation of CO (Heagen-Smith & Wayne, 1968). Also, the leaves of *Coleus blumei*, *Dacus carota*, *Ficus variagatus*, *Phaseolus vulgaris*, and certain other species are reported to be capable of fixing CO (Bidwell & Bebee, 1974); these may act as the global sink for such air pollutants as CO (Hill, 1971). It should be noted, however that at normally encountered levels, there are no known adverse effects of CO on vegetation and meterials.

Carbon dioxide (CO_2) is a colourless and odourless trace gas which occurs naturally in the atmosphere, where it acts as an essential plant nutrient, and as an important determinant of the Earth atmosphere thermal balance.Concern has been expressed that human activities, through the burning of carbon-based fossil fuels and changes in land use practices, are increasing the global atmospheric CO_2 concentration such that this will result in a significant increase in surface air temperature and changes in other climatic parameters. It is predicted that the atmospheric CO_2 concentration will increase from the pre-industrial value of 260-300 ppm (the lower value gaining favour in recent research) to 600 ppm during the next century. Such a multiplication of CO_2 concentration is estimated to cause an increase in the mean global surface air temperature of 3 ± 1.5°C (US Environmental protection Agency, 1983 a; US National Research Council, 1979, 1982 b, 1983 b). The Earth would then be warmer than it has been for the past 125,000 years, the peaks of the last interglacial, or possibly even warmer than it has been for the past two million years.

According to Rupp (1965), with the rate of 30 ppm per year the natural concentration of CO_2 has increased upto 300 ppm during the last 50 years. This could go upto 600 ppm in the air of industrial areas (Cholak, 1952). Fortunately, at least 0.5 percent (5000ppm) of CO_2 in the air is required before the respiration of man is markedly affected.

Robinson (1968) refers to the observation that there has been a steady increase in the atmospheric CO_2 concentration since around 1900. Prior to 1900 the CO_2 concentration was about 290 ppm. It underwent an increase of about 40 ppm (14%) till 1960. Similarly, Sundaram (1977) points out that the present atmospheric background concentration of CO_2 is 330 ppm by volume, which is higher by 10% over the quantities in many earlier millenia. A 14% rise was reported in Hawaii and South

Pole between 1958 and 1974. With a 4% annual increase of fuel consumption, he added, the atmospheric CO_2 will reach 400 ppm by the end of the century. An eight-fold increase is likely to occur in the next two hundred years if the CO_2 absorption by oceans is disturbed by ecological imbalance emaneted from man's mis-use of global resources.

The 'Pioneer' agricultural explosion across North America, Eastern Europe, Australlia, New Zealand and South Africa in the second half of the nineteenth century was believed to have added substantially to the carbon dioxide content of the atmosphere (Adams <u>et al</u>., 1977; Wilson, 1978). However, CO_2 release arising from changes in land-use during the past two or three decades is believed to be small (Revelle, 1982).

At locations far away from urban activities CO_2 concentration was found (Keeling, 1961) to occur between 303 and 320 ppm on a dry gas basis. It should be noted that in any location where vegetation is plantiful, CO_2 concentration greatly varies with typical diurnal cycle of the maximum and minimum concentrations. The largest amount tends to occur at night when photosynthesis comes to its lowest level but decomposition and respiration of organic matter leading to the formation of CO_2 still proceed, the lowest CO_2 concentration tends to occur in the afternoon hours when photosynthesis is at its maximum. The CO_2 concentration, 100 cm. above a maize field was noted to be 0.0675 and 0.045 percents, at night and day respectively (Verduin & Loomis, 1944). There are also considerable seasonal variations in the CO_2 concentration owing to seasonal biologic fluctuations (Tebbens, 1968). Further, there has been a world wide increase of 0.7 ppm per year in the CO_2 concentration. The annual concentration of CO_2 released from the Kasimpur Thermal Power Station has been noted to range from 1.804-2.664 ppm per hour (Amani, 1982 b).

EFFECT OF CARBON DIOXIDE ON PLANTS :

Whether the changes in climate will adversely affect crop yields in major grain - producing areas of the world may be debated, but there is an increasing consensus that increased atmospheric CO_2 will directly enhance crop yields. Controlled growth chamber experiments (as well as green house practices) have established beyond doubt that many plants for which carbon is a limiting nutrient respond to short-term CO_2 enrichment with faster growth and greater yields (Rosenberg, 1981).

At full door light intensity, net photosynthesis in many plants increases with CO_2 concentration upto at least 900 ppm (Cooper, 1982). The extent and nature of the effect depends upon plant biochemistry, growth form, age of plant and states of water and nutrients (phosphorous & nitrogen) in the soil, among other factors. Under normal conditions, 0.03% of CO_2 gas, present in the atmosphere many a times, may act as limiting factor in photosynthetic process. An increase in the amount of CO_2 (up-to 1%) causes a rapid increase in photosynthesis (Kochhar, 1982) and beyond this point it slows down or perhaps makes the process constant. An elevated level of CO_2 concentration caused an increase in the rate of photosynthesis (per unit leaf area), starch accumulation and export, and leaf sucrose concentration in *Glycine max* (Huber *et al.*, 1984). An increase in the photosynthetic rate was also found in winter wheat (Havelka *et al.* 1984); *Glycine max* (Ackerson *et al.*, 1984; Sionit *et al.*, 1987); Spring wheat (Kendall *et al.*, 1985).

Increased rates of photosynthesis, consequently leads to an increased plant yield. Sionit *et al.*, (1987) noted that *Glycine max* plants grown in elevated levels of CO_2 show an increase in the number of pods and seeds. Similar yield increase was found in *Glycine max* (Ackerson *et al.* 1984; Rogerers *et al.* 1984); *Triticum aestivum* (Havelka *et al.* 1984); *Ipomea batatus* (Bhattacharya *et al.*, 1985); *Glycine max* (Baker *et al.*, 1989).

When the concentration of CO_2 goes beyond the desirable value, it inhibits the growth of plants by reducing the photosynthetic process. Reductions in photosynthetic rate was found in soybean by Peet (1984). Similar condition was found in Phaseolus vulgaris (Ehret & Jolliffe, 1985) and some decidous trees (Williams et al. 1986). Whereas the eleavated CO_2 concentration also enhanced the photosynthetic pigments (Chl a and Chl b) in Glycine max (Vu, Joesph et al. 1989), it reduced them in Pinus ponderosa (Houpis et al. 1988). Gorvindjee (1982) noted that photosynthesis is affected by the increased concentration CO_2 (a) by reducing the fraction of soluble protein allocated to RUBP carboxylase/oxygenase and (b) by reducing the enzyme concentration per **unit leaf area** chlorophyll or fresh weight. It has been pointed out by Law and Mansfield (1982) that additional CO_2 may also act at metabolic levels for it increases the rate of photosynthesis and may therefore provide cells with increased capacity for repair processes or for detoxification mechanism.

Higher levels of CO_2 caused an increase in starch (205%), sucrose (109%), reducing sugars (33%), chlorophyll (22%) and soluble proteins (31%), whereas enzyme activity and the km (CO_2) of ribulase biphosphate carboxylase remained un**changed** in case of Glycine max (Vu Joesph et al. (1989). Huber et al. (1984) noted an increase in the content of starch accumulation and leaf sucrose concentration in soybean.

Similarly high starch content was found in Phaseolus vulgaris (Ehret & Jolliffe, 1985), and high soluble sugars (Sucrose) and starch content in G. max (Havelka et al., 1984). Govindjee (1982) points out that the cotton plants grown under high CO_2 concentrations exhibited reductions in the assimilation rate and RUBP c'ase activity per-unit leaf area compared to plants grown in the normal air, thus leading to an increase in weight of per unit of leaf area. However, an increase in the net assimilation rate was found in Echinochlo crusgalli and Elusine indica (Potvin & Strain, 1984).

Kidd (1915) demonstrated that the increased CO_2 concentration has a definite repressing effect on respiration in case of germinating white mustard seeds. Decreased rate of respiration was reported in Commelina communis (Saish et al., 1989). Although numerous studies of leaf respiration have indicated a depressing effect of CO_2 (Delvin, 1973). There is evidence that this effect may be partially indirect. Heath (1950) demonstrated that CO_2 can cause stomatal closure thus limiting the gaseous exchange. This may inturn, raise internal concentration of CO_2 considerably and thereby retarded respiration.

In some plants CO_2 induces partial closure of stomates through which CO_2 enters the leaf and the water vapour simultaneously escapes in transpiration. A reduction in the aperture of leaf stomates was reported in *Vicia faba* (Spence *et al.*, 1984). This partial closure of stomates should still allow some amount of CO_2 to enter, as the CO_2 gradient would be greater in a high CO_2 environment, but must reduce the loss of water vapour as the humidity gradient will be little altered. The net effect is that some plants should be more resistent to water stress (and more tolerant of atmospheric pollution as partially closed stomates impede entry of potentially harmful air pollutants into the leaves). It is suggested that CO_2 should be studied in relation to plant sensitivity to air pollutants (Brandt & Heck, 1968). This relation can be well demonstrated in terms of stomatal responses, as the stomatal reaction to CO_2 could occur even in the presence of a pollutant or its combinants (Majernik & Mansfield, 1972; Srivastava *et al.*, 1975 b; Black, 1982), and it plays an important role in restricting the fluxes gaseous pollutants into a plant which may help to mitigate the effect of pollution but does not eliminate them (Law & Mansfield, 1982). Stomatal conductance was found to be decreased after an exposure of plants to high CO_2 concentration in case of *Ochroma lagopus* and *Pentaclettra macnloba* (Oberbaulr *et al.*, 1985). Williams (1986) also showed reduced stomatal conductance in various decidous trees growing in high CO_2 concentration. However, Havelka *et al.* (1984) showed increased leaf conductance in *Glycine max*.

There are indications that high CO_2 concentration alters photosynthetic characteristics which finally lead to change in growth pattern (Hofstra & Herketh, 1975; Hicklenton & Jollifee, 1978). Leaves of Nerium oleander when grown at twice the atmospheric CO_2 concentrations, were 25-30% greater in fresh weight and soluble protein per-unit area than in untreated leaves (Dawnton et al., 1980).

That the elevated level of CO_2 concentration caused an increase in the total dryweight of plants was reported in Glycine max (Peet, 1984; Rogers, 1984; Allen et al., 1988); Lycopersicum esculentum and six cultivars of Lactuca sativa (Mortensen, 1985); Ipomea batatos (Bhattacharya et al., 1985) and carrot and raddish (Idso & Kinball, 1989). However, no significant difference in total plant dry weight was observed in Pisum sativum (Paez et al. 1980).

Bhattacharya et al. (1985) noted, in case of Ipomea batates, that plants grown in high CO_2 concentration showed increase in the length of main stem, total branch length, number of branches, leaf area and specific leaf weights. The specific leaf weight also increased in Ochroma lagopus and Pentaelettra macnloba (Oberbaulr et al., 1985).

That the additional CO_2 concentration caused an increase in the leaf dry weight was recorded in Phaseolus *vulgaris* (Jolliffe & Ehret, 1985) and *Glycine max* (Sionit, 1983). However a decreased value for leaf dry weight was reported in *Pisum sativum* (Paez *et al.*, 1980). Similarly, leaf area showed higher values in many plants (see O'Leary *et al.*, 1981; Oberbaulr et al., 1985; Sasck, 1986; Richers & Strain, 1988; Baker *et al.*, 1989). Conversely, there was no significant change in the leaf area in *Glycine max* (Leadley, *et al.*, 1988) and *Phaseolus vulgaris* (Jolliffe & Ehret, 1985). Higher concentrations of CO$_2$ considerably retards leaf area ratio (LAR) (See Jolliffe & Ehret, 1985; Rogers *et al.*, 1984; Oberbaulr *et al.*, 1985). However an increase in the net assimilation rate (NAR) was noted in *Glycine max* Merr CV. Bragg (Clough & Peet, 1981; Rogers *et al.*, 1984). Root dry weight gets increased in *Pisum sativum* (Paez *et al.*, 1980) but there was no significant change in *Phaseulus vulgaris* (Jolliffe & Ehret, 1985).

The total above-ground biomass increased in *Glycine max* (Baker *et al.*, 1989) and *Ochroma lagopus* and *Pentaclettra macnloba* (Oberbaulr *et al.* 1985). However, no significant change in the above ground biomass was reported in *Carex bigelowie*, *Betula mana* and *Ledum palustra* (Oberbaulr, 1986). Williams *et al.* (1988) studied high carbondioxide concentration response in *Plantago erecta*, *Micropus californicus*, *Agoreris heterophylla*, *Leyia platyglossa* and *Lasthenia glabrate* showing changes in the biomass of some species while total community biomass had no significant changes.

That the additional CO_2 caused an increase in the relative growth rate (RGR) of plants, was reported in *Bouteloua gracilis* (Richers & Strain 1988) and *Glycine max* (Rogrers *et al.*, 1984). Whipps (1985) also noted an increase in the RGR of roots in *Zea mays*. The overall growth of plants also increased in *G. max* (Sionit *et al.*, 1987), maize (Whipps, 1985); *Boutelow*. *gracilis* (Richers & Strain 1988) and in three aquatic and terestrial species (Idso *et al.* 1987).

Higher CO_2 concentration has been found to cause some injuries in leaves. Houpis *et al.* (1988) reported in two varieties of pine (*Pinus ponderosa* var. ponderosa (Sierran variety) and *Pinus penderosa* Dougl var. *Scopulorum*, symptoms of stress, including mottling and mid-needle abscission and early senescence. The senescence also occurs in *Glycine max* (Sionit *et al.* 1987; Ehret & Jolliffe (1985) found in *Phaseolus vulgaris* that primary leaves showed chlorosis when subjected to elevated CO_2 concentration. Marginal leaf necrosis was reported in *Lycopersicon esculentum* and *Lactuca sativa* (Mortensen, 1985).

OZONE

The complex series of photochemical reactions produces various oxidants, ozone (O_3) and Peroxyacetyl nitrate (PAN) being the most important. These photochemical oxidants are secondary pollutants produced by the action of sunlight in an atmosphere containing reactive hydrocarbons and oxides of nitrogen (Grennfelt & Schjoldager, 1984). As explained earlier, in the presence of radient energy NO_2 quickly splits into NO and atomic oxygen, which combines with the molecular oxygen of the atmosphere to form ozone.

$$NO_2 \xleftrightarrow{hv} NO + O; \quad O_2 \xleftrightarrow{m} O_3$$

where hv = light energy, m = any inert molecule.

The net reaction is :-

$$NO_2 + O_2 \rightleftharpoons NO + O_3$$

Here the back reaction theoretically proceeds faster than the initial reaction so that ozone gets removed from the atmosphere. However, hydrocarbons present in the urban atmospheres react with and remove NO, stopping the back reaction so that ozone accumulates. In the dark, the net reaction is reversed, and NO_2 accumulates at the expense of ozone.

Ozone can form naturally in the atmosphere such that background mean monthly concentrations vary from 0.005 to 0.04 ppm by volume (10-80 $\mu g/m^3$) depending upon latitude and month of the year, Hourly background values range from 0.005 to 0.05 ppm (10-100 $\mu g/m^3$). In contrast, ozone levels in urban areas may reach peak-hourly concentrations of 0.15 to 0.40 ppm (300 - 800 $\mu g/m^3$). In some large cities, maximum one hour oxidant concentrations exceed 0.1 ppm (200 $\mu g/m^3$) on 5-30 percent of days, while in southern california, peak hously values usually exceed 0.10 ppm (200 $\mu g/m^3$)on most days of the month between May and September (World Health Organisation, 1979 b). In 1985, 0.10 ppm of ozone was exceed on 107 days of the year in Los Angeles, on 173 days in Pasadena, and on 166 days in Azusa (US SCAQMD, 1986).

Increased anthropogenic emissions of the precursors of ozone formation have led to increasing tropospheric ozone concentrations in the middle latitudes of the Northern Hemisphere (Angell & Korshover, 1980). Fishman _et al._ (1979) have calculated that infrared - radiation absorption by ozone has made for an increase by 20°C to the average temperature of the Northern Hemisphere. If tropospheric ozone concentrations were to double, it is estimated that global surface temperature would increase by 0.7° to 0.9°C (Hov, 1984; Lal _et al._, 1986).

EFFECT OF OZONE ON PLANTS :

Ozone is a widespread and damaging air pollutant in the united States, Europe, Japan and other industralized areas of the world (Jacobson, 1982; Kozoil & Whatley, 1984; Treshow, 1984). Ozone's deleterious effects on plant growth and agricultural production are well documented (eg; Laurence & Weinstein, 1981; Jacobson, 1982; Heck *et al*. 1982, 1983; Heggestad & Bennett, 1984).

Visible injury on vegetation is one of the earliest and most obvious manifestations of ozone injury. However, ozone effects are not limited to visible injury, they may cause reduced plant growth, decreased yield, changes in crop quality and alterations in susceptibility to abiotic and biotic stresses. Plant foliage is the primary site of ozone impact although significant secondary effects including reduced growth (both roots and foliage) and yield can occur.

Ozone exerts a phytotoxic effect only if a sufficient amount reaches the sensitive cellular sites within the leaf through stomata. Ozone has been noted to cause a decreased stomatal size and stomatal closure in *satsuma mendarin* and *Citrus unshiu* (Matsushina *et al*., 1985). Stomatal conductance has been found to get decreased in *Fraxinus pennsylvanica* (Jensen, 1982); *Triticum aestivum* (Amundson *et al*., 1987);

Helianthus annus (Fujinum *et al.*, 1988) and yellow poplar seedlings (Chappelka *et al.*, 1988). After ozone has entered the leaf through stomata , it can exert some control on uptake, to the active sites within the leaf. Injury will not occur if (1) The rate of ozone uptake is low enough to enable the plant to detoxify or metabolize ozone or its metabolites; or (2) the plant is able to repair or compensate for the ozone impacts (Tingey & Taylor, 1982). This is analogous to the plant responses to sulfur dioxide (Thomas, *et al.* 1950). Cellular damage where the mesophyll cells got disrupted and cell injury increased with increasing ozone concentration was reported in *Picea rubens* (Jean, 1989). In *Raphanus sativus* ozone also induces an increase in both number and size of plastoglobules but a decrease in chloroplast dimension; it causes disruption of tonoplast followed by collapse of cells (Miyaki, 1989), and cellular disturbances that are not repaired or compensated are expressed ultimately as visible injury to the leaf or as secondary effects evident in reduced root growth and/or reduced yield of fruits or seeds.

Ozone induces a diverse range of effects on plants and plant communities. These effects are usually classified as either injury or damage. Injury encompasses all plant reactions such as reversible changes in plant metabolism (e.g.; altered photosynthesis), leaf necrosis, altered plant quality, or reduced growth that does not impair yield or the intended use of the plant (Guderian, 1977). In contrast, damage or yield loss includes all effects that reduce the intended use of the value of the plant, such as a reduction in the quality, aesthetic value, or any impairment in the intended use of the plant. For eg; visible foliar injury to ornamental plants, determintal responses in native species and reductions in fruit and grain production are all considered as damage or yield loss.

For growth to occur, plants must assimilate CO_2 and convert it into organic substances; an inhibition in carbon assimilation (Photosynthesis) may be reflected in plant growth or yield. In several species, ozone (at 0.05 ppm and greater) hampers photosynthesis as measured by gas exchange (eg; U.S. Environmental Protection Agency, 1978; Coyne & Bingham, 1978; Black et al., 1982). Similar inhibitionsin photosynthesis were noted in many plants (See Horsman et al., 1982; Blum et al., 1983; Lener et al., 1987; Amundson et al., 1987). Photosynthetic pigments play an important role in the process and ozone could alter the pigment concentration in plants. When plants were subjected to high ozone concentrations; the foliar pigments (Chlorophyll, Carotenoid etc.) undergo a considerable reduction. It was noted in soybean (Pratt & Krupa, 1981); Vicia faba (Agarwal et al., 1985); Raphanus sativus (Johnstone et al., 1986); Triticum aestivum (Lehnher et al., 1988); Medicago sativa (Takemoto et al. 1988) and Triticum aestivum (Grandjean & Fuhrer, 1989). In contrast, ozone increased the chlorophyll content in Acer succaharum and Quercus rubra (Reich, 1986). However, ozone was found to have no influence on the chlorophyll content of Fraxinus americana and F. pennsylvanica (Catherine et al., 1987) and red spruce seedlings (Alscher et al., 1989). Christopher et al. (1987) noted in Triticum aestivum a decrease in the Hill activity and increase in the solute leakage when plants were affected with ozone.

Biochemical studies showed that ozone (0.12 ppm for 2 hr.) inhibited on enzyme (ribulose-1, 5-biphosphate - carboxylase that catalyzes the assimilation of CO_2 (Pell & Pearson, 1983). Similarly, Lehnher, et al.(1988) noted in Triticum aestivum that photosynthesis in ozone-stressed leaves is limited by ribulose biphosphate carboxylation possibly due to an effect of ozone on the catalysis of ribulose biphosphate carboxylase/oxygenase.

Ozone also causes a remarkable alterations in the protein, starch and carbohydrate contents of the plants. Ozone caused a reduced content of protein in Vicia faba (Agarwal et al.,

1985) and wheat (Lehnher *et al.*, 1988; Grandjean & Fuhrer, 1989). Rebbeck *et al.* (1988) reported in case of *Trifolium repens* that increasing ozone concentrations reduce the energy reserves (Starchs) of roots where shoots were not greatly affected, while in case of *Festuca arundinacea* the energy reserves (Starch + Fructosan) were not affected by ozone. Roots of *Fraxinus pennsylvanica* affected by ozone showed decreased contents of starch, sucrose and reducing sugars (Jensen, 1982). Similarly, less starch and carbohydrates were reported in *Medicago sativa* (Cooley & Manning, 1988) and *Vicia faba* (Agarwal, *et al.* 1985). In contrast, an increase in the reducing sugars of tubers in potato was found by Pell *et al.* (1980). However, ozone did not change the amount of foliar starch and root carbohydrate in red spruce seedlings (Alscher *et al.*, 1989). Same contents of root total nonstructural carbohydrate were also reported in *Trifolium repens*, but the total nonstructural carbohydrate underwent a considerable reduction (Blum *et al.*, 1982).

Plant yield is often thought in terms of dry matter production, and dry matter is largely made up of carbon compounds. Therefore, plant growth and yield are inherently linked to photosynthetic carbon fixation, and the partioning of this assimilate. Ozone stress decreases photosynthesis

(Kozoil & Whetley, 1984; Reich & Amundson, 1984) and alters photoassimilate partitioning in plants. Recent studies on photoassimilate partitioning have used labelled carbon (^{13}C or ^{14}C) to follow the effect of ozone stress on bean (McLaughlin & McConathy, 1983; Okano *et al.*, 1984 a, b; Ito *et al.*, 1985). These studies showed that ozone generally inhibited both CO_2 fixation and translocation in the primary leaf, which is the main source of photosynthate for root growth. Partitioning to potato (*Solanum tuberosum*) tubers is reduced less by ozone than partitioning to shoots and roots (Foster *et al.*, 1983). Leaf and root dry weights were effected approximately equivalantly. The number of tubers is reduced, as well as the tuber size (Pell & Pearson, 1984), but relative tuber weight reductions were less than those of other plant organs (Foster *et al.* 1983). In a study of field-grown potatoes, yield reductions were attributable to small tuber in one cultivar, and fewer tubers in another (Clarke *et al.*, 1983). Ozone also reduces percent dry matter and increases total reducing sugars in tubers (Pell & Pearson, 1984).

Ozone stress has also various effects on dry matter partitioning in trees, though much of the testing is limited to seedlings. Kress and Skelly (1982) exposed several tree species to low levels, (.15 ppm) of ozone, and found that Sycamore (Platanus occidentalis) and loblolly pine (Pinus taeda) were most affected.

Since plant growth and production depend upon the photosynthetically functioning leaves, the ozone has been noted to cause foliar injury (both visible and invisible) in plants. A premature chlorotic mottle of leaf tissue followed by stippling and bleaching of foliage and necrosis was reported in Citrullus lanatus (Decoteau et al. 1987). However old leaves were more affected than young leaves. Similarly small necrotic flecks were reported in Phalaris aquatica (Horsman et al., 1980) and white clover (Beeker, 1989). Foliar injury due to O_3 was also found in other plants (See Bytnrowicz et al., 1988; Fujinuma et al., 1988; Christopher et al., 1989).

The impact of ozone on a number of morphological parameter such as root, stem and leaf dry weights; seed size, number and dry weights and overall growth of the plants has been well studied. Ozone causes considerable reductions in dry weights of root, stem and leaf. Considerable reductions occurred in Fraxinus pennsylvanica (Jensen, 1982); Trifolium repens (Blum et al., 1982); Liriodendron tulipifera (Keith, 1985) and Gossypium hirsutum (Miller et al., 1988). Amthor (1988) reported in case of Phaseolus vulgaris exposed to ozone that relative growth rate (RGR) was significantly reduced by increasing ozone dose and for a given RGR, specific respiration rate was significantly increased. Relative growth rate RGR) also decreased in *Trifolium subterraneum* and *T. repens* (Horsman *et al.*, 1982), *Liriodendron tulipifera* (Keith, 1985) and *Medicago sativa* (Cooley & Manning, 1988). The overall growth of plants decreased in soybean (Amundson, *et al.*, 1986; Kohut *et al.*, 1986; Kohut & Amundson, 1986); *Raphanus sativus* (Carol *et al.* 1988). However, Reich (1986) noted *Quercus rubra* that ozone had no effects on its growth.

The most devastating effect of ozone is its effect on yield reduction. The yield undergoes considerable reduction when plants are either fumigated with ozone or growing in an O_3 enriched atmosphere. Yield reduction has been noted in many plants by several authors (See Kohut & Laurence, 1983; Keith, 1985; Rawlings & Cure, 1985; Temple, *et al.*, 1986; Amundson *et al.*, 1987; Krupa & Manning, 1988; Takemoto *et al.* 1988; Grandjean & Fuhrer, 1989). The data also suggest that ozone impaires the fertilization process in plants. This suggestion has been confined to tobacco and corn studies using low concentration (0.05 ± 0.06 ppm) of ozone. (Feder, 1968; Mumford et al., 1972) and more recently Amundson *et al.* (1986) reported in soybean that ozone delayed the onset of flowering.

ACID RAIN :

"What goes up must come down" is a famous saying. In many cases, though, what comes down is far worse than what went up. This is applied exactly to the phenomenon called 'Acid Rain'. Acid rain approximately contains about 65% H_2SO_4, 30% HNO_3 and 5% HCl.

SO_2 is oxidised to SO_3, which forms H_2SO_4 mist within seconds by reacting with water. Someties, SO_2 directly combines with water and forms H_2SO_3.

In the same way, nitrogen oxides are oxidised to nitrogen dioxide and later combine with water to to form HNO_3. The velocities with which these reactions take place, depend on the degree and kind of pollution. The acid formation may occur instantaneously or may take a couple of weeks. The acids, so formed, show effects on material immediately if the meteorological conditions join hands with pollutants. Humidity, temperature and wind are considered important meteorological factors. Even in highly polluted areas, one may expect the materials and structures without any damage in the absence of humidity. Temperature, no doubt , speeds up the reaction. HCl is emitted directly from coal fired power plants and deposits at relatively shorter distances.

1. $CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$
2. $SO_2 \xrightarrow{\text{Catalysts}} H_2SO_4 \longrightarrow 2H^+ + SO_2^{2-}$
3. $NO \xrightarrow{\text{Catalysts}} HNO_3 \longrightarrow H^+ + NO_3^-$

Impacts of acid rains on agricultural crops and forests may be observed from two different angles. First acid precipitation can directly effect the foliar surface and ultimately the plant, and second, it can indirectly effect the plant through its effect on the soil.

Acid rain effects top soil or specifically the surface of the soil particles severely. Leaching of nutrients in humus layer of the soil may be accelerated and thereby reduce productivity. As such, above ground biomass and below ground biomass (soil biodata) also decrease. Soil respiration is decreased. Manipulations in nutrient cycles in agricultural and forestry lands can result in lowering of fertility over long term.

Acid rain accelerates cuticular erosion and provides an opportunity to pathogens and saprophytes for direct contact with the leaf tissue system. The acid rains may show visual leaf injury, plasmolysation of palisade cells, chloroplast structural damage & damage to surrounding cells, Reduction in plant dry weight and chlorophyll content may also occur. Correlation also exists between increasing rain acidity and increasing foliar leaching of nutrients.

AIR POLLUTANT MIXTURES AND THEIR EFFECTS ON PLANTS :

The air shed around urban and industrial areas is usually contaminated with complex mixture of air pollutants which may be toxic to plants. These pollutants may include solid particulate matter and gases like SO_2, NO_x, O_3, fluoride (F), hydrocarbon (HC), PAN etc. Under natural conditions, the plants growing in such areas, are simultaneously exposed to all these pollutants : obviously the nature and quantum of impact of a mixture of pollutants on vegetation would not be the same as that of a single pollutant.

As early as in 1950, it was suggested that in a pollutant mixture, possibly one pollutant influences the level of plant response to the other pollutants. Thomas *et al.* (1952) in a green house experiment, observed that plants exposed to either O_3 or SO_2 at a particular concentration remained uninjured but there was a significant foliar injury when the plants were exposed to a mixture of the two gases at the same concentration. Subsequent studies have shown that pollutant combinations cause not only the foliar injury but also impair other process to alter the growth and development of plants. So for, in most studies, a mixture of two pollutants is used and the important combinations used are $SO_2 + O_3$, $SO_2 + NO_2$, SO_2 + HF, $NO_2 + O_3$ and a few others with particulates.

For describing the cumulative responses of plants to pollutant mixture, terms like synergistic, additive and antagonistic are used in literature (Tingey & Reinert, 1975). When the level of effect of pollutant's mixture is greater than the sum total of effects of individual pollutants, the effect is known as synergistic, when equal to, then it is additive and when less than additive then antagonistic. In situations when one pollutant of the mixture produces no effect of its own but it helps intensify the effect of the other pollutants, the term 'potentiation' is used. Sometimes in a pollutant mixture there may be marking or hardening effects when one pollutant tends to reduce the effects of other pollutants.

SULPHUR DIOXIDE AND OZONE ($SO_2 + O_3$)

The pollutants SO_2 and O_3 are important with respect to phytotoxicity. Measurable concentrations of these gases are frequently met with-in Urban industrial areas, from where there may drift by air flow to rural areas. The effect on plants of SO_2 and O_3, together in a mixture, first demonstrated by Menser and Heggested (1966), shows that their action was more than additive or synergistic and that the injury threshhold level for individual gases was reduced when they acted in combination. Dochinger *et al.* (1970) showed that mixtures of SO_2 and O_3 at concentrations below the threshhold for SO_2, and at O_2 below the threshhold for ozone, produce symptoms in eastern white pine which were similar to those caused by ozone.

Foliar injury due to exposure of plants to (SO_2+O_3) has been reported in many plants(See, Agarwal, 1982; Rao, 1982; Pratt *et al.*, 1983; Deveau *et al.*, 1987; Rezabeck *et al.* 1989). Reductions in chlorophyll contents and photosynthesis have also been reported in several plant species (See Agarwal *et al.* 1982b; Norby *et al.*, 1985).

Keith (1981) demonstrated that there was a decrease in the relative growth rate, relative leaf area expansion rates, relative leaf weight and total biomass in cuttings of hybrid poplar clone (*Populus deltoides* x *P. trichocerpa*). There was also a reduction in biomass in all F_1 groups of *Raphanus sativus* exposed to high $SO_2 + O_3$ concentration (Chris & Williame, 1989).

$O_3 + SO_2$ mixture caused an inhibition in growth of plants, eg., in soybean (Reinert & Weber, 1980; Norby *et al.*, 1985) and *Hordeum vulgare* (Ashmore & Q al, 1984). Reductions in root, shoot length, number of tillers, phytomass accumulation and net primary productivity were also reported in *Panicum miliaceum* (Agarwal, 1982a).

OZONE AND NITROGEN DIOXIDE (O_3 + NO_2)

Japanese workers made extensive studies on the interactive influence of NO_2 and O_3 on plant growth. However the information available on this aspect is still meagre. Matsushima (1971) showed that the injury level in tomato and pepper plants, exposed to a mixture of 0.4 ppm O_3 and 1.5 ppm NO_2, was less than one when exposed to the same concentrations separately. Similar observations were made by Kress (1980) on ten tree species exposed to O_3 + NO_2.

Reduced relative growth rate of plants exposed to O_3 + NO_2 was observed in sunflower (Shimizu *et al.*, 1984) and *Liriodendron tulipifera* (Jensen, 1985). Osaminto *et al.* (1985) noted a reduction in dry matter production and root/shoot ratio, and a suppression of growth in general.

The transpiration rate of young *Nerium indicum* and *Euonymus japonica* trees was decreased by a mixture with 0.1 ppm each of NO_2 + O_3 (Natori & Totsuka, 1984). Synergistic inhibition of transpiration was observed in sunflower plants treated with NO_2 + O_3 mixture and this effect probably was due to stomatal inhibition by ozone since NO_2 alone had no influence on stomatal aperture (Furukawa *et al.*, 1984). *Phaseolus vulgaris* exposed to O_3 + NO_2 showed an increase in ammonium level and percentage of aspargine. Besides, roots showed remarkable increase in the contents of total amino acids (Ito et al., 1986). In the same plant, Osaminto et al. (1985) showed an increase in the total N content of plants but a reduction in assimilation of NO_2 and concentration of soluble sugars.

PEROXYACETYL NITRATE AND OZONE (PAN + O_3)

The secondary pollutants, PAN and O_3 are extremely toxic to plants. Ozone increases respiration of leaves and Kills the plants by depleting their food, while PAN blocks 'Hill reaction' in photosynthesis, thus killing the plant by shutting down the food production (Taylor et al., 1961; Middleton & Heagen-Smit, 1961; Dugger et al., 1966).

Plant responses to combinations of PAN and O_3 at ambient concentrations are less than additive. However, at high PAN concentrations, PAN and O_3 interact synergistically to produce foliar injury (Kohut et al., 1976). Similarly, sequential exposures of PAN and O_3 produces greater than additive foliar injury in hybrid poplar (Kress, 1972). In pinto bean the responses to PAN and O_3 mixture were additive or synergistic on the adaxial leaf surface and antagonistic on the abaxial surface (Kohut & Davis, 1978). Alternating exposures of petunia plants to ozone followed by PAN or to

PAN followed by O_3 produced injuries which were equal to that produced by O_3 alone in the first case and that produced by PAN in the latter (Nouchi et al., 1984).. However, simultaneous exposures of petunia and kidney bean plants to O_3 and PAN resulted in foliar injury which was less than additive. Temple (1982) reported that combinations of PAN and O_3 generally produced less than additive affects on growth of some tomato cultivars.

SULPHUR DIOXIDE + NITROGEN DIOXIDE AND OZONE (SO_2 + NO_2 + O_3)

Reinert et al. (1982) tried 27 combinations of NO_2, SO_2 and O_3 on 16-day-old radish plants, exposed once for 3 h, and found increasing concentrations of ozone in the presence of increasing concentrations of NO_2 and SO_2 to reduce linearly the root fresh and dry weights. NO_2 was found to play a significant role in the response of radish to SO_2 and O_3. In another trial, radish and marigold plants were fumigated for 9 x 3 h over a 3-week period with 0.3 ppm each of NO_2, SO_2 and O_3. The effects of three pollutants on weight change in radish were found to be independent of each other. In the case of marigold, on the other hand, the effects of SO_2 on root weight were strongly dependent on the presence of both NO_2 and O_3, suggesting complicated interactions (Reinert &

Saunders, 1982). Fangmeier (1989) noted that the forest floor vegetation (geophytes) affected by SO_2 + NO_2 + O_3 show severe loses of leaf area and the above ground life span was reduced upto 3 weeks as expressed by senescense. Trifolium repens and Plantego major exposed to high SO_2, NO_2, and O_3 showed changes with weakly differentiated mesophyll, and different macroscopic and and histological symptoms were apparent (Krol et al., 1982). Petunia plants exposed to a mixture of SO_2 + NO_2 + O_3 showed significantly mole accumulated total S content (Elkiey & Ormrod, 1981).

Eighteen cultivars representing six species of cool season turf grasses were fumigated continuously for 10 days with a mixture of NO_2 + SO_2 + O_3, each gas at a concentration of 0.15 ppm (Elkiey & Ormrod (1980), while cultivars varied in sensitivity, the combined exposure caused more leaf injury and greater reduction in leaf area. These authors suggest that injury by one gas could affect the uptake of others. Since NO_2 proved to be innocuous, the culpit should be either SO_2, O_3 or both together.

PARTICULATE AIR POLLUTANTS

The term suspended particulate matter refers to the wide range of finely divided solids or liquids dispersed into the air by combustion processes (heating and power generation), industrial activities and natural sources. Suspended particulates range in size from 0.1 upto about 25 µm in diameter. The constituents of suspended particulate matter vary over time and space, although typical constituents in urban areas include carbon or higher hydrocarbons formed by incomplete comubstion of hydrocarbon fuels. In Europe, measurements of suspended particulate matter are based on soiling properties and in U.S.A. the monitoring techniques are based on weight. The World Health Organisation (1976 a) recommends the former suspended particulate matter sample to be refferred to as 'smoke' (or sometimes 'soot'), and the latter as 'total suspended particulate' (TSP).

Suspended particulate matter and sulphur dioxide are often regarded as the 'traditional' pollutants of the urban areas. The highest levels of these pollutants occurred during the sulphurous smogs to which most industrial cities have been subjected in the past. The term 'smog' refers to the synthesis of smoke and fog. Smogs are caused by vast quantities of pollutants being emitted from industry as well as domestic sources (for eg; Coal fires, apartment in cinerators) during periods when meteorological conditions fail to disperse the pollution away from the city. With the moisture added to the atmosphere by combustion processes, the availability of vast quantities of condensation nuclei in the form of suspended particulates, and the low temperatures that increase the relative humidity, fog formation is encouraged. The fog droplets readily dissolve SO_2 to produce sulphurous acid thereby adding to the potentially harmful nature of the smog. A polluted fog in less readily evaporated by solar radiation than a 'clean' fog', so the duration of the smog or pollution episode may be prolonged.

There is hardly any place on the earth and in the atmosphere which is 'particulate free'. Particles of fumes, dusts, soot and droplets can be well identified if a sample of air from urban atmosphere is analysed. The particles differ in shape, size and composition and have their individual history in the atmosphere with reference to their mode of origin, growth, interaction and decay (Corn, 1968). There is no sharp line of demarcation between gaseous and particulate matters in the air. However, the most prevalent and persistent suspended solid and liquid particles fall within the range of 0.01 μm to 100 μm. Particles of the smallest size (0.01 μm) are known as aerosols. They form 'mist' with liquid particles and 'dust' with solid particles, regardless of the particle size (Corn, 1968), while the smoke refers to the bye product of combustion.

Human activities, such as the manufacture of various products, introduce organic and inorganic particles into the atmosphere. These products include steel, rubber and a large variety of other items. In fact, almost all operations involving the burning of coal introduce some dust (that is, soot and fly ash) into the atmosphere.

The 'dust' is a complex mixture usually of solid particles only. It may be natural or man-made and viable or non-viable in in nature. The natural dust consists of fungal and algal spores, bodies of bacteria and viruses, pollen grains, mites and their excreta, meteorotic dust, ash of volcanoes, forest fires and dust storms, while the man-made dust are an outcome of his diverse activities such as combustion, handling and processing of solids, vaporizing operations, earth moving operations, explosions, constructions, refuge disposal and traffics.

McCrone et al. (1967) recognised three major types of dusts, the first comprises wind erosion particles which are mostly inorganic substances, such as soils, rocks and minerals, and are not likely to be harmful to plants. The second type consists of industrial dusts, possibly phytotoxic because of being the products of metal refining, foundry operations and cement and glass industries. The third one, a combustion product, consists of coal dust (solid particles) and fly ash which are detemintal for the living world.

The largest particles of the dust present in the polluted atmosphere are short lived and come down to the earth by gravitational pull, thus polluting the entire atmosphere in areas adjacent to the factory, while small particles may float in the air for several days and travel over great distances. Sometimes an interstate and even inter-continental transport of the particles is expected (Heagen-Smit & Wayne, 1968).

Large amount of dust is emitted into the atmosphere by various thermal electric plants and combustion processes using low grade coals. Perhaps 75 percent of the industrial dust (exclusive of soot) comes from fuel combustion (Rupp, 1956). Methem (1952) estimated that from the annual combustion of 180 million tonnes of coal in great Britain, 0.6 million tonnes of ash, 2.4 million tonnes of smoke and 5.2 million tonnes of SO_2 per year are released into the air. Katz (1956) estimated a dust fall of 67.5, 61.2 and 33.3 tonnes/mile^2/month for New York, Chicago and Los Angeles respectively. Several estimates by the "Bureau of Mines" suggest that fly ash released into the atmosphere appears to be about 10%

of the total ash in coal, and the solid waste products in the form of ash, after combustion of coal is about 25 to 30%. This clearly indicates that with the present rate of coal consumption in thermal power stations, we are adding an estimated 12.21 million tonnes of fly ash into the air, the rest getting dumped on land or in water (cited by Fulekar _et al._, 1982).

In a report, Rai (1984) states that three power plants of Delhi (Rajghat, Indraprastha and Badarpur), which use 2,000 - 2,500 tonnes of coal, release about 600 tonnes of fly ash daily. Each ton of the coal ash is said to contain seventy elements including 700 gm (Ni); 500 gm (Ar), 500 gm (Ge), 400 gm (U), 300 gm (Co), 200 gm (Sn), 100 gm (Pb), 20 gm (Bi) and 5 gm (Cd) (See Puri & Katyal, 1984). Textile mills emit considerable amount of cotton dust. Pandit _et al._ (1972) analysed the concentration of the air-borne cotton-dust particles (less than 2 mm in size) from coarse and fine cloth mills located in Maharastra, Vidharbha and Gujarat. They recorded an average dust content of 176, 274 and 763 mg/100 m^3 for fine cloth mills, coarse cloth mills and ginning process respectively.

EFFECT OF PARTICULATES ON PLANTS :

Dust particles are relatively inert and harmless. However, vegetation may be adversely affected by excessive quantities of air borne particles. Particles cover leaves and plug stomata, thereby both reducing the absorption of CO_2 from the atmosphere and the intensity of sunlight reaching the interior of the leaf, thus suppressing growth of some plants by disturbing the water relations, reduced photosynthesis, poor assimilation and sometimes causing necrosis in leaves. Lerman (1972) demonstrated limited clogging of stomata, damage to chloroplasts, disorganization of the cuticle and interference in normal photosynthesis in dust-dew treated bean plants. Necrotic spotting due to the acidity of soot particles was observed on leaves of several plants (Miller & Rich, 1967). The plants treated with coal dust, through heat imbalance, may change the mineral accumulation patterns (Withrow, 1967; Epstein, 1971). Pandey and Simbu (1988) reported that grain showed a reduction in the contents of Fe and P and calorific value but an increase in Ca content. Mineral concentration of the leaves of Diospyron melanoxylon growing near a thermal power plant was studied by Lal and Ambasht (1981). The leaf output was reduced by the fluoride gas.

Fly ash, a common product of coal combustion besides having large amounts of carbon, silica, alumina and iron oxides contains certain other metals such as Ar, Cd, Be, V, Se, Co, Cr, Cu, Hg, Ni, and Zn which are considered to be dangerous for living beings. Kumarvat and Dubey (1988) reported in case of Cassia siamea and Melia azadirchta growing in heavy fly ash and cement dust, a decrease in the chlorophyll content, stomatal conductance, and transpiration rate but a steady increase in leaf temperature and leaf extract pH (towards basic). Protein content and nitrate reductase activity, however, showed an initial increase followed by reductions. Mishra and Shukla (1986) reported that Zea mays and Glycine max treated with fly ash at low concentration showed increase in plant height dry matter production (probably due to boron deficiency) while at high dust concentration there was a decrease in plant growth as well as dry matter production (due to excessive uptake and accumulation of B and alkalinity caused by excessive soluble salt on the leaf surface). A decrease in contents of photosynthetic pigments was also reported under high fly ash concentration. Within two years of its operation many tree species around the Chandasi coal depot Varanasi, are already dead and many more are in the process of dying; several mango trees are standing dead with their branches completely defoliated. Some of the comparatively pollution-tolerant tree species, such as Dalbergia sissoo Roxb. are also severely affected as shown by decortication of bark and stunted growth. In these areas a large amount of coal dust is added to the soil, resulting in the alteration of edaphic properties and subsequently in plant growth (Rao, 1980).

Cement dust, a common air pollutant in the vicinity of the cement factories and around construction sites, is a mixture of Ca, K, Si, and Na oxides. The cement, with particles range from 0.1 to 100 µm in size. The cement dust emanating from the factory settles on surfaces of soil and vegetation, affecting a large area and brings changes in the soil characteristics. The soil near the cement factory becomes alkaline and, therefore unfavourable to plant growth. Under conditions of cement dust pollution plants get encrusted, with cement and consequently suffer reductions in their growth and yield (Singh & Rao, 1981); decrease in photosynthetic pigments (Lal & Ambasht, 1980; Ready & Dubey, 1986; Bokra, 1986) and disturbance in reproductive processes, especially pollination and fertilization (Bokra, 1986). It is likely that cement dust affects plants through leaf encrustation, stomatal plugging, solar radiation interruption and alteration (both in terms of quantity and intra-inter and extra-cellular pH-changes in leaf (See Lerman, 1972; Lal & Ambasht, 1982).

That the plants under cement dust pollution show a decreased intensity of respiration and catalase activity was noted in maize (Bokra, 1981). However, the same author in 1986, in winter barley affected by cement dust, showed an increase in the intensity of respiration and catalase activity but a remarkable reduction was noted in the number of flowers and spikelets. Yield and fertilization were also disturbed. Leaves of maize showed increased radiation intake which inturn increased plant temperature and evapotranspiration. Reddy and Dubey (1988) reported an increase in the stomatal conductance, transpiration rate, free proline but a decrease in chlorophyll contents in Butea monosperma, Ficus benghalensis and Mangifera indica growing in an area polluted with cement dust. A decrease in protein content, moisture content, total ash, fat and crude fibre but an increase in total carbohydrate content were noted in Zea mays (Pandey & Simbu, 1988).

Particulates sometimes indirectly aggrevate the situation in certain industrial areas (Williams et al. 1971). For instance, SO_2 present in the polluted atmosphere adsorbs on these particulates (dust and fly ash etc.), contacts wet tissues (such as inside the leaves) or moisture droplets and turns into H_2SO_4 which affects the sensitive species like sugar maple (Raynal et al., 1982). Studies of Auclair (1976) on the effects of particulate matters on the growth of forests showed no physical effect of dust (cement and coal) an photosynthesis at high light intensity i.e.; higher than 100 Wm^{-2}. However, at low and medium energy levels, photosynthesis got reduced which might cause decrease in growth and yield.

It is an established fact that vegetation acts as a filter for dust, soot and particulates of the atmosphere. A 27% reduction of dust particles in Hyde Park, London, due to a green area of only 2.5 square km. (See Meetham, 1964), a 2-3 times reduction in the dust fall by the development of an 8 meter wide green belt between the street and widely spaced buildings in some Russian cities (Novoderzhkina *et al.* 1966) and 42% reduction in the total dust fall by a canopy of conifers in the urban areas of Ohio USA (Dochinger, 1980) are on record. The dust collecting potential of plant leaf surfaces has been studied by many workers (Das, 1981; Yunus *et al.*, 1985). Yunus *et al.* (1985) studied the dust cleaning efficiency of eight plant species (growing near Lucknow city) in relation to leaf morphology and epidermal features especially to shape and size of leaf, orientation of leaf on the main axis-size and frequency of trichomes and cuticular configuration.

PLAN OF WORK

The following plan of work has been carried out for the comparative study of foliar, stem and root responses of some crop species to the ambient environment at different growth phases.

Selection of the Sites :

To make a comparative study of the effect of air pollution on growth, development and structure of leaves, stem and roots, certain crop species have been selected. The materials for the study will be collected from Aligarh University Campus and Kasimpur Thermal Power Plant Complex, considering the former as a normal location (Site A) and the latter as the polluted one (Site B). Materials will be collected from these sites in different seasons.

Aligarh is situated in the Ganga-Jamuna Doab between 27°29'N and 28°11'N latitude and 77°28'E and 78°34'E longitude. The whole district of Aligarh is located in an almost uniform level plain, the range of altitude being 622-640 feet. Its seasonal calendar contains a winter (December-February), a Summer (March-June), a rainy season (mid June-September) and a season of the southwest retreating monsoon (October-November).

The University Campus was selected as the normal site since the pollution, if at all, is quite nominal here. The only source of any possible air pollution being the light vehicle traffic and sporadic domestic fuel burning.

The Kasimpur town is situated about 16 kms. North-East of the Aligarh City. A Thermal Power Plant came up here some 41 years back on the banks of an irrigation canal which flows in eastword direction. Both the university area and the Kasimpur locality have similar ecological field conditions, particularly. The edaphic ones. However, Kasimpur is heavily polluted due to the presence of a Thermal Power Plant Complex which consists of three power stations 'A', 'B' and 'C' having a capacity of 90 MW, 210 MW and 230 MW. Power generation respectively. On an average the complex consumes about 1,530,715 metric tonnes of bituminous coal per year (Table III). The effluents emerging out of the coal burning are a mixture of many gases, coal dust and ash.

Selection of the Species :

A general survey of the selected sites has been made and the following crop species growing commonly at both the study sites have been selected to conduct the present investigation.

Crop	Botanical name	English name	Family
Pulse	*Cajanus cajan* L.	Red gram	Papilionaceae
	Cicer arietenium L.	Chicken pea	-
	Pisum sativum L.	Garden pea	-
	Vigna mungo L.	Black gram	-
	Vigna radiata L.	Green gram	-
Oil	*Brassica campestris* L.	Yellow Sarson	Brassicaceae
	Brassica juncea L.	Indian mustard	-
	Brassica oleraceae L. var. *botrytis* L.	Cauliflower	-
	Brassica oleracea L. var. *capitata* L.	Cabbage	-
Vegetable	*Daucus carota* L.	Carrot	Apiaceae
	Raphanus sativus L.	Radish	Brassicaceae
	Solanum melongena L.	Egg plant	Solanaceae
	Solanum tuberosum L.	Potato	-
Grain	*Hordeum vulgare* L.	Barley	Poaceae
	Pennistem typhoideum	Pearmilt	-
	Triticum sativum L.	Wheat	-
	Zea mays L.	Maize	-

Parameters to be Studied:

The following parameters have been chosen to make a comparative study of the growth responses in the selected species.

(A) Morphological :

(i) Length of the plant
(ii) Length of the root
(iii) Length of the shoot
(iv) Root biomass
(v) Stem biomass
(vi) Leaf biomass
(vii) Leaf number/plant
(viii) Leaf area / plant
(ix) Per leaf area
(x) Leaf fall and emergence
(xi) Leaf length width ratio
(xii) Petiole length
(xiii) Flowers, fruits, seeds/plant
(xiv) Injuries (types, extent)

(B) Anatomical :

(a) Epidermal features :-

i) Stomatal index and stomatal frequency
ii) Length and width of stomatal aperture
iii) Length and width of guard cell
iv) Length and width of trichomes
v) Size of epidermal cells.
vi) Gross leaf anatomy
vii) Proportional variation of various tissues.

(b) Stem and root anatomy :

i) Fibre length
ii) Vessel length
iii) Vessel width
iv) Area of cortex
v) Area of vasculature
vi) Area of pith
vii) Frequency of vessel elements in stem and root.

(C) Biochemical :

i) Estimation of chlorophyll
ii) Estimation of N, P, K
iii) Estimation of Sulphur
iv) Estimation of Cu, Fe, Mg, Mn, Ni, Pb and Zn

METHODOLOGY

The morphological, anatomical and biochemical responses to air pollution will be determined by applying the following methods.

Morphological Studies :

The plant height, root length and shoot length will be measured in cm. The shoot length covers the plant axis from the ground level to the uppermost growing tip of the main axis. For root length, the main tap root will be measured from the ground to the root tip. The plant height indicates the length of the entire axis extending from root tip to shoot tip. The leaf, root and shoot biomass will be determined by oven drying the material at 80°C for 48 hours and weighing (in grams) on chemical balance. Leaves will be counted per branch and their number multiplied with the total number of branches present in the plant in order to calculate the average leaf number per plant. The leaf area will be estimated with a planimeter in cm^2 and the dimensions of petiole and lamina measured in cm. Flowers, fruits and seeds per plant will be counted in the flowering and post-flowering phases on randomly selected individuals of each species.

Anatomical Studies :

The collected samples will be fixed in FAA and transferred to an alcoglycerol (in case of hard materials viz, root, stem) or 70% alcohol (in case of soft materials viz, leaf) for softening and preservation. To study the anatomical variation within the stem and root, fibres and vessel elements will be macerated by treating with hot HNO_3 (Ghouse & Yunus, 1972). The slices of wood, would be taken from the third internode, and that of the root from 1 cm. below the ground. Of the macerated elements, 50 vessel members and 100 fibres per sample will be measured at random with the aid of an ocular micrometer scale. Transverse sections of stem and root samples will be obtained on a Reicherts sliding microtome, in order to estimate the average width, relative abundance and proportion of the cortical vascular and pith regions. The sections, stained with Heidenhains haematoxylin and Bismarck brown (Johansen, 1940), and dehydrated in ethanol series, will be mounted in canada-balsam. The proportions of the various stem and root components will be calculated by the method based on the weights of paper cuttings of the camera lucida drawings made on a tracing paper of uniform thickness (Ghouse & Iqbal, 1975).

Internal structure of the leaf will be studied in transverse sections. For cuticular studies, epidermal peels will be obtained with the help of HNO_3 using the method evolved by Ghouse and Yunus (1972). The sections and epidermal peels will be stained by the method of Johansen (1940), and then dehydrated in ethanol series. Cells will be measured with the aid of ocular micrometer scale at suitable microscope magnifications. The variation in the relative proportion of different leaf tissues will be determined by the method devised by Ghouse and Iqbal, (1975). Counts of stomata and epidermal cells will be made on a compound microscope at suitable magnifications. Stomatal index (SI) will be calculated by the Salisbury's (1927) formula:

$$SI = \frac{S}{S+E} \times 100$$

Where S and E represent number of stomata and epidermal cells, respectively, in a microscopic field.

BIOCHEMICAL STUDIES :

Estimation of chlorophyll and carotenoid :

Since there is a close correlation between the amount of chlorophyll and the rate of photosynthesis, the primary productivity may be predicted on the basis of chlorophyll estimation (Billore & Mall, 1975; Kumar et al. 1980).

The chlorophyll content of leaves of the selected crop samples will be estimated according to Arnon (1949) using fresh leaf samples. The chlorophyll of one gram fresh leaves will be extracted in 80% acetone in the forenoon. The fresh samples of leaves in three replicates will be soaked in small amounts of 80% acetone, crushed gently with mortar and pestle to extract the chlorophyll and filtered with whatman's filter paper No.1. The volume of the chlorophyll will be made 100 ml by adding 80% acetone (80:20 acetone and distilled water). The absorption at 645 nm and 663 nm and 480 nm of the pigments will be read on spectrophotometer. The chlorophyll concentration in mg per gram of fresh sample will be calculated using the following formulae given by Maclachlan and Zalik (1963) and Daxbury and Yentsch (1956) for chlorophyll and carotenoids, respectively.

$$\text{Chl a mg/g frw} = \frac{12.3\ D663 - 0.86\ D645}{d \times 1000 \times w} \times V$$

$$\text{Chl b mg/g frw} = \frac{19.3\ D645 - 3.60\ D645}{d \times 1000 \times w} \times V$$

$$\text{Carotenoids mg/g frw} = \frac{7.6\ D480 - 1.49\ D510}{d \times 1000 \times w} \times V$$

where, D645 = Value of optical density at 645 absorption spectra.

D663 = Value of optical density at 663 absorption spectra.

D480 = Value of optical density at 480 absorption spectra.

V = Volume of extract

W = Leaf portion weight

d = Length of light path.

Estimation of N, P, K :

Relative proportion of N, P and K in the leaves will be estimated at different growth stages on dry weight basis. Normal leaves from each plant will be taken randomly, dried in an oven for 24 hours and powdered fine wih 72 mesh screen. The powder thus obtained and analysis which will be a accomplished by the methods of Linder (1944) as follows :

Digestion of Sample :

100 mg dry powder of leaves will be taken in a 50 ml Kjeldahl flask. Two ml of pure H_2SO_4 (BDH) will be added and the mixture be heated for about two hours to dissolve the powder. This heating with the acid will turn the content black. After cooling the flask for about

15 minutes, 0.5 ml of chemically pure 30% hydrogen peroxide will be added dropwise. The solution will be heated again for about 30 minutes, until it turns light yellow in colour. Then it will be cooled. With 3-4 drops of hydrogen peroxide, it will be reheated for about 15 minutes to get a clean extract. Excess of hydrogen peroxide will be avoided which would otherwise oxidise the ammonia in the absence of organic matter. The peroxide digested material with be transferred to 100 ml volumetric flask with three or four washings with DDW and the volume be made upto mark. This will serve as a stock solution for the estimation of N, P and K.

Estimation of nitrogen :

According to Lindner (1944), a 10 ml aliquot of the peroxide digested material will be transferred to a 50 ml volumetric flask. Two ml of 2.5 N Sodium hydroxide will be added to neutralise the excess of the acid partially. To prevent the turbidity, one ml of 10% sodium silicate will be added to the flask and the volume be made up. In a 10 ml graduated test tube, 5 ml of aliquot of this solution will be taken and 0.5 ml of Nessler's reagent will be mixed thoroughly. The final volume will be made up with DDW and kept for about five minutes for the maximum colour development.

This solution will be taken in a colorimetric tube and the optical density measured at 525 nm. A blank will also be run simultaneously during determination. A standard curve of known dilution of ammonium sulphate solution will be plotted. Reading of each sample will be compared with this calibration curve.

Estimation of phosphorus :

Phosphorous will be estimated by the method of fiske and Subbarow (1925). In a 10 ml graduated tube, 5 ml of aliquot will be taken and 1 ml of molybdate reagent will be added carefully, followed by 1, 2, 4, amino nepthol sulphonic acid (0.4 ml). This acid will turn the contents blue. The volume will be made up and the solution be allowed to stand for about 5 minutes for the maximum colouration. Later it will be transferred to a calorimetric tube and the optical density will be read at 620 nm. A blank will be run for each determination. A calibration curve will be prepared by using known dilutions of a standard monobasic potassium phosphate solution.

Estimation of potassium :

Potassium will be estimated using a flame photometer. A blank will be run side by side. The readings will be compared with a calibration curve plotted for different dilutions of a standard potassium sulphate solution.

Estimation of sulphur :

The oven-dried samples of leaves will be ground and passed through 72 mm mesh screen. 0.3 gram screened powder and 0.1 ml selanium dioxide (SeO_2) solutions will be digested using 10 ml HNO_3 and 1 ml HCl. The digested material will then be filtered in 100 ml volumetric flask. The volume of the digested material will be made up to 100 ml with 10 ml of 3% glycerol, and added with 5 ml of 2% $BaCl_2$ before using spectrophotometer. Optical density will be noted at 420 nm. Finally, with the help of a standard curve of the potassium sulphate solution, the actual sulphate concentration will be determined and expressed in mg SO_4 in unit dry weight (Patterson, 1958).

Estimation of Cu, Fe, Mg, Mn, Ni, Pb and Zn :

72 mesh screened dried samples of leaves of the selected species will be digested using HNO_3 and $HClO_4$. The digested material will then be filtered in 100 ml volumetric flask and the volume made up to 100 ml with the double distilled water. Cu, Fe, Mg, Mn, Ni, Pb and Zn will be determined in each solution on the atomic absorption spectrophotometer.

STATISTICAL ANALYSIS

The data collected on different parameters pertaining to the foliar study carried out at the different study sites will be statistically analysed as under to determine the degree of authenticity of results.

Mean ($\bar{X}$) :

The arithmetic mean, or simple or the so called average value may be easily computed by taking the sum of a number of values (X_1, X_2, X_3 .... and so on) and dividing by the total number of values (N) involved, thus,

$$\bar{X} = \frac{(X_1 + X_2 + X_3 \ldots\ldots\ldots X_n)}{N},$$

or $$\bar{X} = \frac{X}{N}$$

where X_1, X_2, X_3............... X_n = observations

N = number of observations.

Standard Deviation (σ or S.D.) :

Standard deviation is a measure of fluctuations in a sample produced as a result of chance factor's of sampling from the same population. It may be calculated by the following formula. For each parameter of the study.

S.D. for large sample

$$S.D. = \pm\sqrt{\frac{(\bar{X}-X_1)^2 + (\bar{X}-X_2)^2 + \ldots\ldots(\bar{X}-X_n)^2}{N}}$$

S.D. for small samples :

$$S.D. = \pm\sqrt{\frac{(X-X_1)^2 + (X-X_2)^2 + \ldots\ldots(X-X_n)^2}{N-1}}$$

where, $\bar{X}$ = Mean of the observations involved

X_1, X_2, X_3 ...... = observations

N = Number of observations.

Standard Error ($\sigma \bar{X}$ or SE) of Means :

S.E. of mean is a measure of reliability of a sample mean as an estimate of the population mean. It will be computed by using the following formula.

$$S.E. = \pm\frac{S.D.\ of\ Sample}{\sqrt{n-1}}$$

Standard Error of The Difference of Sample Means (S.E.D.)

It may be defined as the standard deviations computed from the difference between a large number of pairs of means of randomly selected samples from two populations. Standard error of the two samples viz. $\bar{X}$ and $\bar{Y}$ of two different populations becomes important when it is to be judged whether or not they differ significantly.

It will be computed as follows :

$$S.E.D. = \sqrt{\frac{(S.D._1)^2}{n_1} + \frac{(S.D._2)^2}{n_2}}$$

where, $S.D._1$ = S.D. of one samples

$S.D._2$ = S.D. of other sample

n_1 = No. of observations in one sample

n_2 = No. of observation in other sample.

Coefficient of Variation (C.V.) :

This measures the relative magnitude of variation present in observations relative to the magnitude of their arithmatic mean. It is defined as the ratio of S.D. to arithmetic mean expressed as a percentage.

$$\text{eg. } C.V. = \frac{S.D.}{\bar{X}} \times 100$$

where, S.D. = S.D. of the concerned sample or population

$\bar{X}$ = Arithmatic mean.

Test of Significance :

The test of significance is a device to find out whether or not an observed pair of means differs significantly from each other, or this difference is just a result of chance influence. It is a device, a criterion, to arrive at a judgement and confidence about the validity of a result. The following two tests will be applied for the purpose.

Student t-test :

It will be applied to test the significance of the difference between the two sample means (if any), each sample collected from the two study sites.

The following formula will be used to compute t-value which will be compared with the table value of 't' at their particular degrees of freedom. If calculated 't' value exceeds the table value the difference between the two samples will be treated as significant, otherwise the difference will be attributable to chance factor.

$$t = \frac{\text{Difference of two sample means}}{\text{Standard error of the difference}}$$

or $$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{(S.D._1)^2}{n_1} + \frac{(S.D._2)^2}{n_2}}}$$

where, $\bar{X}_1$ = Arithmatic mean of one sample.

$\bar{X}_2$ = Arithmatic mean of the other sample.

$S.D._1$ = S.D. of one sample

$S.D._2$ = S.D. of other sample

n_1 = No. of observation of one sample

n_2 = No. of observation of other sample.

Degree of Freedom (D.F.) :

Degree of freedom, to be applied to the number of data perticularly in t-test will be calculated as follows :

$$D\text{-}F = n_1 + n_2 - 2$$

where, n_1 = No. of observations of one sample

n_2 = No. of observations of other sample.

For its use in the least significant difference analysis (L.S.D.).

$$DF = \left[(T \times R) - 1\right] - \left[(R-1) + (T-1)\right].$$

where, T = Number of treatments

R = Number of observations

Least Significance difference (L.S.D.) :

This test is applied to compare all pairs of means. The following formula will be used to calculate L.S.D.

$$L.S.D. = \sqrt{\frac{2 \times MSE}{r}} \times t\text{-value}$$

where, MSE = Estimated varience of error.

r = No. of replicates.

$$MSE = \frac{SSQE}{(r-1) \quad (t-1)}$$

where, SSQE = Error sum of squires,

r = Number of replicates

t = Number of treatments

SSQE = SSQT — (SSQr - SSQt)

where- SSQT - Total sum of squires.

SSQr = Sum of squires between replications

SSQt = Sum of squares between treatment

SSQT = Sum of the squires of each value and substracted from it correcting factor(C.F.)

$$\text{where, C.F.} = \frac{(\text{Total})^2}{r \times t}$$

$$SSQr = \frac{\text{Sum of squares of replications}}{\text{No. of treatments-1}} - \text{C.F.}$$

$$SSQt = \frac{\text{Sum of squares of treatment}}{\text{No. of replications-1}} - \text{C.F.}$$

<u>Correlation Coefficient (r)</u> :

This is a statistical measure which indicates both nature and degree of relationship between two measurable characteristics, say height (X-Cm) and yield (y-gm). It will be computed as follows :

$$r = \frac{N \Sigma XY - (\Sigma X) \; (\Sigma Y)}{\left[(N \Sigma X)^2 - (\Sigma X)^2\right] \; \left[(N \Sigma Y)^2 - (\Sigma Y)^2\right]}$$

where, x = observations on height

y = observation on yield

OR

$$r = \frac{\Sigma (X-\bar{X}) \quad (Y-\bar{Y})}{\sqrt{\Sigma (X-\bar{X})^2 \quad (Y-\bar{Y})^2}}$$

where, X = observation on one character

$\bar{X}$ = Arithmatic mean of all x observation

Y = Observation on other character

$\bar{Y}$ = Arithmatic mean of all Y observation.

A correlation coefficient may very from-1 (Perfect negative correlation) to + 1 (Perfect positive correlation). Any value close to zero would denote a lack of correlation or a relatively week correlation.

Coefficient of Determination (d) :

It is a derivative of correlation coefficient when expressed in percentage, it shows percent variation.

$$d = (r)^2$$

or $d = 100\ (r)^2$ - expressed in percentage

where d = coefficient of determined

r = correlation coefficient.

Linear Regression :

Correlation coefficient elucidates the nature and degree of relationship between two characteristics. Due to such correlation when variation in one variable brings in acompanying changes in the other, it enables us to predict the value of one variable from the knowledge of other.

The regression line best fitting the observation is given by :

$$\hat{Y} = a + bx$$

$$b = \frac{N \Sigma xY - (\Sigma X) \quad (\Sigma X)}{N \Sigma X^2 - (\Sigma X)^2}$$

$$a = \bar{Y} - b\bar{x}$$

where, $\hat{Y}$ (y-hat) indicates the predicated value of Y for a given value of X. X, Y are observation of two variables, viz., height and yield a, b are the constants.

$\bar{X}$, $\bar{Y}$ are arithmatic means of all observations of the respective variables X & Y.

Processing and Interpretation of Data :

The data collected for quantitative characters will be analysed by a computer running on a computer programme prepared for the above mentioned formulae and the results will be interpreted with reference to climatic and geographical conditions of the study sites.

LITERATURE CITED

Ackerson, R.C., Havelka, U.D. & Boyle, M.G. 1984. CO_2 enrichment effects on soybean physiology II, Effects of stage specific exposure. Crop. Sci. 24(6) : 1150-1154.

Adams, D.F., Mayheew, D.J., Gnagy, R.M., Richey, E.P., Koppe, R.K. & Allen, I.W. 1952. Atmospheric pollution in the ponderosa pine blight area, spokene country, Washington Ind. Eng. Chem. 44 : 1356-1365.

Adams, J.A.S., Mantovani, M.S.M. & Lundell, L.L. 1977. Wood versus fossil fuel as a source of excess carbon dioxide in the atmosphere : a preliminary report. Science, 196, 54-6.

Adomait, E.J., Ensing, J. & Hopstra, G. 1987. A dose-response function for the impact of ozone on Ontario (Canada) grown white bean and an estimate of economic loss. Can. J. Plant Sci. 67(1) : 131-136.

Agarwal, A., Chopra, R. and Sharma, K. 1982a. The state of India's environment. Centre for Science and Environment, New Delhi (India), pp. 189.

Agarwal, M., Nandi, P.K. and Rao, D.N. 1982b. Effect of ozone and SO_2 pollutants seperately and in mixture on chlorophyll and carotenoid pigments of _Oryza sativa_. In : Water Air Soil Pollut. 18 : 449-454.

-------,---------------,--------------- 1985. Response of _Vicia faba_ plants to ozone pollution. Indian J. Environ. Health. 27(4) : 318-329.

-------, and Rao D.N. 1983. Effect of ozone and sulphur dioxide, singly and in combination on the metabolite contents of _Oryza sativa_. Proc. 70th Indian Sci. Congr. ABS. Section VI, pp. 103.

Agarwal, S.B., Agarwal, M., Nandi, P.K. and Rao D.N. 1987. Effect of SO_2 and Ekalux (EC 25) singly and in combination on the photosynthetic pigments of _Oryza sativa_ plants. J. Environ. Biol. 8(4) : 315-322.

Ahmad, S., Ismail, F. and Majeed, J. 1986. Effects of atmospheric pollution on chlorophyll and protein contents of some plants growing in Karachi region (Pakistan). Pak. J. Sci. Ind. Res. 29(6) : 464-467.

Ahmad, Z. and Khan, Kalimullah 1986. Effect of air pollution on the composition of bark in Mangifera indica. J. Tree Sci. 5(2) : 134-135.

Allen, L.H. Jr., Vu, J.C.V; Valle, R.R., Boote, K.J. and Jones, P.H. 1988. Non structural carbohydrates and nitrogen of soybean grown under carbon dioxide enrichment. Crop. Sci. (8) Jan. Feb.

Alscher, R.G. and Amundson, R.G. et al. 1989. Seasonal changes in the pigments, carbohydrates and growth of red spruce as affected by ozone. New Phytol. 113(2) : 211-223.

Amani, A.Z. 1982a. Studies on the pollution dynamics of some common weeds under the stress of environmental pollution M.Phil. dissertation, Aligarh Muslim University, Aligarh (India).

----------- 1982b. Studies on the pollution dynamics of some common weeds under the stress of environmental pollution Ph.D. Thesis, Aligarh Muslim University, Aligarh (India).

---------, Khan, P.R., Ghouse, A.K.M. and Farooqui, M.H. 1979. Vegetative and reproductive growth of Cassia occidentalis under the influence of acute environmental pollution. Geophytol. 9 : 165-166.

Ambasht, R.S. 1984. A Text Book of Plant Ecology. Student's Friends and CO., Varanasi (India).

Amer, S.M., Michael, E. and El-Ashry, Z.M. 1989. Cytogenetic effect of sulphur dioxide on Vicia faba plant. Cytologia (Tokyo) 54(2) : 211-222.

Amthor, J.S. 1988. Growth and maintenance respiration in leaves of bean (Phaseolus vulgaris L.) exposed to ozone in open-top chambers in the field. New Phytol. 110(3) : 319-326.

Amundson, R.G., Kohut, R.J., Schoettle, A.W., Raba, R.M. and Reich, P.B. 1987. Correlative reductions in whole-plant photosynthesis and yield of winter wheat caused by ozone. Phytopathology 77(1) : 75-79.

Amundson, R.G., Roba, R.M., Schoettle, A. and Reich, P.B. 1986. Response of soybean (Glycine max cultivar Hodgson) to low concentrations of ozone : II Effects on growth, biomass allocation and flowering. J. Environ. Qual. 15(2) : 161-167.

Amundson, R.G. and Weinstein, L.H. 1981. Joint action of sulphur dioxide and nitrogen dioxide on foliar injury and stomatal behaviour in soybean. J. Environ. Pollut. 20 : 113-121.

Anda, Angela. 1986. Effect of cement kiln dust on the radiation balance and yields of plants. Environ. Pollut. Ser. A. Ecol. Biol. 40(3) : 249-256.

Angell, J.K. and Korshover, J. 1980. Update of ozone variations through 1979. In J. London (ed.) Proc. of the Quadrennial international ozone symposium, Boulder, Colorado, August 4-9, 393-6.

Anonymous, 1966. Waste Management and control. Natl. Acad. Sci. (U.S.A.). Publ. No. 1400.

Arjunan, N.K. 1989. Green house effect. Yojana, Sept. 16-30, pp. 20-22.

Armantano, J.V. and Menges, E.S. 1987. Air pollution induced foliar injury to natural populations of Jack and White pine in a chronically polluted environment. Water Air Soil Pollut. 33(3/4) : 395-410.

Arnon, D.I. 1949. Copper enzymes in isolated chloroplasts. Plant Physiol 4 : 29-39.

Asadov, G.G. and Mekhtiev, T.A. 1986. Gase resistance of some trees and bushes of the Mediterranean flora. Izr. Akad. Nauk. Az. Ssr. Ser. Biol. Nauk. 0(37) : 35-42.

Ashenden, T.W. 1978. Growth reduction in cocksfoot (Dactylis glomerata L.) as a result of SO_2 pollution. Environ. Pollut. 15 : 161.166.

--------,----- 1979b. The effect of long-term exposure to SO_2 and NO_2 pollution on the growth of Dactylis glomerata L. and Poa pratensis L. Environ. Pollut. 18 : 249-258.

-------------- 1987. Effects of ambient levels of air pollution on grass swards subjected to different defoliation regimes. Environ. Pollut. 45 : 29-27.

---------and Mansfield, T.A. 1978. Extreme pollution sensitivity of grasses when SO_2 and NO_2 are present in the atmosphere together. Nature 273 : 142-143.

Ashenden, T.W. and Williams, I.A.D. 1980. Growth reductions in *Lolium multiflorum* and *phleum pratense* as a result of sulphur dioxide and nitrogen dioxide. Environ. Pollut Ser. A. Ecol. Biol. 21(2) : 131-140.

Ashmore, M.R. and Qnal, M. 1984. Modification by sulphur dioxide of the responses of *Hordeum vulgare* to ozone. Environ. Pollut. Ser. A. Ecol. Biol. 36(1) : 31-44.

Astanin, L.P. and Blagosklonov, K.N. 1983. Conservation of Nature. Progress Publishers, Moscow (U.S.S.R.), pp. 32-51.

Auclair, D. 1976. Effects of dust on photosynthesis, 1. Effects of cement and coal-dust on photosynthesis of spruce. Ann. Sci. For. 33 : 247-256.

Augier, H. and Maudinas, B. 1979. Influence of the pollution on the Photosynthetic pigments of marine phanerogam *Posidonia oceanica* collected from different polluted areas of the region of Marseille (Mediterranean sea, Franc). Oecol. Plant 14(2) : 169-176.

Ayazloo, M., Bell, J.N.B. and Garsed, S.G. 1980. Modification of chronic SO_2 injury to *Lolium perenne* L. by different sulfur and nitrogen treatments. Environ, Pollut. (Series A) 22 : 295-307.

Baker, C.K. and Fullwood, A.E. 1986. Leaf damage following crop spraying in winter barley (*Hordeum vulgare* cultivar Igri) exposed to sulphur dioxide. Crop Prot. 5(5) : 365-367.

Banerjee, A.K. and Chaphekar, S.B. 1980. Effect of sulphur dioxide on germination and early growth of seedlings. Geobios (Jodhpur) 7(1) : 8-11.

Banerjee, A., Sarkar, R.K. and Mukherjee, S. 1983. Reduction in soluble protein and chlorophyll content in a few plants as indicator of automobile exhaust pollution. Int. J. Environ. Stud. 20(3/4) : 239-243.

Becker, M., Saurer, M., Egger, A. and Fuhrer, J. 1989. Sensitivity of white clover to ambient ozone in Switzerland, New Phytol. 112 : 235-243.

Beckerson, D.W. and Hofstra, G. 1979. Effect of SO_2 and ozone singly and in combination on leaf chlorophyll, RNA and protein in white bean (*P. vulgaris* cultivar sanitae). Can. J. Bot. 57(18) : 1940-1945.

Beg, M.U.1980. Vegetation and environmental monitoring. Indian J. Air Pollut. Contr. 3 : 31-40.

Benedict, H.M. and Breen, W.H. 1955. The use of weeds as a means of evaluating vegetation damage caused by air pollution. Proc. Third. Natl. Air Pollut. Symp. : 177-190, U.S.A.

Bennett, J.H. and Hill, A.C. 1973. Absorption of gaseous air pollutants by a standarized plant canopy. J. Air Pollut. Contr. Assoc. 23 : 203-206.

Bennett, J.H., Resh, H.M. and Runeckles, V.C. 1974. Apparent stimulations of plant growth by air pollutants. Can. J. Bot. 52 : 35-51.

Berge, H. 1963. Phytotoxische Immissionen. Paul Parey (Berlin), 100 pp.

Bhattacharya, N.C., Biswas, P.K., Bhattacharya, Sheila., Sionit, Naseer, and Strain, B.R. Growth and yield response of sweet potato to atmospheric CO_2 enrichment. Crop. Sci. (25) Nov. Dec.

Bidwell, R.G.S. and Bebee, G.P. 1974. Carbon monoxide fixation by plants. Can. J. Bot. 52 : 1841-1847.

Biggs, A.R. and Davis, D.D. 1980. Stomatal response of three birch species exposed to varying acute dose of SO_2. J. Am. Soc. Hort. Sci. 105 : 514-516.

Biggs, A.R. and Davis, D.D. 1981. Effect of sulphur dioxide on growth and sulphur content of hybrid popular (Populus maximonizii X Populus trichocarpa). Can. J. Res. 11(4) : 880-833.

Billore, S.K. and Mall, L.P. 1975. Chlorophyll contents as an ecological index of dry matter production. J. Indian Bot. Soc. 54 : 75-77.

Biscoe, P.V., Unsworth, M.H. and Pinckney, H.R. 1973. The effects of low concentration of SO_2 on stomatal behaviour in Vicia faba, New phytol. 72 : 1299-1301.

Black C.R. and Unsworth, M.H. 1979a. A system for measuring effects of SO_2 on gas exchange of plants. J. Exp. Bot. 30 : 81-88.

Black, C.R. and Unsworth, M.H. 1979b. Effects of low concentration of sulphur dioxide on net photosynthesis and dark-respiration of Vicia faba. J. Exp. Bot. 30 : 473-483.

Black, V.J. 1982. Effects of sulphur dioxide on physiological processes in plants. In M.H. Unsworth and D.P. Ormrod, (Eds.), Effects of Air Pollution in Agriculture and Horticulture : 67-92. London, Butterworth Scientific.

----------Ormrod, D.P. and Unsworth, M.H. Effects of low concentration of ozone, singly, and in combination with sulphur dioxide on Net Photosynthesis rates of Vicia faba L. J. Expt. Bot. 33 : 1302-1331.

Bleasdale, J.K.A. 1952. Air Pollution and plant growth. In : Smokeless air, report in J. park Admin. 18 : 300-301.

Blum, U., Smith, G.R. and Fites, R.C. 1982. Effects of multiple ozone exposures on carbohydrate and mineral contents of ladino clover (Trifolium repens cultivar Tillman). Environ. Exp. Bot. 22(2) : 143-154.

Bobrov, R.A. 1952. The effect of smog on the anatomy of oat leaves. Phytopathol. 42 : 558-563.

Bodkin, L.D. 1974. Carbon monoxide and smog. Environment, 16, 34-41.

Bokra, G. 1980. The effect of cement dust pollution on growth and metabolism of Helianthus annus. Environ. Pollut. 12 : 125-133.

Bokra, G. 1981. Effect of cement-klin dust on the maize plant. Acta. Agron. Acad. Sci. Hung. 30(3/4) : 289-296.

Bokra, G. 1986. Effect of cement dust on the growth development, major metabolic processes and yield of winter barley in situ and under controlled conditions. Acta. Agron. Hung. 35(1/2) : 47-52.

Bontoe, J., DeCormis, L. and Louguet, P. 1977. Inhibition, in anaerobic condition, of the closing reaction of stomata of Petargonium in the presence of SO_2. Environ. Pollut. 22 : 75-79.

Brandt, C.S. and Heck, W.W. 1968. Effect of air pollution on plants. In : Air Pollution (ed. A.C. Stern). Academic Press, New York, Vol. I, pp. 401-443.

Bull, J.N. and Mansfield, T.A. 1974. Photosynthesis in leaves exposed to SO_2 and NO_2. Nature 250 : 443-444.

Bush, A.F., Glater, R.A., Dyer, J. and Richards, G. 1962. The effects of engine exhaust on the atmosphere when automobiles are equipped with afterburners. Univ. Calif. Dep. Eng. Rep. no. 62-63.

Bytnerowicz, A., David, M., Olszyk, Gerrit Kats, Phillip J. Dawson. Joanne wolf and C. Ray. Thompson (1987). Effect of SO_2 on physiology, elemental content and injury development of winter wheat. Agric Ecosyst Environ. 20(1) : 37-48.

Bytnerowicz, A., Olszyk, D.M., Fox, C.A., Dawson, P.J., Kats, G., Morrison, C.L. and Wolf, J. 1988. Response of desert annual plants to ozone and water stress in an insitu experiment. Japca (J. Air Pollut. Control Assoc.) 38(9) : 1145-1151.

Cai, J. 1985. The investigation on the destruction of the Fatty Acids of Lipid in Wheat leaves induced by sulphur dioxide and its Mechanism. The Masters paper of Shanghai Institute of Plant Physiology. Shanghai : Academia Sinica.

Capanelli, G., Golle, E., Munari, S. and Ratto, G. 1977. Nitrogen oxides : Analysis of urban pollution in the city of Genoa. Atmos. Environ. 11 : 719-727.

Capron, T.M. and Mansfield, T.A. 1976. Inhibition of net photosynthesis in potato, in air polluted with NO and NO_2. J. Expt. Bot. 27 : 1181-1186.

Carlson, R.W. 1983. Interaction between SO_2 and NO_2 and their effects on photosynthetic properties of soybean (<u>Glycine max</u>). Environ. Pollut. 32 : 11-39.

Catanesw, V., Jonescu, A., Chinea, L., Sandru, V. and Pirvulcsw. 1987. The effect of SO_2 pollution on some cultivated plants. Stud. Cercet. Biol. Ser. Biol. Veg. 39(1) : 76-80.

Catherine, L.E., Jodic, E. and Eileeng, B. 1987. The effect of Ambient ozone pollution and Acidic rain on the growth and chlorophyll content of Green and White ash. Environ. Pollut. **44** : 61-70.

Chadwick, M.J. 1983. Acid depositions and the environment, Ambio 12 : 80-82.

Chand, S. and Kumar, N. 1987. Responses of Avena sativa L. to sulphur dioxide. Indian J. Ecol. 14(2) : 179-184.

Chand, S. and Yadav, N.K. 1989. Effect of SO_2 on seed germination and seed growth of Zea mays. IBC 6 : 13-116.

Chaphekar, S.B. and Karabhari, M.R. 1974. Sulphur dioxide injury to plants, some experiments. Geobios 1 : 141-142.

Chappelka, A.H., Chevone, B.I. and Seiler, J.R. 1988. Growth and physiological response of yellow poplar seedlings exposed to ozone and simulated acidic rain. Environ. Pollut. 49 : 1-18.

Chaudhari, G.S., Rao, N.V. and Inamdar, J.A. 1984. Effect of air pollution on leaf epidermis and architecture of Lycopersicon lycopersicum var. angulata. Indian J. Environ. Health. 26(3) : 238-243.

Chris, T.G. and Williame, W. 1989. Development of lines of radish differing in resistance to O_3 and SO_2. New Phytol. 112(3) : 353-361.

Clarke, B.B., Henninger, M.R. and Brennan, E. 1983. An assessment of potato losses caused by oxidant air pollution in New Jersey. Phytopathology 73 : 104-113.

Clough, J.M. and Peet, M.M. 1981. Effects of intermittent exposure to high atmospheric CO_2 on vegetative growth in soybean. Physiol. Plant. 53: 565-569.

Cooley, D.R. and Manning, W.J. 1988. Ozone effects on growth and assimilate partitioning in Alfalfa, Medicago sativa L. Environ. Pollut. 49 : 19-36.

Cooper, C.F. 1982. Food and fibre. In W.C. Clark (ed) carbon dioxide. Review 1982, Oxford : Oxford University Press, 299-320.

Corn, M. 1968. Nonviable particles in the air. In : Air Pollution (ed. A.C. Stern); Academic Press, New York, Vol. I, pp. 47-94.

Costonis, A.C. 1971. Effect of ambient SO_2 and O_3 on eastern white pine in a rural environment. Phytopathol. 61 : 717-720.

Cowling, D.W. 1978. Growth of the grass (Lolium perenne L.) Exposed to SO_2. K J. Expt. Bot., 99(112) : 1029-1036.

Cox, R.A. and Penkett, S.A. 1971. Photo-oxidation of atmospheric SO_2. Nature 229 : 468-488.

Coyne, P.E. and Bingham, G.E. 1978. Photosynthesis and stomatal light responses in snap beans exposed to hydrogen sulphide in ozone. J. Air Pollut. Control Assoc. 28 : 1119-1123.

Crittenden, P.D. and Read, D.J. 1978. The effect of air pollution on plant growth with special reference to SO_2. II growth studies with Lolium perenne L. New Phytol. 80 : 49-62.

Daines, R.H. 1968. Sulphur dioxide and plant response. J. Occup. Med. 10 : 84-92.

Daly, E.J., Hoddinott, J. and Dale, M.R.T. 1988. The effect of oil spill chemicals on carbon translocation rates in Phaseolus vulgaris L. Environ. Pollut. 52(2) : 151-163.

Darrall, N.M. 1986. The sensitivity of net photosynthesis in several plant species to short-term fumigation with sulphur dioxide J. Exp. Bot. 37(182) : 1313-1322.

Das, Gupta, S.N. 1957. Air pollution in relation to plant diseases presidential adress, section of Botany, 45th session, Proc. Indian Sci. Cong. Assoc. 88-107. Madras.

Das, T.M. 1981. Plants and pollution. Presidential adress, section of Agricultural Science, 68th Session. Proc. Indian Science Cong. Assoc. 1-17. Varanasi.

Dassler, H.G. 1963. Problems of research on fume damage to forests. Biol. Zentralbl. 82 : 217-228.

David, M.O., Bytnerowicz, A. and Carl, A.F. 1987. SO_2 effects on plants exhibiting crassulaean Acid metabolism Environ. Pollut. 43 : 47-62.

Davies, T. 1980. Grasses more sensitive to SO_2 pollution in condition of low irradiance and short days. Nature 284 : 483-485.

Debnath, H.S. and Nayar, M.P. 1983. Comparative studies on the stomata of some arboreal taxa in the industrial area and non-industrial area of greater calcutta. Indian J. Bot. 6(1) : 58-60.

Decoteau, D.R., Simon, J.E., Eason, G. and Reinert, R.A. 1987. Ozone induced injury on field grown wate melons. Hort Sci. 21 (6 Sect. 1) : 1369-1371. BA 87(7) : 69016.

Dekok, L.J., Thompson, C.R. and Mudd, J.B. 1982. Effects of H_2S on water extractable sulphydryl content of crop plants. In : Effects of Gaseous Air Pollution in Agriculture and Horticulture (eds. M.H. Unsworth and D.P. Ormrod). Butlerworth Scientific, London, pp. 501.

DeSanto, Vizo, A., Bartoli, G., Alfani, A. and Inani M. 1979. Responses of *Mentha piperita* L. and *Arabidopsis thaliana* L. to fumigation with SO_2 at different concentrations. J. Environ. Sci., Health part A Environ. Sci. Eng. 14(4) : 313-332.

Deveau, J.L., Ormrod, D.P., Allen, O.B. and Beckerson, D.W. 1987. Growth and foliar injury responses of maize, soybean and tomato seedlings exposed to mixtures of ozone and sulfur dioxide. Agric. Ecosyst. Environ. 19(3) : 223-240.

Devlin, R.M. 1973. Plant physiology. Affiliated East-west Press Pvt. Ltd., New Delhi, pp. 206-219.

Dochinger, L.S. 1968. The impact of air pollution on eastern white pine: The chlorotic dwarf disease. J. Air. Pollut. Control Assoc. 18 : 814-816.

Dochinger, L.S. 1980. Interception of air borne particulates by tree plantings. J. Environ. Qual. 9 : 265-268.

Dochinger, L.S. and Calvert, J.G. 1978. Air Pollution sources : General effects and trends. In New Directions in Century 3, Strategies for Land and Water use. Soil Conserv. Soc. Am. Proc. 33 : 187-193.

Dohmen, G.P., McNeill, S. and Bell, J.N.B. 1984. Air Pollution increases *Aphis fabae* pest potential. Nature 307 ; 52-53.

Dorries, W. 1932. Uber die Brauchbarkeit der spectroscopic phaophytin probe in der Rauchshaden - Diagnostik. Z. pflanzen Kr. Gallenk. 421 : 257-273.

Dubey, P.S. 1983. Additive toxicity of SO_2 and herbicides - a new pollution problem. In : Proc. Symp. on Air Pollution Control (New Delhi) (Nov. 83) 1 : 115-118.

Dubey, P.S., Trivedi, L., Shringi, S.K. 1982. Sulphur dioxide concentration and correlated chlorophyll loss in tree species Sci. & Cult., 48 : 145-146.

Dugger, M. (Ed.), 1974. Air pollution effects on plant growth. Advances in chemistry series 3. Washington DC : American Chemical Society.

Dugger, W.M., Koukol, Jane and Palmer, R.L. 1966. Physiological and biochemical effects of atmospheric oxidants on plants. J. Air. Pollut. Contr. Assoc. 16 : 467-471.

Durmishidze, S.W. and Nutsubidge, N.N. 1976. Absorption and transformation of nitrogen dioxide by higher plants. Doklady. Academii Nauk SSSR, 227 : 232-235 (RUSS).

Duxbury, A.C. and Yentsh, C.S. 1956. Plankton pigment monographs. J. Marine Res., 15 : 19-101.

Ehert, D.L. and Jolliffe, P.A. 1985. Photosynthetic carbon dioxide exchange of bean plants grown at elevated carbon dioxide concentrations. Can. J. Bot. 63 : 2026-2030.

Elkiey, T. and Ormrod, D.P. 1980. Response of turfgrass cultivars to ozone, sulphur dioxide, nitrogen dioxide, or their mixture. J. An. Soc. Hort. Sci. 105 : 664-668.

Elkiey, T. and Ormrod, D.P. 1981. Sulfate, total sulfur and total nitrogen accumulation by petunia (*Petunia hybrida*) leaves-exposed to ozone, sulphur dioxide and nitrogen dioxide. Environ. Pollut. Ser. A. Ecol. Biol. 24(3) : 233-242.

Elkiey, T. and Ormrod, D.P. 1981b. Sorption of O_3, SO_2, NO_2 or their mixture by nine *Poa pratensis* cultivars of differing pollutant sensitivity. Atmos. Environ. 15 : 1739-1743.

Elkiey, T. and Ormord, D.P. 1981c. Sulphur and nitrogen nutrient and misting effects on the response of blue grass to ozone, sulphur dioxide, nitrogen dioxide or their mixture. Water, Air and Soil Pollut. 16 : 177-186.

Epstein, E. 1971. Effect of soil temperature on mineral element composition and morphology of the potato plant. Agron. J. 63 : 664-666.

Fangmeier, A. 1989. Effects of open-top fumigations with SO_2, NO_2 and ozone on the native herb layer of a Beech forest. Environ. Exp. Bot. 29 : 199-213.

Farooq, M. and Beg, M.U. 1982. Effect of acute levels of sulphur dioxide on barley (Hordeum vulgare) seedlings, Indian J. Environ. Health 24(3) : 215-218.

Feder, W.A. 1968. Reduction in tobacco pollen germination and tube elongation induced by low levels of ozone Science, 160 : 1122.

Fedotor, I.S. Karaban, R.T., Tikhomiror and Sisigina, T.I. 1983. Evaluation of sulphur dioxide effects on pine stands. Lesovedenic 0(6) : 23-27.

Ferm, M., Samuelsson, U., Sjodin, A., Greennfett, P. 1984. Long-range transport of gaseous and particulate oxidized nitrogen compounds. Atmos. Environ. 18 : 1731-1735.

Fisher, F., Kramer, D. and Ziegler, H. 1973. Elektronenmikroskopische under - Sucjungen. SO_2 begaster. Blatter von Vicia faba. I. Beobachtungun an chloroplasten mit akuter schadigung. Protoplasma. 75 : 83-96.

Fishman, J., Ramanthan, V., Crutzen, P.J. and Liu, S.C. 1979. Tropospheric ozone and climate. Nature, 282; 818-20.

Foster, K.W., Timm, H., Labanauskas, C.K. and Oshima, R.J. 1983. Effects of ozone and sulphur dioxide on tuber yield and quality of potatoes (Solanum tuberosum cultivar Centennial Russt). J. Environ. Qual. 12(1) : 75-80.

Fowler, D. and Cape, J.N. 1982. Air Pollutants in Agriculture and Horticulture. In : M.H. Unsworth and D.P. Ormrod (Eds.), Effects of Gaseous Air Pollution in Agriculture and Horticulture. 3-26 : London : Butterworths.

Freer-Smith, P.H. 1984. The responses of six broad leaved trees during long-term exposure to SO_2 and NO_2. New Phytol. 97(1) : 49-61.

Fujinuma, Yasami; Furukawa, Akio and Aigo, Ichiro, 1988. Effect of ozone on stomatal conductance in sunflower leaves : Age - dependent inhibition. Environ. Control. Biol. 26(3) : 38-90.

Fulekar, M.H., Naik, D.S. and Sharma, S. 1982. Dangers from fly ash. Science Reporter 19 : 171-174.

Furukawa, A., Isoda, O., Iwaki, H. and Totsuka, T. 1980. Interspecific difference in resistance to SO_2. Res. Rep. Nalt. Inst. Environ. Stud. (Japan) NO. 11 : 113-126.

Furkwa, A., Yokohama, M., Ushijima, T and Totsuka, T. 1984. The effects of NO_2 and/or, O_3 on photosynthesis of sunflower leaves. Res. Rep. Natl. Inst. Environ. Stud. Japan 65 : 89-97.

Gabor, T. 1987. The effects of air pollution on trees as Ajka Hungary II Histological and morphological investigations on the stem and leaves of black pine (Pinus nigra) trees. Biol. Abr. 84(8) : 80907.

Garg, K.K. and Varshney, C.K. 1981. Effect of air pollution on the leaf epidermis at the submicroscopic level. Experientia (Basal) 36(12) : 1364-1366.

Garsed, S.G., Rutter, A.J. and Relton, J. The effects of sulphur dioxide on the growth of Pinus sylvestris in two soils. Environ. Pollut (Series A) 24 : 217-232.

Ghouse, A.K.M. and Iqbal, M. (1975). A comparative study on the cambial structure of some arid zone species of Acacia and Prosopis Bot. Notiser, 128, 327-31.

Ghouse and Khan, A.U. 1978. Environmental pollution and epidermal structure in Psidium guajava L. Proc. Int. Symp. Environ. Agents and their Biol. Effects, Hyderabad (India) 3 : 41-44.

Ghouse, A.K.M. and Khan, F.A. 1983. Growth responses of Melilotus indica J. to air pollutants emerging out of coal burning Geobios 10 : 227-228.

Ghouse, A.K.M. and Khan, F.A. 1984. The effect of air pollutants on the growth responses of Solanum nigrum. Acta. Bot. Indica, 12(1) : 93-94.

Ghouse, A.K.M., Khan, F.A., Khair, S., Usmani, N.A. and Sulaiman, I.M. 1985. Anatomical responses of Chenopodium album to air pollution caused by coal burning. Acta. Bot. Indica. 13(2) : 287-288.

Ghouse, A.K.M., Khan, F.A. and Pasha, M.J. 1984a. Effect of air pollution on wood formation in Dalbergia sissoo, a timber tree of gangetic plain. J. Tree Sci. 3(1 & 2) : 140-142.

Ghouse, A.K.M., Khan, F.A., Salahuddin, M. and Rasheed, M.A. 1984b. Effect of air pollution on wood formation in Tectona grandis. Ind. J. Bot. 7 : 84-86.

Ghouse, A.K.M., Mahmooduzzafar., Iqbal, M. and Dastigiri, P. 1989. Indian J. applied pure Biol, 4 (2): 147-149.

Ghouse, A.K.M., and Saquib, M. 1986. Grwoth responses of some weeds of an agro-ecosystem to air pollution. Acta. Botonica Indica. 14(spl): 234-235.

Ghouse, A.K.M. and Yunus, M. 1972 preparation of epidermal peels from lea ves of gymnosperms by treatment with hot 60% HNO_3. Stain Technol. 47, 322-24.

Ghouse, A.K.M., Zaidi, S.H. and Atique, A. 1980. Effect of air pollution on the foliar organs of Callistemon Citrinus J. Sci. Res. 2(3): 207-209

Gilbert, O.L. 1983. The growth of planted trees subject to fumes from Brick works. Environ. Pollut. 31: 301-310

Glater, R.S., Solberg, R.A. and Scott, F.M. 1962. A developmental study of the leaves of Nicotiana Glutinosa as related to their Smog- sensitivity. Am. J. Bot. 49: 954-970.

Gopal, B., and Bhardwaj, N. 1979 Elements of ecology. Vikes pub. House Pvt. Ltd. New Delhi. pp. 173-176.

Ghorham, E., and Gordon, A.G. 1963. some offects of smelter pollution upon aquatic vegetation near sabury, Onatrid. Can J. Bot. 41: 371-378.

Gould, R.P., Minchin, P.E.H. and young, P.C. 1988. The effects of sulphurdiexide on phloem transport in two cereals. J. Exp. Bot. 39(205): 997-1007.

Govindjee, 1982. Environmental regulation of photosynthesis. In: Photosynthesis. Academic fress, New York, Vol. II. pp. 263-343.

Grandjean, A., and Fuhrer, J. 1989. Growth and leaf sensence in Spring wheat (Triticum aestivum) grown at different ozone concentrations in open-top field chambers. Physiol. plant. 77: 389-394.

Grennfelt, P., and Schjoldager, J. 1984. Photochemical Oxidants in t troposhere: a mounting menace, Ambio, 13,61-7.

Grunwald, C., 1981. Foliar fatty acids and sterols of soybean (Glycine mox cultivar wells) field fumigated with So_2 plant physiol (Bathesda) 68(4): 868-871.

Guderian, R., 1977. Air pollution: phytotoxicity of Acid gases and its significance in Air pollution control. Ecological studies 22. Springer verleg (Berlin).

Gupta, M.C., and Ghouse, A.K.M., 1986. Fruit quality and yield of Abelmoschus esculentus Moenchin relation to air pollution. Acta. Bot. Indica 14(2): 191-194.

Gupta, M.C., and Ghouse, A.K.M., 1986. The effects of Coal-smoke pollutants on the leaf epidermal Archetecture in Solamun melongena. Variety pusapurple long. Environ. Pollut. (S-A) 41: 315-321.

Gupta, M.C., and Ghouse, A.K.M., 1987. Cuticular geography, pigment content and anatomical traits of Ficus bengalensis. J. Tree Sci. 6(2): 106-110.

Gupta, M.C., and Ghouse, A.K.M., 1988. Leaf epidermal responses of Tridux procumbens L. to coal-smoke pollution. Proc. Nate. Acad. Sci. Indian. Sect. B (Biol. Sci.) 58(1): 93-96.

Hallgren, J.E., 1978. Physiological and Biochemical Effects of Sulphur dioxide on plants. In: J.O. Nriagu (Ed.), Sulfur in the Environment. Part 2. Ecological Impacts: 164-209. New York: John Wiley & Sons.

Haselhoff, E., Bredemann, G. and Haselhoff, W. 1932. Entstehung Evekennung Und Beurtcilung Von Rauchschaden. Verlags Buchhandlung Gebruder Borntraeger (Berlin)

Haselhoff, E., and Lindau, G., 1903. Die Beschadigung der Vegetation durch Rauch. Borntraeger, Leipzig.

Havelka, U.D., Wittenbach, V.A., and Boyle, M.G. 1984. Co_2 enrichment effects on wheat yeild and physiology. Crop Sci. (24) Nov. Dec.

Heagen, Smit, A.J., and wayne, L.G., 1968. Atmospheric reactions and seavening processes In: Air pollution. (ed. A.C. Stern). Academic press. New York, Vill. I. pp. 149-186.

Heagle, A.S., 1982. Interactions between air pollutants and parasitic plant diseases. In M.H. unsworth and D.P. Ormrod (Eds.)., Effects of Gaseous Air pollution in Agriculture and Horticulture: 333-348. London: Butterworth Scientific.

Heath, O.V.S., 1950. Studies in stomatal behaviour. V. The role of carbon dioxide in the light response of stomata. J. Exp. Bot. 1:29.

Heath, R.L., 1980 Initial events in injury to plant by air pollutants. Ann. Rev. plant physiol. 31: 395-431.

Heath, R.L., 1984. Air pollutant effects on biochemicals derived from metabolism: organic, fatty and amino acids. In, M.J. Koziol and F.R. Whatley (Eds.)., Gaseous Air pollutants and plant Metabolism: 275-290. London. Butterworths.

Heck, W.W., 1968 a Effect of Oxidant and pollutants (Discussion of A.C. Taylor, 1968)., J. occup. Med.10: 496- 499.

Heck, W.W., 1968 b. Factors influencing expression of Oxidant damage to plants. Ann. Rev. phytopathol. 6: 165-186.

Heck, W.W., 1982. Future directions in air pollution research. In: Effects of Gaseous Air pollution in Agriculture and Horticulture. (eds. M.H. Unsworth and D.P. Ormrod). Butterworth Scientific., London. pp. 411-435.

Heck, W.W., Taylor, O.C., Adams, R. Bingham, C., Miller, J., Preston, E. & Weinstein, L. 1982. Assessment of crop loss from ozone. J. Air pollut. control Assoc. 32: 353-361.

Hedgecock, G.G., 1912. Winter Killing and smelter injury in forests of Montana. Torreya. 12 25-30.

Heggestad, H.E., 1988. Reduction in soyabean seed yields by ozone air pollution. J. air pollut. Control Assoc. 38(8), 1040-1041.

Heggestad, H.E. & Bennett, J.H., 1984. Impact of atmospheric pollution on agriculture in: M. Treshaw (Ed.) Air pollution and plant life: 239-252. New York: John Wiley & Sons.

Heggestard, H.E., Bennett, J.H., Lee, E,H. and Douglas, L.W., 1986 Effect of increasing doses of sulphur dioxide and ambient ozone on tomatoes: plant growth, leaf injury, elemental composition, fruit yields, and quality. Phytopathology. 76(12): 1338-1344.

Hesebe, T., Ichikawa, N., Yamagami, Y: and Kurokawa, H., 1986. visible injury of fruit trees due to sulphur dioxide fumigation: 1. Symptoms of acute specks of necrosis and the difference of sensibility among five friut trees. Bull Hokkaido prefect Agric. Exp. Stn. 0(54): 49-56.

Hicklenton, P.R., and Jolliffe. P.A., 1978. Effects of green house Co_2 enrichment on the yield and photosynthetic physiology of tomato pant Can. J. plant Sci. 58: 801-817.

Hildemara, M., and Fiedler, H.J., 1989. Model and field trials on the effect of sulpur dioxide on micro organisms in spruce raw humus. B.A. J.uly 1989.

Hill, A.C., 1971. Vegetation: A sink for atmospheric pollutants. J. Air pollut. contr. Assoc. 21: 341-346.

Hill, A.C. & Bennett, J.H., 1970 Inhibition of apparent photosynthesis by nitrogen oxides. Atmos. Environ. 4: 341-348.

Hill, A.C., Hill, S., Lamb, C.& Barett, T.W. 1974. Sensitinty of native desert vegetation to So$_2$ and to So$_2$ and No$_2$ combined. J. Air pollut. control Assoc. 24, 153-157.

Hobbs, P.V., Harrison, H., and Robinson, E., 1975. Atomospheric effects of pollutants. Science 183: 909-915.

Hofstra, G. and Hesketh, J. D. 1975. In: Environmental and Biological control of photosynthesis. (ed.R. Marelle). Tunk, The Hague. pp. 71-80.

Horsman, D.C., Nicholls, A.O. and Calder, D.M. 1980. Growth responses of *Dactylis glomeratr* (cultivar Newzeland Grassland), *Loluim perenne* (cultivar victorium) and *phalaris aquatica* (ciltivar Australian) to chronic ozone exposure. Aus. J. Plant physiol. 7(5): 511-518.

Horsman, D.V., Nicholls, A.O., and Calder, D.M., 1981. Effects of chronic ozone exposure on the growth of *Trifoluim subterraneum* and *Trifolium repens*. Aus. J. plant physiol. 8(415): 405-408.

Houpis, J.L.J., Surano, K.A., cowles, S. and shinn, J.H., 1988. Chlorophyll and carotenoid concentration in two varieties of *pinus ponderosa* seedlings subjected to long term devoted Co$_2$. Tree physiol. 4(2): 187-193.

Hov, O., 1984., Ozone in the troposphere: high level pollution. Ambio, 13, 73-9.

Huber, S.C., Rogers, H., and Israel, D.W., 1984. Effect of Co$_2$ enrichement on photosynthesis and photosynthete partitioning in Soybean (*Glycine max*) leaves. Physiol. Plant. 62, 95-101.

Idso, S.B., and Kimball, B.A., 1989. Growth response of carrot and radish to atmospheric Co$_2$ enrichment. Environ. & Exp. Bot. 29, 135-139.

Idso, S.B., Kimball, B.A., Anderson, M.G. and Mauney, J.R. 1987. Effects of atmospheric CO_2 enrichment on plant growth. Agric Ecosyst. Environ. Vol. 20(1) : 1-10.

Inamdar, J.A. and Chaudhari, G.S. 1984. Effects of environmental pollution on leaf epidermis and leaf architecture. J. Plant Anat. Morphol. (Jodhpur) 1(1) : 1-8.

Iqbal, M., Mahmooduzzafar and Ghouse, A.K.M. (1987). Impact of air pollution on the anatomy of Cassia occidentalis L. and Cassia tosa L. Ind. J. Applied & Pure Biol. 2 :

Iqbal, M., Mahmooduzzafar, Kalimullah and Ahmad, Z. (1986). A plant grows under the stress of environmental pollution. Res. J. Pl. Envi. 3 : 5-7.

Ito, O., Okano, K., Kuroiwa, M. and Totsuka, T. 1985. Effects of NO_2 and O_3 alone or in combination on kidney bean plants (Phaseolus vulgaris L.) : Growth, partitioning of assimilates and root activities. J. Exp. Bot. 36 : 652-662.

Ito, O., Okano, K. and Totsuka, T. 1984. Effects of NO_2 and O_3 kidney bean plants. II Amino acid pool size and composition. Res. Rep. Natl. Inst. Environ. Stud. Japan 66 : 15-24.

Ito, O., Okano, K. and Totsuka, T. 1986. Effects of NO_2 and O_3 exposure alone or in combination on kidney bean plant : Amino acid content and composition. Soil Sci. Plant Nutr. 32(3) : 351-364.

Jacobson, J.S. 1982. Ozone and the growth and productivity of agricultural crops. In. M.H. Unsworth and D.P. Ormrod (Eds.). Effects of gaseous air pollution in agriculture and Horticulture 293-304. London : Butter worth Scientific.

Jacobson, J.S. and Hill, A.C. 1970. Recognition of air pollution injury to vegetation : A pictorial atlas. Air Pollut. Coutr. Assoc. pp. 109.

Jaeger, H.J. 1976. Location of Sulphur in spruce needles treated with sulphur dioxide Eur. J. For. Pathol. 6 : 25-29.

Jahansen, D.A. 1940. Plant microtechnique. McGraw Hill Book Company, I.N.C., New York and London.

Jalees, K. 1983. Sulphur dioxide and particulate matter. Science Reporter 20: 699-700.

Jean, F., Jona, T.R. and Cumming *et al.* 1989. Long term ozone exposure affects winter hardiness of red spruce New Phytol. 113(1): 85-96.

Jensen, K.F. 1982. Growth analysis of hybrid poplar cuttings fumigated with ozone and sulphur dioxide Environ. pollut. (Series A) 26: 243-250.

Jensen, K.F. 1985. Response of yellow poplar seedlings to intermittent fumingation. Environ. pollut. (Series A) 38: 183-191.

Johnsen, I. Sochting, U. 1973. Influence of air pollution on the epiphytic lichen vegetation and bork properties of deciduons trees in the copenhagen area Oikos 24: 344-351.

Johnstone, H.F. 1952. Properties and behaviour of air containminants. In: Air pollution (ed. L.C. Me Cabe). Me grow Hill Book Co., New York.

Kaji, M., Yoneyama, T., Totsuka, T. and Iwaki, H. 1980 Absorption of atmospheric No_2 by plants and soils. VI Transformation of No_2 absorbed in the leaves and transfer of the nitrogen through the plants. Res. Rep. Nate. Inst. Environ. Stud. Japan 11: 51-58.

Kalimullah., Mahmooduzzafar., and Ahmad, Z. 1987. Impact of air pollution on the radial system of Bark in *Mangifera indica.* Roxb. Indian J. Applied & pure Biol. 2(2): 49-50.

Kammerbauer, H., Selinger, H., Roemmelt. R., Ziegler-Joens, A., Knoppik, D. and Hock, B. 1987. Toxic component of motor vehicle emmision for the spure *Picea abies.* Environ. *Pollut*. 48(3): 235-244.

Karenlampi, L. and Houpis, J.L.J. 1986. Strcutural conditions of mesophyll cells of Pinus ponderosa var. scopulorum after sulphur dioxide fumigation. Con. J. For. Res. 16(6) : 1381-1385.

Katainen, H.S., Makinen, E., Jokinen, J., Karjalainen, R. and Kellonaki, S., 1987. Effects of sulphur dioxide on the photosynthetic and respiration rates in scots pine seedlings. Environ. Pollut. 46(4) : 241-252.

Katz, M. 1939. Effects of sulphur dioxide on vegetation. Natl. Res. Counc. (Canada) Publ. No. 815. 447 pp.

Katz, M. 1952. The effect of sulphur dioxide on conifers. In : Air Pollution. (ed. L.C. McLabe). McGraw Hill Book Company, I.N.C. New York, Chap. 8.

Katz, M. 1956. City planning industrial plant location, and air pollution. In : Air Pollution Head Book. (eds. P.L. Magill, F.R. Holden and C. Ackley). McGraw Hill Book Company, New York, Section 2, pp. 1-53.

Katz, M. and Ledgham, G.A. 1939. In : Effect of sulphur dioxide on vegetation. Chap.II. Natl. Res. Counc. (Canada) Publ. No. 815, pp. 262-287.

Katz, M., Ledgham, G.A., and McCallum, A.W. 1961. Some aspects of the physical and chemical nature of air pollution, in Air "Pollution", pp. 97-158. W.H.O. (Geneva) Monogr. no. 46.

Katz, M., and McCallum, W.W. 1952. Effects of sulphur dioxide on conifers. In : L.C. McLabe (Ed.), Air Pollution. Proc. U.S. Tech. Conf. Air Pollut. 84-96 : New York : McGraw-Hill.

Keith, J.F. 1981. Growth analysis of hybrid poplar cuttings fumigated with ozone and SO_2. Environ. Pollut. (S-A) 26 : 243-250.

Keith, F.J. 1985. Response of yellow poplar seedlings to intermittent fumigation. Environ. Pollut. 38 : 183-191.

Kendall, A.C., Turner, J.C., Thomas, S.M. and Keys, A.J. 1985. Effects of CO_2 enrichment at different irradiances growth and yield of wheat. J. Exp. Bot. 36 (163) : 261-273.

Keul, Martin, Lazar-Keul, Georgeta and Vinitila-Rozalia 1984. Evaluation of the effects of air pollution on forest trees by determining sugar content and measuring growth. Stud. Univ. Babes, Bolyai Biol. 29(1) : 22-26.

Khan, A.A. and Malhotra, S.S. 1978. Biosynthesis of lipids in chloroplasts isolated from Jack pine needles. Phytochem. 17 : 1107-1110.

Khan, A.U. 1982. Studies on the effect of air pollution on the growth activity of Dalbergia sissoo Roxb. Ph.D. Thesis, Aligarh Muslim University, Aligarh (India).

Khan, F.A. and Khair, S. 1984a. Response of Polygonum glabrum to air pollution caused by coal firing IBC 1A : 51-52.

Khan, F.A. and Khair, S. 1984b. Growth responses of Desmodium triflorum to air pollution caused by fossil fuel burning. Acta, Bot. Indica. 12 :

Khan, F.A. and Khair, S. 1985. Growth responses of Desmodium triflorum to air pollution caused by fossil fuel firing. Acta. Bot. Indica. 13(2) : 261-262.

Khan, F.A., Khair, S. Usmani, N.R. and Sulaiman, I.M. 1984a. A note on the anatomical responses of polygonum to air pollutants arising out of coal burning. IBC. IA : 127-128.

Kidd, F. 1915. The controlling influence of carbon dioxide III. The retarding effect of carbon dioxide on respiration. Proc. Roy. Soc. (London) B. 89-136.

Knabe, W. 1966. Rauchschadenforschung in Nordamerika. Forstarchiv 37 : 109-119.

Kochhar, P.L. 1982. Plant Ecology. Raton Prakashan Mandir, Delhi. pp. 194-202.

Kohut, R.J. and Davis, D.D. 1978. Responses of pinto bean to simultaneous exposure to ozone and PAN. Phytopathol. 68 : 567-569.

Kohut, R.J., Davis, D.D. and Merrill, W. 1976. Response of hybrid poplar to simultaneous exposure to ozone and PAN. Plant Dis. Report. 60 : 777-780.

Kohut, R. and Laurence, J.A. 1983. Yield response of red kidney bean *Phaseolus vulgaris* to incremental ozone concentrations in the field. Environ. Pollut. Ser. A. Ecol. Biol. 32(3) : 233-240.

Kondop N. and Sugahara, K. 1978. Changes in transpiration rate, of SO_2 - resistant and - sensitive plants with SO_2 fumigation and the participation of abscisic acid. Plant Cell Physiol. 19 : 365-373.

Koritz, H.G. and Went, F.W. 1953. The physiological action of smog on plant. I. Initial growth and transpiration studies. Plant Physiol. 28 : 50-62.

Koziol, M.J. and Cowling, D.W. 1981. Effects of exposure to SO_2 on the production of epicuticular wax in *Lolium perenne* L. Environ. Pollut. 26 : 183-186.

Koziol, M.J. and Jordan, C.F. 1979. Changes in carbohydrate levels in red kidney beans (*Phaseolus vulgaris*)L.) exposed to sulphur dioxide J. Exp. Bot. 29 (1/2) : 1037-1044.

Koziol, M.J. and Whatley, F.R. (Eds.), 1984. Gaseous Air Pollutants and Plant Metabolism. London : Butterworths.

Kress, L.W. 1972. Response of hybrid poplar to sequential exposures of ozone and PAN. Centre for air environment studies. Pa State Univ. CAES Publ. No. 259-271.

Kress, L.W. and Skelly, J.M. 1982. Response to several eastern forest tree species to chronic doses of ozone and nitrogen dioxide. Plant Dis. Rep. 66 : 1149-1152.

Krishnamurthy, R., Babu-Ramesh., Anbazhagan, M., Banerjee, G. and Bhagwat, K.A. 1986. Physiological Studies on the leaves of some avenue trees, exposed to chronic-low levels of air pollutants. Indian For (112(6) : 503-511.

Krishnayya, N.S.R. and Bedi, S.J. 1986. Effect of Automobile Lead pollution on *Cassia tosa* L. and *Cassia Occidentalis* L. Environ. Pollut. (S-A) 40 : 221-226.

Krol, P.J., Steubing, L., Welting, H.G. and Posthumus, A.C. 1982. Histological and cytological investigation of *Trifolium repens* and *Plantago majer* after fumigation with the emission example of nitrogen dioxide ozone and sulphur dioxide. Angew. Bot. 56(5/6) : 295-306.

Krupa, S.V. and Manning, W.J. 1988. Atmospheric ozone : Formation and effects on vegetation. Environ. Pollut. 50 : 101-137.

Kumar, S. and Prakash, C.B. 1977. Air Pollution from sulphur dioxide in India. Chem. Age India, 28 : 465-472.

Kumar, A., Shamshery, A.P. and Kumar, P. 1980. A study of dry matter production and plant pigment in three grasses. Comp. Physiol. Ecol. 5 :98-100.

Lal, B. and Ambasht, R.S. 1980. Effect of cement dust pollution on leaves of *Psidium guajava*.I. Pigment content and leaf biomass. Indian. Jour. Environ. Health. 22 : 231-237.

Lal, B. and Ambasht, R.S. 1981. Mineral concentration of leaves of *Diospyros melanokylon* tree near a thermal power plant. Proc. V. Internat. Symp. Environ. Biogeochem. (Stockholm) Abs. p. 60.

Lal, B. and Ambsht, R.S. 1982. Impact of cement dust on the mineral concentration of *Psidium guajava*, Environ. Pollut. 29 : 241-247.

Lal, M., Dube, S.K., Sinha, P.C. and Jain, A.K. 1986. Potential climatic consequences of increasing anthropogenic constituents in the atmosphere. Atmospheric Environ., 20, 639-42.

Lalman and Singh B. (1988). Growth response of *Vigna mungo* to SO_2 pollution. Symposium on environmental risk assessment and management and 9th Annual session of academy of environmental biology, India.

Lane, P.I. and Bell, J.N.B. 1984. The effects of simulated urban air pollution on grass yield : Part 2-Performance of *Lolium perenne*, *Phelum pratense*, and *Dactylis glomerata* fumigated with SO_2, NO_2 and/or No. Environ. Pollut. (Ser.A), 35 : 97-124.

Larssen, S. and Friberg, A.G. 1980. Malinger of Luftforurensinger i Oslo, Januarmars. 1979. Radhusgatan St. Hanshaugen. NILU Rapport 32/80.

Larson, R.I., McCurdy, J.R., Johnson, P.M. and Heck, W.W. 1988. An air quality data analysis system for interrelating effects, standards, and needed source reductions part 10. Potential ambient ozone standards to limit soybean crop reduction. JAPCA (J. air pollut. control Assoc.) 38 (12) : 1497-1503.

Lathe, F.E. and McCallum, A.W. 1939. The effect of sulphur dioxide on the diameter increment of conifers. In : M. Katz, Effect of sulphur dioxide on vegetation, Natl. Res. Counc. (Canada) Publ. No. 815 : 447 pp.

Lauenroth, W.K. and Dodd, J.L. 1981. Chlorophyll reduction in western wheat grass (*Agropyron smiths*) exposed to sulphur dioxide. Water air Soil Pollut. 15(3) : 309-316.

Laurence, J.A. and Weinstein, L.H. 1981. Effects of air pollutants on plant productivity. Ann. Rev. Phytopathol. 19 : 257-271.

Law, R.M. and Mansfield, T.A. 1982. Oxides of nitrogen and the green house atmosphere. In : Effect of Gaseous Air Pollution in Agriculture and Horticulture. (eds. M.H. Unsworth and D.P. Ormrod). Butterworth Scientific, London pp. 93-112.

Leadley, P.W., and Reynolds J.F. 1988. Effects of elevated CO_2 on estimation of leaf area and leaf dry weight of soybean. Amer. J. Bot. 75(11): 1771 - 1774.

Lehnher, B., Maechler, F., Orandjean, A. and Fuhrer, J. 1988. The regulation of photosynthesis in leaves of field grown spring wheat (*Triticum aestivum* L. cultivar Albis) at different levels of ozone in ambient air. Plant physiol (Bathesda) 88(4) : 1115-1119.

Lerman, S. 1972. Cement-Kiln dust and the bean plant (*Phaseolus vulgaris* L. *Black valantine* var.); in-depth investigations into viversity of california, Riversible.

L'Hirondelle, S.J. and Addison, P.A. 1985. Effects of sulphur dioxide on leaf conductance, xylem tension, fructose and sulphur levels of Jack pine (*Pinus blanksiana*) seedlings. Environ. Pollut. Ser. A. Ecol. Biol. 39(4) : 373-386.

L'Hirondelles, S.J., Addison, P.A. and Huebert, D.B. 1986. Growth and physiological responses of aspen and jack pine to intermittent sulfur dioxide fumigation episodes. Can. J. Bot. 64(11) : 2421-2427.

Linder, R.C. 1944. Rapid analytical methods for some of the more common inorganic constituents of plant tissue. Plant Physiol. 19 : 70-89.

Linzon, S. 1969. Symptomatology of sulfur-dioxide injury vegetation. In : N.L. Lacasse and W.J. Moroy (Eds.) Hand book of effects Assessment : Vegetation Damage. Pa. State Univ. Sect. 8. 1-3- University Park, Pannsylvania.

Li, Z.G., Liu, Y., Wu, Y.M. and Yu, S.W. 1980. Studies on the response and resistance of plants to SO_2. III. The exposure of plants to SO_2 and stress ethylene production. Acta Phytophysiol. Sinica 6 : 47-55. (In chinese with English abstract).

Lockyer, D.R. 1985. The effect of sulphur dioxide on the growth of Lolium multiflorum, Dactylis glomerata and Phleum pratense. J. Exp. Bot. 36(173) : 1851-1859.

Ma, T.H. Isabandi, D., Khan, S.H. and Tseng, Y.S. 1973. Low level of SO_2 enhanced chromated aberrations in Tradescantia pollen tubes and seasonal variation of the aberration rates. Mutation Res. 21 : 93-100.

Ma, T.H. and Khan, S.H. 1976. Pollen mitosis and pollen tube growth inhibition by SO_2 in cultured pollen tubes of Tradiscantia. Environ. Res. 12 : 144-149.

MacCormick, R.A. : 1968. Air pollution climatology, In : Air pollution. (ed. A.C. stern) Academic Press, New York, Vol. I : 275-320.

MacLachlan, S. and Zalik, S. 1963. Plastid structure chlorophyll concentration and free amino-acid composition of a chlorophyll mutant of barley. Can. J. Bot., 41 : 1053-1062.

Mahmooduzzafar; Iqbal, M. and Ghouse, A.K.M. 1987. Anatomical responses of Achyranthes aspera to air pollution. Indian J. Applied and pure Biol. 2(2) : 45-47.

Majernik, O. and Mansfield, T.A. 1972. Stomatal responses to raised atmospheric CO_2 concentrations during exposure of plants to SO_2 pollution. Environ. Pollut. 3 : 1-7.

Malhotra, S.S. 1976. Effects of sulphur dioxide on biochemical activity and ultrastructural organisation of pine needle chloroplasts. New Phytol. 76 : 239-245.

Malhotra, S.S. and Blanel, R.A. 1980. Diagnosis of Air pollutants and Natural stress symptoms on Forest vegetation in Western Canada. Information report NOR-X-228. Forestry Service, Environment Canada.

Malhotra, S.S. and Hocking, D. 1976. Biochemical and cytological effects of sulfur dioxide on plant metabolism. New Phytol. 76 : 227-237.

Malhotra, S.S. and Khan, A.A. 1984. Biochemical and physiological impact of major pollutants. In M. Treshov (Ed.), Air pollution and plant life : 113-157. Chichester : John Wiley & Sons.

Malhotra, S.S. and Sarkar, S.K. 1979. Effects of sulfur dioxide on sugar and free amino acid content of pine seedlings. Physiol. plant. 47 : 223-228.

Mansfield, T.A. 1976. Effects of air pollution on plants. Cambridge University Press, Cambridge, London.

Mansfield, T.A. and Freer-Smith, P.H. 1981. Effects of urban air pollution on plant growth. Biol. Rev. 56 : 243-368.

Mansfield, T.A. and Freer-Smith, P.H. 1984. The role of stomata in resistance mechanisms. In : M.J. Koziol and F.R. Whatley (Eds.), Gaseous Air Pollutants and Plant Metabolism : 131-146. London : Butterworth.

Mansfield, T.A. and Majernik, O. 1970. Can stomata play a past in protecting plants against air pollution? Environ. pollut. 1 : 149-154.

Mansfield, T.A., Whitmore, M. E., Pande, P.C. and Freer-Smith, P.H. 1985. Responses of herbaceous and woody plants to dry deposition of SO_2 and NO_2. Proc. of NATO Advanced Research Workshop, Toronto, Canada.

Marchwinska, E. and Kucharski, R. 1987. The combined influence of sulphur dioxide and heavy metal containing particulates on beans, carrots and Parsley. Environ. Monit. Assess. 8(1) : 11-26.

Martin, A. and Barber, F.R. 1984. Acid gases and acid in rain monitored for over 5 years in rural East Central England. Atmos. Environ. 18 : 1715-1724.

Masaru, N., Syozo, F. and Saburo, K. 1976. Effects of exposure to various injurious gases on germination of Lily Pollen. Environ. Pollut. 11 : 181-188.

Matsushima, J. 1971. On composite harm to plants by sulphurous acid gas and oxidant. Indust. Pub. Damage. 7 : 218-224.

Matsushima, J., Yonemori, K. and Iwao, K. 1985. Sensitivity of Satsuma mandarin (Citrus unshiu) to ozone as related to stomatal function indicated by transpiration rate, change of stem diameter and leaf temperature. J. Amm. Soc. Hortic. Sci. 110(1) : 106-108.

McCool, P.M., Musselman, R.C. and Teso, R.R. 1987. Air pollutants yield loss assessment for four vegetable crops. Agric. Ecosyst. Environ. 20(1) : 11-21.

McCrone, W.C., Draftz, R.G. and Dally, J.G. 1967. The particle Atlas. Ann. Arbor. Sci. Publ. Inc., Ann.Arbor. Mich. 406 pp.

McLaughlin, S.B. and McConathy, R.K. 1983. Effects of SO_2 and O_3 on allocation of C-Labelled photosynthate in Phaseolus vulgaris. Plant Physiol. 73 : 630-635.

Meethan, A.R. 1952. Atmospheric pollution. Pergamon press, Oxford.

Meethan, A.R. 1964. Atmospheric pollution. Ist origin and prevention. permgamon Press, Oxford.

Mejstrik, V. 1980. The influence of low sulphur dioxide concentrations on growth reductions of Nicotiana tabacum cultivar Sawsun and Cucumis sativus cultivar unikat. Environ. Pollut. Ser. A. Ecol. Biol. 21(1) : 73-76.

Menser, H.A. Jr., Heggestad, H.E. and Grosso, J.J. 1966. Carbon filters prevents ozone fleck and premature serescene of tobacco leaves. Phytopathol. 56 : 466-467.

Middleton, J.T. 1961. Photochemical air pollution damage to vegetation from polluted atmosphere. J. Air. Pollut. Contr. Assoc. 8 : 9-15.

Middleton, J.T. and Heagen-Smith, A.J. 1961. Occurrence, distribution and significance of photochemical air pollution in the U.S., Canada and Mexico. J. Air. Pollut. Contr. Assoc. 11 : 129-134.

Middleton, J.T., Kendrick, J.B. Jr. and Schwalm, H.W. 1950. Injury to herbaceous plants by smog or air pollution. Plant Dis. Rep. 34 : 245-252.

Milchunas, D.G. Lauenrotn, W.K. and Dodd, J,L. 1981. Forage quality of Western Wheatgrass (Agropyron smithi) exposed to sulphur dioxide. J. Range Manage. 84(4) : 282-285.

Miller, J.L. 1983. Input output study of agricultural losses in the ohio River Basin due to air borne residuals. Diss. Abst. Int. Pt. A. Hum. Soc. Sci. 43(7) : 134.

Miller, J.E., Patterson, R.P., Heagle, A.S. Pirsely, W.A. and Heck, W.W. 1988. Growth of cotton under chronic ozone stress and two levels of soil moisture. J. Environ. Qual. 17(4) : 635-643.

Miller, P.M. and Rich, S. 1967. Soot damage to greenhouse plants. Plant Dis. Rep. 51 : 712.

Mishra, L.C. 1980. Effects of sulphur dioxide fumigation on groundnut Arachis hypogea L. Environ. Exp. Bot. 20 : 397-400.

Mishra, L.C. 1982. Effect of environmental pollution on the morphology and leaf epidermis of Commelina benghalensis. Environ. Pollut. Ser. A. Ecol. Biol. 28(4) : 281-284.

Mishra, L.C. and Shukla, K.N. 1986. Effects of flyash deposition on growth, metabolism and dry matter production of maize and soybean. Environ. Pollut. (S-A). 42 : 1-13.

Miyake, H., Matsumura, H., Fujinuma, Y. and Totsuka, T. 1989. Effects of low concentrations of ozone on the fine structure of radish leaves. New Phytol. 111(2) : 187-196.

Morrison, G.F. 1980. Nitrogen Oxides from coal combustion Abatement and control. Report IEA coal Research London.

Mortensen, L.M. 1985. Nitrogen oxides produced during carbon dioxide enrichment : II Effects on different tomato (Lycopersicum esculentum) and Lettuce (Letuca sativa L. cultivars). New Phytol. 101(3) : 411-416.

Mudd, J.B. 1975. Sulphur dioxide. In : Responses of plants to Air Pollution (eds. J.B. Mudd and T.T. Kozlowski). Academic Press, New York, pp. 9-22.

Mudd, J.B. and Kozlowski, T.T. 1975. Responses of plants to air pollution. Academic Press, New York, 383 pp.

Mumford, R.A., Lipke, H., Laufer, D.A. and Feder, W.A. 1972. Ozone induced changes in corn pollen. Environ. Sci. Technol. 6 : 427-430.

Murray, A.J.S. and Wellburn, A.R. 1985. Differences in Nitrogen metabolism Between cultivars of tomato and pepper during exposure to glasshouse atmospheres containing oxides of nitrogen. Environ. Pollut. 39 : 303-316.

Murry, F. 1984. Responses of subterranean clover cultivar (Trifolium subterraneum cultivar woogenellup) and rye grass (Lolium Perenne cultivar Tetralite) to sulphur dioxide under field conditions. Environ. Pollut. Ser. A. Ecol. Biol. 36(3) : 239-250.

Naegel, J.A. (Ed.), 1973. Air pollution damage to vegetation. Advances in chemistry series 122. Washington, D.C. : American Chemical Society.

Nandi, P.K., Agarwal, M. and Rao, D.N. 1986. Effects of fumigating rice plant with sulphur dioxide on photosynthetic pigments and non-structural carbohydrates. Agric Ecosyst. Environ. 18(1) : 53-62.

NAS, 1977, Ozone and other photochemical oxidants. Nat. Acad. Sci., Washington D.C. : pp. 13-44.

Natori, T. and Totsuka, T. 1984. Effects of mixed gas on transpiration rate of several woody plants. 1. Interspecific difference in the effects of mixed gas on transpiration rate. Res. Rep. Nalt. Inst. Environ. Stud. Japan 65 : 45-52.

Navari-Izzo, F., Izzo, R. Quartacci, M.F. and Lorenzini, G. 1989. Growth and soluto leakage in Hordeum vulgaris exposed to long term fumigation with low concentration of SO_2. Physiol. Plant 76 : 445-450.

Nebe, W., Schierhorn, E. and Ilgen, G. 1988. R E M-investigations and chemical analysis of Norway Spruce needles growing in polluted atmosphere, Flora (Jena). 181 (5/6) : 409-414.

Noland, T.L. and Kozlowski, T.T. 1979. Effect of SO_2 on stomatal aperture and sulphur uptake of woody angiosperm seedlings. Can. J. For. Res. 9 : 57-62.

Norby, R.J. and Kozlowski, T.T. 1981. Interaction of SO_2 concentration and post fumigation temperature on growth of five species of woody plants. Environ. Pollut. (Series A) 25 : 27-39.

Norby, R.J. and Kozolowski, T.T. 1983. Flooding and SO_2 stress interaction in *Betula papyrifera* and *B. nigra* seedlings. For. Sci. 29(4) : 739-750.

Norby, R.J., Richter, D.D. and Luxmoore, R.J. 1985. Physiological process in soybean inhibited by gaseous pollutants but not by acid rain. New Phytol. ~~x~~ 100(1) : 79-85.

Nouchi, I., Mayumi, H. and Yamazoe, F. 1984. Foliar injury response of Pentunia and Kidney bean to simultaneous and alternate exposures to ozone and PAN. Atmos. Environ. 18 : 453-460.

Novoderzhkina, Yu, G., Andrianova, L.A. and Zheldahkova, G.G. 1966. Effects of planting on the sanitary and hygienic conditions of densely populated settlements. In : AICE Survey of U.S.S.R. Air Pollution Literature (ed. M.Y. Nuttonson), Vol. 11, 24-31, Amer. Inst. Crop. Ecology, Silver Spring.

Noyes, R.D. 1980. The comparative effects of sulfur dioxide on photosynthesis and translocation in bean. Physiol. Plant Pathology 16 : 73-79.

NRC 1939. Effect of sulphur dioxide on vegetation. Nalt. Res. Counc. (Canada). Publ. No. 815 : 447 pp.

Nyomaskay, K., Fridalszky, L., Vertesery, B. and Szasz, J. 1986. Maize seedlings raised in air space containing sulphur dioxide. Acta Agron Hung. 25 (1/2) : 53-62.

Oberbauer, S.F., Sionit, N., Hastings, S.J. and Oechel, W.C. 1986. Effect of CO_2 enrichment and nutrition on growth, photosynthesis, and nutrient concentration of Alaskan tundra plant species. Can. J. Bot. 64 : 2993-2998.

Oberbauer, S.F., Strain, B.R. and Fetcher, N. 1985. Effects of CO_2 - enrichment on seedling physiology and growth of two tropical tree species. Physiol. Plant. 65 : 352-356.

Odum, E.P. 1971. Fundamental of Ecology. 3rd Edn. W.B. Sanders and Co., Philadelphia.

Okano, K., Ito, O., Takeba, G., Shimizu, A. and Totsuka, T. 1984a. Effects of NO_2 and O_3 alone or in combination on kidney bean plants. V. 13 c-assimilate partitioning as affected by N_2 and or/O_3. Res. Rept. Natl. Inst. for Environ. Studies No. 66. Ibaraki, Japan : National Institute for Environmental studies.

Okano, K. Ito, O., Takeba, G., Shimizu, A. and Totsuka, T. 1984b. Alteration of C-assimilate partitioning in plants of <u>phaseolus vulgaris</u> exposed to ozone. New phytol. 97 : 155-163.

Okano, K., Tatsumi, J., Yoneyama, T., Kono, Y. and Totsuka, T. 1984. Comparision of the fates of $^{15}NO_2$ and CO_2 absorbed through a leaf of rice plants. Res. Rep. Natl. Inst. Environ. Stud. Japan. 66 : 59-67.

Okano, K. and Totsuka, T. 1985. Growth responses of plants to various conc. of NO_2. Environ. Pollut. 38 : 361-373.

O'Leary, James W. and Knecht, George N. 1981. Elevated carbon dioxide concentration increases stomate numbers in <u>Phaseolus vulgaris</u> leaves. Bot. Gaz. 142(4) : 438-441.

Osmuito., Okano, K., Kuroiwa, M. and Totsuka, T. 1985. Effects of NO_2 and O_3 alone or in combinations on kidney bean plants (<u>Phaseolus vulgaris</u> L.) : growth, partitioning of assimilates and root activities. J. Expt. Bot. 36(165) pp. 652-662.

Pelowski, B. 1986. Industrial emissions on the generative organs of <u>Pinus sylvestris</u> L. Katowicach 0(808) : 58-68.

Panda, S. 1989. Effect of environmental pollution on physiological aspects of plants. Indian J. Applied and Pure Biol. 4(1) : 55-58.

Pandey, D.D. and Simbu, A.K. 1988. Response of grain characteristics of agroecosystem to cement dust pollution. Symposium on environment and management and 9th annual session of academy of environmental biology.

Pandey, S.N. and Rao, D.N. 1978. Effects of coal-smoke sulphur dioxide pollution on the accumulation of certain minerals and chlorophyll content of wheat (<u>Trticum aestivum</u>) plants. Trop. Ecol. 19(2) : 155-162.

Pandit, V.I., Sabnis, C.V., Pampattivar, V.L. and Kothari, J.V. 1972. An investigation of exposure of the textile workers to cotton dust. Indian J. Environ. Health. 14: 23-45.

Patel, J.D. and Devi, S.G. 1984. Ultrastructural Variations in leaves of Streblus asper growing near a fertilizer complex. Phytomorphology 34(1-4): 140-146.

Patel, J.D. and Devi, G.S. 1985. Studies on leaf epidermis of some angiosperm species growing under pollution stress of a fertilizer complex. J. Plant Anat. morphol. (Jodhpur). 2(1): 1-10.

Patel, J.D. and Devi, S.G. 1986. Variations in chloroplasts of leaf mesophyll cells of Syzysium cumini L. and Tamarindus indica L. growing under air pollution stress of a fertilizer complex. Indian J. Ecol. 13(1): 1-4.

Patterson, G.D.Jr. 1958. Sulphur in chlorometric determination of non-metals (ed.) D.F. Blotz. Inter Science Publication, Inc. New York.

Pawar, K. 1982. Pullution studies in Nagda area due to Birla Industrial Complex discharges. Ph.D. Thesis, Vikram University, Ujjain, India.

Pawar, K. and Dubey, P.S. 1983. Response of two crop varieties to sulphur dioxide, Indian J. Air Pollution Control, 4(3): 3-5.

Peet, M.M. 1984. Co_2 enrichment of soybeans, Effect of leaf/pod ratio. Physiol. Plant. 60: 38-42.

Peiser, G.D. and Yang, S.F. 1979. Ethylene and ethane production from sulfur dioxide - injured plant. Plant Physiol. 63: 142-145.

Pell, E.J. and Pearson, N.S. 1983. Ozone - induced reduction in quantity of ribulose-1-5 biphosphate carboxylase in alfalfa foliage. Plant Physiol. 73: 185-187.

Pell, E.J. and Pearson, N.S. 1984. Ozone induced reduction in quantity and quality of pototа cultivars. Inviron. Pollut. (Series A) 35: 345-352.

Pell, E.J., Weissberger, W.C. and Speroni, J.J. 1980. Impact of ozone on quantity and quality of green house grown potato plants, Environ. Sci. Technol. 14(5): 586-571.

Pfeffer, H.U., Kulske, S. and Beier, R. 1982. Berichte uberdie Luftqualitat in Nordrhein - Westfalen. Landeranstant fur Immissionsschutz der Landes Nordrhein - Westfalen, Essen. TEMES Jahresberight 1982.

Pierre, M. and Queiroz, O. 1988. Air pollution by sulphur dioxide amplifies proteins of spruce needles. Physiol. Plant. 73(3): 412-417.

Potvin, C. and Strain, R.B. 1981. Effect of CO_2 enrichment and temperature on growth in two C_4 weeds. Echinochlo crusgalli and Elevsine indica Can. J. Bot. 63: 1495-1499.

Prasad, B.J. and Rao, D.N. 1979. Influence of nitrogen dioxide on photosynthetic apparatus and net primary productivity of wheat Plants Triticum aestivum. Cultivar RR21. Acta. Bot. Indica. 7(1): 16-21.

Prasad, B.J. and Rao, D.N. 1981. Growth responses of Phaseolus aureus plants to petro - cake pollution. J. Exp. Bot. 32(131): 1343-1350.

Prasad, B.J. and Rao, D.N. 1982. Relative sensitivity of a leguminous and a cereal crop to SO_2 pollution.

Pratt, G.C., Kromroy, K.W. and Krupa, S.V. 1983. Effects of ozone and sulphur dioxide on injury and foliar concentrations of sulphur and chlorophyll in soybean, Glycine max. Environ. Pollut. Scr. A. Ecol. Biol. 32(2): 91-100.

Pratt, G.C. and Krupa, S.V. 1981. Soybean (Glycine max) cultivar Hodgson response to ozone. Phytopathology 71(1): 1129-1132.

Puri, M.K. and Katyal, M. 1984. Microelements of the environment. Science Reporter 21: 283-284.

Rabe, R. 1981. Effects of air pollutants on plant metabolic processes and their consequences for the stability of ecosystems. Angew. Bot. 55(3/4): 211-226.

Rabe, R. and Kreeb, K.H. 1980. Bioindication of air pollution by chlorophyll destruction in plant leaves. Oikos 34(2): 163-167.

Rai, U. 1984. High level of air pollution in Delhi. In: The Times of India. 19th Dec., 1984, pp. 11.

Ranyol, D.J., Roman, J.R. and Eichenlaub, W.N. 1982. Response of tree seedlings to acid precipitation. I. Effects of substrate acidity on seed germination, Environ. Expt. Bot. 22: 377-383.

Rao, D.N. 1972. *Mangifera indica* L. bioindicator of air pollution in the tropics. Proc. 22nd Int. Geograph Conf., Montreal. pp. 292-293.

Rao, D.N. 1981. Phytomonitoring of air pollution. In proceedings of the WHO workshop on biological indicators and Indias of Environmental Pollution 1-8, Usmania Univ. Hyderabad.

Raza, S.H. and Bano, Z. 1981. Response of Blackgram (T-9) to ammonia pollution. Indian J. Bot. 4(2): 173-176.

Raza, S.H. and Rao, N.B. 1988. A note on the response of maize plants to ammonia pollution. Indian J. Bot. 11(2): 123-128.

Rebbeck, J., Blum. U. and Heagle, A.S. 1988. Effects of ozone on the regrowth and energy reserves of a ladino clover - tall fescue pasture. Appl. Ecol. 25(2): 259-282.

Reddy, K.V., Rao, M.V. and Dubey, P.S. 1988. Cement dust pollution response of tree species symposium on environment and management and annual session of academy of environmental biology.

Reich, P.B. and Amundson, R.G. 1984. Low level ozone and/or sulphur dioxide exposure causes a linear decline in soybean (*Glycine max* cultivar Hark) yield. Environ. Pollut. Ser. A. Ecol. Biol. 34(4): 345-356.

Reich, P.B., Schoettle, A.W. and Amundson, R.G. 1986. Effects of O_3 and acidic rain on photosynthesis and growth in sugar Maple and Northern Red Oak seedlings. Environ. Pollut. (S-A) 40: 1-15.

Reinert, R.A. and Sanders, J.S. 1982. Growth of radish and marigold following repeated exposure to nitrogen dioxide, sulfur dioxide and ozone. Plant. Dis. 66: 122-124.

Reinert, R.A, Shriner, D.S. and Rawlings, J.O. 1982. Responses of radish to all combinations of three concentrations of nitrogen dioxide, sulphur dioxide and ozone. J. Environ. Qual. 11: 52-57.

Reinert, R.A. and Weber, D.E. 1980. Ozone and sulphur dioxide induced changes in soybean (Glycine max cultivar Dave) growth. Phytopathology. 70(9): 914-916.

Revelle, R. 1982. Carbondioxide and world climate, Scientific American, 247, 31-41.

Reynolds, K.L., Zanelli, M. and Laurence, J.A..1987. Effects of sulphur dioxide exposure on the development of common in field - grown red Kidney beans, Photopath. 79(2): 331-334.

Rezabek, C.L., Morton, J.A., Mosher, E.C. Prey, A.J. and Cummings, C.J.E. 1989. Regional effects of sulphur dioxide and ozone on eastern white pine (Pinus strobus) in eastern wisconsis (U.S.A.) Plant dis 73(1): 70-73.

Riding, R.T. and Boyer, K.A. 1983. Germination and growth of pine seedlings exposed to 10-20 pphm SO_2. Environ. Pollut. 30: 245-253.

Riechers, G.H. and Strain, B.R. 1988. Growth of blue grama (Boutelour gracidis) in response to atmospheric CO_2 enrichment, Can. J. Bot. 66: 1570-1573.

Roberts, B.R. 1976. The response of field grown white pine seedlings to different sulphur dioxide environments. Environ. Pollut. 11: 178-180.

Robinson, E. 1968. Effect on the physical properties of the atmosphere. In: Air Pollution (ed. A.C. Stern): Academic Press, New York, pp. 349-400.

Robinson, E. and Robinson, R.C. 1970. Gaseous nitrogen compared pollutants from urban and natural sources. J. Air. Pollut. Contr. Assoc. 20: 303-306.

Rogers, H.H., Cure, J.D., Thomas, J.F. and Smith, J.M. 1984. Influence of elevated CO_2 on growth of soybean plants. Crop Science 24.

Rogers, H.H., Jeffries, H.E., and Witherspoon, A.M. 1979. Measuring air pollutant uptake by plants. Nitrogen dioxide. J. Environ. Qual. 8: 551-557.

Rohrman, F.A. and Ludwig, J.H. 1965. Sources of sulphur dioxide pollution. Chem. Ing. Prog. 61: 59-63.

Roseberg, N.J. 1981. The increasing CO_2 concentration in the atmosphere and its implication on agricultural productivity. I. Effects on photosynthesis, Transpiration and water use efficiency. Climate change, 3: 265-279.

Rossana, A.T.Jr. 1966. Air pollution principles. Proc. Int. Sec. Air Pollut. Contr. Assoc. Washington.

Rowland Bomford, A.J., Lea, P.J. and Wellburn, A.R. 1989. NO_2 flux into leaves of nitrate reductase deficient barley mutants and corresponding changes in nitrate reductase activity. Environ. and Exptal. Bot. 29: 439-444.

Ruffin, J., Williams, D., Banerjee, U. and Pinnix, K. 1983. The effect of some environmental gaseseun pollutants on pollar wall proteins of certain air borne pollen grains. A preliminary study. Grana, 22(3): 171-176.

Rupp, W.H. 1965. Air pollution principles. Proc. Int. Sci. Air Pollut. Contr. Assoc., Washington.

Salgare, S.A. and Acharekar, C. 1988. Effect of industrial pollution at chembur on the chlorophyll content of wild plants. Symposium on environmental risk asessment and management and 9th annual session of academy of environmental biology. India.

Salgare, S.A. and Anis, Mohd. 1988. Effect of ambient air at chembur on the organic content of the seeds of some trees. Symposium on environmental risk assessment and management.

Salgare, S.A. and Chakaraborty Devi 1988. Effect of industrial pollution at chembur on the leaf anatomy of cultivated plants. Symposium on environment and management and 9th annual session of academy of environmental biology.

Salgare, S.A. and Rane, Sulabha 1988a. Effect of ambient air at Lalbaug on pollen physiology of *Allamanda cathartica.* Symposium on environmental risk assessment and management and 9th annual session of academy of environmental biology.

Salgare, S.A. and Rane, Sulabha 1988b. Effect of ambient air at Lalbaug on pollen physiology of *Cassia siamea*. Symposium on environmental risk assessment and management and 9th annual session of academy of environmental biology.

Salgare, S.A. and Rane, Sulabha 1988c. Effect of ambient air at Lalbaug on pollen physiology *Gliricidia sepium*. Symposium on environment and management and 9th annual session of academy of environmental biology

Salgare, S.A. and Sebestian, K.J. 1988a. Effect of ambient air at Andheri on pollen physiology of *Catharanthus roseus* (red flower). Symposium on environment and management and 9th annual session of academy of environmental biology.

Salgare, S.A. and Sebastian, K.J. 1988b. Effect of ambient air at Andheri on pollen physiology of *Hamelia patens*. Symposium on environment and management and 9th annual session of academy of environmental biology.

Salisbury, E.J. 1927. On the case and ecological significance of stomata frequency with special references to the wood land flora. Phil. Trans. Roy. Soc.

Saquib, M., Ahmad, Z. and Ghouse, A.K.M. 1986. Effect of air pollution on the anatomy of *Chenopodium album* L. growing in an agroecosystem near Aligarh (India). Indian J. Applied & Pure Biol. 1(2): 98-99.

Sardi, K. 1981. Changes in the soluble protein content of soybean *Glycine max* L. Pea *Pisum sativum* L. under contineous SO_2 and soot pollution. Environ.Pollut. (S.A.). 25: 181-186.

Sasck, T.W. 1986. Implication of atmospheric CO_2 enrichment for the physiological ecology and distribution of two introduced woody venes. *Pueraria lobati* and *Lonicera japonica*. Diss. Abst. Int. Pt. B- Sci. & Eng. 47(2): 218.

Satyanarayana, G., Bhatnagar, A.R. and Acharya, U.H. 1988. Effects of flyash pollution on Datura innoxima. Environ. Ecol. 6(1): 92-95.

Satyanarayana, N.V., Prasad, P. and Madhava, K.V. 1985. Effect of sulphur dioxide on growth and reduction of Pigeon pea (Cajanus cajan). Proc. Ind. Acad. Sci. Plant Sci. 95(3): 199-202.

Saxe, H., 1983. Long term effects of low levels of SO_2 on bean plants (Phaseolus vulgaris). I. Immission, response pattern of net photosynthesis and transpiration during life long, contineous measurements. Physiol. Plant. 57: 101-107.

Saxe, H. 1989. Diagnostic parameters for selecting against novel spruce (Picea abies) decline: IV Response of photosynthesis and transpiration to SO_2 + NO_2 exposure. Physiol. Plant. 76: 362-367.

Saxe, H. and Murali, N.S. 1989. Diagnostic parameters for selecting against novel spurce (Picea abies) decline. II. Response of photosynthesis and transpiration to acute NO_2 exposure. Physiol. Plant. 76: 349-355.

Scheffer, T.C. and Hedgecock, G.G. 1966. Injury to North western forest trees by SO_2 from smelters. U.S.D.A. Tech. Bull. 1117-49.

Schroeder, J. & Reuss, C. 1883. Die beschadigung der vegetation durch rauch and die oberharzer huttenrauchschaden. Berlin, 333p.

Schuck, E.A., Pitts, J.N.Jr. and Wam, J.K.S. 1966. Relationships between certain meteorological factors and photochemical smog. Int. J. Air pollut. 10: 689-711.

Scurfield, G. 1960. Air pollution and tree growth. For Abstr. 21: 339-347, 517-528.

Setterstrom, C. and Zimmerman, P.W. 1939. Factors influencing susceptibility of plants to sulphur dioxide. I. Contrib. Boyee Thompson Inst. Plant Res. 10: 155-181.

Shaish, A., Roth-Bejrano, N and Italic, C. 1989. The response of stomata to CO_2 relates to its effect on respiration and ATP level. Physiol. Plant. 76: 107-111.

Sharma, A.K. 1981. Impact of the development of Science and technology on environment Presiaential Adress, Indian Sci. Congr., pp. 1-43.

Sharma, G.K. and Butler, J. 1973. Leaf cuticular variation in Trifolium repens L. as indicators of environmental pollution Environ. Pollut. 5: 287-2983.

Sharma, G.K., Chandler, C. and Salemi, L. 1980. Environmental pollution and leaf cuticular variation in Kudzu (Pueraria lobata willd). Ann. Bot. 45: 77-80.

Sharma, G.K. and Tyree, J. 1973. Geographic leaf cuticular and gross morphological variations in liquidamber Styraciflua L. and their possible relationship to environmental pollution. Bot. Gaz. 134: 179-184.

Sharma, S. 1986. Flyash powder plant pollutant. Science Today, August 1986: 20-21.

Shimizu, H., Oikawa, T. & Totsuka, T. 1984. Effects of low concentrations of NO_2 and O_3 alone and in mixture on the growth of sunflower plants. Res. Rep. Natl. Inst. Environ. Stud. Japan, 65: 121-136.

Shriner, D.S., Cure, W.W., Heagle, A.S., Heck, W.W., Johnson, D.W., Olson, R.J. and Skelly, J.M. 1982. Analysis of potential agriculture and forestry impacts of long range transport air pollutants. ORNL Report No. 5910. Oak Ridge, Tennessee, U.S.A. Oak Ridge National Laboretory.

Shringi, S.K. 1982. Response of a few plants against sulphur dioxide. M.Phil. Thesis, Vikram University Ujjain, India.

Sidhu, S.S. and Singh, P. 1977. Foliar sulphur content and related damage to forest vegetation near a linear board mill in Newfoundland (Canada). Plant Dis. Rep. 61: 7-11.

Sij, J.W. and Swanson, C.A. 1974. Short-term kinetic studies on the inhibition of photosynthesis by sulphur dioxide. J. Environ. Qual. 3: 103-107.

Singh, A.K., 1982. Effect of coal dust pollution on Butea monosperma. Vijnana parished Anusandhan Patrika 25(1): 19-24.

Singh, N. and Rao, D.N. 1986. Influence of sulphur dioxide on the growth and productivity of *Phaseolus aureus* plants. Acta. Bot. Ind. 14(2): 230-235.

Singh, N. and Rao, D.N. 1988. Effect of sulphur dioxide on injury and foliar concentrations of pigments, ascorbic acid and sulphur in *Vigna radiata* L. J. Environ. Biol. 9 (I Suppl). 107-118.

Singh, S.N. 1980. Synergistic action of particulate and gaseous pollutants on the growth of *Triticum aestivum* L. J. Exp. Bot. 31(25): 1701-1705.

Singh, S.N. and Rao, D.N. 1981. Growth of wheat (*Triticum aestivum*) plants exposed to cement dust pollution. Water Air Soil Pollut 14(0): 241-250.

Singh, S.N., Yunus, M., Srivastava, K., Kulshreshtha, K. and Ahmad, K.J. 1985. Response of *Calendula officinalis* L. to long term fumigation with SO_2. Environ. Pollut. 39: 17-25.

Sinn, J.P. and Pell, E.J. 1984. Impact of repeated nitrogen dioxide exposures on composition and yield of potato foliege and tubers. J. Am. Soc. Host. Sci. 109: 481-484.

Sinn, J.P., Pell, E.J. and Kabel, R.L. 1984. Uptake rate of nitrogen dioxide by potato plants. J. Air. Pollut. Control. Assoc. 34: 668-669.

Sionit, N. 1983. Response of soybean to two levels of mineral nutrition in CO_2 enriched atmosphere Crop Sci., 23.

Sionit, N., Strain, B.R. and Flint, E.P. 1987. Interaction of temperature and CO_2 enrichment on soybean: Growth and dry matter partitioning. Can. J. Plant Sci. 67: 59-67.

Skye, E. 1968. Lichens and air pollution, a study of cryptogamic epiphytis and environment in the Stockhohm region. Acta Phytogeographica Succica. 52: 8-123.

Spence, R.D., Sharpe, P.J.H. and Powell, R.D. 1984. The role of the epidermal cells in the CO_2 responses of stomata of *Vicia faba* L.

Sprugel, D.G., Miller, J.E., Muller, R.N., Smith, H.J. and Xerikos, P.B. 1980. Sulphurdioxide effects on yield and seed quality in field grown soybeans (*Glycine max*, cultivar wells). Phytopathology 70(12): 1129-1133.

Srivastava, H.S., Jolliffe, D.P. and Runeckles, V.C. 1975a. Inhibition of gas exchange in bean leaves by NO_2. Can. J. Bot. 53: 466-474.

Srivastava, H.S., Jolliffe, D.P. and Runeckles, V.C. 1975b. The effect of environmental condition on the inhibition of leaf gas exchange by NO_2. Can. J. Bot. 53: 475-482.

Srivastava, H.S. and Ormrod, D.P. 1984. Effects of nitrogen dioxide and nitrate nutrition on growth and nitrate assimilation in bean leaves. Plant Physiol. 76: 418-423.

Stephens, E.R., Hanst, P.L., Doerr, R.C. and Scott, W.E. 1956. Reactions of NO_2 and organic compounds in air. Ind. Eng. Chem. 48: 1498.

Stern, A.C. 1968. Air pollution, Vol. I. Air pollution and its effects. N.Y. Academic Press.

Steve Van Matre. 1984. Need for ecological education In. The Times of India. 13th July, 1984.

Sun, E.J. and Su, H.J. 1985. Fluoride injury to rice plants caused by air pollution emitted from ceramic and brick factories. Environ. Pollut. Ser A. Ecol. Biol 34(4): 335-342.

Takaoki, Takeshi and Mitan, K. 1986. A new fumigation method for measuring the effects of sulphur dioxide on photosynthesis of bryophytes and Lichens. Lindbergia 12(1): 60-66.

Takemoto, B.K., Johnson, A.G., Parada, C.R. and Olszyk, D.M. 1989. Physiology and yield of field grown *Brassica oleracea* L. exposed to acidic fog. New Phytol. 112(3): 369-375.

Takemoto, B.K., Olszyk, D.M., Johnson, A.G. and Parada, C.R. 1988. Yield responses of field grown crops to acidic fog and ambient ozone. J. Environ. Qual. 17(2): 192-197.

Taylor, O.C., Dugger, W.M.Jr., Cardiff, E.A. and Darley, E.F. 1961. Interaction of light and atmospheric photochemical (Smog) with in plants. Nature 192: 814-816.

Taylor, O.C. and Eaton, F.M. 1966. Suppression of plant growth by NO_2. Plant Physiol. 41: 132-136.

Taylor, O.C. and Thomprov, C.R. Tingley, D.T. and Reinert, R.A. 1975. Oxides of Nitrogen. In: Responses of plant to air pollution (Eds. J.B. Mudd and T.J. Kozlowski). Academic press New York and London, pp. 121-139.

Tebbens, B.D. 1968. Gaseous pollutant in the air. In: Air pollution (ed. A.C. Stern). Academic Press, New York, pp. 23-46.

Temmerman, L.D. 1982. Acute and subacute damage to vegetation by ammonia following accidental pollution in Agriculture and Horticulture (eds. M.S. unsworth and D.P. or mezod) Butterworth Scientific, London, pp. 468-469.

Temple, P.J. 1982. Effects of peroxyacetyl nitrate (PAN) on growth of plants. Dissertation, University of California.

Temple, P.J. 1988. Injury and growth of Jeffery pine and giant sequoia in response to ozone and acidic mist. Environ. Exp. Bot. 28(4): 323-333.

Temple, Fa, C.H. anc Taylor O.C. 1985. Effects of SO_2 on stomatal conductance and growth of Phaseolus vulgaris. Environ. Pollut. (A Ecol. Biol.) Vol. 37, No. 3, pp. 267-279.

Teresa, J. and Mansfield, T.A. 1982. The effect of SO_2 on growth and development of seedlings of Pheleum pratense under different light and temperature environment. Environ. Pollut. 27: 57-71.

Terutaka, K., Kasuya, M., Kagamimori, Kozuka, Hiroshi and Kawano, S. 1989. Effect of air pollution on tannin biosynthesis and predation demage in Cryptomeria japonica. Biol. Abst. 87(9): Ref. No. 97181.

Thomas, M.D. 1951. Gas damage to plants. Ann. Rev. Plant Physiol. 2: 293-322.

Thomas, M.D. 1956. The invisible injury theory to plant damage J. Air Pollut. Coutr. Assoc. 5: 205-208.

Thomas, M.D. 1961. Effects of air pollution on plants In: Air Pollution. WHO Monograph Ser. 46. WHO Geneva. pp. 233-278.

Thomas, M.D. and Hendricks, R.H. 1956. Effects of air pollution on plants. In: Air pollution Hand Book (eds. P.L. Magill, F.R. Holden and C. Ackley) McGraw Hill Book Company, New York. Section 9, pp. 1-44.

Thomas, M.D. and Handricks, R.H. 1958. Air pollution with relation to agronomic crops. I. General status of research on the effects of air pollution on plants. Agron. J. 50: 545-550.

Thomas, M.D., Handricks, R.H., Collier, T.R. and Hill, G.R. 1943. The utilization of sulphate and sulphur dioxide on vegetation. Ind. Eng. Chem. 42: 2231-2235.

Thomas, M.D., Hendricks, R.H. and Hill, G.R. 1944. Some chemical reactions of sulphur dioxide after absorption by alfalfa and sugar beets. Plant Physiol. 19: 212-226.

Thomas, M.D., Hendricks, R.H. and Hill, G.R. 1950. Sulphur metabolism of plants. Effects of SO_2 on vegation. Ind. Eng. Chem. 42: 2231-2235.

Thomas, M.D., Hendricks, R.H. and Hill, G.R. 1952. Effect of air pollution on plants. In: L.C. Mccabe (Ed.), Air Pollution 41-65: New York: McGraw Hill.

Thompson, C.R. 1985. Effects of SO_2 on growth and yield of winter crops grown in California. NIIS, Spring Fieldva (USA) pp. 193.

Thomson, W.W., Dugger, W.M.Jr. and Plamer, R.L. 1965. Effect of peroxyacetyle nitrate on ultrastructure of chloroplasts. Bot. Gaz. 126: 66-72.

Tingey, D.T., Reinder, R.A., Dunning, J.A. and Heck, W.W. 1971. Vegetation injury from the interaction nitrogen dioxide and sulphur dioxide. Phytopathol. 61: 1506-1511.

Tingey, D.T. and Reinert, R.A. 1975. The effect of ozone and sulphur dioxide singly and in combination on plant growth. Environ. Pollut. 9: 117-125, Tingey, D.T. and Taylor, G.E. 1982. Variation in plant response to ozone: a conceptual model of physiological events. In M.H. Unsworth and D.P. Ormroa (Eds), Effects of Gaseous air pollution in Agriculture and horticulture: 113-138. London Butterworths.

Tomer, Y.S. and Kumar, N. 1987. Effects of sulphur dioxide on *Raphanus sativus* L. Ind. J. Ecol 14(2): 173-178.

Treshow, 1970. Environment and plant Response, McGraw Hill, New York.

Treshow, M. (Ed). 1984. Air pollution and plant life. Chichester: John - Wileys Sons.

Trivedi, L. and Dubey, P.S. 1983. Vegetation damage due to Satpura Thermal Power station at North Betual Forest Division. In D.N. Rao, T.P. Sharma and U.R. Sing (Eds.) Air Pollution Problems and Perspective: 343-350.

Troiano, J.J. and Leone, I.A. 1977. Changes in growth rate and nitrogen content of tomato plants after exposure to NO_2. Phytopathology 67: 1130-1133.

Tsukahara, H., Kozlowski, T.T. and Shank, Lin, J. 1987. Response of *Betula platyphylla* var. Japonica seedling to SO_2. J. Yamagata Agric For. Soc. 0(44): 5-12.

Turk, R., Wirth, V.S. Lange, C.L. 1974. CO_2 - Gaswechsel-Untersuchungen Zur SO_2. Resistenz von Flechten. Oecologia 15: 33-64.

Unsworth, M.M. 1981. Air pollution and plant productivity. In: Physiological processes limiting plant productivity (ed. C.B. Johnson). Butterworths, London pp. 293-306.

Unsworth, M.M., Biscove, P.V. and Pinckney, H.R. 1972. Stomatal responses to sulphur dioxide. Nature 239: 458-459.

U.S. Environmental Protection Agency. 1978. Air Quality Criteria for Ozone and other photochemical oxidants. EPA-600/8-78-004. Research Triangle Park, N.C.: U.S. Environmental Protection Agency.

US EPA (Environmental Protection Agency) 1983a: Can We Delay a Greenhouse Warming: Washington, D.C.: US Environmental Protection Agency, US Government Printing Office.

US National Research Council 1977a: Carbon Monoxide, Washington, D.C.: National Academy Press.

US National Research Council 1979. Carbon Dioxide and Climate, a scientific assessment. Washington, D.C. National Academy Press. Ad Hoc Study Group.

US National Research Council 1982b. Carbon Dioxide and Climate; a second assessment. Washington, D.C. National Academy Press, Carbon Dioxide Climate Review Panel.

US National Research Council 1983b. Changing climate. Washington, D.C.: National Academy Press Carbon Dioxide Assessment Committee.

US SCAQMD 1986. Air Quality Data 1985. El Monte, California: SCAQMD.

Van Haut, H. and Stratmanna, H. 1970. Farbtafelatlar uber Schwefeldioxid Wirkungen an Pflanzen. Essen, W. Germany: Verlag W. Girardet.

Varshney, C.K. and Garg, J.K. 1978. A quantitative assessment of SO_2 emission from fossil fuel in India. J. Air Pollut. Contr. Assoc. 28: 1141-1142.

Varshney, C.K. and Garg, K.K. 1980. Significance of leaf Surface characteristics in plant responses to air pollution. Water, Air and Soil Pollut. 14: 429-433.

Varshney, S.R.K. and Varshney, C.K. 1981. Effect of SO_2 on Pollen germination and Pollen tube growth. Environ. Pollut. 24: 87-92.

Verduin, J. and Loomis, W.E. 1944. Absorption of carbon dioxide by maize. Plant Physiol. 19: 278.

Vijayan, R. and Bedi, S.J. 1988. Effect of sulphur dioxide on <u>Syzygium cumini</u> Skeel (Jamun) and its amelioration by ascorbic acid treatment. Ind. J. Environ. Health 30(2): 155-162.

Vu, Joseph, C.V., Allen, L.H.Jr. and Browes, G. 1989. Leaf ultrastructure carbohydrates and protein of soybeans grown under CO_2 enrichment. Environ. Exp. Bot. 29: 141-147.

Wada, M., Shimizu, H. and Kondo, N. 1987. A model system to study the effect of sulphurdioxide on plant cells. II. Effect of sulphite on fern spore germination and rhizoid development. Bot. Mag. Tokyo 100 (1057): 51-62.

Weber, E. 1982. Air pollution assessment methodology and modeling. Vo.2. New York: Plenum press.

Wellburn, A.R., Capron, T.M., Chan, H.S. and Horsman, D.C. 1976. Biochemical effects of atmospheric pollutants on plants. In: Effects of Air pollutions on plants. (ed. T.A. Mansfield). Cambridge University Press, Cambridge, London, PP. 105-114.

Wellburn, A.R., Higginson, C., Robinson, D. and Walmsley, C. 1981. Biochemical explanations of more than additive inhibitory effects of low atmosphric levels of sulphurdioxide plus nitrogen dioxide upon plants. New Phytol, 88: 223-237.

Wellburn, A.R., Mayernik, O. and Wellburn, F.A.M. 1972. Effects of SO_2 and NO_2 polluted air upon the ultrastructure of chloroplasts. Environ. Pollut. 3: 37-39.

Wellburn, A.R., Wilson, J.and Aldridge, P.H. 1980. Biochemical responses of plants to nitric oxide polluted atmosphere. Environ. Pollut. 22: 219-228.

Wentzel, K.F. 1956. The part played by industrial and domestic smoke in damage to forest by fumes and in atmospheric pollution. Forstarchiv 27: 84-89.

Whips, J.M. 1985. Effect of CO_2 concentration on growth, carbon distribution and loss of carbon from the roots of maize. J. Exp. Bot. 36(165): 644-651.

Whitby, G.S. 1939. The effects of sulfur dioxide on vegetation. Chem. Ind. 58: 99.

Whitmore, M.E. and Frees-Smith, P.H. 1982. Growth effects of SO_2 and/or NO_2 on woody plants and grasses during spring and summer. Nature 300: 55-57.

Whitemore, M.E., and Mansfield, T.A. 1983. Effects of long term exposures to SO_2 and NO_2 on Poa pratensis and other grasses. Environ. Pollut. 31: 217-235.

Williame, E., Williams, K., Garbutt and Bazzaz, F.A. 1988. The response of plants to elevated CO_2 performance of an assemblage of serpentine grassland herbs. Environ & Exp. Bot. 28(2).

Williams, R.J.H., Lloyd, M.M. and Ricks, G.R. 1971. Effects of atmospheric pollution on deciduous wood land. I. Some effects on leaves of Quercus petraea (Mattuschka) Leibl. Environ. Pollut. 2: 57-68.

Willims, W.E., Garbutt, K., Bazzar, F.A., Vitousek, P.M. 1986. The response of plants to elevated CO_2. Two deciduous forest trees communities. Oecologia 69(3): 454-459.

Wilson, A.T. 1978. Pioneer agriculture explosion and carbon dioxide levels in the atmosphere. Nature, 273, 40-1.

Wilson, G.B. and Bell, J.N.B. 1986. Studies the tolerance to sulphur dioxide of grass populations in polluted areas. New Phytol. 102(4): 563-574.

Winner, W.E. and Mooney, H.A. 1980. Ecology of SO_2 resistance: Photosynthetic changes of shrubs in relation to SO_2 absorption and stomatal behaviour. Oecologia (Berl.) 44: 296-302.

Withrow, R.B. 1967. Light as modifying influence on the mineral nutrition of plants. In: Mineral nutrition of Plants (ed. E. Trong). Oxford and IBH Publ. Co., New Delhi (India). PP. 389-410.

Woo, K.C. and Canvin, D.T. 1980. Effect of ammonia on photosynthetic carbon fixation in isolated spinach leaf cell. Can. J. Bot. 58: 505-510.

Wood, F.A. 1967. Air pollution and shade trees. Proc. 43rd Int. Shade Tree Confr. PP. 66-82.

Woodstock, Lowell, W. and Tsao, H. 1986. Influence of Ammonia vapours on the dry seeds of soybean, corn, and peanut. Crop. Sci. Vol. 26, May-June.

Woodwell, G.M. 1970. Effects of pollution on the structure and physiology of ecosystems. Science 168: 429-433.

World Health Organisation 1972. Health Hazards of the Human Environment. Geneva. World Health Organization.

World Health Organization 1976a. Selected methods of measuring air pollutants Offset Publ. World Health Organization, Geneva, 24.

World Health Organization 1979b. Environmental Health Criteria 7: Photochemical Oxidents. Geneva World Health Organization.

Wright, G.R., Jewczyk, S., Onrot, J., Tomlinson, P. and Shephard, R.J. 1975. Carbon monoxide and the urban atmosphere. Arch. Environ. Health, 30, 123-9.

Yoneyama, T., Arai, K. and Totsuka, T. 1980. Transfer of nitrogen and carbon from a mature sunflower leaf 15 No. 2 and 13 CO_2 feeding studies. Plant cell Physiol. 21: 1367-1381.

Yoneyama, T., Yasuda, T., Yazaki, J. and Totsuka, T. 1980. Absorption of Atmospheric NO_2 by plants and soils VII. NO_2 absorption by plants: Reevaluation of the air-soil-root route. Res. Rep. Natl. Inst. Environ. Stud. Japan. 11: 59-67.

Yunus, M. and Ahmad, K. 1981. Changes in the cuticular and epidermal features of the weed, *Calotropis procera* (Asclepiadaceae), due to air pollution. Kalikasan 10(2/3): 275-282.

Yunus, M., Ahmed, K.J. and Gale, R. 1979. Air Pollutants and epidermal traits in *Ricinus communis* L. Environ. Pollut. 20: 189-198.

Yunus, M., Dwivedi, A.K., Kulshreshtha, K. and Ahmad, K.J. 1985. Dust loadings on some common plants near Lucknow city. Environ. Pollut. (Ser. B) 9: 71-80.

Yunus, M., Kulshreshtha, K., Dwivedi, A.K. and Ahmad, K.J. 1982. Leaf surface traits of *Ipomea fistulosa* Mart. ex. Choisy as indicators of air pollution. New Bot. 9: 39-45.

Yunus, M., Srivastava, K., Jafri, S. and Ahmad, K.J. 1981. Response of some plants to sulphur dioxide. Kalikasan, Philip. J. Biol. 10: 115-117.

Yu, S.W. and Wang, C.H. (Eds.) 1981. Symptoms of Air Pollution injury in plants - A pictorial Atlas. Shanghai; Shanghai Sci. Tech. Pub. (In Chinese).

Zaidi, S.H., Amani, A.Z., Farooqui, M.H. and Ghouse, A.K.M. 1979. Leaf epidermal structure of *Croton bonplandianum* Baill. in relation to air pollution.

Zeevaart, A.J. 1974. Induction of nitrate reductase by NO_2. Acta Bot. neerl. 23: 345-346.

Zeevart, A.J. 1976. Some effects of fumigating plants for short periods with NO_2. Environ. Pollut. 11: 97-108.

Ziegler, I. 1973a. Effect of sulphite on phosphoenolpyruvate carboxylase and malate formation in extracts of Zea mays. Phytochem. 12: 1027-1030.

Ziegler, I. 1973b. The effect of air polluting gases on plant metabolism. In: F. Coulston and F. Korte (Eds.), Environmental Quality and Safety. Global Aspects of Chemistry, Texicology and Technology as Applied to the Environment. 181-208. Stuttgart, Georg. Thieml Publishers.

Ziegler, I. 1975. The effect of SO_2 pollution on plant metabolism. Res. Rev. 56: 79-105.