Chapter 4

DISCUSSION

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The main objectives of the study were to know :

- The pollutants concentration and the impact of pollutants on morphological and yield parameters of the plants.
- Behaviour of different crop species exposed to pollution at the field level to study morphological, growth & yield parameters, to know the biochemical mechanisms of response
- Impact of single air pollutant on particular species under simulated conditions.
- Antidotic effect of chemicals on plants exposed to pollutants.

The results are discussed and findings are supported with pertinent literature and possible conclusions.

4.1 PATTERN OF POLLUTANT CONCENTRATION AT DIFFERENT ZONES

Vegetation exposed to pollutant stress are influenced by various factors (Mackenzie and Ashry,1989). Plants have an inherent capacity to absorb, detoxify or metabolically incorporate or expel the pollutant (Bucher,1984). Variation in species,varieties or even in cultivars affect the plant responses. Concentration and pattern of occurrence of pollutants as well as atmospheric factors like temperature, relative humidity wind direction and its speed etc. have great impact on responses of plant (Jones and Mansfield,1982, Murray,1984). In the long term in proportion to average concentrations variations are important in addition to the means (Roberts *et al.*,1983). Fluctuating concentrations of pollutants causes more stress than steady amounts,to which plants can be adopted at the cellular and physiological level (Wellburn _et_ _al_.,1976). All the developmental aspects of modern life like transportation, heterogenity of industries,power generation, space heating and refuse burning etc. adversely affect growth and development of the plants directly or indirectly (as was observed in the present study). Variable exposures may be more injurious to crops than continuous low concentration exposures.

SO_2 and NO_x were monitored in all the experimental zones because of their prevalence in the ambient air. Annual and seasonal mean pollutants concentration with the wide range (minimum to maximum) were recorded at all the zones. Still some peaks might have been missed because the monitoring was not continuous (due to inadequate monitoring facilities). At zones V, VI,VII & VIII high values of peak concentrations were recorded (Table 5). Peak concentrations due to accidental leakage and intermittent fluctuations have a great deleterious impact on the plants and sometimes this injury does not correlate with the average concentration as was observed in the present study. Plants in the field have lesser chance for detoxifying the absorbed pollutants due to lack of sufficient pollution free times. Hence the damage reported in the field conditions should be taken as an integral effect of all the existing conditions.

In simulated conditions also episodic higher exposures of SO_2 cause more damage (L' Hirondelle _et_ _al_.,1986). Pollutant's concentration is generally kept constant in fumigation studies, which is in marked contrast to the behaviour of pollutant concentration in field studies. Ground level concentration often exceeds the annual mean concentration near high concentration of point sources and multiple emission sources (Anon, 1981; Garsed and

Rutter,1982). Some of the experimental zones were nearer to the road side hence plants were not only affected by primary pollutants present in air but also with autoexhaust emissions. Some of which lead to formation of secondary pollutants viz O_3,PAN, etc.(Reich and Amudson,1985; Krishnayya and Bedi,1986a). Gases frequently are oxidized to compounds that from Secondary particles e.g. SO_2 to SO_3 or hydrocarbons to organic nonvolatile acids and photochemical haze. The sequence of events leading to interaction between air borne materials and vegetation begins with relase and transport of an effluent to the atmosphere adjacent to vegetation (Hosker and Lindberg,1982). SO_2 is a recognised agent causing significant damage to natural vegetation. Foliage yield of some grasses is decreased by exposure to low concentration of SO_2 for long duration (Murray,1984). The mixture of sulphur dioxide and nitrogen dioxide may accentuate the response that are characteristic of sulphur dioxide. Generally plants seem to be less sensitive to oxides of nitrogen than to either ozone or sulphur dioxide. But NO_x can also cause deleterious effects in combination with SO_2 and O_3.

Plants exposed to SO_2 and NO_2 together show more damage because SO_2 nullifies the beneficial effect of NO_2 (klumpp et al.,1988). Dassler and Bortitz (1988) concluded that in combination of pollutants, threshold value of individual pollutant decreases. This report is in confirmation with the results of the present study revealing that mixture of low concentration of pollutants play more singificant role than the isolated effect and combination of pollutants even at low concentration can cause considerable damage.

4.2 FIELD SURVEY OF COMMON CROPS

The environmental conditions before, during or even following exposures interact to determine the plants responses. Air pollution stress reduced the growth, yield and quality of the crop with or without visible injury (Olszyk et al.,1986; Dustin and Raynal,1988). All the three crop species (wheat, paddy and maize) exhibited reduction in various growth parameters and yield at all the zones (Ludger et al.,1988)

4.2.1 **Triticum aestivum** Linn.

Wheat is a major cereal crop grown during winter. This crop recorded reduction in all the parameters at all the zones. maximum damage was recorded at zone VIII (Windward). This was due to accidental leakage of localized pollutants (Cl_2) in addition to other pollutants like SO_2, NO_2 & SPM (Suspended Particulate Matter). At zone VII high reduction was recorded though the zone was in leeward direction, its close situation to the source resulted in high damage to the crop. Maximum SO_2 concentration was recorded at zone V (Windward) hence depicted more dmage than zones VI, IV,III,II & I in all the parameters.

4.2.2 **Oryza sativa** Linn.

Rice is the major source of calories for 40% of the world's population. The crop was grown during monsoon at all the zones. The zones VII, VI & III were in windward direction, hence recorded more damage in all the parameters as compared to the other zones. Short term high peak pollutants concentration also added to the damage. At zones VIII, V & IV (leeward) varying degree of damage was recorded due to their close proximity to the source. Though zone III (Windward) was at a long distance (3 Km) from main industrial source (Fig.1), during monsoon the industrial emission combined with autoexhaust and resulted in reduction of all growth parameters. This was due to combined effect of a industry (Universal Dyestuff in the close vicinity) emitting local pollutants (Cl_2), and autoexhaust pollution.

4.2.3 *Zea mays* Linn.

Maize is grown world wide and after wheat it is the most widely grown cereal crop. It is a double use food crop i.e.food for humans and feed for live stock. Zones VII, VI & III were in the windward direction, maximum damage was recorded in all parameters at zone VII. At zone VII the foliar damage recorded was 20.7%. Zone VIII exhibited damage in maize crop though located in leeward direction, it is located nearest to the source and is exposed to intermittent high fluctuations of pollution concentration. Lesser damage was recorded at zones V, IV,III & II, situated in leeward dirction. Though zones II & I were close to the source but recorded less damage due to less emission of pollutants (Table 5).

Reduction in various growth parameters as observed in all the three species is supported by many reports (Baker et al.,1986; Darall,1986; Bytnerowicz et al.,1987a; Ormrod et al.,1988). Reduction in growth parameters is the result of alterations of various metabolic processes (Singh et al.,1990a). Exposure to pollutants reduce relative growth rate (RGR) and net assimilation rate (NAR) which ultimately results in reduction in plant productivity (Norby and Kozlowski,1981; Pandya & Bedi,1990). The crops recorded more damage at zones nearer to the pollution sources than the damage recorded along the increasing gradient. This may be due to decrease in pollution load with the increasing distance from the source (Elkiey and Ormrod,1981; Vijayan and Bedi,1988a; Pandya and Bedi, 1989; Krishnayya and Bedi,1990).

4.3 POTTED PLANT EXPOSURE

During the experiment uniformity in plant material and cultural practices viz., water, soil, fertilizer, insecticide etc. were maintained to avoid the influence of factors other than air pollution. Hence the present study the plants grown at all the zones differed only in exposure to different quality of the air. Pollution effects were recorded through changes in morphological, biochemical and yield parameters in all the three crop species.The damage was more at high pollution zones VIII, VII, VI & V than zones IV, III, II & I. A correlation in ambient air status and damage in plants was recorded due to reaseons mentioned in 4.2.2 and 4.2.3. The damage was also influenced by meteorological parameters viz., wind speed, wind direction, seasons (winter and monsoon),temperature, relative humidity and rainfall. Maximum sensitive crop species among the crop studied was wheat. Paddy was also equally sensitive during monsoon due to higher atmospheric humidity and rich soil moisture. Maize crop was comparatively resistant than other two crops. Wheat plants recorded maximum damage at all the zones. The trend was as following:-

VIII > VII > V > IV > VI > III > I. At zones VIII, VII, V & IV plants recorded higher damage than other zones.These zones had high concentration of pollutants viz, SO_2, NO_x,SPM and were nearer to the emission source. The zone VIII had high concentration of chlorine.

High sensitivity of wheat species to these pollutants resulted in severe damage. Zones VII, VI, III, II & I were in leeward direction and recorded lesser damage. Maximum damage was recorded at 80 days i.e. during reproductive phase which ultimately affected the yield (Baker et al., 1987). Plants with dry foliage have shown that climatic conditions typical of winter (low irradiance and short days), lead to slow growth and increase in the adverse effects of pollutants on growth (Davies, 1980).

Paddy (monsoon) crop was grown at all the zones except at zone VIII. This zone was in leeward direction during this season. This crop depicted maximum damage at 80 days at zone VII. The crop damage at all the zones recorded the following trend.

VII > VI > III > V > IV > II > I

Zones VII, VI, III & II were in the windward direction and zones V, IV & I were in the leeward direction. Foliar damage is expected to be increased considerably by the higher uptake rate of SO_2 and other water soluble pollutants (Hallgren,1984).The absorption rate increases as pollutant solubility increases (Bedi et al.,1982). Plants exposed to mixture of pollutants continuously in field, loses the ability to recover. The altered biochemical mechanism from the early exposures reduces plant's capacity to tolerate later exposures (Puckett et al.,1973).

Maize crop was recorded comparatively resistant to mixture of pollutants than wheat and paddy. The fact that resistance to one pollutant can not necessarily be correlated with resistance to another. Hence the damage recorded at all the zones was conspicuous, though it was less in comparision to other two crops. The damage recorded the following trend.

VII > VI > III > V > IV > II > I

Maximum damage was recorded at zone VII. Zones VII, VI, III & II were in windward direction. Though zone II was nearest to the source, recorded less damage in the crop plants because of less emisison of pollutants and zone III which was 3 Km away from the main source (Fig.3) recorded more damage due to combined effect of a local industry (dye stuff) and auto exhaust emission source. Zones V, IV & I in leeward direction recorded lesser damage than zones VII, VI & III.

4.3.1 GROWTH

Economic loss in production, resulting from SO_2 and other mixture of polutants is the result of a continuous process of growth reduction over the life cycle of a species (Larry, 1982).

4.3.1.1 Root length

Physiological changes in plants take place after the uptake of major gaseous air pollutants which then exert substantial effects on growth of roots. The decrease in growth of underground parts are due to decrease in growth of the above ground parts, because shoot synthesied food becomes too deficient to maintain the normal growth rate. Thus when roots and ears have a high demand of photosynthate, the plants under stress of pollutants reduce photosynthesis which ultimately is reflected in reduction of growth (Singh and Rao, 1982; Agrawal _et al_.,1983). The restricted development of root systems in plants exposed to pollutants may be due to inhibition of translocation of assimilates from leaves (Koziol,1984). The effect of the deposition of pollutants in soil has brought about gradual change over a number of years, which leads to various adverse effects on roots (Kasana and Mansfield,1986). Bell (1982) noted greater response in roots than in shoots of grasses . Wheat plants exposed to SO_2 and HF and their combination recorded decrease in root length, shoot length and yield due to disrupted metabolic activities in plants (Sharma and Rao, 1983).

In the present study all the three crop species recorded significant reduction in root length as compared to reference samples (Fig.10).

4.3.1.2 Shoot length

Pollutants reduced the plant growth and development leading to reductions in their various morphological characters like, root length, shoot length etc. in all the three crop species studied. It is also supported by Agrawal _et al_., (1983). Generally the above ground parts of the plants are likely to be affected more by air pollutants than roots because they are directly exposed to pollutants.

The reduction in root length, shoot length, number of leaves etc in shortend life cycle were some of the indications of growth suppression (Pandey and Rao, 1978). Sulphur dioxide resulted in reduced plant height (Shimizu _et al_.,1980, Kats _et al_.,1985,Singh _et al_.,1990a). Low dose exposure of **Loblolly pine** to O_3,NO_2 & SO_2 in combination can result in significant height growth supression (Kress et al.,1982). Reduced growth of trees due to air pollution is thought to be due to lower availability of metabolites (Kozlowski, 1980). Dwarfness of plants results due to improper translocation of synthesized food in plants exposed to SO_2, NO_2 & O_3 (Ito et al.,1984). A reduction in shoot lengths might have resulted from a retarded photosynthetic rate due to decreased photosynthetic areas caused by leaf injury (Sij and Swanson, 1974; Singh et al.,1990a).

4.3.1.3 Number of leaves

Reduction in number of leaves was recorded over reference plants in all the crop species exposed to pollutants. Similar observations were recorded by Taniyama et al.,(1977), Sharma and Rao (1983). Reduction in number of plant's parts is more likely to be caused by a decreased supply of assimilates (Ormrod,1982). The reduction in number of harvested leaves showed a negative impact on yield (Court and Hendel,1989). Plants growing in industrial vicinity show a common symptom of reduction of leaves over reference plants (Sisodia and Bedi, 1986). Bell and Clough (1973) reported reduction in number of leaves in plants exposed to pollutants.The hybrid poplar exposed to O_3 recorded decrease in number of leaves when compared to unexposed plants (Reich and Lassoie,1985). Detection of phytotoxic nature of NO_2 has been based upon symptoms on the leaf lamina, colour change of the leaves, reduction in number of leaves and growth in wheat plants (Prasad and Rao,1979). Combination of SO_2 + NO_2 caused significant reduction in the number of leaves (Ashenden and Williams, 1980).

In the present study wheat and paddy crops exhibited more reduction in number of leaves than maize crop.

4.3.1.4 Total leaf area

The foliage of vegetative canopies serves as a very effective receptor for airborne substances. Foliage also provides a surface of interaction for particulate substances that may range from biologically toxic to those essential for life processes (Hosker and Lindberg,1982). The effect on yield of marketable produce is a direct result of foliage reduction. Reduction in leaf-area reduces total photosynthetic area (Baker et al.,1987).Crop plants appear to be more sensitive than tree plants to most air pollutants in terms of visible foliar injury (Kress et al.,1982). Dubey et al.,(1982) noted reduction in leaf-area of plants growing in polluted atmosphere. Similar observations were recorded by Pawar et al.,(1978) and Singh et al.,(1985). At zone VIII premature leaf fall was observed due to accidental emission of chlorine and ethylene during the present study. Plants exposed to pollutants degrade chlorophyll earlier, which brings early senescence (Miyake et al.,1989), ultimately affecting the productivity of the plants.

SO_2 reduced leaf-area by injuring existing leaves (Saxe,1983). Mature leaves were more susceptible to polutant than younger leaves as in the present study. Elkiey and Ormrod (1979) found that middle aged leaves of **Petunia** cultivars were generally more sensitive to O_3 + SO_2 than younger leaves. The visible foliar injury recorded in mature leaves was due to higher rate of pollutants accumulation. Plants exposed to SO_2 + NO_2 reduced the dry wt. and yield associated with reduction in leafarea (Ashenden and Williams,1980). 30% reduction in leafarea of exposed wheat plants was recorded over reference plants (Harold and Jones,1950). In the present study wheat and paddy showed more leafarea damage than maize crop.

4.3.1.5 Injury index

Leaf by virtue of its unique position and functions experiences greater changes in surrounding environ and such modifications are likely to serve as markers of environmental pollution (Khan et al.,1990).

The visible foliar injury was recorded in all the three crop species at high pollution zones V,VI,VII & VIII. At rest of the zones reduction in growth parameters was recorded but without visible injury. Previously it was commonly accepted that reductions in growth occurred when relatively high concentrations caused visible injury (Shimizu et al.,1984, Pell and Puente,1986, Muir and Mc Cune,1988). Sometimes the physiological activity of affected plants is impaired before any external symptoms are visible (Brewer et al.,1960, Mudd and Kozlowski, 1975, Crittenden and Read, 1978, Wang et al.,1986). Combination of pollutants were present in the field and resulted in more growth suppression irrespective of foliar injury. Photosynthesis was decreased even when no tissue damage in the leaves took place. Visible injury became apparent when 65 to 70% decrease in photosynthesis was recorded in rice and corn plants (Taniyama et al.,1976,Taniyama 1979).

In the present study at zones V, VII & VIII foliar injury recorded during winter season was due to short term peak concentrations of SO_2 & NO_x pollutants. At zone VIII foliar inury was maximum due to sudden leakage of local pollutant chlorine (reported), early leaf senescence was also observed at this zone. Concentration of chlorine was recorded high (1.27 times) at zone VIII as compared to the reference sample. At zones III, VI & VII visible foliar injury was recorded during monsoon. The leaves showing visual damage from 40 days (age) onwards. Maximum damage was recorded at 80 days in all the three species studied. The young but fully expanded leaves were the first to show injury whereas those which were still expanding were least affected.

Foliar injury was observed more during cool and short days. Winter conditions augmented the sensitivity of plants to pollutants (Bytnerowicz et al.,1987a). Leaves of wheat fumigated with 100 ppb SO_2 were severely injured (Baker and Fullwood,1986). Guderian and Stratmann (1962) have demonstrated that sulphur dioxide induced growth suppression without visual leaf necrosis. Multiple ozone exposure caused an additive adverse effect leading to development of foliar injury symptoms and reduction in growth of plants (Agrawal et al.,1985).

Combination of air pollutants like O_3 + SO_2 can induce synergistic effects on foliar injury, growth and yield (Heggested and Bennett,1981, Ormrod, 1982, Olszyk and Tingey,1985). Plants exposed to SO_2 + NO_x caused significant growth reductions without any correlation with visible injury in Populus species (Andrea and Ormrod,1986). The pattern of foliar visible injury typical of a pollutant, occured at sites where SO_2 or NO_2 sorption was over a threshold value. This difference in gas absorption occured due to boundary layer and stomatal resistance at local sites (Omasa et al.,1984). Raddish and cucumber leaves both exhibited visible injury that was synergistic or greater than additive response when exposed to the pollutants mixture (Beckerson and Hofstra,1979).

The leaves of wheat crop at zone V showed interveinal chlorotic and necrotic symptoms of injury, which it is characteristic of SO_2 pollution effect. A similar type of injury was recorded by Prasad et al.,(1979) in wheat plants. Reliable indicators of injury, at higher concentrations, causing serious injury to leaves are necrosis for expanded leaves and reduction in chlorophyll concentration, dry weight and surface area for expanding leaves (Olszyk and Tibitts,1982).

4.3.1.6 Epidermal Traits

Leaves by virtue of their location and structure are the organs of plants which face the main onslaught of air pollutants. Being the outermost layer, the epidermis is relatively more exposed to hazards of air pollution than other tissues. Some of the epidermal features like, size and frequency of epidermal cells, stomatal frequency and stomatal index often act as modifiable traits and can be useful in determining the type and extent of air pollution damage (Yunus and Ahmed, 1979, Ahmed et al.,1988).

Epidermal traits of wheat and paddy crops revealed significant differences in the frequency and size of epidermal cells and stomata of polluted and reference samples. Stomatal density and stomatal index was reduced and number of epidermal cells per unit area were increased in crop species of polluted zone as compared to the reference samples. Similar observations was made in kudzu (**Pueraria tobatto** Willd.) populations by Sharma et al.,(1980).

Stomatal frequency decreased with increasing amounts of pollution (Sharma and Butler, 1973; Godzik and Sassen,1978,Sharma et al., 1980; Kondo et al.,1984). This adaptation might be to decrease the amount of poisonous gases getting into the leaf tissue and protects the plant against pollution. Inspite of these adaptations, the damage recorded was more in the present study depending on opening of stomata for long duration.

The opening or closing of stomata is due to need for CO_2 for photosynthesis and O_2 for respiration and the prevention of excessive water loss by transpiration respectivelly. Heath (1980) suggested that SO_2 may cause stomatal opening or closure depending on concentration and duration of exposure and the resultant osmotic and biochemical effects (L'Hirondelle et al.,1986). Long exposures may lead to permanently open and paralysed stomata (Jensen and Roberts, 1986). Environmental factors viz.,adequate soil water, optimal mineral nutrition, high relative humidity and sufficient irradiance will also lead to stomatal opening, subjecting the leaf tissue to maximal pollutant entry (Carlson,1979; Norby and Kozlowski,1982). Relative humidity at 30.70% increased O_2 uptake fourfold and SO_2 uptake threefold which resulted in high damage (Mansfield and Freer Smith, 1984).

Stomatal pathway is undoubtedly the major route for pollutant uptake during conditions favourable to growth but is not a continuously available pathway like the cuticle. Fowler and Unsworth (1979) estimated that during the day, in wheat 70%of the SO_2 was absorbed through stomata and remaining 30% was absorbed by the cuticular surface. Disintegration of cuticle and epidermis due to pollutants also allow the entry of pollutants unhindered (Adams et al.,1984; Barnes et al.,1988).

Plants exposed to pollutants exhibited damage in cuticular, epidermal and stomatal parts of wheat and paddy, it was suggested due to wet foliage during winter and monsoon seasons.

4.3.1.7 Biomass

There was substantial reduction in the dry weight of all the three crop plants exposed to pollutants. In comparison to control samples the phytomass was maximum reduced at 100 days in exposed plants. Similar reductions in dry matter accumulation of SO_2 treated plants have been reported by Bell and Clough (1973) and Pandey and Rao (1978). Maximum reduction in phytomass accumulation at 100 days can be attributed to increased respiration and decreased photosynthesis (Matsuoka,1978, Prasad and Rao,1981). The fifty percent decrease in total dry weight of rice plants in the area of the air pollution seems to be due to invisible injury (Taniyama and Sawanaka,1975). Similar results are recorded in the present study.

Plants exposed to SO_2 decrease assimilate availability and dry matter accumulation, which depends on leafarea and light interception (Baker et al.,1987). Mixture of pollutants can reduce the dry weight of plant more than a single pollutant (Elkiey et al.,1988, Goodyear and Ormrod,1988). The reduction of biomass accumulation can be ascribed to the lowering of photosynthetic activity in presence of SO_2 and H_2S. Plants exposed to mixture of SO_2 + NO_2 pollutants exhibited significant reduction in root and shoot dry weight and showed combined effect by 40% reduction in total dry weight (Richard and Mansfield,1989). Chlorophyll and ascorbic acid contents were reduced in wheat plants exposed to pollutants which have an ultimate impact on its biomass. In fumigated plants yield (in terms of dry matter) was less as compared to that of the controls (Boralkar and Chaphekar, 1979). Decrease in phytomass accumulation eventually lead to decreased net primary productivity of exposed plants. It is hypothesized that in response to SO_2 toxicity, material and chemical energy in wheat plants were diverted from sites of growth and storage to sites where repair was needed (Koziol and Jordan,1978; Prasad and Rao,1981) and thus the net accumulation is reduced.

In the present study wheat and paddy were sensitive to mixture of pollutants while maize was recorded as comparatively resistant species to the mixture of pollutants.

4.3.1.8 Relative growth rate (RGR) and net assimilation rate (NAR)

Reduction in RGR and NAR was recorded in all the three crop species exposed to mixture of pollutants. Reduction in RGR and NAR was more at zones VIII, VII, VI & V where average and peak pollutants concentrations were high. Similar observations were recorded by Huebert et al.,(1985) and Murray (1985). Visible injury symptoms did not appear in plants species until NAR had decreased considerably. The result of these metabolic and visible responses appeared to be related to differences in sulphur uptake and higher gas exchange rates for deciduous species than conifers (Addison et al., 1984).

Atkinson et al., (1987) reported that high reductions in NAR cause significant reduction in RGR. Plants exposed to SO_2 caused transient decrease in net assimilation rate (L'Hirondelle et al.,1986). Reduction in NAR was increased with increase concentration of SO_2. Duration of exposure had no significant effect on NAR indicating the importance of rate of SO_2 uptake rather than che total amount absorbed (Huebert et al., 1985, Baxter et al., 1989b). It is also in support of our results that peak exposures to pollutants for short periods may be of primary importance in determining the survival of plants in industrial areas. Crittenden and Read (1978) also suggested that chronic SO_2 injury to grasses may be highest when RGR is maximum. The correlation between RGR and inhibitory effects of SO_2 may be related to higher demands of stored metabolites at high growth rates (Norby and Kozlowski,1981).

4.3.2 Biochemical Parameters

Air pollutants interfere with various metabolic processes of plants prior to visible injury manifestation. This alters the biochemical parameters in the plants under pollution stress viz.,chlorophylls, proteins, ascorbic acid, sugars etc. it was observed that chlorophyll, protein and ascorbic acid were reduced at maturation stages in normal case also (reference) When the values were compared with polluted zones the reduction was maximum at later stages which may be due to additional effect of pollution and senescence.Reduction in above biochemical parameters resulted in reduction in yield of all three crop species.

4.3.2.1 Chlorophyll

The content of chlorphyll in leaves which is a principal photosynthetic pigment, may be an important index of physiological activities of leaves (Aoki et al.,1984, Schulz, 1986; Silberstein and Galum, 1988). The extent of reduction in pigment contents kept on increasing with both the pollutant dose and plant age (upto 60 days) in the present work. Plants exposed to gaseous pollutants exhibited reduction in foliar chlorophyll content (Beckerson and Hofstra,1979 and Shukla *et al.*,1990). These reductions lead to a decrease in net photosynthesis (Reich and Lassoie,1985, Plucinska,1988, Greitner and Winner,1989), which can be regarded as a consequence of an altered metabolism (Sij and Swanson,1974). Chlorophyll-a was found to be reduced more than chlorophyll-b in all the three crop species exposed to mixture of pollutants in the present study. Breakdown of chlorophyll in plants under pollution stress has been reported by several workers. Chlorophyll-a is degraded to phaeophytin by replacing Mg^{++} ions from chlorophyll molecules while chlorophyll-b is degraded to the formation of chlorophyll-b (Malhotra,1977; Treshow, 1984;Singh *et al.*,1990b). This chlorophyll destruction is caused due to formation of free oxygen radicals resulting due to inhibited photosynthesis.

Chlorophyll-a is the most important pigment for the photosynthesis in plants. Its high sensitivity to SO_2 affects CO_2 fixation adversely and thereby hampers the plant growth and development. Chlorophyll-a was about two times moré susceptible to SO_2 than chlorophyll-b and four times more than carotenoids (Singh *et al.*,1990b). Effect of SO_2 on chlorophyll concentration might help to explain the inhibition of photosynthesis. The inhibitory effect of SO_2 might be connected with an impaired phosphorylation (Sij and Swanson,1974, Hallgren and Gezelius, 1982).

The chloroplasts being the preferential site of action for SO_2 are the first to be affected. It starts by disintegration of chloroplast membrane simultaneously affecting the leaf pigments located on thylakoid membrane.

When the fumigation time was prolonged, damage to the reaction centre of photosystem II became prominent which reduced photosynthesis (Shimazaki et al.,1984). Sulphite in the cytoplasm might be a major toxicant for inhibition of photosynthesis (Sakaki and Kondo, 1985, Marques and Anderson,1986, Muschinek et al.,1987). Maize crop in the present study showed lesser chlorophyll reductions than wheat and paddy.

4.3.2.2 Sugars

Plants exposed to gaseous pollutants alter the balance of a plant's carbon economy to reduce growth and yield (Koziol, 1984). Carbohydrates are important indicators of energy status and growth potential of plants. The effects of gaseous pollutants on rates of photosynthesis and respiration, induce changes in carbohydrate metabolism. Concentrations of sugar can be altered in exposed plants even without causing visible symptoms of injury or reductions in growth and yield (Koziol,1984).

In the present investigation decrease in total soluble sugars and increase in reducing sugars were recorded in the foliar tissues of all the three crop species at all the zones over reference sample. Similar observations were recorded by Dugger and Palmer, (1969), Koziol, (1980), Koziol and Cowling (1980).

Baxter et al., (1989a) reported that bisulphite ions depressed photosynthesis which reduced the availability of energy and carbon skeleton for detoxifying HSO_3. The decline in soluble sugars may be an inhibitory effect of SO_2 on their biosynthesis and also due to partial breakdown of non-reducing carbohydrates into simple reducing sugars (Malhotra and Sarkar,1979). Reduction in soluble sugar content of plants exposed to pollutants has been reported by several workers (Prasad and Rao, 1981, Kuppers and Klumpp,1988, Pandya,1989, Krishnayya and Bedi,1989). SO_2 inhibited the production of carbohydrate in old matured leaves, where the reduction of carbohydrate concentration corresponded with the loss of chlorophyll (Saxe,1983).

The increase in reducing sugars may be due to changes in respiration (Dugger and Palmer, 1969). The increased concentration of reducing sugars after fumigation with SO_2 was either due to their increased biosynthesis or due to the breakdown of reverse polysaccharides rich in reducing sugars (Malhotra and Sarkar, 1979). Our results on three crop speices are in good agreement with these findings. The amount of reducing sugars was appreciably high in pollutant exposed plants because sucrose hydrolysis is catalysed by acid (Agrawal et al.,1983). Reduced photosynthetic efficiency of affected plants could reduce the accumulation of photosynthates, leading to lower concentrations of starch and energy in the grains but to higher concentration of reducing sugars. Such changes ultimately cause deterioration in quality and flavour of grains (Agrawal et al., 1983).

4.3.2.3 Proteins

Protein is a useful parameter and has been suggested as an indicator of SO_2, O_3, their combination and autoexhaust effects (Nandi et al.,1980, Banerjee et al., 1983). Reduction, in protein content altered the metabolism of the plant and reduced growth and yield (Singh et al.,1990a). In the present study wheat and paddy recorded more reduction in protein content than maize crop. The reduction in protein, carbohydrate and other energy rich compounds led to decrease in the calorific values of exposed plants (Prasad and Rao,1982).

Reduction in protein availability affects various metabolic functions and also limits the availability of proteins as structural components to new membranes (Khan and Malhotra, 1983). A decrease in the total protein content after SO_2 fumigation has been reported for a number of plants (Godzik and Linsken 1974, Constantinidou and Kozlowski,1979). Such a decrease could be attributed to breakdown of the existing protein and to reduce de-novo synthesis. The effects became more severe with longer exposures irreversible in clean air (Malhotra and Khan,1984), which was caused by its destructive effects on cellular membrane and cellular organisation. (Beckerson and Hofstra,1979). **Vicia faba** plants exposed to O_3 altered the foliage metabolism, which is followed by reduced translocation of metabolites to roots and affected the development of nodules and nitrogen availability, which in turn restricted the protein synthesis (Agrawal et al.,1985). Plant senescence is also associated with increase in the rates of breakdown of chlorophyll and proteins after SO_2 fumigation (Murray,1984). SO_2 fumigation resulted in increased sulphur containing amino acids due to increased breakdown of pine needles proteins (Malhotra and Sarkar,1979, Ito et al.,1986).

4.3.2.4 Ascorbic acid

Ascorbic acid is an antioxidant and is a free radical scavenger, and is an important factor in providing protection to living tissues (Lee et al.,1984). Varshney and Varshney (1984) reported that species having high ascorbic acid content are more tolerant to air pllution (Choudhary and Rao, 1977). Plants exposed to SO_2 reduced ascorbic acid cotnent (Vijayan and Bedi, 1988b, Krishnayya and Bedi,1990). The reduction in level of ascorbic acid in pollutant exposed plants has been ascribed to enzyme toxicity and sulphonation of SH groups (Mapson,1958). Decrease in ascorbic acid content vis-a-vis the decrease in yield of SO_2 exposed plants is due to auto oxidation of ascorbic acid (Nandi et al.,1981).

In the present study maize crop had higher ascorbic acid content than wheat and paddy crops resulting in greater tolerance to pllution stress. Alscher (1984) reported that plants having bases for SO_2 tolerance have greater amounts of glutathione ascorbate and better regeneration of thiol groups.

4.3.2.5 Pollutant accumulation

a. Sulphur

Sulphur is an essential macroelement for plants and its various forms are necessary in the intermediary plant metabolism. SO_2 absrobed from the air also can supply sulphur for plant nutrition when grown in sulphur deficient soil. Environmental conditions like sunlight, wind and adequate soil moisture can affect uptake of SO_2 and SO_2 injury. In addition, time of day and season, plant factors such as genotype nutrition, stage of growth and tissue maturation determine the sensitivity of tolerance of a particular plant species to SO_2 injury (Linzon et al.,1979, Rennenberg,1984). Absorption and accumulation of pollutants in plant tissues is reported by many workers (Elkiey and Ormrod,1981, Keller, 1981, Rowlatt et al.,1982). Sulphur accumulation in SO_2 exposed plants has been widely used as indicator of SO_2 polution (Mass et al.,1987a, 1987b, Bytnerowicz, et al.,1987b, Blanka,1988). Plants under stress may survive either by avoiding or by tolerating pollution products. Plants avoid pollution products by increasing boundary layer resistance and changing stomatal behaviour (Ayazloo et al.,1982).

In the present study maize crop showed less sulphur accumulation in foliar tissues than wheat and paddy crops. Higher accumulation of sulphur of polluted zones was related to SO_2 levels of respective zones, except at zone VIII. Zone VIII had higher levels of SO_2 during winter even than the foliar sulphur accumulation was not that high. This was due to presence of high concentration of chlorine at this zone. Chloride ions with their small volume and high uptake rates suppress the uptake of other ions (Guderian,1977).

Some plants can accumulate large amounts of sulphur without showing injury symptoms (Bytnerowicz et al.,1980). The concentration of total sulphur in leaves was strongly and directly correlated with the SO_2 exposure concentration (Treshow,1984, Olszyk et al.,1987). High uptake of SO_2 may result in accumulation of sulphur above its toxicity levels.

SO_2 is rapidly oxidized to sulphate in messophyll cells. Sulphite and HSO_3^{--} are the major chemical species formed upon dissolution of SO_2 in aqueous solutions (Puckett et al.,1973). Both SO_3^{--} and HSO_3^{--} have been shown to be phytotoxic to many biochemical and physiological processes (Zeigler,1975, Malhotra and Hocking,1976).Plants resistance to SO_2 can be attributed to its greater capacity to convert more toxic SO_3^{--} to less toxic SO_4^{--} (Alscher et al.,1987).

b Chloride

Higher cloride concentration was recorded at zones II & VIII. No significant difference was found between zones I,III, IV, V, VI & VII. Plants recorded higher chloride content in zone II and zone VIII had highest chloride concentration. Leaf necrosis were directly proportional to accumulation of chloride (Fuber and Erismann,1980). Plants have been shown to concentrate higher chloride content from the atmosphere in the foliar tissues, leading to visible damage (Petolino and Leone,1980). Physiologically,chloride is involved in different metabolic reactions.

Wheat plants showed high damage at zone VIII and less at zone II, which shows high sensitivity towards chlorine at zone VIII. At zone VIII due to presence of high concentration of SO_2, NO_x, SPM and chlorine caused higher damage than at zone II due to low concentration of SO_2, NO_x and chlorine.The leakage of chlorine was recorded at zone II in early stage, hence plants could recover and impact was not depicted in reduction of yield. Whereas the leakage of chlorine at zone VIII occured during reproductive phase, which reflected in heavy reduction in yield.

4.3.3.3 Yield

Losses of crop yield and quality may be especially important, as agriculture becomes more intensive in an attempt to feed, growing populations and to produce important economical crops (Olszyk and Thompson,1985). Plants exposed to air pollutants exhibited reduction in all growth parameters which was reflected in reduction of yield. There is considerable evidence that variable exposures may be more injurious to crops than continuous exposure even though the two patterns may result in the same concentration, dose and hours (Amudson,1983). Sporadic variable concentrations may be more representative of actual ambient exposures near sulphur dioxide sources than continuous exposures. The most important effect of air pollutants in long term exposure is their interaction with the reproductive processes.

Wheat and paddy crops were sensitive to mixture of pollutants at all the zones. The reduction in apparent quantum yield found with exposure to SO_2 + NO_2 suggested pollutant induced chlorophyll destruction. An increase in the rate of respiration would also account for a decrease in quantum of yield (Carlson,1983), which was most closely correlated with the concentration of SO_2 plus NO_2. The reduction in yield of seed was caused mostly by reduction in size of individual grains.

The correlation between total sulphur content and crop yield reduction was recorded in the present study. Maize crop was comparatively tolerent to mixture of pollutants than wheat and paddy. The yield of maize crop was reduced less in plants exposed to SO_2 than in plants exposed to combination of pollutants.

The reduction in the yield of plants exposed to gaseous pollutants is a common phenomenon. Reduction in yield was seen in barely when exposed to fluctuating concentrations of SO_2 (Baker et al.,1986,Ayer and Bedi 1990). SO_2 exposure reduced the yield of wheat plants (Bytnerowicz et al.,1987b, Ayer and Bedi, 1991). Reduction in yield due to air pollutants was reported by Kats et al.,1985). Bell and Bedi (1985), Olyszyk et al.,(1986) and Vijayan and Bedi (1989).

4.4 ARTIFICIAL FUMIGATION

The reduction due to pollution stress is reflected in growth, biochemical and yield parameters and is influenced by environmental factors like wind speed, wind direction, temperature, season, fluctuation in concentration of pollutants etc. in field conditions. Whereas in artificial fumigation experiments, cultural paractices can be uniformly maintained under known conditions of temperature, humidity etc. to avoid effect of other factors except air. To know the difference between fluctuating pollutant concentration in field and constant pollutant concentration in controlled condition, fumigation study was conducted. Artificial fumigation study is important because direct comparisions are usually made with single gas exposure. The glasshouse constitutes a specific environment in terms of sources and pollutants.

The lack of good correlation of responses in the laboratory and in the field is due to (1) inadequate air movement in some controlled exposures resulting in high diffusion resistance in the boundary layer (2).The fluctuations of air pollution concentrations in the field with upto 10 times the daily mean occuring occasionally in industrial areas, compared with control exposures near the daily mean (3). The presence of several pollutants in field and known pollutant and uniform concentration for known duration in laboratory experiments (Tingey *et al*.,1973, Heagle *et al*. (1974), Ashenden and Mansfield, 1978).

The present study was conducted to know the reasponse of three crop species to pollution (SO_2) stress under controlled conditions and to find out maximum susceptibility age. The reduction recorded under simulated conditions was less than the field conditions. Another reason for reduced injury may be due to plant's ability to recover in pollution free period. Dassler and Bortitz (1988) have reported that plants are able to compensate the shock effects of high pollutants concentration without considerable damage, if they get pollution free period after such shocks. Fluctuating concentration of pollutants in field may cause more stress than steady amounts of pollutants under simulated conditions to which a plant may easily adapt at cellular and physiological level (Wellburn et al.,1976). The rate of recovery was decreased in plants exposed to high pollutant concentration and with increasing exposures under simulated conditions.

In the present study plants exposed to SO_2 reduced biochemical parameters and growth which ultimately decreased by productivity. Effects of sulphur dioxide on various growth and biochemical parameters has already been discussed earlier (4.3.1 & 4.3.2.). Chlorophyll destruction was correlated with increase sulphur concentration which showed direct impact on reduction in yield. Wheat and paddy crop species were sensitive whereas maize crop was comparatively less sensitive toSO_2 pollution stress.

4.5 MITIGATION OF POLLUTION DAMAGE

Plant's photosynthetic cells can tolerate a certain level of toxic intermediates (superoxide anion, hydroxyl radical, hydrogen peroxide and lipid peroxides) because of the presence of several endogenous protective mechanism including ascorbate, glutathione and enzyme before cellular damage occurs (Jablonski and Anderson,1982). Various crop management practices, such as nutrient supplements have been used to reduce air pollution injury in plants with some success in laboratory experiments (Vijayan and Bedi,1988b, Krishnayya and Bedi,1988a). Mitigation experiments were also done by many workers to reduce the phytotoxic effect of O_3 (Olszyk and Tingey,1984, Lorenzini et al.,1987). Nandi et al.,(1985) used calcium hydroxide and observed that it helped the **Vigna** plants to reduce the SO_2 injury, to some extent, they also used potassium ascrobate as an antidoe to SO_2 phytotoxicity (Nandi et al.,1981). Ethylene diurea (EDU) decreased the foliar injury in woody plants by increasing the activity of enzymes superoxide dismutase and catalase having scavenging capacity for free radicals formed in presence of ozone (Lee and Bennett,1982,Bennett et al.,1984, Roberts et al., 1987).

In the present investigation mitigation studies were done under simulated conditions and as well as in the field conditions. The experiments in simulated conditions were done for all the three crop species exposed to SO_2, single air pollutant, whereas experiments in field conditions were done for wheat crop exposed to mixture of pollutants in the ambient air.

4.5.1 Ascorbic Acid Treatment Effects

Ascorbic acid in plants play an important role in determining their resistance to sulphur dioxide pollution. Ascorbic acid in the presence of SO_2 is reduced or converted into Dehydroascorbic (DHA) or oxalic acid or other convertible carbohydrates (Young and Loewus,1975). Ascorbic acid occurs as such and in its oxidised form the dehydroascorbic acid in all plant tissues. Ascorbic acid has been reported to act" In Vivo" as an antioxidant and functions as a co-substrate of plant perioxidase such as ascorbate peroxidase system (Castillo and Greppin,1988). Ascorbic acid is predominant in chlorophyllous leafy parts of plant. Chlorophyllous tissues are the main SO_2 absorption organs and so ascorbic acid becomes an easy target of SO_2 toxicity. Association of major portion of ascorbic acid with chloroplast helps in the scavenging process (Beck et al.,1983). It is a powerful reductant responsible for the photoreduction of protochlorophyllide (Rudolph and Bukatsch,1966). Ascorbic acid is an important electron donor in photosynthesis which stimulates CO_2 fixation (Mapson,1958,Champigny and Gibbs, 1969) and activates defence mechanism under stress conditions (Lewin,1976). Ascorbic acid can replace water in light reaction II so its loss would lead to serious consequences in plant metabolism (Varshney and Varshney,1984). Lee et al.,(1984) observed that similar antioxidant and free radical scavenging capacity of ascorbic acid helps in protection of plants against lipid peroxidation and leaf damage.

Ascorbic acid acts as a powerful reductant and seems to mediate the reduction of sulphite to hydrogen sulphide thereby reducing the toxicity of SO_2 (Silvius et al.,1976) which makes plants tolerent against SO_2 effects (Sekiya et al.,1982).The reduction in level of ascorbic acid in plants exposed to pollutants has been attributed to enzyme toxicity and sulphonation of SH groups (Mapson,1958). In the normal condition the important function of ascorbic acid is detoxification of photosynthetically reduced O_2 or its product H_2O_2 inhibits CO_2 fixation, so to scavenge H_2O_2 at the sites of its origin is necessary for photosynthesis (pandya ,1989). The active involvement of ascorbic acid in many physiological and biochemical processes increase its importance as a protector.

In the present study plants treated with ascorbic acid recorded increase in various growth and biochemical parameters, ultimately resulted in increase yield. Linear increase in recovery was observed with increasing concentration of ascorbic acid 0.005 0.0075 0.01 M under simulated conditions. Sulphur accumulation was less in treated plants than in the untreated plants which reduced the injury. The maximum percentage recovery in yield of wheat, paddy and maize crops recorded was 56.40, 57.33 and 27.59 respectively over reference plants (exposed and untreated). In field experiments the recovery was increased in all growth and biochemical parameters (except reducing sugar and sulphur) with increase in the concentration of ascorbic acid treatment (0.005M,0.01M). But the plants treated with 0.02M (A3) ascorbic acid exhibited less recovery than 0.01M (A_2) in all the parameters studied. This may be due to reduction in uptake of ascorbic acid in A_3 treated plants. Ascorbic acid uptake is inhibited at low pH. At low pH dehydroascorbate formation is increased. Dehydroascorbate is an analogue substrate for the ascorbate translocator, and interferes with the uptake of ascorbate (Beck et al.,1983). In the present study also higher concentration of applied ascorbic acid might have resulted in such situation which reduced its uptake. Similar results have also been recorded by Pandya and Bedi(1990). In the present study positive correlation was observed between concentration of ascorbic acid in plants and mitigation of pollution injury. The plants in field experiments recorded 43.10, 31.52 and 20.67 percent yield recovery in A_2, A_3 and A_1 plants respectively.

4.5.2 Urea Treatment Effects

4.5.2.1 Growth Parameters

The metabolism of foliar applied urea has been studied extensively and reviewed by Boynton (1954),Wittwer and Teubner(1959), Cowling and Lockyer (1978) in **Bean, tomato, cucumber, corn celery** and **potato** plants. Foliar spray of urea is readily absorbed by diffusion and distributed rapidly by plants,where energy source is apparently not required.Nitrogen, phosphorus and potassium are readily absorbed by aerial plant parts, often several times more efficiently than from supplementory soil treatments (Bagal and Shingte,1984). Urea is converted to ammonia during night,and during day glutamine accumulates. Distribution and conversion of nitrogen from foliar applied urea to useful metabolite components in the plants is evidenced by greening up of the entire aerial parts. Thus the foliar spray of urea enhances the growth and development of plants by invigorating the metabolic processes.

In the present investigation the foliar spray of urea functioned as source of nitrogen which in turn reduced the injury caused by pollutants (Davison and Bailey, 1982, Pandey, 1982). Plants treated with urea spray of different concentrations showed linear correlation with increase in percentage recovery in all growth parameters. It stimulated the growth in plants exposed to SO_2, it may be due to greater proportion of assimilated sulphur from SO_2 utilised in metabolic processes and reduces its harmful effects (Lauenroth et al.,1983). The total leaf area was increased in plants treated with urea and exposed to pollutants which resulted in dilution of absorbed pollutant per unit area and reduced the damage (Bell,1985).

4.5.2.2 Biochemical Parameters

The results of the present study clearly indicate that an increase in the nitrogen supply to wheat plants is correlated with a decrease in their susceptibility to combination of pollutants. The plants treated with urea (0.16M, 0.32M and 0.64M) showed higher chlorophyll,protein, soluble sugars and ascorbic acid than plants exposed to mixture of pollutants and untreated with urea. Ascorbic acid content was also more in treated plants and infact the ascorbic acid content of urea treated plants was more than ascorbic acid treated plants. The reducing sugar and sulphur were reduced in treated plant over reference plants.

The positive effect of nitrogen supply is due to its important role in protein metabolism which causes reistance in the plants (Pandey, 1982, Ulrich, 1984). Nitrogen supply decreased the absorption of SO_2 in plants (Leone and Brennan,1972).Urea on the leaf surface forms ammonia which prevents the lowering of the pH of leaf tissues as well as rapidly combining with SO_2 to form ammoniam sulphate which is less toxic to plants. Ammonia helps in the rapid oxidation of SO_2 to SO_4 in the case of urea sprayed and SO_2 exposed plants. Rapid foliar absorption of urea helps in biosynthesis of amino acid specially glycine which provides skeleton of pyrrole ring of chlorophyll molecule (Singh and Rao, 1985).

proper care should taken to explore the maximum mitigatng potential of the agent at right stage, with periodic treatments during the entire life cycle of a species. Maximum accumulation of mitigating agent (EDU) was in mature leaves of sugarmaple.

In the present study among the urea treated plants, maximum percentage recovery in yield was in U_3 plants (55.58) which was followed by U_2 (37.02) & U_1 (25.19) respectively over reference sample. This may be due to the improved production potential of the treated plants as the damage to photosynthetic leaf and chlorophyll is checked by urea spray. Pandey (1982) reported that the quality of grains with respect to their protein, carbohydrate, the caloric value and mineral contents was also found to be improved in treated and exposed plants. In the present study also it was possible to increase the yield in the plants grown in polluted area by increasing nitrogen supply to wheat plants.

The maximum cost benefit ratio in yield of plants treated with ascorbic acid and urea was recorded in least concentration of chemical in any experiment. The highest benefit was recorded in U_1 (1:2.45) treatment. It was followed by U_2 (1:1.85) & U_3 (1:1.46) cost benefit ratio in respective treatment. The recovery in different parameters was more in other treatments (U_2 & U_3) but the economical loss was maximum recovered by the U_1 treatment.

4.6 FUTURE SCOPE OF WORK

Different varieties of the investigated plants species can be tried to designate the most resistant one.

- Maize crop was recorded relatively resistant than wheat and paddy. On this species still more anatomical and biochemical parameters viz stomatal behaviour, chloroplast study, glulathione, thiol groups,peroxidase activity and superoxide dismutase (SOD) etc. can be studied to know their role in plant metabolism. These parameters will help to compare pollution effect in plants of polluted region and non-polluted region.

- Different pollutants other than SO_2 like NO_2, chlorine, ammonia and combinations of these pollutants can further be studied under simulated conditions by varying concentration of pollutants. Threshold limits of pollutants for individual species can be determined.

- Continuous monitoring in experimental area to be done for correlation of pollutants concentration and plant inury to record the impact of peak concentrations during shut up, start up or accidental emissions.

- In mitigation studies ascorbic acid and urea spray treatments showed reduction in injury to plants exposed to pollutants. Other chemicals viz., Potassium ascorbate,calcium hydroxide, fungicide, ethylene diurea can be tried to reduce pollution injury. The economic benefit was recorded maximum in least concentration of urea spray, hence more experiments of wider range concentrations of urea in simulated and filed conditions can be studied which can help to achieve better yield with lesser expensive chemicals.