Chapter 4

# DISCUSSION

CONTENTS Page No.

As mentioned earlier the main objectives of the study were to know:

1. **Response of plants to different concentrations and combinations of ambient air pollutants.**

2. **Differential response of different species to same air quality status.**

3. **Response of a particular species at different ages, under simulated contions.**

4. **Efficiency of some chemicals in mitigating pollution effects.**

The data collected during the study provided good information on the above aspects. The results are discussed and the findings are supported with pertinent literature and possible conclusions have been drawn.

## 4.1 PATTERN OF POLLUTANT CONCENTRATION AT DIFFERENT ZONES

The impact of pollution on the vegetation is influenced by various factors. Response of plants is not only dependent on the chemical composition and concentration of pollutants in the air but also to the pattern of occurence of these pollutants. Jacobson & Mc Manus (1985) concluded from their experiments that consideration of temporal variation is very important when the aim is to determine the effects on growth, yield and reproductive capacity of plants. Crops may respond to average concentration in long term but it is likely that variations are also important in addition to means. In field conditions crops are continually exposed to more or less pollution stress as pollution free times are very rare (Guderian, 1977). Presence of wide variety of pollutant sources like different types of industries, autoexhaust, domestic fuel, etc., (as was observed in present study) decrease the chances of occurence of pollution free periods and intensify the effects. The static condition of plants make them helpless to avoid such situations.

In the present study monitoring for $SO_2$ and $NO_x$ was only done because they were the major and common pollutants in all the zones. A wide range of average pollutant concentration was observed at different zones. In addition to the average, peak concentrations during the monitoring period also showed wide variations. At zone V, VI, VII and VIII high values of peak concentrations were recorded (Table 5). Still some peaks might have been missed because the monitoring was not continuous. In reviewing the response of plants (Lichens) in field conditions Huebert *et al.*, (1985) concluded that short term peak concentrations were of primary importance in determining the survival of plants in industrial area, particularly near pollution point sources where uniform concentrations are unlikely. Under simulated conditions also episodic fumigations of $SO_2$ had greater effects than constant low exposures on aspen and jack pine (L'Hirondelle *et al.*, 1986).

Besides these common pollutants each zone had some local pollutants. Most of the zones under investigation were near roads having heavy automobile traffic. Presence of primary pollutants (e.g. $NO_x$) and auto-exhaust emissions lead to the formation of secondary pollutants like $O_3$ and PAN in hot and illuminated conditions (Fontan & Lopez, 1984; Lorenzini, 1987). Damage by these pollutants in such conditions has been reported earlier (Bambawale, 1986; Krishnayya & Bedi, 1986). Sabratnam *et al.*, (1984) reported that in a mixture of $SO_2$, $NO_x$ and $O_3$, Ozone alone was responsible for 75% of the total damage to beans and corns. zone II and VIII had chlorine as a local pollutant (emitted from alkalies and hydrochloric acid manufacturing industries respectively). Effect of chlorine are not widely studied but its toxicity is well known (Guderian, 1977; Vijayan & Bedi, 1989).Presence of these local pollutants intensified the effects of common pollutants which were reflected in high damages. Presence of multiple point sources also intensified the effects. With a single point source plants are periodically exposed to short term peak concentration, frequency distribution of which is not always log-normal. On the contrary with multiple point sources plants are exposed to more frequent occurence of short term peaks, generally with higher concentration than the short term peak concentration in single point source emission (Larry, 1982). These peaks are ten times more than the daily mean in multiple source area (Ormrod, 1982). Further the peak concentrations (higher emissions) of pollutants may occur at different times for different pollutants in natural environment. Such patterns may have considerable impact, with the preconditioning of plants by one pollutant affecting their response to a later peak concentration of another pollutant. Higher concentration of $NO_x$ than $SO_2$ was recorded at all the zones which gave more than additive effects. When $SO_2$ and $NO_x$ are present together, $SO_2$ nullifies the beneficial effects of $NO_2$ and results in more damage (Freer-Smith, 1984; Klumpp *et al.*, 1988). In recent studies it has been emphasized that for combination of pollutants threshold values of individual pollutant is of little importance, as jointly very low concentration of pollutant can also produce significant effects (Dassler & Bortitz, 1988). This clearly shows that if the combination is more complex (types of constituents) effects are also more. All the discussed points, if taken together clearly support the findings of the present study.

## 4.2 FIELD SURVEY OF COMMON CROPS

Plants being stationary are continuously exposed to environmental conditions, response to which is exhibited in various ways. Air pollution stresses have been known to cause damage to vegetation. Reduction in various growth parameters is observed in plants growing under pollution stress conditions (Murray, 1984; Lorenzini *et al.*, 1985; Dustin & Raynal, 1988). All the three species (tobacco, potato & pigeon pea) studied showed reduction in various parameters at most of the zones.

### 4.2.1 *Nicotiana tabacum* Linn.

Tobacco was grown at all the zones. It showed reduction in all the parameters studied at all the zones (except at zone II). Higher damage was recorded at zone VI and VII which had higher pollution concentration during monsoon. At zone VIII reduction in growth parameters was less as compared to previous two zones but accidental leakage of localized pollutant ($Cl_2$), near maturity stage of crop resulted in heavy yield loss. At zone II increase in various growth parameters over reference was recorded. This can be due to affinity of this species to low levels of chlorine (recorded at zone II) like some chlorophillic plants (Guderian, 1977).

### 4.2.2 *Solanum tuberosum* Linn.

Potato was cultivated at few zones (III, IV, V & VI). It showed varying degree of reduction in various parameters at different zones (except at zone III). Maximum yield reduction (31.8%) was recorded at zone Va which was maximum polluted zone (WW) in the season and was nearest to the source. Increase in various parameters over reference was observed at zone IIIa, IIIb & IIIc. These zones were in leeward direction from the pollution source during period of study. Pollutant concentration was also less than reference. Low concentration of $SO_2$ can increase the plants growth (Murray, 1986) and $NO_2$ also at low levels is helpful in plant's growth (Tischner *et al.*, 1988). Lorenzini and Materazzi (1985) observed significant tuber fresh weight increase at low pH levels, they speculated that inputs of sulphate might have stimulated plant productivity. Such effects in present study also might have occured. At zone IIIb maximum increase in yield was due to better cultural practices (higher dose of fertilizers), adapted by the local farmers.

### 4.2.3 *Cajanus cajan* Spreng.

Pigeon pea showed very high damage at most of the zones where crop was grown. This shows high susceptibility of this species to the recorded pollution levels. Very high damage was recorded at zone VII (60% defoliation) during monsoon when the zone was in windward direction. Short term high concentration of pollutants as was observed by high peaks (Table 5) was the cause for this. This damage resulted in high yield loss because the crops could not recover even when the zone was in leeward direction. This clearly shows influence of peaks of pollutant concentration on long term productivity. Leaf fall in pigeon pea when exposed to high concentration of $SO_2$ has been observed (Pawar, 1981) and this is due to production of ethylene under stress condition (Wolfenden *et al.*, 1988).

Reduction in various growth parameters as observed in all the three species is supported by many reports (Bell, 1980; Bedi *et al.*, 1982; Agrawal *et al.*, 1983; Dustin & Raynal, 1988 etc). Reduction in growth parameters is a result of alteration of various metabolic processes (Bull & Mansfield, 1974; Koziol & Jordan, 1978; Carlson, 1983). Pollutant exposure reduce net assimilation rate (NAR) and relative growth rate (RGR) and ultimate result is reduction in plant productivity. It was observed that the species showed more damage nearer to the pollution source and the damage was reduced along the gradient (at zone III and V). This was because the pollution load decreased with the increasing distance from the source. It has been reported that species show more sensitivity near the source than at distant point (Guderian & Kueppers, 1980; Vijayan & Bedi, 1988[b]).

The species studied served as bioindicators of air polllution but difference in soil, water and other microenvironmental conditions also might have influenced the effects and impaired the comparability of results for differential sensitivity of species and their age of maximum susceptibility.

## 4.3 POTTED PLANT EXPOSURE

In field grown crops the effect of pollution could not be isolated due to variable factors viz. edaphic, nutritional and different cultural practices in different zones under investigation. To avoid the influence of factors other than the air pollution, uniformity in plant material and cultural practices was maintained. This helped in achieving identical conditions at all the zones and only difference in quality of air influenced the plant's growth. Pollution effects were exhibited through different morphological and biochemical parameters investigated for all the three crops, (except at zone II where tobacco showed better growth than reference for which interpretation is given at 4.2.3.4.c). It was observed that the damage was more at high pollution zones V, VI, VII and VIII. A definite relation between ambient air status and damage in plants was observed. At zones, where average concentration of pollutants was high, simultaneously mingled with high peak concentrations of pollutants, plants exhibited more damage. Pollutant concentration at a particular zone in particular season was influenced by meteorological parameters specially wind direction and speed so more damage at windward zones and comparatively lesser at leeward zones was observed in all the three species. Although some variations were observed due to presence of local pollutants (at zone VIII) and closer location of pollution source (at zone VI). Tobacco and egg plants are long-term crops and complete their life cycle in two seasons (monsoon and winter). The behaviour of both the crops was different in different seasons and in the same season it changed with age.

Maximum sensitivity by tobacco during monsoon was exhibited at 80 days in all the parameters, at all the zones. The order of damage recorded at different zones was VII >VI > V > IV > III > VIII > I. During winter change in wind direction resulted in maximum damage at zone V (WW) which was the maximum polluted zone during this season. The damage at other zones was in order of VI > VII > VIII > IV > III > II > I. At zone II better growth of tobacco was observed as compared to reference. This zone was comparatively less polluted and local environmental conditions (presence of low concentration of chlorine) modified the effects. Low concentration of chlorine may promote growth of some plants while at high concentrations it gives deleterious effects (Guderian, 1977). This may be the reason for better growth of tobacco at zone II and reduced growth at zone VIII (where higher concentration of chlorine was recorded).

Egg plant showed greater sensitivity than tobacco in all the parameters. Most adverse effects during monsoon were recorded at 80 days, at all the zones. The order of damage was VI > VII > VIII > V > IV > III > II.

During winter maximum damage was recorded at zone VIII. This zone was in windward direction and had high concentration of $SO_2$, $NO_x$ and chlorine (3:1) high sensitivity of species to these pollutants resulted in severe damage. At zone VI and VII (LW) the damage was comparatively less than monsoon but even then the percent reduction was very close to that occured at zone V (WW) having maximum concentration of $SO_2$ and $NO_x$ (Table 5). This shows high sensitivity of crop in early ages, because damage occured at that age could not be recorded even if the pollutant concentration was lowered down at later stages.

At zone I slight improvement over reference was recorded at early ages (upto 80 days) while in later stages (after 80 days) deleterious effects were observed. At this zone the concentration of $SO_2$ was very low at early ages of crop and this might have helped in better growth while the concentration increased at later stages and produced damaging symptoms. Murray (1986) proposed that at low concentration $SO_2$ may be beneficial for growth but at higher concentration it is severely inhibitory. There is an abrupt threshold between beneficial and deleterious effects which is determined by environmental conditions and biotic factors. In studying long term effects of combination of $SO_2$ and $NO_2$ Freer Smith (1984) also reported that for the first few weeks the effects were antagonistic but in long term this changed to additive effects. Behaviour of egg plant at zone I is supported by these findings.

Potato is a short term crop and completed its life cycle in one season (winter) only. At all the zones damage recorded was maximum at 60 days showing higher sensitivity of crop at that age. The order of damage recorded was VIII > V > VI > VII > IV > II > I.

All the three species investigated showed response to pollution status through various parameters studied which are discussed further.

### 4.3.1 Growth

#### 4.3.1.1 Height

Height reductions were observed in all the three crops. Stunted appearence of plants exposed to pollution is result of reduced growth (Taniyama, *et al.*, 1977; Agrawal *et al.*, 1983; Dustin & Raynal, 1988). Alteration of various metabolic processes specially inhibition of photosynthesis as was observed by Carlson (1983) and Darall (1986) results in less production of photosynthate which ultimately reduces the growth. Ito *et al.*, (1984[b]) reported improper translocation of synthesised food in kidney bean exposed to combination of $SO_2$, $NO_2$ and $O_3$. This can also result in dwarfness of plants. Roberts and Schnipke (1983) observed that total height and rate of height growth were significantly reduced in polluted areas where combination of pollutants were present.

#### 4.3.1.2 Number of leaves

It was observed that number of leaves of plants exposed in polluted area was less as compared to reference. Reduction in number of leaves is the result of reduced growth and has been reported by many workers (Taniyama *et al.*, 1977; Bell, 1980). Davies (1980) reported that in $SO_2$ exposed *Phleum pratense* emergence of 5th leaf was inhibited and rate of extension of emerged leaves was also reduced. In plants growing in industrial area, reduction in number of plant parts is a common symptom of pollution stress specially in long term exposures (Santo *et al.*, 1979; Shringi, 1986; Sisodia & Bedi, 1986). Reduction in number of plant parts is more likely to be caused by a decreased supply of assimilates (Ormrod, 1982). In studying translocation pattern of $SO_3^{--}$ in *Vicia faba*, Garsed & Mochrie (1980) concluded that sulphur compounds accumulate in meristems, this can affect morphogenesis and will result in altered growth and development. The yield of crops like tobacco will be negatively affected in such conditions. Court & Hendel (1989) reported that reduction in the number of harvested leaves had a negative impact on yield. Reich & Lassoie (1985) reported that the number of leaves in $O_3$ exposed hybrid poplar was always less than in unexposed plants and resulted in significant growth reductions.

#### 4.3.1.3 Total leaf area

Of all the plant organs, leaf is the most sensitive to external factors. This sensitivity rests on the fact that the major portion of important physiological processes are concentrated in the leaf, which acts as the centre of variability or plasticity of the organism. Yield of plants depends strongly upon light interception and thus on leaf area. Reduction in leaf area reduces total photosynthetic area (Baker *et al.*, 1987). Sensitive species when exposed to pollutants singly or in combination show reduction in leaf area (Ashenden & Mansfield, 1978; Boralkar & Chaphekar, 1979; Heggestad *et al.*, 1981; Sharma & Rao, 1983). Very low concentration of $SO_2$, $NO_2$ and $O_3$ also caused significant reduction in leaf area of *Pinus taeda* when they were present in combination (Kress *et al.*, 1982). In the present investigation also leaf area of exposed plants was reduced. Tobacco showed better tolerance than egg plant and potato. Norby *et al.*, (1985) observed that inhibitory effects of acid rain and gaseous pollutants were mediated through a reduction in leaf area ratio and thus in loss of photosynthetic area. Shimizu *et al.*, (1984) also concluded that growth reductions in sunflower plants exposed to combination of $O_3$ and $NO_2$ could have resulted from a loss of photosynthetic leaf area. The species studied also exhibited reduction in their total leaf area and this reduction ultimately resulted in loss of productivity.

#### 4.3.1.4 Injury index

All the three species exhibited visible symptoms only at high pollution zones (V, VI, VII & VIII) while growth reductions were recorded at other zones also. The concept that detrimental effect of pollution is always associated with visible injury (Thomas, 1951) is now discarded. Plants may exhibit visible injury under high concentration of pollutants (Tingey *et al.*, 1973; Constantinidou & Kozlowski, 1979; Shimizu *et al.*, 1984, Pell & Puente, 1986;

Muir & McCune, 1988), but substantial growth reductions occur without any visible injury also (Ashenden & Mansfield, 1978; Bell, 1980). In the present investigation visible symptoms were observed where short term peak concentrations were comparatively high. At zone VIII leaf fall was observed in potato and egg plant. This zone was characterised by the presence of a local pollutant chlorine, accidental leakage of which caused a sudden leaf fall. In stress condition sensitive species are reported to produce ethylene (Peiser & Yang, 1979; Bucher, 1984). Primary function of stress ethylene is to accelerate abscission of organs (Abeles & Abeles, 1972). In present investigation leaf fall was observed in potato and egg plant which may be due to their higher susceptibility to chlorine. Tingey *et al.*, (1978) observed a relationship between chlorine concentration and stress induced ethylene, production of which was dependent on species. In this context tobacco seemed to be comparatively tolerant. Drying of leaves of potato was also observed at zone VI & VIII at zone VI high peak concentration of $SO_2$ and $NO_x$ were recorded, while at zone VIII the concentration of chlorine was very high (3.1). These acute exposures might have caused excessive transpiration leading to drying of leaves. Excessive transpiration under pollution stress has also been reported by Black *et al.*, (1982) this confirms the results of present study.

68

It was observed that growth reductions and amount of visible injury were not positively related. Study demonstrated that moderately polluted environments have the potential of causing significant growth suppressions without any visible injury or with a very slight amount of visible injury. Similar types of observations were recorded by Kress *et al.*, (1982) where the concentrations used were very low. Combination of pollutants was present in the field and this resulted in more growth suppression irrespective of foliar injury. Andrea & Ormrod (1986) also observed that combination of $SO_2$ and $NO_X$ caused significant growth reductions in *Populus* species specially when $NO_x$ was in higher concentrations and reductions did not show correlation with visible injury. Lorenzini *et al.*, (1985) observed that different strains of alfalfa showed a complete lack of correlation between acute and chronic exposures of pollutant mixtures, response of different strains was also different. This is the reason for variation in response of the three species. In studying effects of $SO_2$ & $NO_2$ exposures on sunflower Omasa *et al.*, (1984) concluded that pattern of foliar visible injury, typical of a pollutant, occured at sites where the integrated $SO_2$ or $NO_2$ sorption was over a threshold value and the difference in gas absorption occured due to boundary layer and stomatal resistance at local sites. Zech *et al.*, (1985) observed that magnesium content of needles of some coniferous trees was very low in high pollution areas. They concluded that this mineral deficiency under pollution stress may be responsible for visible injury.

In subtle effects of pollutants early senescence of leaves is also a common symptom (Peterson & Arbaugh, 1988). All the three species showed early senescence of leaves. It is supported by the work of Baker *et al.*, (1987) who observed that after achieving maximum leaf area rate of senescence was increased in $SO_2$ exposed winter barley. Murray (1984) also observed that $SO_2$ induces increase in senescence, which is associated with increased rate of breakdown of chlorophyll and protein. Reich (1983) concluded that accelerated leaf aging due to $O_3$ exposure was at least partially responsible for declining net photosynthetic capacity of poplar leaves. Kato & Shimizu (1985) suggested that early senescence of leaves is due to breakdown of chlorophyll molecule, which in normal cases occurs only at maturity, while in pollution affected plant chlorophyll is degraded early and therefore brings early senescence. Similar observations were reported by Miyake *et al.*, (1989). Early senescence reduces the photosynthetic capacity of leaves and thus will affect productivity of plants. In case of tobacco, it is very important as the quality as well as quantity of saleable leaves depend largely on their colour. Akimoto & Hiroko (1985) observed that the dry weight/unit area was depended on the colour of leaves and highest quality of crop was obtained when leaves had sufficient maturation time after topping. The mature leaves of tobacco at polluted zones were turned to blackish-brown colour (due to burning) while at reference zone the leaves were golden brown, a colour required for good saleable quality. The maturation time was also shortened at polluted zones. Such effects adversly affect the quality of crop and result in economic loss. In other two crops also early senescence affected the productivity.

### 4.3.1.5 Epidermal traits

69 It was observed that epidermal traits of plant species studied were changed under pollution stress. Stomatal density and stomatal index were reduced. Number of trichomes and epidermal cells per unit area were increased in all the species.

The epidermis being the outermost protective layer in all organisms, exhibits modification and abnormalities in form, structure and function with the changes in the surrounding environment and such modifications are likely to serve as indicators of environmental pollution. The results of the present study are supported by the work of Yunus & Ahmed (1979), Vijayan & Bedi (1988c) Sharma & Butler (1973) and Sharma (1975) also reported such modifications in many species and suggested these to be adaptation against pollution. Increased density of trichomes may be of help in trapping the particulate matter falling directly on the leaf surface, which is otherwise likely to block the stomatal pores and causes injury to the leaves, thus increased density of trichomes may be another adaptation to abate pollution damage by providing an outer line of physical defence (Garg & Varshney, 1980; Gupta & Ghouse, 1986). Inspite of such adaptations plants are damaged by pollutants. This is because of dissolution of toxic gases on moist foliar surfaces from where they enter via cuticle (Posthmus, 1983). Disintegration of cuticle by the acidic activity of pollutants also allows the entry of pollutants (Godzik & Sassen, 1978; Barnes *et al.*, 1988; Kerstiens & Lendzian, 1989).

Huttunen & Soikkeli (1984) observed that epicuticular wax erosion occured around the stomata of conifer needles and caused deleterious effects. The absorption of gaseous pollutants is not dependent only on the number of stomata but also on their opening, which again is governed by various factors. Environmental factors like light, temperature and humidity play an important role in this. It has been observed that constant exposure to pollutants result in wider opening of stomata in some species (Majernik & Mansfield, 1971; Noland & Kozlowski, 1978). In long term exposures paralysis of guard cells has also been observed (Black & Black, 1979). This will result in constant entry of pollutants.

More damage in high humidity and high temperature conditions have been recorded because of wider opening of stomata (Norby & Kozlowski, 1982; Jensen & Roberts, 1986). High damage during monsoon in tobacco and egg plant in the present investigation may be because of such conditions. Prolonged exposure might have also caused wider opening of stomata in potato. Sometimes closing or reduction in stomatal pore size also occurs due to pollution stress (Sharma & Butler, 1973; Gupta & Ghouse, 1986). Mansfield & Freer-Smith (1984) suggested that this closure is not a desirable way of avoiding stress due to pollution. A true avoidance mechanism would involve closure in advance of stress conditions, rather than as an event secondary to that stress. Such conditions will definitely reduce plant productivity which may be either by hampered gas exchange or by greater pollutant uptake. Reduction in growth of all the three species, inspite of epidermal adaptations is supported by the above findings.

#### 4.3.1.6 Biomass

The dry matter accumulation in plant parts was reduced as compared to reference in all the three crops. Dry matter accumulation is the net result of various metabolic processes working together in the plant, which are altered by pollutant exposures resulting in reduced accumulation of assimilates. The reduction may be due to loss of photosynthetic area, retardation of critical anabolic processes or the acceleration of particular catabolic processes (Shimizu *et al.*, 1984). Baker *et al.*, (1987) reported that dry weight of plants depend strongly upon light interception and thus on leaf area, exposure to $SO_2$ decreases assimilate availability and dry matter accumulation. Combination of pollutants also significantly reduce the biomass accumulation and mostly the combination effect is more than the effect of a single pollutant (Dueck *et al.*, 1986; Elkiey *et al.*, 1988; Goodyear & Ormrod, 1988). The comparative tolerance (less reduction) in tobacco as compared to other two crops can be explained on the basis of its foliar response. Both the later crops showed higher foliar (visible and invisible ) damage which ultimately resulted in highly reduced biomass accumulation while tobacco showed comparatively lesser damage. At zone VIII tobacco showed lesser damage in some parameters (height, number of leaves) but at later stages very high foliar damage (burning) reduced the net biomass. Lesser damage in tobacco at earlier stages was due to its comparatively more tolerance to lower level of chlorine, while at later stages the pollutant concentration was high (3.1) and resulted in severe damage.

#### 4.3.1.7 Relative growth rate (RGR) and net assimilation rate(NAR)

Growth analysis for RGR and NAR revealed negative impact of pollution in all the three species. In early stages both the rates were reduced at all the zones (except at zone II where tobacco showed better growth). Reduction in RGR and NAR has been observed in plants exposed to pollutants (Jensen, 1981; Norby & Kozlowski, 1981[a]; Ito *et al.*, 1984[b]; Murray, 1985). Both the values are related and while lesser RGR is related to reduced NAR (Murray, 1985), reduction in NAR is associated with reduced photosynthesis (Reich & Amundson, 1985). Atkinson *et al.*, (1988) reported that high reductions in NAR cause significant reduction in RGR. All the three species investigated exhibited more reductions in both the rates at high pollution zones (V, VI, VII, VIII) where average as well as peak concentrations were very high. Similar types of observations were recorded by Huebert *et al.*, (1985) who observed that peak exposures were of primary importance in determining growth rate reductions in lichens. They also suggested that rate of $SO_2$ absorption plays major role than the total absorption. The species investigated also showed more reductions when rate of sulphur accumulation was more . All the three species showed very high reduction in most of the parameters when their RGR was higher . This shows their high susceptibility at that age. Norby & Kozlowski (1981[b]) observed that $SO_2$ effects on some woody tree species were more when their RGR was higher. They attributed this to higher demands of stored metabolites at that time, when rate is slow, utilization of stored metabolite is also low and growth is less affected. Olszyk *et al.*, (1987) also reported high susceptibility of plants in suitable growth conditions. They concluded that plants during active growth have more air pollutant sensitive tissue and therefore are more affected at that time. Results of the present study are also in conformity with the above studies.

Differential response of all the three species was observed which was due to difference in pollutant absorption rate (Baxter *et al.*, 1989[b]). In addition to the influence of leaf characteristics on the uptake of sulphur and subsequent NAR reduction the capability of a plant to convert absorbed $SO_2$ into nontoxic forms also influences species sensitivity (Addison *et al.*, 1984). This may be the reason for high sensitivity of egg plant & potato and comparatively more resistance of tobacco. In all the three species at later stages increase in RGR and NAR over reference was observed. Ito *et al.*, (1984[b]) also reported such situations and attributed it to adaptation to pollution stress.

### 4.3.2 Biochemical Parameters

Even the hidden injury to plants, under pollution stress, can also be detected through various biochemical parameters e.g. chlorophylls, sugars, proteins,etc. Initially each pollutant interacts biochemically with the most sensitive receptor. Ultimately this is reflected in production loss with long-term exposures.

#### 4.3.2.1 Chlorophyll

Chlorophyll content and its degradation in plants has been widely used as pollution indicator (Le Blanc & Rao, 1973; Chaphekar *et al.*, 1980; Schulz, 1986; Silberstein & Galum, 1988). Chlorophyll is one of the main factor which influence the rate of photosynthesis. In acidic medium, which normally is formed after pollutant absorption, chlorophyll *a* loses its $Mg^{++}$ ions and is converted into photoinactive (nonfunctional) phaeophytin (Rao & Le Blanc, 1966; Treshow, 1984). Malhotra (1977) suggested that chlorophyll *b* is converted into chlorophyllide *b*. In all the three studied species it was observed that chlorophyll *a* was more sensitive than chlorophyll *b*, similar type of results have been earlier reported by many workers (Bell, 1980; Ayer & Bedi, 1986; Kumar, 1986). Mandre *et al.*, (1986) suggested that chlorophyll *a*/*b* ratio can be used as an indicator of the state of plants in industrial territories.

Chlorophyll damage due to pollution hampers photosynthesis and plant productivity. Reduction in net photosynthesis has been observed in pollution exposed plants (Plucinska, 1988; Greitner & Winner, 1989). Darall (1986) reported that gaseous pollutants like $SO_2$ can reduce plant growth at concentration too low to cause visible damage, mainly through its adverse effects on photosynthesis. The solubility of $SO_2$ is very high in aqueous system. Because of diffusion gradient $SO_2$ is trapped in organelles which are neutral or alkaline, and as photosynthesis requires an alkaline pH it is directly affected by acidification of the medium (Pfanz & Heber, 1986). Sulphite ions have been found to be more effective than other sulphurous compounds. (Khan & Malhotra, 1982; Sakaki & Kondo, 1985; Marques & Anderson, 1986; Muschinek *et al.*, 1987). Free radical formation in pollutant pathway also inhibits photosynthesis (Kato & Shimizu, 1985).

Decrease in chlorophyll content may be due to its destruction (Trites & Bidwell, 1987) or due to reduced biosynthesis (Krishnamurthy & Rajachidambaram, 1986). Disruption of chloroplast structure may also add to this decrease (Jung & Wild, 1988). In all the three species less chlorophyll content at the pollution zones is attributed to such conditions. This led to less photosynthesis and thus to growth reduction. Ernst *et al.*, (1985) reported that pollutant exposed plants showed mineral deficiency specially of $Mg^{++}$ and $Mn^{++}$ which resulted in reduced photosynthesis. They concluded that depression of photosynthesis may not only be due to a primary injury of the energy fixing system, but also to some of its mineral nutrient based processes. Tobacco showed lesser chlorophyll reductions than egg plant and potato. This helped the former species to withstand the pollution effects more tolerantly than the later two species Genetic factors also might have played a role in chlorophyll sensitivity (Muschinek *et al.*, 1987).

### 4.3.2.2 Sugars

Plant growth and development represent a complex series of coordinated events which are ultimately dependent upon the carbon economy of the plant. Exposure to gaseous pollutants can however alter the balance of a plant's carbon status resulting into retarded growth and reduced yield (Koziol, 1984). Alteration in carbohydrate metabolism may be through different processes, reduction in rate of photosynthesis is a major one. Enser & Heber (1980) reported that sugar formation was reduced in acidic medium due to reduced photosynthesis. Reduction in soluble sugar content of plants exposed to pollutants has been reported by many workers (Koziol & Cowling, 1980; Prasad & Rao, 1981; Kuppers & Klumpp, 1988). It has been reported that carbohydrates help in repair processes of pollution damage(Carlson, 1983). Koziol & Jordan (1978) observed that decrease in carbohydrate content in kidney bean was associated with perturbation of photosynthesis and increased rate of transpiration. They concluded that carbohydrate's chemical energy is used in repairing processes reflecting in increased rate of respiration. Because photosynthesis is reduced diversion of energy from building of new tissue to repair causes decrease in productivity and sugar content. Baxter *et al.*, (1989[a]) reported that bisulphite ions depressed photosynthesis which reduced the availability of energy and carbon skeleton for detoxifying $HSO_3^{-}$. In Any way reduction in carbohydrate content reduces the growth, which was observed in all the three species.

In addition to $CO_2$ uptake and respiration, translocation of assimilates is also an important factor determining the availability of photosynthate for growth processes. Partitioning of carbohydrates is altered by pollution (Jones & Mansfield, 1982; Ito *et al.*, 1984[b]; Lorenzini & Materazzi, 1985). Okano *et al.*, (1984) reported that inhibition of translocation to roots may be beneficial to leaves and stem but ultimately it results in reduced growth because supply of water and mineral nutrients is reduced due to change in root growth. Kuppers & Klumpp (1988) in studying the effects of acid rain on potato observed reduced tuber growth and they suggested that perturbation of phloem loading and transport might be the reason for that. Reduced tuber growth in the present investigation also may be because of such conditions. In case of potato increase in sugar content of leaves as compared to reference was observed at few zones (VI & VIII) this may also be due to inhibition of translocation as was observed by Ito *et al.*, (1984[b]).

Starch content of potato tubers was reduced as compared to the reference. This reduced the quality of crop. Quantity and quality are the most important aim of plant productivity and thus this reduction is economically very important.

#### 4.3.2.3 Nicotine

Nicotine content of tobacco leaves is a major factor which determines the saleable quality of this crop. Except at zone II and VIII the crop showed reduction in nicotine content at all other zones. Nicotine content in tobacco is dependent on many factors like soil, cultural practices, species etc. but here none of it was applicable as all the factors were uniformly maintained, except quality of the ambient air at different zones. It was observed that nicotine content was reduced (8-40%) as compared to reference at most of the polluted zones (except at zone II and VIII). This showed that the pollution stress with the inhibition of primary metabolism (photosynthate accumulation) may also inhibit secondary metabolism (e.g. nicotine synthesis).

An important factor which governs nicotine synthesis is involvement of specialized proteins in enzymic regulation. Intracellular channeling of precursors or co-substrates to the site of alkaloid biosynthesis requires a specific protein which limits its production rate (Luckner, 1980). Effect of gaseous pollutants on proteins and enzyme activities is well known (Ulrich, 1984; Schulz, 1986; Zedler *et al.*, 1986). There is possibility that gaseous pollutants might have affected the enzymic regulation of alkaloid biosynthesis resulting in reduction of nicotine content. Early senescence also might have reduced the quantity of this alkaloid as discussed earlier (4.3.1.4). Danica (1989) also reported that under stress condition quality of tobacco was degraded.

Increase in nicotine content at zone II and VIII was observed. At both the zones chlorine was present. At zone II low concentration of chlorine helped in better growth and yield which might have increased the nicotine content. At zone VIII also chlorine was present but at higher concentration which produced deleterious effects. Even then the nicotine content was higher than reference. Association of chloride may be a factor for that but it is not confirmed and further investigation is required.

### 4.3.2.4 Pollutant accumulation

**a. Sulphur**

Absorption and accumulation of pollutants in plant tissues is reported by many workers (Pyatt, 1973; Elkiey & Ormrod, 1981; Keller, 1981; Rowlatt *et al.*, 1982). Sulphur is an essential nutrient for all plants. Plants growing in sulphur deficit soil can use gaseous sulphur ($SO_2$) as an additional sulphur source. However when the intake of sulphur dioxide exceeds a certain threshold the toxicity of this sulphur source causes severe reduction in growth. This threshold varies considerably between different species, varieties and even within individuals of same variety. Environmental factors also play an important role in absorption of pollutants. The ultimate response of plants depends on various factors determining comparative sensitivity or tolerance (Rennenberg, 1984). Extensive study has been done on sulphur accumulation in $SO_2$ exposed plants and it has widely been used as indicator of $SO_2$ pollution (Posthmus, 1983, Maas *et al.*, 1987[a], 1987[b]; Blanka, 1988). All the three species in the present investigation showed higher accumulation of sulphur at polluted zones which was related to $SO_2$ levels at those zones (except at zone VIII). Zone VIII had high levels of $SO_2$ during winter even then the foliar sulphur accumulation was not that high. This was because of presence of high concentration of chlorine at this zone. Chloride ions with their small volume and high uptake rates supress the uptake of other ions (Guderian, 1977).

$SO_2$ absorbed from the atmosphere is rapidly metabolized. Physiological fate of the incoming $SO_2$ is determined within a short time of uptake, sulphite formation on wet cell walls is largely responsible for the physiological damage caused by $SO_2$ (Garsed & Read, 1977). Differential response to sulphur accumulation and sensitivity was reflected by the species studied. The ability of plants to survive under pollution stress results either from avoidance or the tolerance to pollution products. Avoidance mechanism in higher plants may include boundary layer resistance, stomatal behaviour (Sestak *et al.*, 1971; Ayazloo *et al.*, 1982) or reduction of sulphite in chloroplasts to produce $H_2S$ (Rennenberg, 1984; Stratigakos & Ormrod, 1985). In the present study it was observed that net accumulation of sulphur was more in tobacco while the damage was comparatively less. On the other hand it was observed that rate of pollutant accumulation in early stages was more in egg plant and less in tobacco. Damage at this stage was also very high in egg plant. This sensitivity of egg plant showed relation with rate of pollutant accumulation, similar type of observations were recorded by Lorenzini & Panattoni (1986) . Norby & Kozlowski (1982) also reported that rate of pollutant uptake is more important than the amount. More damage at higher uptake rates is expected as compared to greater total accumulation in longer terms. Response of egg plant and tobacco in early stages is confirmed by these reports.

Tolerance at later stage in tobacco can be attributed to its greater capacity to convert more toxic $SO_3^{--}$ to less toxic $SO_4^{--}$. $SO_2$ tolerant plants develop various strategies to protect themselves against $SO_2$ damage. If they do not exclude the pollutant their degree of susceptibility depends greatly on the capacity to neutralize $SO_2$ and its toxic products in metabolism. Injuries of a plant finally result from the exhaustion of its repairing and compensating potential which leads to faster alteration in metabolism (Jager *et al.*, 1986). Alscher *et al.*, (1987) also attributed the tolerance of a pea cultivar to its greater $SO_3^{--}$ to $SO_4^{--}$ conversion capacity. Higher net accumulation and comparatively less damage in tobacco can be due to such factors. Sulphur accumulation in potato leaves and tolerance or sensitivity of the species could not be compared to other two crops because of difference in exposure duration. Individually the crop showed correlation between foliar sulphur content and $SO_2$ concentration in ambient air at most of the zones. It also exhibited higher sensitivity at stages when rate of sulphur accumulation was more.

**b. Nitrogen**

Foliar nitrogen content in all the three species was more at polluted zones as compared to reference. Higher accumulation was recorded at zones V, VI & VII where ambient $NO_x$ concentration was comparatively higher. No linear relationship between $NO_x$ concentration and nitrogen content was observed. This was because the nitrogen oxides were present in combination with other gaseous pollutants. Elkiey & Ormrod (1981) observed that if present singly, $NO_2$ absorption shows correlation with its concentration in exposure medium but in mixtures of gases, absorption of $NO_2$ is inhibited and no direct correlation can be established between these two. Similar type of observations were recorded by Roberts *et al.*, (1986). They reported that the plant species proved to be good sinks for $SO_2$ than for $NO_2$ and in combination competitive effect was suggested. Non linear correlation of $NO_2$ and $N_2$ in present study may be attributed to this.

$NO_2$ at low levels can be beneficial and generally its threshold value is higher than $SO_2$, but long term effects (greater accumulation) or high concentrations are harmful to plants (Srivastava & Ormrod, 1986; Scott *et al.*, 1989). In combination with other pollutants it potentiates the phytotoxic effects of other pollutants resulting in more than additive effects (Wellburn *et al.*, 1981; Klumpp *et al.*, 1988). This is the reason for reduced growth and damage to other parameters observed in the present study.

In studying $NO_2$ metabolism in plants Tischner *et al.*, (1988) suggested that detoxification of pollutant product is via nitrate assimilate pathway. This detoxification capacity differs with species. Anderson & Mansfield (1979) attributed the differential response to the difference in nitrite reduction capability of plants. Okano *et al.*, (1988) reported that the total amount of $NO_2$ absorbed was primarily dependent on size of plants (foliar receptive area) but susceptibility was related with the rate of absorption.

**c. Chloride**

Increase in foliar chloride content as compared to reference was observed at zone II & VIII. Both the zones had chlorine as a local pollutant. Monitoring data for chlorine shows that at zone VIII higher concentration of chlorine was present as compared to zone II (2.1). At zone II tobacco showed better growth than reference. Physiologically chloride is involved in different metabolic reactions. Chloride ions are hydrophilic and have an imbibing effect on colloidal protoplasm and because of this property they induce wilt resistance. Further replacement of nitrate ions with chloride ions in colloidal chemical reactions may lead to increase in yield of some plants (Guderian, 1977). Behaviour of tobacco at zone II may be attributed to its affinity towards low concentration of chlorine. At the same time the same crop showed damage at zone VIII where chlorine concentration was higher in combination with high concentrations of $SO_2$ and $NO_x$ (Table 5). This showed that high concentration of chlorine is not favourable for tobacco. High concentrations of other pollutants also deteriorated the condition in this zone.

Egg plant and potato showed damage at both the zones which shows their high sensitivity towards chlorine. Chloride ions in excess (threshold values of which is species specific) can lead to destruction of chlorophyll and disruption of carbohydrate budget (Guderian, 1977). The toxicity caused by chlorine is explained on account of formation of HCl and HClO in cell sap (Taniyama, 1979). These toxic effects of chlorine caused high damage to egg plant and potato.

In all the three species it was observed that the rate of pollutant absorption was more in early ages which was correlated with the more susceptibility at that age. The rate of absorption was less in tobacco at early ages than in other species and this was the reason for its comparatively more tolerance. One more factor was dilution of pollutant per unit leaf area, the pollutant absorption per unit leaf area was less in tobacco than other two species and helped in lessening of damage.

Bell (1985) also observed that species having more leaf area were more tolerant, because of dilution of absorbed pollutant in wider area.

### 4.3.3 Yield

Any effect of air pollution on growth or biochemical parameters of a plant is reflected in its ultimate production (economic yield). Estimates of the effects of air pollutants on crop productivity should be characterized with effective dose of pollutants (variable concentration, frequency and duration of exposure) as they apply to the subsequent effects on plants. The final effect is likely to be a season - long integration of all these factors (Baker *et al.*, 1986). Mixture of pollutants in industrial areas also add to this, consideration of all these factors can only give an idea of the net effect on a crop production system (Laurence & Weinstein, 1981).

The yield products of all the three species were different. Tobacco yield was based on its leaf dry weight and reduction in this has been discussed earlier.

Egg plant yield was its fruit fresh weight. Percentage flowering and fruiting both were reduced at all the zones with decrease in fruit weight also. The most important effect of air pollutants in long term exposure is their interaction with the reproductive processes. Ernst *et al.*, (1985) observed that mixture of $SO_2$ and $O_3$ inhibited the process of flowering in *Silene cucubalus* which they interpreted as the result of a changed allocation of photosynthates. This also reduced the seed weight. High reduction in flowering and fruiting was observed in raspberry and blueberry growing near a phosphorus plant (Staniforth & Sidhu, 1984). Inhibition of pollen germination and/or pollen tube elongation was observed in some forest tree species which was due to pH susceptibility of pollen caused by acid rain. This effect was responsible for the lack of seed set (Cox, 1984, 1988[a], 1988[b]). In studying combination effects of pollutant Dueck *et al.*, (1986) observed that mixture of $SO_2$ and $O_3$ strongly inhibited fertilization of flowers in *Silene cucubalus*. Reduction in percentage fruiting in egg plant was attributed to such effects. Inhibition of pollen germination and pollen tube growth of some plant species was observed in the studied area (Krishnayya & Bedi, 1986). Fruit yield reduction in tomato and some fruiting trees have also been reported from the area under present investigation (Bell & Bedi, 1985; Vijayan & Bedi, 1989). All these reports support yield reduction in egg plant.

Potato yield was significantly reduced at polluted zones. This was because tuber growth was inhibited which may be due to less photosynthesis and/or inhibition of translocation. Yield reduction in agricultural crops exposed to pollutants is a common phenomenon. Significant reductions have been observed in such conditions (Heggestad *et al.*, 1981; McCool *et al.*, 1986; Bytnerowicz *et al.*, 1987[a]). Potato has shown high yield reductions in earlier studies also (Pandya & Bedi, 1986).

Yield reductions were observed due to overall impact of all the damages. Reduction in quantity of yield was associated with quality deterioration. Nicotine content of tobacco leaves was reduced at most of the zones. Starch content of potato tubers showed significant decrease at all zones. In egg plant reduced flowering, and premature fall of flowers and fruits resulted in net reduction of yield.

The damages observed in all the species were related with the pollutants concentration in the atmosphere. Analysis of variance clearly revealed that variations between species, between localities, between seasons and their interactions were significant.

## 4.4 ARTIFICIAL FUMIGATION

Under artificial fumigation study, conditions can be controlled as per requirement and the effect of required and uniform concentration at different ages can be investigated. Tobacco is an important cash crop of the studied area. The study was conducted to know the response of this crop, to pollution ($SO_2$) stress under controlled conditions and to find out maximum susceptibility age.

### 4.4.1 Growth Parameters

All the growth parameters studied showed reduction as compared to unexposed plants. Crop showed maximum sensitivity when its RGR was maximum (60-80 days). This confirmed the results of the previous study (4.3.1). Effects of sulphur dioxide on various growth parameters have already been discussed earlier (4.3.1).

### 4.4.2 Biochemical Parameters

Reduction in various biochemical parameters (except sulphur) was recorded in exposed plants as compared to unexposed plants. Deleterious effects of $SO_2$ on pigment content and sugars have been discussed earlier (4.3.2). The effects on protein and ascorbic acid are discussed here.

#### 4.4.2.1 Proteins

Proteins are the major components of biological membranes and play an important role in various metabolic processes. $SO_2$ exposure reduces protein content of plants (Constantinidou & Kozlowski, 1979; Skarby, 1984). This reduction may be due to inhibition of its biosynthesis (Sardi, 1981; Khan & Malhotra, 1983) or due to hydrolysis of synthesized proteins (Malhotra & Sarkar, 1979). Hydrolysis of protein results in increase in free amino acid content and it has been observed by many workers (Godzik & Linsken, 1974; Ito *et al.*, 1986). Reduction in protein availability by either of the above mentioned ways affects various metabolic functions and also limits the availability of proteins as structural components of new membranes (Khan & Malhotra, 1983).

#### 4.4.2.2 Ascorbic acid

Of all the biochemical parameters investigated, ascorbic acid content showed highest sensitivity. Ascorbic acid is a strong reductant, it activates many physiological processes and defence mechanisms (Mapson, 1958). $SO_2$ fumigation reduces ascorbic acid content of plants (Varshney & Varshney, 1984; Vijayan & Bedi, 1988[a]) this is because of oxidising property of $SO_2$ which oxidizes ascorbic acid into dehydroascorbic acid at low pH (Beck *et al.*, 1983). Major portion of ascorbic acid content in plants remains associated with chloroplast (Beck *et al.*, 1983) and carbohydrates are precursors of ascorbic acid (Bhatt & Reganayagi, 1987), damage to these two components may also reduce the ascorbic acid content of exposed plants which was also observed in the present study.

#### 4.4.2.3 Sulphur

Foliar sulphur content of exposed plants showed continual increase over unexposed plants. The rate of sulphur accumulation was maximum at the time of maximum RGR ( 60-80 days). This showed positive relation between rate of uptake and sensitivity.

Effects on all the above parameters reduced the vigour of the exposed plants, ultimately decreasing the productivity. It was observed that the damage was comparatively less under simulated conditions than in the field conditions. This may be largely due to the sporadic nature of fumigation combined with the ability of plants to recover during periods of very low or no pollution stress . Dassler & Bortitz (1988) have reported that plants are able to compensate the shock effects of high pollutant concentration without considerable damage, if they get pollution free period after such shocks. Results of present study are supported by this. In field the stress was continuous and more due to combination of pollutants which gave additive effect.

## 4.5 MITIGATION OF POLLUTION DAMAGE

Efforts have been made to minimize the pollution injury to plants by various means. Adjustment of crop nutrition under pollution stress conditions has resulted in better growth of plants (Ayazloo *et al.*, 1980; Lauenroth *et al.*, 1983). Even pollutants at low level can increase the growth of plants to some extent (Murray, 1986). Application of some chemicals has also shown an improvement from pollution damage. 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 attributed this to neutralization of $SO_2$ acidity by alkaline calcium hydroxide. Ascorbic acid also helped in mitigation of deleterious effects of $SO_2$ (Krishnayya & Bedi, 1988; Vijayan & Bedi, 1988[a]). Similar observations were recorded by Nandi *et al.*, (1981) who used potassium ascorbate for the study. Ozone is a known phyto-toxicant, attempts have been made to minimize its toxic effects. Some fungicides helped in reduction of $O_3$ injury (Olszyk & Tingey, 1984; Lorenzini *et al.*, 1987). Ethylene diurea (EDU) also worked as antioxidant and reduced the foliar damage caused by $O_3$ (Bennett *et al.*, 1984; Roberts *et al.*, 1987). Lee & Bennett (1982) reported a positive correlation between the tolerance enhanced by EDU and increased activity of enzymes superoxide dismutase and catalase, these enzymes are scavengers for free radicals formed in ozone induced injury and therefore their increased activity resulted in reduced injury. Most of these studies were done in controlled conditions and mostly against single pollutant effect. In the present investigation studies were done under simulated conditions as well as in natural field condition where mixture of pollutants were present.

### 4.5.1 Ascorbic Acid Treatment Effects

Ascorbic acid activates many physiological and biochemical mechanisms in plants and is an important factor in determining plant growth (Mapson, 1958). It's most important function in normal condition is detoxification of photosynthetically reduced $O_2^{\cdot -}$ or its product $H_2O_2$. $H_2O_2$ inhibits $CO_2$ fixation therefore a powerful system to scavenge $H_2O_2$ at the site of its origin is a prerequisite of photosynthesis. Association of major portion of ascorbic acid with chloroplast helps in this scavenging process (Beck *et al.*, 1983). All these roles of ascorbic acid help in better growth of plant as was observed in the present study (3.4.1). Under stress conditions also ascorbic acid plays very important roles. It has been observed that plants containing higher ascorbic acid content are more tolerant to pollution stress (Varshney & Varshney, 1984; Tanaka *et al.*, 1985). Lee *et al.*, (1984) also observed similar type of results and concluded that antioxidant and free radical scavenging capacity of ascorbic acid (aa) helps in protection of plants against lipid peroxidation and leaf damage. Reduction in foliar damage of aa treated plants in present study was due to this. NAR of treated plants was more than untreated plants (upto 60 days). Ascorbic acid maintains the integrity of chloroplasts which otherwise would have been damaged by $SO_2$ (Krishnayya & Bedi, 1989). Beck *et al.*, (1983) observed that 30-40% of the total ascorbic acid content lies in the chloroplast. Protection of this organelle thus will increase the ascorbic acid content as well as rate of photosynthesis. Such effects might have occured in the present investigation also, as a result of which NAR was increased in initial stages, ultimately resulting in better growth and more biomass accumulation.

Another important function of ascorbic acid is reduction of absorbed $SO_2$ to $H_2S$ (Silvius *et al.*, 1976). Emission of $H_2S$ has been reported as protective mechanism against accumulation of excess sulphur compounds (Tomascz, 1985). It has also been reported that more emission of $H_2S$ results in more tolerance of some species against $SO_2$ effects (Sekiya *et al.*, 1982). Ascorbic acid activity this way also is important in determining tolerance. Alscher *et al.*, (1987) reported that glutathione content was positively correlated with relative tolerance of pea cultivars. Ascorbic acid protects glutathione and both of these compounds are reported to play an important role in cell protection against oxidative damage (Castillo & Greppin, 1988). Involvement of ascorbic acid in so many physiological and biochemical processes increase its importance as a protector. Its role in $SO_2$ reduction helps plants in protection from pollution stress. In the present investigation it was observed that sulphur accumulation was less in aa treated plants than in untreated plants, this reduced the injury and resulted in improvement of various growth and biochemical parameters which ultimately resulted into increased yield. Linear increase in recovery was observed with increasing concentration of aa (0.005 < 0.0075 < 0.01 M) in experiment conducted under simulated conditions. While in field experiment when concentration was increased (0.05 < 0.01 > 0.02 M) the recovery was decreased. Maximum recovery in all the parameters was recorded in $A_2$ (0.01 M) treatment. In $A_3$ treatment ascorbic acid content was also less than $A_2$ treated plants showing that uptake of aa was reduced. Uptake of ascorbic acid 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 present study also higher concentration of applied ascorbic acid might have resulted in such situations which reduced the uptake. However in all the cases positive correlation between endogenous ascorbic acid content and recovery was observed, which showed that ascorbic acid was taken up by plants, when it was supplied exogenously and helped in mitigation of pollution injury.

### 4.5.2 Urea Treatment Effects

#### 4.5.2.1 Growth parameters

Urea treatment also resulted in better growth of plants as compared to untreated plants. Urea is a well known source of nitrogenous fertilizer. Its application results in better vegetative growth. When applied foliarly it is easily absorbed and is distributed rapidly in plant body (Reinbothe & Mothes, 1962). Its foliar application is preferable than soil application (Bagal & Shingte, 1984). In pollution affected plants reduction of pollution injury has been observed by modifying the nutrient supply and high nitrogen supply in $SO_2$ treated plants has shown recovery from damage (Cowling & Lockyer, 1978; Davison & Bailey, 1982; Pandey, 1982). In the present investigation also it was found that urea functioned as nitrogen source and minimized the injury. Lauenroth *et al.*, (1983) also observed that *Agropyron* growth was enhanced when nitrogen fertilizers were used. They concluded that this growth stimulation permitted a greater proportions of the assimilated sulphur from $SO_2$ to be utilized in metabolic processes and thus reduced its harmful effects. Leaf area of all the treated plants was increased as compared to untreated plants in all the three species. Increase in leaf area may compensate for reduced photosynthesis (Ayazloo *et al.*, 1980). Bell (1985) also reported that increase in leaf area results in dilution of absorbed pollutant per unit area and lessens the damage. In present study also these factors might have played a role.

### 4.5.2.2 Biochemical parameters

Improvement in biochemical parameters was observed. Chlorophyll content of treated plants was more than untreated plants. Rapid foliar absorption of urea helps in biosynthesis of amino acids specially glycine which provides skeleton of pyrrole ring of chlorophyll molecule (Singh & Rao, 1985). Baxter *et al.*, (1989[a]) also reported a positive correlation between chlorophyll content and nitrogen loading of *Sphagnum* plants. The increase in chlorophyll content in all the three studied species is supported by these findings. Ascorbic acid content was also more in treated plants and in fact the aa content of urea treated plants was more than aa treated plants (Table 42). A large portion of ascorbic acid in plants remains associated with chloroplast (Loewus, 1971; Beck *et al.*, 1983). Higher chlorophyll content in urea treated plants thus may be the reason for higher ascorbic acid content. Role of ascorbic acid in reduction of pollution damage has already been discussed which resulted in better growth of treated plants.

Significant increase in protein content of treated plants was observed. When applied foliarly urea is enzymatically hydrolysed at leaf surface and is rapidly absorbed (Reinboth & Mothes, 1962). This easy incorporation of urea (specially its amide group) might have resulted in high protein content. Ulrich (1984) observed that higher turnover rate of proteins give tolerance to plants. In present investigation also this might have helped the plants to recover from the damage. Sulphur accumulation in treated plants was less as compared to untreated plants at any stage. This may be due to higher ascorbic acid content, role of which in $SO_2$ reduction has already been discussed.

It was observed that maximum recovery by all the three species, in all the treatments (urea and ascorbic acid both), was exhibited at their higher relative growth rate periods. This may be because of high metabolic rates at that time which might have resulted in more utilization of mitigating agent. This in turn gave maximum recovery at later stages. In early experiment (3.3) it was observed that maximum sensitivity of the species was related with their higher growth rate periods. This suggests that practical control of pollutant injury requires determination of maximum sensitivity age of plants. Proper care should be taken to explore the maximum mitigating potential of the agent at right stage, with regular periodic treatments during the entire life cycle of a species. Roberts *et al.*, (1987) also observed that maximum accumulation of mitigating agent (EDU) was in mature, fully developed leaves of sugarmaple where pollutant injury was most pronounced. Results of present investigation also show similar type of results.

Three doses of each chemical were given and it was observed that the percentage benefit was maximum at least concentration of chemical in any experiment. Maximum benefit was gained by $U_1$ (3.5.2) 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.

In present investigation urea treatment was found to be more implicable, economically, than the ascorbic acid treatment.

## 4.6 FURTHER SCOPE OF THE WORK

The present study revealed differential response of different species investigated. Some more species can be tested for selection of the best scavenger. In studied species also different varieties can be tried to select the best fitted for the area.

Lesser reduction in tobacco was observed as compared to other two species. On this species more work can be done using different parameters like some enzymes, thiol groups, total sulphydryl group etc. The most sensitive parameter can be selected and can be compared among different varieties for the selection.

Under simulated conditions different combinations of pollutants can be tried and by varying the concentrations major toxic pollutant and its threshold can be determined to get an idea of toxicity of different pollutants. This can help in visualizing the pollutant effects under field conditions.

In mitigation studies it was observed that both the chemicals used (urea and ascorbic acid) helped in reduction of pollutant injury. Other chemicals can also be tried. Different doses can be used to determine optimum dose. Trial of varieties of chemicals can help in selection of best and the cheapest one.