# Discussion

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Number of *in vitro* studies stands countless against *in vivo* studies. But then for its practicality and realistic nature field research always gained more importance. In some of the studies, open-top chambers were used for assessing the plant response to single or multiple pollutant dosage. Sanders *et al.* (1995) found that plant growth response in open-top chambers was altered due to changes in microclimate. Pollutant fluxes were found to be higher in chambers than in fields (Sellden & Pleijel 1995). Davidson and Wu (1990) summarised dry deposition data from fields and chambers and acknowledged limitations in understanding field conditions. Similar type of over simplicity of chamber studies and complexity in field conditions were observed by others (i.e., Kropff *et al.* 1989, Olszyk *et al.* 1989, Cape 1993, Krupa *et al.* 1994, Sellden & Pleijel 1995) while assessing air pollutant impact on plants. In natural conditions specifications about the air pollutant concentrations are obscure. There are many factors that interact with pollutant mixture, and plants' response may differ from the expected one. To broaden the scope of the present study, trees exposed to air pollutants under field conditions were selected for their suitability for **green belt** on the basis of growth and pollutant scavenging capacity.

Field studies are fraught with many complexities. Some of these are changes in water and nutrients, varying mixtures of pollutants, meteorological conditions etc. Changes in vegetation structure (Steubing *et al.* 1989, Brankenhielm & Qinghong 1995, Fischer *et al.* 1995) and function (Krupa & Nosal 1989, Temple 1989, Mohren *et al.* 1993, Clapperton & Reid 1994, Kandler & Innes 1995) in response to environmental stresses including air pollutants are well documented. Van Den Driessche and Langebartales (1994) observed that drought stress reduces damages to trees when exposed to ozone. Pearson and Mansfield (1994) observed reductions in growth when ozone was combined with water stress. They assumed that continuous long term exposure may have a negative impact. Varied plant responses due to mixtures of air pollutants were reported by Ashenden *et al.* (1995). Chappelka and Chevone (1995) had reviewed environmental stresses such as light, drought and cold. They observed the existence of air pollutant-cold tolerance interactions and concluded that trees with long life cycles will commonly experience many periods of drought and episodes of pollutant exposure of varying duration, timing and severity. Study area of this investigation showed variation in the pollutant concentration and meteorological conditions. They acted together on the growth pattern of trees. Results of this study are discussed keeping all these complexities in view.

**Variations in Soil**

Soil composition for the major plant nutrients was similar (Table 7) at all the sites. Increased electric conductivity (EC) at polluted sites suggested higher ionisation due to pollutant deposition. Similar type of enhanced soil conductivity was found by Misra *et al.* (1993). Reduced sulphur content in the soils at the control site suggested increased deposition of sulphur compounds in polluted sites. Rennenberg (1984) also reported higher sulphur deposition in polluted areas due to air pollution (chiefly $SO_2$). Soils of the study area were alkaline in nature. At times, temporal changes in pH around industries are expected due to the presence of acid forming gases. On long run, it can change soil composition and retard plant growth (Leith *et al.* 1995[b]). Brankenhielm and Qinghong (1995) predicted that perennial plants may react slowly to small changes in soil. Zoettl and Huettl (1991) have recorded air pollutant effects on soil processes. To avoid soil contamination Matzner and Murach (1995) suggested reductions in the emission levels of $SO_2$, $NH_3$ and NOx. Lesser changes in the analysed soil parameters of the present study area indicated that the soil quality of the selected sites did not differ much because of the industrialisation. Hence it was assumed that soil quality *per se* had minimal impact on the growth difference of the trees.

**Fluctuations in air quality data**

Plant's response to air pollutant mixtures differs from the one seen with single pollutant exposure. Mode of joint action of pollutants depends on the type and concentration of air pollutants as well as on plant species and their variety (Kosta-Rick & Manning 1993). In field conditions mixtures of toxic gases around urban and industrial areas are a trite. Especially $SO_2$ and $NO_x$ mixtures are common (Murray *et al.* 1994[c]). Data obtained for major air pollutants in the study area are for sulphur dioxide ($SO_2$), oxides of nitrogen ($NO_x$) and suspended particulate matter (SPM). These air pollutants indicated higher concentrations as compared to control. Their dispersion and deposition were influenced by wind direction and flow. Sulphur dioxide concentration was very high all throughout the study tenure. It was upto six-times higher to the concentration at control. Nitrogen oxides concentration was upto two fold and particulate matter was high for first two study periods at polluted sites. Higher $NO_x$ concentrations in the industrial area might be responsible for the formation of secondary pollutants such as ozone (Krupa & Manning 1988). The presence of other unmonitored air pollutants (Table 5) with their derivatives and precursors can also act synergistically. Wahid *et al.* (1995) reported the presence of unmonitored pollutants in industrial area. In the same field area, Krishnayya (1989) reported similar type of multiple pollutant impact on the tree growth. In the present study, $SO_2$ and $NO_x$ were higher than that of control but their concentrations varied from site to site. $NO_x$ was high during Jul-Sept at all the sites. There was higher concentration of $SO_2$ during all the periods. Toxic effects of $SO_2$ were found to be additively increased by the presence of NO and $NO_2$ (Wellburn 1990). $SO_2$ and $NO_x$ are responsible for acidification in air and soil which may retard plants' routine function. In U.K. all soil survey maps for acidification and exceedance for soil acidification are based on sulphur and nitrogen deposition (Ashenden *et al.* 1995). Similar type of variations on the impact of air pollutants can be expected in this study.

**Impact of mixtures of air pollutants on vegetation**

Mixtures of gases have been responsible for damages to vegetation. Other air pollutants are also known to alter the plant growth. $SO_2$ and $O_3$ were responsible for leaf abscission (Bosac *et al.* 1993) and for stem injury (Kargiolaki *et al.* 1991). Both $SO_2$ and $NO_2$ are potential nutrients after uptake as they oxidise to sulphate and nitrate respectively (Murray *et al.* 1994[b]). Similarly, Wolfenden *et al.* (1991) have seen accumulation of sulphite and nitrite in spruce trees even during dormancy. Back *et al.* (1993) reviewed physiology and stress metabolism of woody plants exposed to air pollutants mixture and expressed extreme difficulties in result prediction. In this study also uncertainty of field conditions due to the presence of different pollutants and their varied concentrations was observed. Wind flow pattern and site specific (micro-level) pollutants had greater impact on growing trees. Leaf fall was maximum in the sites remaining in down-wind direction to the petrochemical and refinery complexes. Hydrocarbons could be responsible for higher leaf abscission at these sites. Sawada *et al.* (1989) reported increased leaf abscission due to hydrocarbons around an oil refinery. Other sites falling in north-east side had ammonia as one of the major air pollutants which is released from a fertilizer company. Wahid *et al.* (1995) predicted that ammonia is responsible for significant growth reductions. Because of the presence of micro-level pollutants, correlation between the available ambient air quality data and tree growth became difficult in this study.

**Visible damage and gross variations in growth**

Trees at polluted sites showed reduced vegetative growth after severe defoliation or apical bud mortality. This was often seen in evergreens. They tried to keep foliage round the year. On heavy leaf fall entire crown produced new leaves and flushed vegetatively like a deciduous species (Plate 2). This multiple vegetative flush might be very expensive for them. There will be more number of young leaves at polluted sites as compared to control. Young leaves are known to be more sensitive because of higher pollutant uptake (Sheppard 1994). To avoid this, many times mature leaves with visible injury remained with the crown for longer duration. This has given a heavily damaged appearance to evergreens. Fredericksen *et al.* (1995) also found greater damage due to the presence of injured leaves throughout the growing season. Bussotti *et al.* (1992) have reported more reductions in the crown densities of evergreens due to industrial air pollution. As compared to deciduous species evergreens preferred to have vegetative growth over reproductive one. Reductions in flowering and fruiting were more in evergreens as compared to deciduous trees. In both evergreens and deciduous, flower and premature fruit drop were common at polluted sites. Vijayan (1988) has recorded reduced fruiting in an evergreen tree species (i.e. *Eugenia jambolana*) from the same study area.

Height of the trees was reduced at polluted sites. This has resulted in stunted appearance of the trees. Species like *Anogeissus latifolia, Bauhinia racemosa, Holoptelea integrifolia, Mangifera indica, Streblus asper* and *Tamarindus indica* have shown stunted canopies with dried apical buds and altered canopy structures. Ali (1993) has recorded similar type of stunted growth due to air pollutant loads in the industrial area of Egypt. Reduced height of trees resulted in reduced canopy depth. Among evergreens canopy depth at certain sites was more because of early branching of the main trunk. This however has not resulted in any increase of over all size of the canopy. There were reductions at the peripheral sides of the canopy which resulted in reduced canopy radius. Deo Narayan *et al.* (1994) also have found reduction in canopy cover in trees growing around aluminium factory. In *Acacia, Azadirachta, Cordia, Mimusops, Moringa* and *Pithecellobium*, the reductions in tree height were negligible. They exhibited lesser reductions in canopy depths and cover. In this study *Acacia, Mangifera* and *Tamarindus* exhibited change in canopy shape and transparency. All these three trees exhibited flattened crown tops as well as lateral crown parts. According to Moorby and Wareing (1963) ageing and loss of apical control in tree crown may eventually flatten the top of the canopy. In industrial area trees with flat canopies suggested apical bud loss due to pollutant deposition rather than ageing as they were not old trees. Remphrey and Davidson (1992) have found that after abortion of shoot tip, the lost meristem is usually replaced by lateral shoot tip. They also said that terminally replaced shoots were typically shorter than normal terminal shoots. Hynynen (1995) reported that crown size has major importance to tree growth and survival. Reduction in canopy size and apical bud distortion found in this study simply means reduced tree development and vitality.

**Apical growth and tagging study**

In the tagging experiment, apical bud mortality was found both in deciduous and evergreen species at heavily polluted sites. After the death of apical bud further growth occurred by means of lateral branches. This had changed the canopy form. Studies (Kennedy & Brown 1984, Fisher 1986) have shown that environmental factors have profound effects on tree crown development. An important factor influencing the crown development is the loss of shoot and shoot tip abortion, which may be genetically programmed (Millington 1963). Factors such as insect damage (Solomon 1983, Holopainen 1990), frost (Davidson & Remphrey 1990, Holopainen 1990), browsing (Bergstrom & Danell 1987) and pruning (Porter 1989) are often involved. Yet no detailed literature is available for pollutant impact on shoot growth and crown architectural changes. Clarke and Murray (1990) found altered leaf ontogeny and apical growth due to $SO_2$. Tagging experiments of this study had shown that there was considerable reduction in shoot length in evergreens as compared to deciduous species. Foliage number reduction was high in *Holoptelea* suggesting decrease in number of internodes also. Whereas, *Tamarindus* and *Azadirachta* could produce leaves more than control due to severe defoliation near fertilizer company but shoot lengths were severely reduced in them resulting as bushy growth. Pearson and Mansfield (1994) discussed the reduction of number of internodes which they assume can alter canopy architecture. This is in conformity with the present study. In *Azadirachta* none of the tagged twigs showed dried apical buds suggesting its continued growth. However there was an accelerated senescence and abscission leading to reduced leaf longevity. Chappelka and Chevone (1992) have discussed that such type of accelerated senescence and abscission had greater impact on tree growth. According to them reduced crown density is a combined effect of canopy development, branch form, senescence and abscission of leaves and death of the shoot tip. Wiltshire *et al.* (1993) monitored leaf fall on marked branches by counting leaves in apple trees exposed to ozone. He found accelerated fall among old leaves and predicted severe impact on long run. Present study is in agreement with these findings. The tagging experiment showed that after the abortion of apical bud, lateral branches given out were shorter with closely arranged leaves.



**Internodal length and girth**

Internodal length and girth were measured to see growth of the sampled twigs which were reduced at polluted sites. These reductions had manifested in lessening of the over all tree growth. There are reports pertaining to stem/shoot length and diameter, which were notably lessened in plants exposed to different air pollutants (Clarke & Murray 1990, Wellburn 1990, Bor-Hung Sheu 1994). As compared to deciduous species, evergreen species showed lesser reductions in this study. Among evergreen trees, reductions in the internodal length were more than the reductions in the girth. This has resulted in compactly arranged leaves.

In deciduous species both internodal length and girth were reduced proportionately. This has resulted in bushy appearance of trees at polluted sites. Ali (1993) observed similar type of bushy appearance in plants growing in agro-industrial environment of Egypt. It was due to reduced stem height and diameter. Singh *et al.* (1990) noted retarded plant growth on exposing them to $SO_2$, due to decreased shoot length. The present study is in conformity with the previous findings.

**Leaf area**

Leaf area is one of the indicators of plant growth. It is responsible for photosynthesis and biomass production. Reduced leaf area would result in reduced biomass production. Reduction in leaf area due to air pollutants is well documented (Clarke & Murray 1990, Misra *et al.* 1993, Wiltshire *et al.* 1994). In the present study leaf area at the polluted sites was reduced due to lessened leaf size, changes in leaflet number, leaf area damage and reduced leaf longevity. Leaf fall at the polluted sites was dependent on wind flow pattern. It was heavy in the sites falling in the western direction of the industrial belt. Khan *et al.* (1990) recorded 38 % reduction in leaf area in the plants growing in prevailing wind direction due to maximum pollution load. In this study heavy leaf fall observed was compensated soon after monsoon and/or due to change in wind direction. Thus in Aug leaf area equalled to that of control at sites falling westwards. This showed that trees can recover under favourable conditions. Rain fall might be responsible for minimising pollutant levels by diluting them. On the otherhand, reduced leaf area was noted at sites falling on eastern side during same period. This could be due to higher pollutant load because of wind flow. Such type of altered leaf phenology can be expected to affect other tree functions. Reich *et al.* (1992) said that leaf phenology is important because it is related with the processes such as tree growth productivity, flowering and fruiting, plant water stress, leaf gas exchange etc. In compound-leaved trees like *Azadirachta* and *Tamarindus*, there was an increase in leaf production as a consequence of leaf fall. But average leaf area was less due to reduced leaflet number as well as leaf size. In other species, there were leaf area reductions due to lessened leaf size throughout the canopy. Shaw *et al.* (1993) have reported reduced leaf size due to delay in bud burst. At industrial sites of this study leaf longevity was decreased due to early leaf fall. This might have resulted in an overall decline of photosynthetic leaf area. Patterson and Rundel (1995) concluded that needle retention, chlorosis of leaf, and whole plant carbon gain during physiologically active period are the most important factors for growth attributes. Similarly, Woodbury *et al.* (1994) suggested that increased abscission will result in reduced photosynthetic leaf area which will cause reduction in whole plant carbon assimilation. This will result in negative feedback and concomitant decrease in growth in subsequent years. In the present study similar types of cumulative growth reductions can be visualised as trees are continuously exposed to air pollutants.

**Biomass accumulation**

Biomass accumulation was hampered at all the polluted sites. It was indicated by reduced biomass of leaves and stems. This has resulted in an over all reduction in twig biomass. Similar to leaf area, leaf weight was influenced by leaf longevity. Leaf fall had remarkably reduced leaf weight at the polluted sites as seen in loblolly pine (Temple *et al.* 1993). Decreases in total plant weight were recorded as a result of ozone treatment (Edwards *et al.* 1992). $SO_2$ and $O_3$ altered translocation such that greater proportion of photo-assimilates were retained in the shoots for defence and repair (Spence *et al.* 1990, Friend & Tomlinson 1992). Chappelka and Chevone (1992) said that after senescence and abscission, altered allocation of dry matter becomes marked due to significant leaf loss. Leaf weight reductions in response to air pollutants were reported (Clarke & Murray 1990, Singh *et.al.* 1990, Ali 1993, Misra *et al.* 1993). Similarly there are reports on reduced stem mass (Woodbury *et al.* 1994, Murray *et al.* 1994[a,b]). Wellburn (1990) noted reduced shoot weight in burr medic due to $SO_2$ and in white clover due to NO and $NO_2$. Ashenden *et al.* (1995) recorded more reductions in stem dry weights as compared to roots on treating white clover with $SO_2 + NO_2 + O_3$. They considered this as an additive effect of pollutants. In the present study pollutant mixture might have been responsible for the over all reductions in the biomass at polluted sites. Leaf weight reductions (20 %) as compared to control were heavy in *Acacia, Anogeissus, Bauhinia* and *Mimusops*. Reductions in branch weight in *Moringa, Acacia, Azadirachta, Bauhinia* and *Pithecellobium* were between 5-60 % as compared to control. There were two trends found in biomass accumulation. Both leaf weight and branch weight were less during

Aug at sites falling in north-east of the industrial belt. While other sites (falling in the west), had reduced biomass during Feb. This was irrespective to tree's phenology indicating influence of air pollution loads. Like the deciduous species there were heavy fluctuations in the branch weights of *Tamarindus, Acacia* and *Streblus* suggesting their sensitivity. There were minimal leaf weight and branch weight reductions in *Cordia* and *Holoptelea* suggesting their tolerance.

**Growth Analysis**

According to Ledig (1974) growth analysis is a technique used to separate growth into component processes in order to examine the effects of endogenous and exogenous influences on plant productivity. Present study can be called as a classical growth analysis which involves collection of data from a series of regular discrete harvests and subsequent calculation of mean values from integral or interval formulae. Growth analyses have been used widely to study environmental influences, including air pollution (Tingey *et al.*, 1979), on plants. Growth ratios are derived values from the actual growth readings. They are calculated for comparisons among growth parameters. In the present study leaf area ratio (LAR), specific leaf area (SLA) and leaf weight ratio (LWR) were calculated. To compare leaf to branch biomass, LWt/ BWt ratio (tissue density) was calculated. Leaf area ratio is an index of leafiness and expresses the proportion of assimilatory surface to respiratory mass (Chappelka & Chevone 1989). It is composed of specific leaf area and leaf weight ratio. Thus in the present study LAR and SLA gave the area of leaf/leaves required to accumulate one g dry weight of twig and leaf/leaves respectively.

Deciduous and evergreen species have shown differences in SLA and LAR. In evergreens SLA and LAR values were higher at polluted sites. The reason for that is the reductions in biomass were higher (both in leaves and twigs) than those in leaf area. Similarly Chappelka *et al.*, (1985) have noted significant reductions in growth parameters but increased LAR in $O_3$ + $SO_2$ treated plants. Deciduous species have exhibited lessened LAR and slightly reduced SLA values than that of control. This was due to lesser biomass reductions as compared to leaf area reductions. Clarke and Murray (1990) found no change in SLA due to linear increase in leaf area and weight. They observed that *Eucalyptus rudis* exposed to 132 μg $m^{-3}$ $SO_2$ could form new leaves of similar density. Reich *et al.*, (1991[b]) said that leaf mass to area (LMA or inversely SLA) changes with phenology. Eschenbach and Kappen (1996) also observed seasonal (temporal) changes in SLA depending on phenology. Short-lived leaves generally have higher SLA (Reich *et al.* 1991[a,b]). Sobrado (1991) found that deciduous species with shorter-lived leaves (average 9 mo) also had lesser construction and maintainance costs than evergreen species with longer-lived (average 12 mo) leaves. In the present study, this type of proportionate ratio of area to weight can be expected for deciduous species which has kept them just below control. Exceptionally, *Bauhinia* had higher SLA and LAR at polluted sites because of heavy biomass reductions.

Leaf weight ratio (LWR) and leaf to branch weight (LWt/BWt) ratios moved together with few exceptions. This suggested that leaf weight has a major contribution in twig weight. Except *Azadirachta* and *Pithecellobium* all the trees had lesser amounts for leaf weight ratio and leaf to branch weight ratio. This suggested that reductions in leaf weight were more than the reductions in branch weight. Among all the species, *Holoptelea integrifolia* showed minimal reductions in leaf and branch weight, which resulted in less reductions in LWR and leaf to branch weight ratio. In evergreens like *Mangifera, Streblus* and *Tamarindus* leaf weight ratio was increased at heavily polluted sites suggesting biomass allocation from branches to newly expanding leaves. Probably increased leaf fall and continuous new leaf production might have been involved in this phenomenon. Similar type of allocation was recorded from roots to leaves on an increased defoliation intensity in herbaceous species (Caldwell *et al.*, 1981) and in saplings of tree species (Cornelissen 1993[a,b]). They have recorded increased shoot to root ratio. Gaseous air pollutants are known to alter translocation such that greater proportion of photoassimilates was retained in shoots for defence and repair (Spence *et al.* 1990, Friend and Tomlinson 1992). This type of change in carbon allocation by increased shoot to root ratio where in accelerated ageing was compensated on root to shoot allocation is recorded (Cooley & Manning 1987; Lechowicz 1987). In the present study such type of allocation of biomass can be visualised from branches to leaves which might have resulted in an increase in the ratio of leaf to branch weight.

**Reproductive cycle**

Reproductive processes are known to be susceptible to environmental stresses (Rao *et al.* 1992) including pollutants (Dubay & Murdy 1983). Yet very little information exists concerning the impact of air pollutants on reproductive processes (Bosac *et al.* 1994). In the present study trees' reproductiveness at polluted sites were affected. Reduced number of flower per inflorescence (FL/IN), inflorescences per branch (IN/BR) and fruits per branch (FR/BR) were observed. Reductions were more in evergreens because of their preference for vegetative growth. Hay and Newton (1996) reported maintenance of vegetative growth over reproductive one on the application of severe defoliation regime. Krishnayya and Date (1996) have reported reduced fruit production as a consequence of altered biomass partitioning in *Trigonella foenum-graecum*. In the present study, reduced biomass production could be responsible for altered partitioning of biomass and subsequent reduction in reproductive growth. This can be said as an indirect impact of air pollution. During flowering and fruiting, there was severe flower and fruit drop indicative of direct air pollutant impact on reproductive cycle at polluted sites. Bosac *et al.* (1994) have described direct and indirect pollutant impacts based on exposures to reproductive and vegetative components respectively. Edge *et al.* (1994) explained concept of 'latent injury'. It can be expressed as reduced reproductiveness without any visible damage to previous vegetative growth. Thus there exists a growth cycle of one year of foliar and reproductive linkage through storage of photosynthates (Kozlowski

1992). It was noticed in the present study that trees at polluted sites had altered phenology (Gavali *et al.* 1997) which has changed the timing of reproductive cycle. Altered timing for reproductive cycle might be responsible for lessening damages in *Anogeissus, Azadirachta* and *Pithecellobium*. These trees could show comparatively less number of fruit reductions. Fruiting was affected heavily in *Mangifera, Bauhinia, Holoptelea* and *Tamarindus*. The failure of reproductive capability could be dependent on mobilisation of food materials. It was indicated that prior to fruiting branch weight in evergreens was more and then it was reduced during fruiting. In deciduous species branch weight was increased at the time of fruiting suggesting heavy resource allocation from branches to growing twigs. Lechowicz (1995) said that if developing fruits depend on either current photosynthate or retranslocation of mineral nutrients from foliage then a consistent relationship between the timing of foliar senescence and fruit maturation can be expected.

It is important to note that plants with inherent capabilities of longer periods for reproductive cycle could get adjusted by altering their timing for flowering and fruiting. This was seen among *Moringa*, and *Pithecellobium*. In *Bauhinia, Mangifera, Tamarindus* and *Holoptelea* fruiting was reduced heavily as they have comparatively short time for flowering. This might be the reason for the least fruit production in these trees. Lechowicz (1995) concluded that changes in the reproductive phenology potentially can change the reproductive success of trees in a region. Present study is in conformity with all the citations.

**Sulphur accumulation**

Pollutant accumulation in plants is studied widely (Wolfenden *et al.* 1991, Szarek 1995). Pollutant uptake often can be beneficial (Kosta-Rick & Manning 1993, Murray *et al.* 1994[b]) or harmful (Friend & Tomlinson 1992, Ashenden *et al.* 1995). Trees are known to take up atmospheric pollutants. $SO_2$ is a toxic gaseous air pollutant for plants (Wellburn 1990). Plants can detoxify $SO_2$ to an extent and store it in the form of sulphate (Rennenberg 1984). Sulphur uptake by foliage was studied by comparing $SO_2$ concentration zonation based on wind direction from the source (Liblik *et al.* 1995). Raitio *et al.* (1995) studied atmospheric $SO_2$ gradients in arctic Russia to northern most Europe and found high correlation between foliar sulphur and estimated mean $SO_2$ concentration. They rated estimation of foliar sulphur as a better indices than wet, dry deposition and concentration of particulate sulphate. It is a commonly used parameter for estimating the deposition of atmospheric S compounds (Fangmeier 1989). In this study sulphur content at control was more in leaves and stem during one sampling period. On the otherhand at polluted sites, it was more in leaves during May and was less in branches. In the mo of Nov, S content was reduced in leaves and was increased in branches. This suggested that excess sulphur accumulated in leaves during May (might be present in the form of $SO_4$) could have been translocated into stems during Nov at polluted sites. Bell *et al.* (1995) have studied partitioning and redistribution of sulphur during sulphur stress. They recovered radiolabelled $SO_4^{-2}$ from roots when applied to the abraded surface of mature leaves, while that applied to young leaves was mostly retained in them and was not translocated. There are studies of leaf age dependent sulphur uptake (Sheppard 1994). Altered phenology and reduced leaf longevity seen in this study might be responsible for varied sulphur uptake. Solvik *et al.* (1995) stated that stomatal $SO_2$ uptake depends not only on emission of $SO_2$ but also on stomatal conductance and canopy features, which varied with the time. Inspite of growth reductions and reduced leaf longevity in the present study trees at polluted sites had higher sulphur accumulation. Few of them have shown good sulphur accumulation revealing their suitability for plantation in sulphur-rich environment. Similar to this, Clarke and Murray (1990) noted increased sulphur accumulation and leaf abscission in *Eucalyptus rudis*. Their results also suggested that species with higher sulphur content in branches and leaves can be planted in $SO_2$ polluted environment.

**Dust capturing**

Dust capturing is one of the important role of trees in pollution abatement. In the areas with heavy dust pollution, thick vegetal canopy cover can effectively remove the dust and make the environment clean. There are studies (Kennedy 1980, Brabec *et al.* 1981, Yunus *et al.* 1985) describing quantification of dust cover on vegetation. Even chemically inert dust can affect photosynthesis and transpiration by covering and plugging stomata (Hirano *et al.* 1995). Shukla *et* al. (1990) noticed stunted growth without foliar damage in *Brassica* plants when treated with cement dust. Eveling (1986) found removal of cuticular wax due to dust. Removal of cuticular wax can expose epidermis and other foliar tissues to the atmospheric air pollutants which can cause foliar damage. In the present study dust deposition on foliar surfaces was more during summer at control as well as at polluted sites. Even ambient air quality data showed increased concentration of suspended particulate matter (SPM) during summer. Bor-Hung Sheu (1994) has recorded impacts of dusts especially during drier period of the year. He also discussed that local climatic conditions may lead to enhanced pollutant impact. In the present study, site 2 falls between a refinery and a fertilizer company with a gypsum-dumping site. This would be responsible for more dust settling in winters than in summers as seen at other sites. Excess deposition was a local phenomenon, wherein, wind flowing from NW might be involved.

Dust capturing capacity can be linearly correlated with leaf area, which in turn is depended on leaf emergence and development. This study revealed that mature, fully expanded leaves were capable of holding maximum dust. Evergreens did not show much varied dust deposition amount among the two study periods. However, deciduous species displayed seasonal effect as their leaf area differed. They showed wide differences in the captured dust during summer and winter. Among the selected species, trees with simple, hairy and broad leaf habit had maximum dust capturing.

**Pollution abatement and green belt designing**

Industrialisation and urbanisation have immensely increased air pollution levels. Its consequences have now been realised world-over. United Nation's Economic Commission for Europe had come up with a Long Range Trans-boundary Air Pollution (LRTAP) convention in 1987. In that 16 countries joined to form '30 % club' by a resolution for a 30 % reduction in sulphur emission by 1993. Several countries questioned the validity of 30 % as the reduction target and refused to sign. In 1988, this convention agreed to adopt a *Critical levels* and *loads* approach in the development of future protocols. Accordingly for a given ecosystem, critical level and load should be assigned and to be compared with the actual or estimated concentrations at locations where that ecosystem is present (Sanders *et al.* 1995).

Transport of pollutants from source to the forest (receptor) begins with turbulent diffusion into the atmosphere at the source during which a substantial transformation of chemical form can take place (Murphy Jr & Sigmon 1990). Transport is accomplished by air parcels (eddies) of higher concentration downward to the forest. This indicates that checking air pollution near the source is very important.

Air pollution management on broad-scale is very difficult. Pollution dilution over a broader area is a commonly used method which need modification at source level. Reduction in emission levels itself is the best measure for air pollution reduction. Kageson (1995) suggested that cost effective measures should be put forward. Zundel *et al.* (1995) discussed cost effective measures to reduce $CO_2$ emission which according to them will also result in the significant reduction of $SO_2$ and $NO_x$. They said that restructuring of energy system is a major emission reduction option and discussed technological options currently available to reduce $SO_2$ and $NO_x$ emissions. It includes abatement technology and high efficient energy conversion technology. Above mentioned options if implemented practically, can bring out revolution in pollution reduction strategies all over the world. But then all those techniques are pretty expensive. The cost effectiveness is on the higher side which requires equally sound technological advancement.

Forests are known to take up atmospheric pollutants (Kozlowski & Constantinidou 1986, Van Dam *et al.* 1991, Van Stempvoort *et al.* 1991). Schmieden and Wild (1995) were of the opinion that exposure to air pollutant and other stress factors had no linearly correlated effect on the highly complex organism 'tree'. It is because of its numerous mechanisms such as buffering, filtering, detoxification and repair by which trees are able to avoid or impede permanent damage. Tree plantations or green belts therefore are suggested as one of the strategies for industrial air pollution amelioration (Clarke & Murray 1990, Ahmad *et al.* 1991, Bhattacharya 1994). Green belt plantation around air polluting units can never be a claim for the removal of air pollutants at the region. Yet, effectively planted trees in a green belt can potentially remove considerable amounts. Chaudhuri (1994) reviewed all the available references pertaining to the trees' amelioration to environment hazards. He showed a great need for good plantation to reduce air pollution. Agrawal and Tiwari (1997) stated that cultivation, conservation of certain trees which are fast growing, resistant or sensitive to certain pollutant can make environment clean to some extent. They suggested that recommendations should be there to grow vegetation around sources to check the pollution. Rao and Dubey (1989) concluded that fast growing tree species *Cassia siamea* is better equipped to strive well in areas predominant with low $SO_2$ levels. Okano *et al.* (1989) found that the tree species showing high rate of $NO_2$ absorption were very susceptible to the mixture of $NO_2$ and $O_3$. In selecting plant species for purifying the $NO_2$ - polluted atmosphere, there should be a compromise between the efficiency of $NO_2$ absorption and its tolerance to the photochemical oxidants.

Air pollutant transport between air layers is dependent on mechanical factors as well as on the stability of atmosphere (Monteith & Unsworth 1990). Rate of transport is controlled by size (direction) and energy (speed) of the eddies, which in turn are dependent on state of larger-scale atmosphere and atmosphere-forest interactions. Mechanical turbulence is caused by moving air and vegetation. The structural properties of vegetation determine the roughness. The rougher the surface, the more mechanical turbulence will be produced. Sellden and Pleijel (1995) have quoted the importance of properties of surface for the gas exchange between the atmosphere and the vegetation. Atmospheric deposition onto vegetation occurs by dry and wet deposition. Of which, dry deposition accounts for a larger fraction (Dasch 1989, Schaefer & Reiners 1990). In the vicinity of sources, dry deposition is determined by the configuration of the sources, types of sources and pollutant mixing in the atmosphere. For high level sources, the deposition near the source is less and increases with the down-wind until it reaches a maximum and decreases again. For ground level sources, the dry deposition takes place near to the source where concentrations are highest and decreasing down-wind (Erisman 1992). Draaijers (1993) saw enhanced dry deposition in the forest edge leading to a significant down-wind depletion of gases and particles, resulting in reduced dry deposition in the forest interior. Economopoulos (1991) has developed pollutant dispersion model for ground level receptors. He concluded that, the impact of plume rise and buoyancy over no-buoyancy induced dispersion assumption was generally over 2 km. For the receptors within 2 km distance, the impact was higher and significant variation has been observed. These studies indicate that green belt plantation should be based on stack height, wind flow (Meteorology), type of pollutants etc. Based on two types of stack heights, two separate plantation strategies can be adopted. Those are (1) for high level source/s and (2) for low/ground level source/s. As there will be less deposition in wake region of high level sources, plantation of moderate and sensitive species can be mixed near the source. With an increase in concentration down-wind upto its maximum, there should be gradual increase in the number of tolerant species in combination with moderate ones. At the point of maximum concentration/deposition, only tolerant species should be planted. Again in the periphery a combination of moderate and sensitive ones can be planted. Near the ground level sources, only tolerant species should be planted. They can be surrounded by a mixture of tolerant and moderate trees. Green belts for both the patterns of pollutant settlement usually should be in circular-form around the source/s. For greater efficiency, circular green belts can be widened in prevailing wind flow direction. It is also advisable to keep fast growing tolerant species in close vicinity to the source and thorny species out side the green belt for protection. Literature shows that seedlings and saplings of trees are more sensitive to air pollution. Hence plantation should be done well before the actual industrial functioning. This will give an established and functional green belt. Draaijers (1993) said that to minimise adverse effects of air pollution, effect diminishing measures aimed to reduce or slow down the effects should be conducted. Those are forest fertilizer, litter layer removal and forest grazing. Adjustment of forest canopy and/or edge structure provide opportunity for reducing atmospheric input. Similarly Van Breemen and Van Dijk (1988), Boxman *et al.* (1994) have reported revitalisation of forest trees in nitrogen stress after fertilization. Pokhriyal and Nautiyal (1991) have briefly discussed multidimensional utility from green belts. They argue that planting on the site or near by will not suffice; but tree's multiple role located in the neighbourhood of industrial complexes should be emphasised. They also focused need for technical expertise for green belt raising. Thus green belt should not be developed only as an air purifier but it should be allowed to develop as a major component of the industrial ecosystem by increasing number of species and their interactions.