Results

RESULTS

Data presented (including secondary data) are described under separate headings and depicted in tabular form (Tables 2-22).

Meteorological data is obtained for two years (Apr 1994-Mar 1996) in accordance with the period of sampling (Figure 2 and Table 4). **Air quality data** is obtained for sulphur dioxide (SO_2), nitrogen oxides (NO_x) and suspended particulate matter (SPM). For these, averages of maximum, minimum and annual mean values are calculated (Table 6). **Soil quality data** is procured for the soil samples collected from each site (Table 7). **Tree positioning** and **Visible symptoms** observed are presented depending on vegetation survey and periodical observations. Each sampled tree was plotted on the graph paper and a map for each site was prepared (Figure 2). Visible symptoms were recorded from time to time. In **Growth Parameter Study**, averages of each growth parameter come from a minimum of 18 samples. **Statistical Analysis** was conducted for each growth observation by performing Analysis of Variance (ANOVA) test. Standard Errors ($\pm$ SE) were also calculated (Table 8-19). In **Tagging experiment**, averages of 6-12 growth readings measured from intact branches are presented (Table 20). **Dust deposition** is studied by measuring dust on known leaf area (atleast 9 samples) and expressed per unit foliar surface (Table 21). **Sulphur accumulation** is studied by analysing sulphur content (4 samples) per unit dry weight of leaves and branches (Table 22).

Meteorological data

A brief account of overall climatic conditions is mentioned in Materials and Methods. Average monthly maximum and minimum temperatures were calculated. Total rain fall was calculated for two years and presented (Figure 3). Wind direction (above 5 % of each month's observation) and average wind speeds are given (Table 4).

Generally weather remained dry (except during rainy season) with high temperatures in summer months. May had the highest average of minimum and maximum

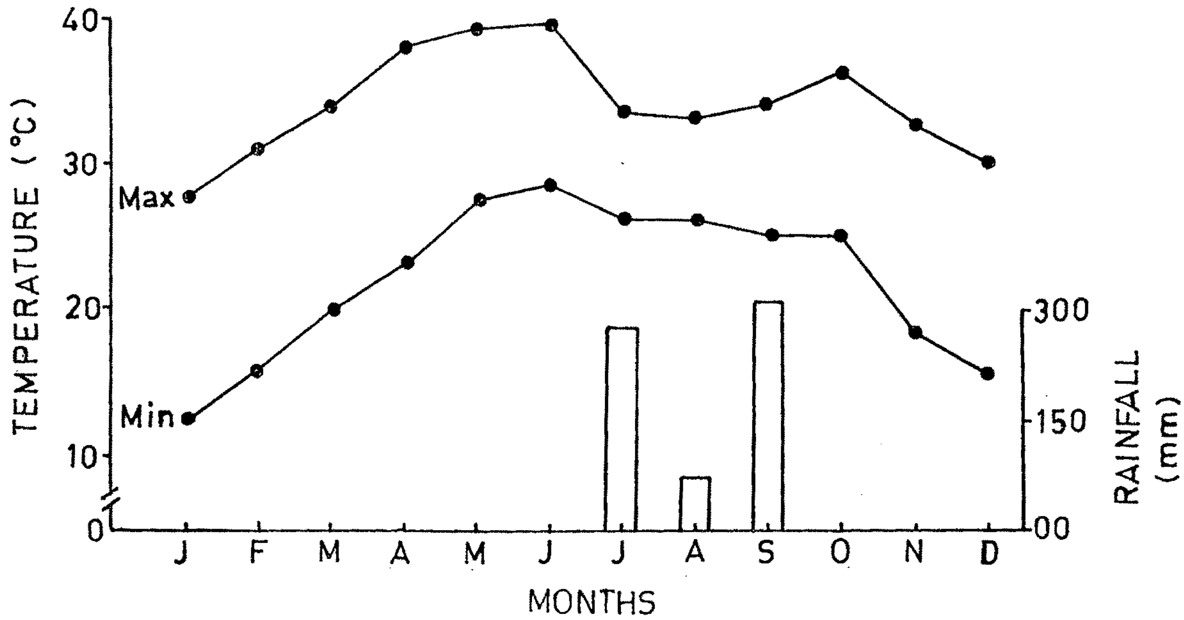

Figure 3 : Monthly maximum and minimum temperature means alongwith mean rainfall □ for 1994-96.

temperatures ranging from 27.3 - 39.8° C. January had the lowest averages of minimum and maximum temperatures (13.8 - 282° C). Average annual rainfall of two years was 932.2 mm.

Wind flow pattern can be seen in two aspects namely wind direction and wind speed (Table 4). Among the four study periods, 1st and 2nd showed wind flow from South and South-Westerly directions for major part of the time. It had the maximum speed during May-Aug. These winds caused very heavy dust deposition. Third period had predominance of calm conditions and if wind flow was there, it flowed in different directions (i.e., North-West, North and North-East). During Oct, maximum number of calm days were recorded. The 4th (last) period had a different flow pattern. In addition to NW and N directions, it flowed from the West. Month of Mar exhibited further change in wind direction with SE or even NE winds.

Overall, wind flowed from SW and S directions with higher speeds during Apr-Sept. Oct mo had either calm days or wind flowed with minimal speeds from NW and N. Calm conditions remained upto Mar (Table 4).

Soil quality data

Soil of the study area is loam-clay type and yellow-ochre in colour. There were no major differences among the tested parameters in the soils of control and polluted sites. Electric conductivity (Ec = 0.19 Ω m^{-2}) and Sulphur content (1.47 mg g^{-1}) were the least at control site. They were high at all the polluted sites, where Ec ranged from 0.35 - 0.76 Ω m^{-2} and Sulphur varied from 1.56 to 5.83 mg g^{-1}.

Soils at all the sites are alkaline in nature with pH ranging from 8.6-9.2. Percentage of nitrogen in organic carbon (% N, OC) ranged between 0.34 - 0.82. Phosphorus (P_2O_5) varied from 3 to 6 Kg Ac^{-1} and potassium (K_2O) ranged from 120-275 Kg Ac^{-1} in concentration (Table 6).

Approximately 75 % of the study area is occupied by agricultural fields. This gave a semi-natural state to the sites chosen. Trees present in the fields and on their edges have got water and fertilizers whenever they were supplied to the growing crops. This has lessened the chances of water stress or nutrient deficiency symptoms on the foliar surfaces. Thus, the reasons for the assumptions of damage due to air pollution are justified and satisfactory.

Air quality data

Ambient air quality data was available for four spots. One was at control and the other three were located between polluted sites. Data of polluted sites are mentioned as spot 1,2 and 3 while the one at control is described as control. Spot 1 was located near polluted site 4, spot 2 was nearer to sites 2,3 and 5, and spot 3 was situated between the sites 6,7 and 8. Data were available for SO_2, NO_x and SPM (Table 7).

Sulphur dioxide

At control averages of maximum (11.6 $\mu g\ m^{-3}$) and minimum (7.6 $\mu g\ m^{-3}$) concentrations were recorded during 3rd and 2nd periods. Among the polluted sites, spot 3 exhibited the highest SO_2 concentration. Maximum concentration was 48.8 $\mu g\ m^{-3}$ during 1st period and minimum (35.1 $\mu g\ m^{-3}$) was during 3rd period. At spot 1, maximum concentration was 43.7 $\mu g\ m^{-3}$ and minimum was 30.0 $\mu g\ m^{-3}$. Though spot 2 stood third among polluted sites by having an average maximum of 34.8 $\mu g\ m^{-3}$ and minimum of 28.8 $\mu g\ m^{-3}$ SO_2 (Table 6), these were three-four times to the concentrations of control.

Oxides of nitrogen

At control averages of maximum and minimum concentrations were 22.6 and 15.2 $\mu g\ m^{-3}$ during 2nd and 4th periods. At all the polluted spots, NO_x concentrations were higher (upto two times) as compared to control. Spots 1 and 3 had 31.9 and 30.0 $\mu g\ m^{-3}$ during 4th period while spot 2 had 32.9 $\mu g\ m^{-3}$ as maximal average concentration during 3rd period. Average minimum concentrations were varied at polluted spots. Spot 1 had 28.0 μg m^{-3} during 3rd period, spot 2 had 27.0 μg m^{-3} during 2nd period and spot 3 had 26.9 μg m^{-3} during 1st period (Table 7).

Suspended Particulate Matter

At control suspended particulates were low (162.6 μg m^{-3}) during 2nd period and high (403.0 μg m^{-3}) during 3rd period. Spot 3 had lesser concentration (275.1 μg m^{-3}) during 2nd period. It was 302.9 and 285.2 μg m^{-3} respectively at spots 1 and 2 during 3rd and 4th periods. All the polluted spots had higher concentrations of particulates during 1st period. They were 382.7, 400.8 and 368.1 μg m^{-3} at spots 1,2 and 3 (Table 7). Overall, SPM did not show wider variations as were seen in SO_2 and NO_x.

Tree Positioning and Visible Symptoms

Control site had agricultural fields with closely arranged trees on the edges of fields. It formed a thick green belt. Tree positioning at sites 3,6 and 7 were similar having mixed canopy. Sites 6 and 7 had uneven terrain resulting in varied canopy levels. This facilitated sheltering of some crowns to escape from sporadic emissions. At sites 2 and 5, some of the trees were placed distantly. Rest were relatively closely positioned on the field-edges forming moderately crowded canopies. These had lesser visible symptoms. Sites 4 and 8 have sparse tree distribution, where almost every individual tree crown is exposed singly showing acute symptoms.

Few important **Visible symptoms** recorded on the crowns are

* Canopy or side of the canopy facing towards the pollution source showed greater visible symptoms.
* Interveinal chlorosis (yellowing) finally lead to necrotic patches (browning) and leaf abscission (plate 2B and C).
* Higher concentrations of pollutants (usually at sites 4, 6 and 7) had resulted in the mortality of apical buds. Subsequent growth was carried out by axillary (lateral) buds (Plate 3A).

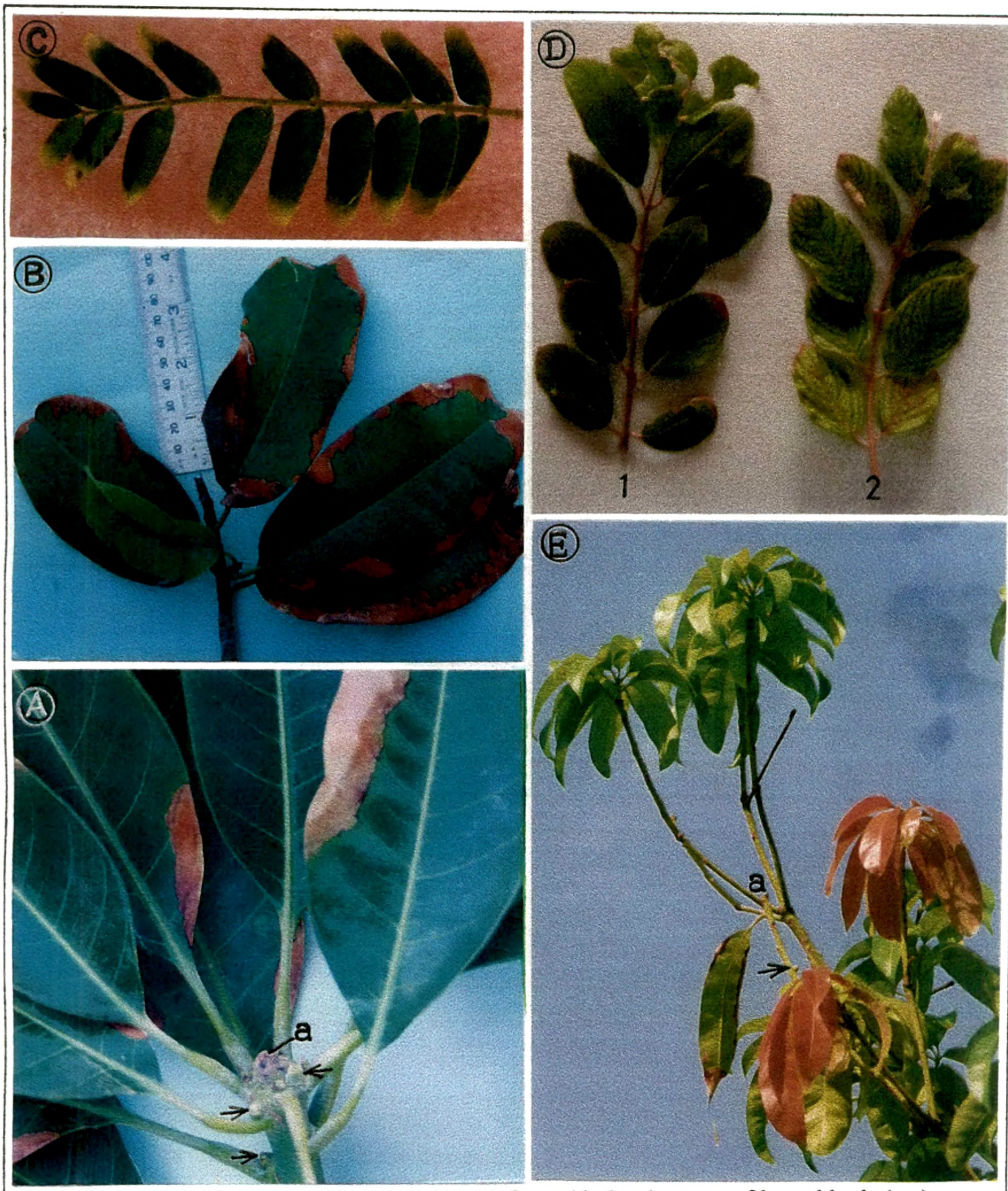

Plate 2 : **A** and **E**, Dried apical bud (a) in *Mangifera* with development of lateral buds (→). **B**, Necrosis on the leaves of *Mimusops*. **C**, Chlorosis in *Tamarindus*. **D**, Twigs of *Anogeissus* from control (1) and polluted (2) sites.

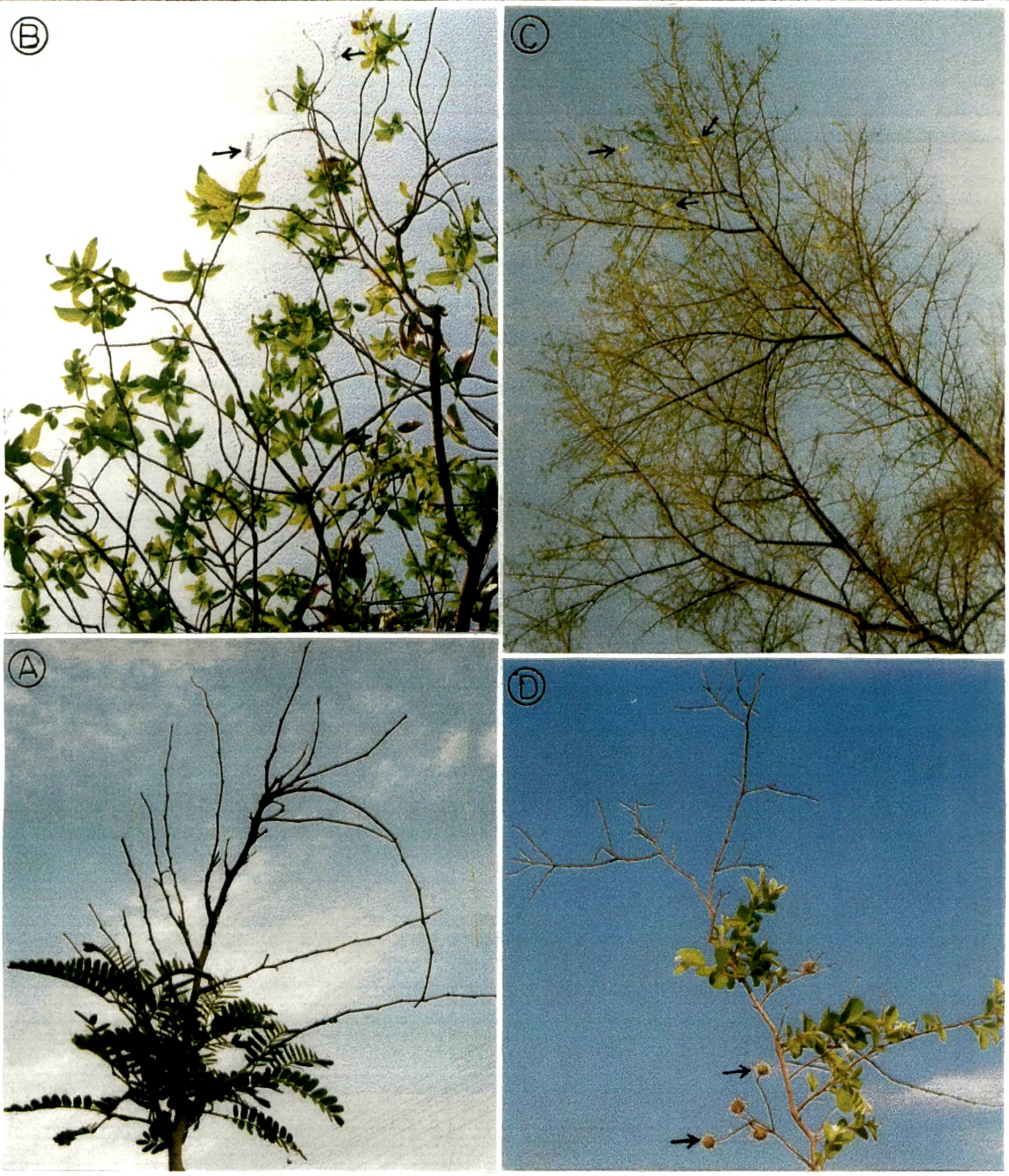

Plate 3 : **A**, Altered branching pattern in *Tamarindus*. **B, Phenological changes in** *Mangifera* with flushing of new leaves after heavy leaf fall on the entire canopy and lesser number of inflorescences (→). **C**, Crown transparency and lesser fruiting (→) in *Acacia*. **D**, Altered branching pattern in *Anogeissus* with fruiting (→).

* Evergreens tried to remain green by producing lateral branches of secondary, tertiary orders and so on after the death of previous lateral buds. This resulted in their bushy (stunted) canopy.
* If a deciduous species happened to be exposed continuously during flushing period, then it behaved like an evergreen. If the exposure was at any other time, then premature leaf fall was seen, which was followed by prolonged leaflessness phase.
* Deciduous species also exhibited delayed leaf production.
* Heavy leaf fall among evergreens at site 6 had compelled them to behave like a deciduous one. They produced new foliage throughout the canopy at one stroke (Plate 3B).
* Tree species with longer duration of reproductive phase have shown temporal shifting in flowering and fruiting.
* Evergreens maintained their usual seasonal trend for reproductive phase. Fluctuations were seen only in the quantity produced.
* As the distance between the tree species and the source increased density of the canopy was also increased (Plate 4).

GROWTH PARAMETER STUDIES

Twelve tree species were considered for growth parameter studies based on their availability at selected localities. One site with minimal pollutant load (located far away from the industrial area) was referred to as control for comparisons. Seven polluted localities (sites 2-8) were selected from the industrial zone. The study was carried out for two years (i.e. from April 1994 to March 1996). There were four study periods for each year. At each site, sampling was done at a regular time interval of 85 ($\pm$ 5) days.

Plate 4 : **Green belt effect** : Increased crown density from the source (S) to down-wind (→) explaining the importance of canopies in pollution abatement.

Format of the description

(i) Tree species are alphabetically elaborated.

(ii) Their general description is given.

(iii) Their growth parameter readings at control and polluted sites are mentioned. Evenness seen at both the years of sampling facilitated for combining the data and represent it as averages. Each period is mentioned as a calendar month to have an idea of the ongoing season. At times, observations are expressed as percentage of growth seen as compared to control.

(iv) At the end, their phenological observations such as vegetative growth (flushing), leaf fall, flowering and fruiting are mentioned.

Acacia nilotica

Acacia is an evergreen tree of moderate size with black, short cylindrical trunk. Leaves are bipinnately compound (feathery) with small, dull-green leaflets. The branches are forked, hard and spreading, bearing leaves on the periphery.

A total of 44 trees were studied from six sites including control. They were ranging from 6.6 to 8.3 m in height (Ht) and 83 to 112 cm in circumference at breast height (CBH). Spread of canopy (Cr) varied from site to site. It had maximum radius at control (3.83 m). At polluted sites it ranged from 2.70 - 3.65 m. Branching started at 1.80 m height at control, which was the lowest. At polluted sites it was ranging between 1.80 - 2.10 m. This enabled the tree to form greater canopy depths at control (Figure 4).

Annual average of internodal length (IL) was more but girth (G) of the branches was less at control (Table 8). Total leaf lets (LL) at control were more which was reflected in higher leaf area (LA). Minimal LA was found at sites 5 and 2 (i.e. 56.8 and 65.6 %). Leaf area damage (LD) was observed at sites 6 and 7 (Table 8). Leaf

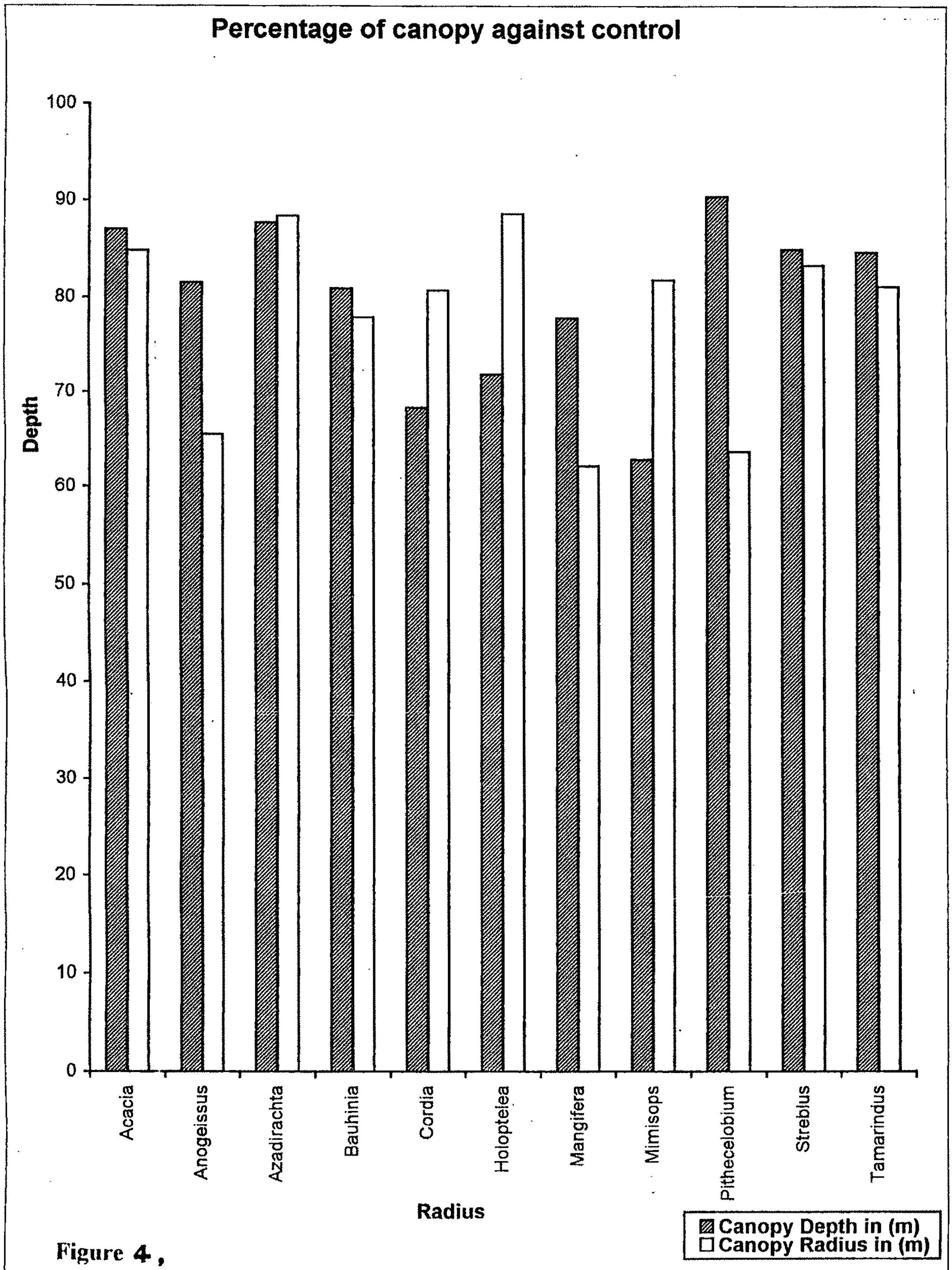
Percentage of canopy against control
Depth
100
90
80
70
60
50
40
30
20
10
0
Acacia
Anogeissus
Azadirachta
Bauhinia
Cordia
Holoptelea
Mangifera
Mimisops
Pithecelobium
Streblus
Tamarindus
Radius
Canopy Depth in (m)
Canopy Radius in (m)

Figure 4,

fall (LF) was seen at all the polluted sites. Sometimes, partial LF was observed in the form of fall of some leaf lets. This was reflected in reduced LA. Leaf area ratio (LAR) and specific leaf area (SLA) at polluted sites (3,5 and 6) was high. It also revealed that reductions were more in twig weight (TWt) than in LA. Leaf weight ratio (LWR) as well as ratio of leaf weight (LWt) and branch weight (BWt) at polluted sites remained below control.

At control LWt increment was during Aug and it reached it's peak during Nov. At polluted sites 2 and 7, highest LWt was during Feb where as at sites 3, 5 and 6 LWt was maximal during May (Table 8). This suggests that differences in the accumulation of biomass in leaves must have altered leaf ageing. At site 6, decline in LWt was observed twice due to new leaf formation during Aug and Feb. This showed the lessening of leaf longevity. There was an overall phenological shift at all the polluted sites.

Phenology and reproductive cycle: At control trees have shown leaf production during Feb. Leaf flush could be seen along with flowering and fruiting during Jul - Aug. Fruits remained upto Oct and simultaneous leaf fall was seen.

At polluted sites (2 and 3) in Jul itself flowering was observed which was similar to that of control. At site 6, flowering initiated in Apr and stretched upto Sept. Some trees have shown fruiting till Nov. Site 7 did not show such a phenological shift in reproductive cycle.

Anogeissus latifolia

This is a heavily branched deciduous tree. Canopy is composed of numerous thin branches bearing small, rounded, glabrous leaves.

A total of 43 individual trees were studied. They were present at sites 1-7. CBH at all the sites varied from 80 to 95 cm. Their height and spread of canopy were found to be reduced at polluted sites. Height ranged from 7.4 to 9.2 m at all the polluted sites, while at control it was 10.2 m. Similarly, canopy at control was 4.96 m and at polluted sites it was ranging between 2.11 - 4.43 m.

Average IL and G were high at control (i.e. 1.53 and 0.12 cm respectively). At polluted sites IL ranged from 0.98 - 1.26 cm and G varied from 0.09 - 0.12 cm. Sites 4,6 and 7 showed reduced IL during Aug and Feb due to new growing branches. Average LA (7.2 cm^2) remained high at control against all the polluted sites. LA at sites 2,5 and 6 was similar to that of control during Aug (Table 9). This was due to rainy season. Unseasonal LF was observed at all the polluted sites. It was highest at sites 7 and 3 during Feb. LWt as well as BWt were low at all the polluted sites. Average LWt at control was 0.50 g. While at sites 7 and 3 it was just 0.24 and 0.30 g. Average BWt at polluted sites ranged from 0.05 to 0.07 g. It was 0.08 g at control. Reduced leaf and branch weights had resulted in reduced TWt. This has resulted in higher LAR at site 3. LA and LWt reductions were high at sites 2 and 7, which resulted in lessened LAR and SLA. Rest of the sites could achieve control LAR and SLA values. Reduced LWR and LWt/BWt ratio was indicative of remarkably reduced LWt at all the polluted sites.

Phenology and reproductive cycle: At control old leaves have shown maximum growth during Apr. Then there was a leaf fall in May-Jun. Trees were flushed heavily after receiving rains. Some individuals however have shown leaf formation during Jun. This was reflected in increased LA but reduced LWt. In all the polluted sites, old leaves were seen during Jun like that of control. At sites 4,6 and 7 leaf production was observed twice in a year (i.e. during Aug and Feb). This reduced longevity was revealed by LF with subsequent reduction in LWt. Flowering and fruiting were seen during Jan-Apr. Reproductive cycle at polluted sites did not vary much. At sites 2 and 6 it was extended from Feb-Jun. Flowering at site 4 was as much as control.

Azadirachta indica

This is a semi-evergreen compound leaved species. It also described as a deciduous in drier areas. As older leaves fall, younger leaves in tufts start coming from the tips of branches. Canopy never becomes entirely defoliated.

This tree was present at all the sites and the study was conducted on 67 individuals. Their height ranged from 7.2 to 9.3 m and spread of canopy varied between 2.3 - 3.5 m. They were belonging to a CBH range of 90-130 cm.

Average periodical IL and G were lower than control at all the polluted sites (Table 10). During May and Nov at sites 3,6 and 7, the trees had IL readings similar to that of control. Variations in the leaf let number (LL) of sampled leaves at control and polluted sites were minimal. Control displayed more LL in Aug. At sites 4 and 6, LL number was close to that of control. LA at polluted sites was remarkably reduced ranging from 21.4 - 46.8 %. Leaf area damage (LD) was found at sites 6 and 4 (4.2 and 3.6 % of average LA respectively). LF was observed during Nov at all the polluted sites indicating lessened leaf longevity. At sites 6 and 8 lowest LWt (76.3 and 68 %) was recorded. It increased during Aug at sites 3,4 and 6, and was minimal at sites 7 and 8 (Table 10). This change was due to the positioning of sites on windward and leeward directions. Decreased LWt was coincided with LF. BWts at all the polluted sites were less than that of control. LAR values at sites 4,5,7 and 8 were a bit lower than the control. SLA readings were similar to that of LAR. LWR at all the polluted sites was high due to heavy TWt reductions. LWt/BWt ratio at sites 3,6 and 8 have shown lower readings than those at control.

Phenology and reproductive cycle: At control, *Azadirachta* showed leaf shedding from the upper crown region during Jan-Feb. By the time, leaf fall reached to the lower side of the crown, new leaves started emerging from the upper region. In some trees leaf fall was seen upto the end of Mar but simultaneous new leaf production enabled trees not to become entirely defoliated at any time. New growing shoots gave inflorescences from the axil of young leaves (during Feb-Apr) on which fruit setting was seen upto Jun.

Reproductive phase at all the polluted sites had shown different patterns depending on leaf phenology. Trees at sites 3,7 and 8 had produced floral reproductive buds during Feb-Mar. Fruit setting was seen upto Jun which was concurrent with the observations of control. At sites 4 and 5, flowering as well as fruiting was only during Apr-Jun. Site 6 had its reproductive phase during Jan-Mar and then during Jul-Sept. This was due to uneven leaf production as a result of heavy leaf fall. Thus flushing of leaves twice in a year was an unusual phenomenon at site 6 as compared to all other sites.

Bauhinia racemosa

Bauhinia is a small to moderate sized deciduous tree. It has bi-lobed leathery leaves forming dense canopy. It has short, tough bole with compactly placed branches.

This species is not very common and present at five sites only. At all the sites a minimum of 3 and a maximum of 5 individuals were sampled. A total of 17 trees were studied. They were ranged from 5.0 - 6.8 m in height and 2.31 -3.47 m in Canopy radii.

At control minimal LA was observed during May with the least LWt because of new leaf production. It gradually increased upto Aug and peaked in Nov. Leaf ageing was observed during Nov and LF occurred during Jan-Feb. Averages of all the parameters except LAR and SLA were higher at control. LA at site 6 was the least accounting for 70.7 % as compared to control. LF and LD were more at site 2. Reductions in LWt were more at site 6 (i.e., upto 46.5 %). BWt at sites 5 and 6 were the least (62 and 74.2 % respectively). LWt and BWt reductions have resulted in overall TWt reductions (Table 11) at polluted sites. LAR at all the polluted sites was high. Reduced LWt has resulted in higher SLA values at polluted sites. LWR at all the polluted sites was reduced. LWt/BWt ratio was reduced at all the polluted sites except at 5 and 6, where highly reduced BWt has resulted in higher readings.

Phenology and reproductive cycle: At control new leaves were produced during Mar-May. At times this was stretched upto Jun. These leaves remained on the canopy upto Dec and then leaf fall was started. Flowering was started during Feb when canopy was semi-transparent. Fruits remained throughout the year.

There was no remarkable shift in leaf phenology and reproductive cycle at polluted sites. Only reductions in number of inflorescences per branch (IN/BR) and flowers per inflorescence (FL/IN) were seen (about 40 to 85 %). This has resulted in reduced (≅ 50 %) fruit setting recorded as fruits per branch (FR/BR) at polluted sites (Table 11).

Cordia dichotoma

It is a deciduous, small to moderate sized tree. It has broad, round, thick and rough leaves. *Cordia* has short, stout bole with drooping branches forming a patchy canopy.

At each site (except 4), 3-5 individuals were chosen. A total of 24 individual trees were studied. Their height and CBH were ranging from 5.7 to 7.7 m and 75-110 cm respectively. Spread of canopy ranged between 2.40 to 3.90 m.

LA was maximum at control. It was lowest at site 7 and highest at site 3 among polluted sites (Table 12). LD was high at sites 3,6 and 7 which accounted for 6.5, 7.6

and 14 % of their respective average periodical LA. Sites 6 and 7 had shown LF on a higher scale (i.e., > 2 per 10 observed leaves). LWt at all the polluted sites was less. Both LWt and BWt were the lowest at site 7. It was due to two leaf flushing periods (i.e., once during May-Jun and again in Aug). At control, the trees exhibited lower LAR and SLA as against the polluted sites. This was due to their ability to accumulate more biomass. LWR and LWt/BWt ratio too was high at control.

Phenology and reproductive cycle: At control in the end of Jun new leaf production was observed. Initially leaves were light green and thin. They gradually developed into dark-green, rough and thick during rainy season. Mature leaves were seen in Sept. Inflorescences were observed in the axils of old leaves during Mar. At the same time, leaf senescence started and lasted upto mid-Jun. During Jun itself, ripen (whitish - yellow) fruits appeared alongwith very few necrotic old-leaves.

There was no alteration in phenology at polluted sites. Sites 2 and 8 had displayed similar levels of fruiting equal to that of control. At sites 3,6 and 7 it was less (ranged between 65-85 %) as compared to control.

Holoptelea integrifolia

This is a deciduous, broad leaved tree species with short, deeply fissured stem. It grows from the lateral buds forming forked sympodial branches. This further repeats for several times and forms heavily branched canopy. The crown remains moderately thick with numerous thin branches.

A total of 58 individuals were studied. Excepting site 8 this species was present at all the sites. Their sizes varied from 8.0 - 10.5 m in height and 95.2 - 110.2 cm in CBH. Spread of canopy was slightly more at control (3.61 m). At all the polluted sites it ranged from 2.96 to 3.55 m. Similarly canopy depth varied from site to site. Branching started at 1.75 m at control and at site 2. It started from 1.80 - 2.11 m at rest of the sites. This has resulted in the formation of much deeper and broader canopies at control and site 2.

Trees at control displayed higher average periodical IL and G. They were minimal at site 7. Damaged leaf area (LD) was maximum at sites 2 and 7. Leaf fall (LF) was high at sites 3,6 and 7 (Table 13). Reduced LA at sites 6 and 7 (26.1 and 27.5 cm^2 respectively) was due to LD and LF. LA at control was 40.0 cm^2. LWt had lower readings which ranged from 2.01 - 2.51 g at all the polluted sites against control's 3.11 g. Average annual BWt at polluted sites varied from 0.36 - 0.46 g. This too was below the control's (0.48 g) BWt. Reductions in LWt were higher than those in BWt. At all the polluted sites LAR was less than that of control. The differences between LA of polluted and control sites were higher than the differences in TWt. SLA at polluted and control site did not show much variation, suggesting reductions in LA at polluted sites attributed by equally reduced LWt. LWR at control was high. LWt and BWt ratio at all the polluted sites was lower (ranged from 4.51 - 5.82) than that of control (6.75).

Phenology and reproductive cycle: *Holoptelea* had new leaf formation starting from Feb. and extending upto Jun at control. Leaf fall too occurred for longer durations. It started in Jan and lasted upto May. Leaf Phenology varied from tree to tree and there was a considerable gap (> 1 mo) in the initiation and abscission of leaves. Young leaves were thin and tomentose. Similar to *Cordia* they became thick after receiving the rains. Old leaves were rough and devoid of hairs. From the axils of fallen leaves, short racemes were given out during Apr-May. Later on they developed green, winged circular fruits in May-Jun.

Reproductive phase did not show altered flowering time at polluted sites. At sites 4,6 and 7, percentage of flowering was reduced. This has resulted in lesser fruit production. At site 4, number of flowers per inflorescence (5.4 FL/IN) and fruits per branch (2.7 FR/BR) were very less as compared to control (i.e., 16 FL/IN and 28.5 FR/BR).

Mangifera indica

This is an evergreen, broad-leaved tree species with dense, dome-shaped canopy. It has straight, stout, short bole with almost perpendicular branches. Leaves positioned within the canopy often remain attached with the branches for more than a year. They remain devoid of axillary buds unlike the leaves present towards the periphery or near the tips of the branches.

Sampling was done for 50 individual trees present at seven sites. Their height varied from 7.0 to 10.7 m and CBH ranged in 116-151 cm. Canopy cover (average radius) ranged from 3.21 - 6.25 m.

At control, during May maximal IL (0.92 cm) with minimal G (0.57 cm) was observed. It was due to newly flushed leaves. They had lesser LA (77.5 cm^2) and LWt (9.76 g). At polluted sites 3,6 and 8, exactly reverse trend was seen. Trees showed minimal IL and maximum G as well as more LA and higher LWt (Table 14). This was due to presence of old leaves on short mature branches. Newly flushed shoots were observed during Nov and Feb at sites 3,6 and 8 indicating a shift in leaf phenology. Average LA at control was more (81.9 cm^2). It was minimal at site 7 (58.1 cm^2) and 5 (57.8 cm^2). LD was seen throughout the year. It was maximum at site 6 (8.5 cm^2) followed by site 7 (2.5 cm^2). LF was not found during May at any of the sites. It was heavy at sites 2,6 and 8 during rest of the three sampling periods. LWt and BWt at control showed higher readings. They were minimal at site 7 (Table 14). Excepting site 6, LAR and SLA were less at all the polluted sites. This was due to less LA at polluted sites. LWR as well as LWt/BWt ratio at site 7 was higher than that of control due to lesser biomass accumulation in the branches. Rest of the polluted sites showed lesser ratios due to heavy LWt reductions.

Phenology and reproductive cycle : At control major leaf flush was started from Mar and persisted upto Jun on most of the branches. Few branches displayed growth of reproductive buds. Some branches produced new leaves on receiving rains and shoot growth was continued upto Sept. Heavy rains with greater wind speeds resulted in the fall of few green leaves along with seasonal foliar senescence at all the sites.

Reproductive cycle at control was started from Feb onwards. Flowering continued upto Jun. This pattern was seen at all the sites. Only the productivity made the difference. Flowers per inflorescence were 56.6 at control. It was minimal at site 6 (i.e., 8.1 FL/IN). At site 6, two distinct flush periods were observed, once during Feb and other during Aug. Thus, altered foliar phenology was observed but reproductive cycle was not shifted.

Mimusops hexandra

This is an evergreen tree with short, hard bole. Branches are uneven in size forming a dense crown. Leaves are dark-green and broader at apex with a notch. They are thick and wax-coated on upper side with a prominent midrib. Leaf stalk is short and tough which does not allow the leaf blade to flutter.

Mimusops is represented by 24 individuals from the sites 1,2,4 and 5. Their sizes varied between 136.3 - 162.7 cm in CBH and 7.1-10.9 m in height. Average canopy radii ranged from 3.14 to 5.91 m.

At sites 2 and 5, the IL and G showed similar readings to that of control. At site 4 there were heavy reductions in all the growth parameters (Table 15). LA was 21.6 cm^2 at site 4 against 30.0 cm^2 at control. LD at sites 2 and 4 was > 11 % of their respective LA. Average LF at site 4 was high (i.e., 4.2 leaves per 10 leaves), which occurred during Aug-Sept and Feb-Mar. LWt and BWt at all the sites were lower than that of control. LWt at site 4 was the least accounting for 59 % of control. It was 78-80 % at sites 2 and 5. There was a remarkable reductions in BWt (46.5 % against control) at site 4. BWt values at sites 2 and 5 were at par with control. LWR at site 5 was high because of heavily reduced TWt. LWt/BWt ratio at sites 2 and 5 was less, but at site 4 it was more than control. As compared to LA reductions among trees of polluted sites, LWt reductions were greater. This has resulted in an increased LAR and SLA at polluted sites (Table 15).

Phenology and reproductive cycle : At control, *Mimusops* had major leaf production during Apr-Jul. It had also shown post-monsoonal foliar flush at some points within the crown. Flowering started in Nov in the axils of old leaves by means of single solitary flowers. In some individuals, flowers were present on the fascicles. They developed into fruits during Apr. Only solitary flowers are considered for the comparisons with control. The control had 6.2 FL/BR. Reproductive cycle at control was during Jan-Apr. While at polluted sites it was from Feb to Jun. Fruiting was reduced from 0.2 FR/BR at site 4 to 1.8 FR/BR at site 2 against control's 4.4 FR/BR.

Moringa pterygosperma

Moringa is a deciduous fast growing tree species. It has a thick, soft stem and delicate branches bearing tripinnately compound leaves. Leaf lets are small, roundish and fleshy. Apical dominance is seen among branches with irregular, transparent crown. Generally trees are pruned for leaves and fuel wood. Thus it become rare to find an undisturbed tree.

Total 58 individuals of *Moringa* were studied. It was absent only at site 8. Height of the studied individuals varied from 5.4 - 6.1 m. Their trunk's circumferences varied from 80 to 120 cm and spread of canopy from 2.0 to 3.2 m.

At control average IL was not higher than those at sites 2,3 and 4 but G was the highest suggesting that trees at control tried to grow uniformly. IL at control was minimal during Feb with highest LWt (Table 16). IL at sites 3 and 5 was minimum during Feb and Nov. LWt and BWt were reduced due to newly flushed twigs. LD and LF was also seen suggesting that trees were exposed to heavy emissions. Sites 4 and 7 had less IL during Aug. LWt and BWt were reduced because of newly flushed twigs as seen at control. Average LWt at all the polluted sites was reduced considerably (ranged from 6.90 - 11.12 g) as compared to that of control (12.87 g). Similarly, BWt was less by 53 and 64 % at sites 7 and 5 as compared to control. Sites (3 and 5) falling on the western side and sites (4 and 7) falling on the eastern side showed different growth trends. LAR at all the polluted sites was below to the value of control. SLA at control and polluted sites did not vary much. LWR and LWt/BWt ratio at control had lesser readings than polluted sites (except site 4).

Phenology and reproductive cycle : At control, it behaved like a typical deciduous species with distinct leaf fall during Mar-Apr. New leaves then given out from the branch tips with elongated shoots. During Jul-Sept it had flowering and fruits remained upto Mar.

Reproductive cycle was altered at polluted sites. Site 5 showed flowering during Apr-Jun and then in Oct-Nov, but fruit setting was observed only during May-Jul. Similarly site 6 had two flowering periods (i.e., during Feb-Mar and Jul-Aug) but no fruiting was seen during Aug. Fruit production was less (ranging from 0.6 - 2.0 FR/BR) at sites 7,6 and 5 as compared to control (3.8 FR/BR).

Pithecellobium dulce

Pithecellobium is a moderate sized, thorny evergreen tree. It forms heavily branched canopy with several laterals. Usually trunk is not straight. It bends and divides into 2-3 branches in different directions forming an uneven semi-transparent canopy. It has thin dissected leaves with four lobes present on twice dichotomously forked midrib (petiole).

The study was conducted on 55 individuals present at all the sites. Their height and CBH varied from 6.8 - 9.8 m and 80 - 105 cm respectively. Canopy radii ranged between 2.4 to 4.8 m.

Average IL at all the polluted sites was less. The girth of the branch was more. IL and G observations of May were low. During Aug it was minimal and again it increased for rest of the periods. Control readings always remained on the top. LA at all the polluted sites was considerably less. Site 4 had minimal growth readings, where LA was 50.5 % and LWt was 51.3 % as compared to control. BWt too was only 37.6 % to that of control. LD was seen during Aug at site 4. At sites 6 and 7, damage to leaf area was seen during Nov to Feb. All these have led to a remarkable reduction in LA, which was reflected in lowered LWt and BWt. LF at site 7 was found during Jan-Feb, May-Jun and during Aug. At sites 6 and 8 it was during Feb and Aug (Table 17). There were more fluctuations in LWt at sites 4 and 6 among four sampling periods. At control fluctuations in LWt were minimal, which was normal evergreen's phenological expression. Due to higher LD and LF this species had uneven growth pattern at polluted sites. Annual averages of LAR and SLA at control were less than that of all the polluted sites. LWR at site 7 was very less due to higher reductions in LWt as compared to TWt. Rest of the sites had higher LWR due to heavy TWt reductions. LWt and BWt ratio at polluted sites was higher indicating that trees at polluted sites could not accumulate similar levels of biomass in their branches.

Phenology and reproductive cycle : At control, it produced new leaves during Jun-Aug. Reproductive cycle was in months of Nov-Jun. Fruiting was seen from Dec and by May ripen fruits were observed. Reproductive cycle within a tree as such was lengthy, and flowering and fruiting were seen together in Mar-Jun.

At all the polluted sites reproductive phase was observed during Nov to Mar, except at site 5 where it occurred during Jan-Mar. Thus, polluted sites exhibited lesser duration of reproductive cycle. At sites 4,6 and 8, fruit productivity was hampered (Table 17).

Streblus asper

This is an evergreen tree species. It can grow in various forms from small to moderate sizes. It has numerous branches on a short, stout, light-grey bole. It bears a dense crown of dark-green, rough leaves of various sizes and different phyllotaxies. It is often subjected to pruning and appears as a bushy shrub.

It was present at all the sites and 60 individual trees were investigated. They were ranging from 3.8 to 4.6 m height. Their CBH varied from 88.7 - 103. 0 cm and canopy radii ranged between 1.05 - 2.32 m.

Periodical averages of IL, LA, LWt and BWt were higher at control. Girth (G) at polluted sites (except 4 and 6) was similar to that of control. Premature LF at all the polluted sites was seen during Aug and Nov, which indicated reduced leaf longevity. During Jan-Mar, seasonal leaf fall occurred at all the sites including control (Table 18). At sites 6 and 7, LF was found during all the study periods, indicating frequent pollution exposures. LA was influenced by LF whereas, LWt was affected by both LD and LF. For this reason, there was reduced LWt at sites 2 and 3 during Aug and Nov. At other polluted sites (except 4), LWt reductions were seen irrespective of favourable season (post-monsoon). Average LAR was more at site 6. It was less than control at all the sites. At control, SLA was less during Aug due to increased LWt. It was more at sites 2,4 and 5 due to reduced LWt (Table 18).

Average SLA at sites 2,3,7 and 8 was less than control because of reduced LA during all the periods. LWR and ratio of LWt and BWt showed slightly reduced readings at polluted sites.

Phenology and reproductive cycle: At control, *Streblus* was never seen with barren canopy. During Oct-Dec, it had major leaf fall and during May-Jul too, it showed leaf senescence. Along with the onset of monsoonal showers, trees produced new leaves. When those branches became 5-6 mo old, they exhibited flowering (during Jan-Mar). Fruiting occurred during Apr-May.

Leaf phenology at polluted sites was differed due to heavy leaf fall mainly during Sept to May. At sites 2,3 and 6 (i.e., falling on western side of the industrial belt), it had early flowering; while at sites 4,7 (falling in the East) and 5, plants exhibited delayed flowering. Thus, like *Pithecellobium* this evergreen showed altered reproductive cycle. There was a difference of 3 mo as compared to the reproductive cycle of control.

Tamarindus indica

Tamarindus is a huge, evergreen, paripinnately compound leaved tree. It has thick, stout bole bearing heavily branched, dome-shaped, dense crown. Old branches can be found perpendicular to the main trunk.

This tree was present at sites 1 to 6 with 34 individuals. Their height varied from 6.3 to 8.3 m and CBH ranged from 87.3 to 147.3 cm. Canopy differed in sizes and their average radii ranged from 3.77 - 4.66 m.

At control, IL was more during the first two samplings (i.e., May and Aug) with less G indicated new twig extensions. During Nov, IL was reduced with an increase in G (Table 19). BWt was 0.18 g during the mo of May and Aug. In Nov, it was 0.33 g.

In Feb IL was increased and G had decreased indicating further growth. Sites 2,3 and 5 exhibited similar trends with that of control for IL and G. Though IL at these sites was high, BWt was low. At sites 4 and 6 the trend was altogether different. Both the sites revealed lower G readings during Nov. At the same time, IL was minimal at site 4 and was maximal at site 6 (Table 19).

At control LA was less (i.e., 14.5 cm^2) during Aug and was maximum (23.6 cm^2) in Nov. During Feb and May, it was slightly lower (i.e., 19.2 and 20.6 cm^2) due to natural seasonal leaf fall. Site 4 displayed similar growth but, LF was very high (8.4 leaves per 10 leaves) during Aug. IL was high at site 4 with reduced G, LA and LWt suggesting vegetative flush. Site 6 showed LF during May, Nov. and Feb months. It was explicited by reduced LWt and also by declined BWt. LAR and SLA values at all the sites were higher than those at control. LWR and LWt/BWt ratio was less at all the polluted sites. There were lesser fluctuations among averages of four sampling periods for LWt/BWt ratio at control suggesting harmonious growth. Those fluctuations were more at polluted sites, suggesting uneven biomass accumulations.

Phenology and reproductive cycle : At control *Tamarindus* behaved like a typical evergreen tree without a distinct vegetative flush period. It had leaf fall during Mar-May, resulting in a moderately transparent canopy. Leaf fall was followed by new foliar flush without any lapse in time. This was observed among branches of higher orders (present in the outer periphery) of the canopy. On the otherhand, sheltered leaves (present within the crown), did not show senescence during Mar-Jun. Young trees however remained dense throughout the year. Leaf production occurred from Apr-Sept. Flowering was observed from Mar. It was followed by fruiting.

Reproductive cycle lasted upto Jun. Some fruits were seen even during Jul. Reproductive cycle was found to be severely affected at site 6 as fruits within canopy were minimal. At sites 4 and 3, they were averaging 0.2 FR/BR. At site 2 they were

2 FR/BR equalling the observation of control. At sites 4 and 3 fruit setting occurred during Jan-Mar. indicating shifted reproductive phenology. Fruiting at rest of the sites was seen during Apr-Jun like that of control.

Tagging experiment

Tagging was done on the growing branches of the trees selected for growth studies. The study was carried out for comparing simultaneous phenological changes with growth parameter studies. Trees of similar circumference (i.e., nearly of same age) were selected. Growing branches (twigs) of outermost periphery of the crown were tagged to minimise spatial discrepancies. Tagged branches were more or less of similar shoot lengths and leaf number in the beginning.

Among the studied species, *Holoptelea integrifolia* revealed a typical deciduous nature with leaf flush only once in a year. At control, it has leaf fall during Jan-Feb, followed by new leaf initiation during Mar along with increments in shoot length. Among all the sites, it had maximum leaf production and shoot length increments at control. Polluted sites have reduced leaf longevity. At site 3, leaf fall was early (during Nov-Dec) but leaf initiation occurred only after May. Sites 4,6 and 7 displayed dried growing tips during Jun with new branches coming up from axillary positions for further growth. Similar type of growth was recorded at sites 2,3 and control. The difference was that shoot tip continued its growth. Site 6 exhibited no leaf production during Jun. There it was observed after rainfall (Table 20).

Azadirachta displayed only one vegetative flush period (Mar-Jun) at control. At polluted sites leaf flushing occurred for more number of times. It flushed twice (during Oct and Mar-Jun) at sites 4 (Figure 5) and 7. Thus at site 4, it had maximum number of leaf production. Increments in shoot length were highest at control and lowest at site 8. Uneven leaf phenology at polluted sites revealed its semi-evergreen nature (Table 20).

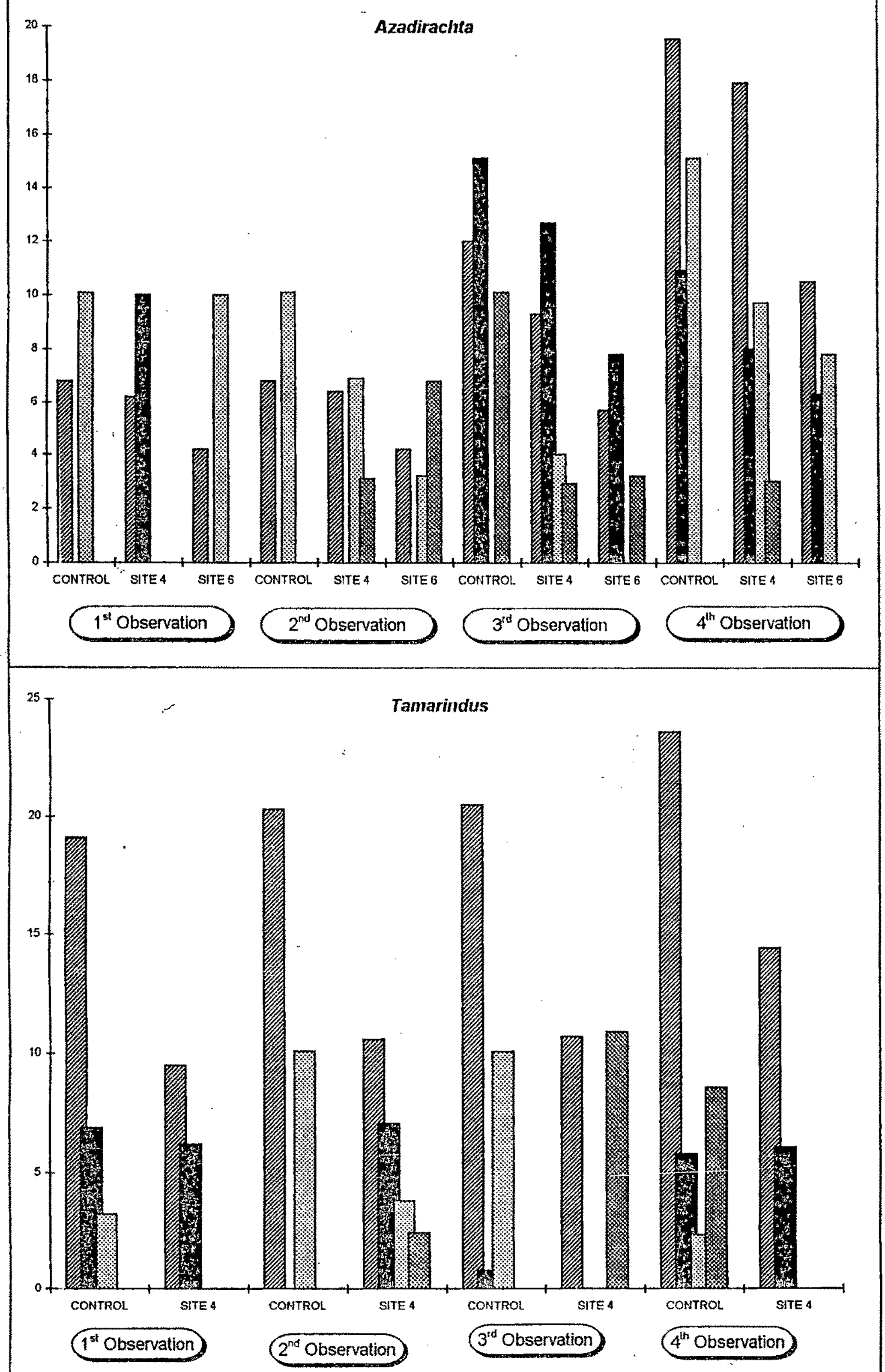

Figure 5: Growth measurements on tagged branches for four observations at an interval of 0.65 (+1) d from 1st wk of Oct. 1995 indicating

Shoot length
Immature leaves
Mature leaves
Absent leaves

Among evergreens, *Tamarindus indica* was studied at sites 2 and 4, other than control. Leaf production occurred during Oct and during Mar-Jun. At site 2, it was delayed and no new leaves were observed during Mar. At site 4 too, new leaves were not produced during Mar but they were produced during Oct-Dec. Like *A. indica*, this species produced more number of leaves at site 4. Shoot length increment was the highest at control (Figure 5).

Streblus asper at control had stem elongation throughout the study period with simultaneous leaf production owing to its evergreen nature. Leaf production and shoot length increments were the highest at control. Sites 2 and 3 had similar phenology with that of control but shoot lengths were considerably reduced. Sites 4 and 6 exhibited stagnant growth during Dec-Mar. At site 7, from Oct to Mar there was no increment in shoots and no new leaf production (Table 20).

Mangifera indica revealed new leaf production during Oct and Mar-Jun at control. Leaf fall mainly occurred during Mar-Jun. It had stagnant shoot lengths during Dec-Mar. At site 2, similar type of phenology was observed. Sites 3 and 6 had new leaf production only during Mar-Jun. Control stood on the top by producing maximum number of leaves and highest shoot lengths (Table 20).

Thus, each tree with its own phenological pattern differed in its growth approach at different sites. Among them, the highest growth reductions were noted in *Tamarindus* at site 4. On the contrary, *Azadirachta* could produce more leaves at site 4 as compared to control. *Mangifera's* growth was affected by minimal number of leaves produced at site 7. Increment in shoot lengths at site 6 were also less. *Holoptelea* too had hampered shoot extensions and reduced leaf longevity (premature leaf fall). Stagnation in the shoot lengths of *Streblus* was seen. Overall growth reductions were maximum at sites 4 and 6 and it was minimum at site 2.

Dust deposition

At control dust settled was high during summer. *Cordia* had the highest deposition averaging 1.47 g m^{-2} followed by *Bauhinia* (1.34 g m^{-2}) and *Holoptelea* (1.11 g m^{-2}). *Azadirachta* could collect very little dust (Table 21) averaging 0.36 g m^{-2}. *Acacia* had the least (0.17 g m^{-2}) dust deposition.

At all the polluted sites dust deposition was more during summer. However site 2 had more dust in some trees during post-monsoonal season indicating highly localized anthropogenic activity. Sites 7,3 and 2 stood as heavily dust polluted sites with nearly two and half times of dust deposited or even more as compared to control.

Control site had minimal difference in the two season's dust amount (only 0.23 g m^{-2}) when averages of all the trees were compared. It was maximum at site 7 and 3 (1.43 and 1.13 g m^{-2}). Rest of the sites ranged between 0.41 - 1.08 g m^{-2} (Table 21).

At the polluted sites *Holoptelea, Anogeissus* and *Bauhinia* displayed maximum dust holding capacity. *Tamarindus* and *Azadirachta* had minimal dust and *Acacia* had the least.

Ranking of dust holding capacity for the studied trees in decreasing order was *Holoptelea* > *Anogeissus* > *Bauhinia* > *Mimusops* > *Cordia* > *Streblus* > *Mangifera* > *Pithecellobium* > *Tamarindus* > *Azadirachta* > *Acacia*.

There was a small difference between summer and post-monsoonal dust amounts among evergreens, whilst deciduous species had wider gap (Table 21).

Sulphur accumulation

Based on the sulphur accumulation at control the twelve tree species can be put into four broad categories.

(1) *Acacia* and *Mangifera* shared similar pattern upto Nov. Both had high readings in Aug. In Feb, *Acacia* had lower and *Mangifera* had higher sulphur contents.

(2) *Azadirachta* and *Bauhinia* followed another pattern with a gradually lessened S content from May to Feb.

(3) In *Cordia, Holoptelea* and *Mimusops*, there was higher S accumulation during May and Nov, and it was lowered in Aug and Feb.

(4) Rest of the species (*A. latifolia, M. pterygosperma, P. dulce, S. asper and T. indica*) had reduced S content during Aug which increased enormously in Nov. It increased further in Feb (Table 22).

Trees of categories (3) and (4) were found to be good S accumulators at polluted sites. Sites 2 and 3 showed similar pattern of S accumulation. Sites 4 and 6 had shown different patterns. This indicated that positions of sites might have been responsible for their S absorption patterns.

Trees at polluted sites showed differences in S accumulation trends as compared to control. Those trees following the same pattern are (1) *Azadirachta* and *Bauhinia* at sites 3,4 and 6 (2) *Cordia* at site 3 (3) *Holoptelea, Streblus* and *Tamarindus* at site 4 and (4) *Mangifera, Moringa* and *Pithecellobium* at site 6 (Table 22). Results also revealed that *Anogeissus, Holoptelea, Moringa* and *Pithecellobium* generally could maintain similar S accumulation patterns at all the sites. All these trees are high S accumulators at polluted sites.

Evergreen and deciduous species showed different S content. Evergreens such as *Tamarindus* and *Streblus* showed higher content in Nov. *Mangifera* leaves had higher S at polluted sites throughout the year (except site 6 during Aug). *Pithecellobium* accumulated higher amounts at sites 2 and 6 during Aug and Nov. On an average, *Tamarindus* accumulated 128 % of sulphur at site 4 while *Streblus* had 109 % at sites 4 and 6 as compared to control. *Mangifera* showed highest S content (131-170 %) at polluted sites (Table 22).

Stems of *Acacia* revealed high (1.1 - 1.7 times) S content and *Streblus* was right on the top with 2-5 times S accumulation. *Tamarindus* too, showed it's excellence by accumulating 1.7 - 3.2 times sulphur during May and 1.1 - 1.7 times during Nov at all the polluted sites. *Mangifera* exhibited 1.7 to 2.3 times sulphur during May. *Azadirachta* and *Pithecellobium* during May and Nov had higher S accumulation. Thus mo of Nov was found to be favoured by all evergreens for maximum S accumulation in leaves and stems (Table 22). The other notable phenomenon is that, when S content was more in leaves, it was usually less in stems and vice-versa. Among the deciduous *Anogeissus* and *Holoptelea* had good S contents at polluted sites. *Moringa* had high S during Aug and Nov. *Cordia* (except in May) had higher S content at polluted sites. Similar is the case of *Bauhinia*.

Overall *Moringa* accumulated 110 % of sulphur at site 3. At polluted sites (4 and 6) it had values similar to that of control. *Anogeissus, Holoptelea* and *Cordia* exhibited greater capacity for S accumulation with 1.5 times to the levels of control.

In the stems of deciduous species, *Moringa* had higher S accumulation during May (1.6 - 2.2 times) and Nov (1.1 - 1.5 times). Similarly *Holoptelea* (Sites 4 and 6), *Anogeissus* (Sites 2 and 4), and *Bauhinia* (site 4) had higher S contents for both the months. *Cordia* had higher (2-5 times) sulphur like that of evergreens.

All the studied species exhibited higher sulphur content at sites 4 and 6 (Table 22).

Statistical data

Standard error ($\pm$ SE) was calculated for each growth parameter (18-60 readings) for each tree species (Tables 8 to 19). Analysis of variance (ANOVA) was carried out by using SPSS PC+ package to find out whether the differences seen among different species, seasons, and localities are significant or not. The analyses showed that the differences among different groups are significant ($P < 0.5$). Interactions between the groups were also significant ($P < 0.5$). This was due to obvious differential responses among species which varied significantly when seen temporally and spatially as air pollutant levels varied.