Chapter IV

# DISCUSSION

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## 4.1 FIELD SURVEY

### 4.1.1. SURVEY OF GENERAL VEGETATION NEAR A FERTILIZER COMPLEX

The impact of industrial air pollution on natural vegetation has been studied along a gradient by many workers (Garyson,1956, Gordon and Gorham,1963, Chaphekar,1972, Guderian and Kueppers, 1980). In the present investigation, a sharp decline in number of herbaceous species was recorded near the source of pollution. The number of herbaceous species (in 30 quadrats of 1 x $1m^2$ size) at 0.5 Km. distance was 31, whereas at 1.5 and 2.5 Km. distance it was 40 and 51 respectively. Such observations i.e. increase in species diversity while moving away from the source was earlier reported by Garyson,1956, Gordon & Gorham,1963, Guderian and Kueppers, 1980.

At 0.5 Km. distance, all the plant species exhibited visual damaging symptoms, may be due to close vicinity of the source and heavy load of pollution. Plants like *Amaranthus spinosus*, *A. viridis*, *Cassia occidentalis*, *C. tora*, *Gynandropsis pentaphylla*, *Peristrophe bicalyculata*, *Tribulus terrestris*, *Tephrosia purpurea*, *Vernonia cinerea* etc., exhibited 50% foliar damage. Among the other species *Tridax procumbens*, *Launaea nudicaulis*, *Cocculus villosus*, *Canavalia ensiformis* showed below 20% damage. All other species exhibited 20 to 50% damage (Table 9).

Among the total plant species recorded at 1.5 Km. distance from the source 85.9% species exhibited foliar symptoms. At this distance 81.4% of the herbaceous species were recorded with visible damaging symptoms. Species like Boerhavia diffusa, Evolvulus alsinoides, Gomphrena celosioides, Portulaca quadrifida, Trianthema monogyna, etc., did not show any visible damage, whereas Achyranthes aspera, Aeschynomene indica, Desmodium triflorum, Ipomoea sepiaria, Lippia nodiflora, Mollugo oppositifolia etc., exhibited below 20% damage. Plants like Cassia occidentalis, C. tora, Xanthium strumarium etc., exhibited more than 50% damage. All the remaining species showed 20 to 50% foliar damage (Table 9). Thus the species which were not exhibiting any visual damage were considered as resistant species and which exhibited more than 50% damage were grouped as highly sensitive ones. The other group of species which were exhibiting 20 to 50% damage were considered as medium sensitive.

In quadrat study, additional species like Aeschynomene indica, Commelina benghalensis, Mollugo oppositifolia etc., were recorded at 1.5 Km. distance from the pollution source. At 2.5 Km. some more species like Amaranthus polygamus, Anisomeles ovata, Boerhavia repanda, Urena lobata etc., were recorded. This may be, as observed by Guderian and Kueppers (1980) that " The species which are sensitive to pollution fail to establish near the source, as the pollution load decreases with increasing distance, the species diversity increases."

Among shrubs Bougainvillea spectabilis, Kirganelia reticulata, Lawsonia inermis etc., were showing more than 50% leaf area damage at 0.5 Km. distance from the point source, revealed their sensitivity to air pollution. At this distance Euphorbia tirucalli, Opuntia dilleni etc., were less affected and their resistance may be due to presence of latex and succulent nature.

Among the trees Ficus benghalensis, Terminalia catappa etc., were comparatively less damaged whereas Mangifera indica, *Acacia nilotica, Diospyros cordifolia, Holoptelea integrifolia, Manilkara hexandra, Pithecellobium dulce etc., (Table 8) were exhibited more than 50% damage at 0.5 Km. distance. Most of the other species were showing 20 to 50% damage (Table 8).

At 1.5 Km. distance from the pollution source, trees like *Acacia nilotica, Mangifera indica, Moringa pterygosperma, Pithecellobium dulce etc., were exhibiting more than 50% foliar damage. At 2.5 Km. distance 33% of the recorded tree species were without any visible damage, whereas trees like *Acacia nilotica, Bauhinia racemosa, Diospyros cordifolia, Ficus religiosa, Pithecellobium dulce, etc., exhibited below 20% damage. This shows that at this distance these

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*Acacia nilotica (L.) Del. sub sp. indica Brenan species can exhibit better growth performance. *Mangifera indica* exhibited more than 50% visual damage even at the distance of 2.5 Km. from the source, this shows its higher sensitivity to industrial air pollution (Rao, 1972, Prasad *et al*., 1979).

### 4.1.2. STUDY ON TREES GROWING ALONG THE NATIONAL HIGHWAY NO. 8: A GRADIENT ANALYSIS

The present investigation revealed the combined effect of industrial air pollution and autoexhaust pollution, caused severe damage to the trees growing along the National Highway No. 8. Same aged trees exhibited a high variation in the growth performance, especially very high damage to trees was recorded in Sector 4 of the study belt i.e. opposite to the fertilizer complex. Sulphur dioxide which is one of the major industrial pollutants retards the growth and causes heavy damage to the plants (Katz 1949, Thomas and Hendricks 1950, Choudhary and Rao, 1979). Similar to industrial air pollution, autoexhaust in which oxides of sulphur, nitrogen, carbon, hydrocarbon and lead are present also have phytotoxic effect (Ward *et al*., 1974, Parker, 1977, Lynn, 1976, Flueckiger *et al*., 1979, Krishnyya and Bedi, 1986). It changes the rate of photosynthesis, transpiration, affecting chlorophyll content there by reducing the biomass accumulation (Heck and Brandt, 1977, Roberts, 1974).

Fig. 4.9.1 . Impact of air pollution on roads side trees — Dalbergia sissoo Roxb.

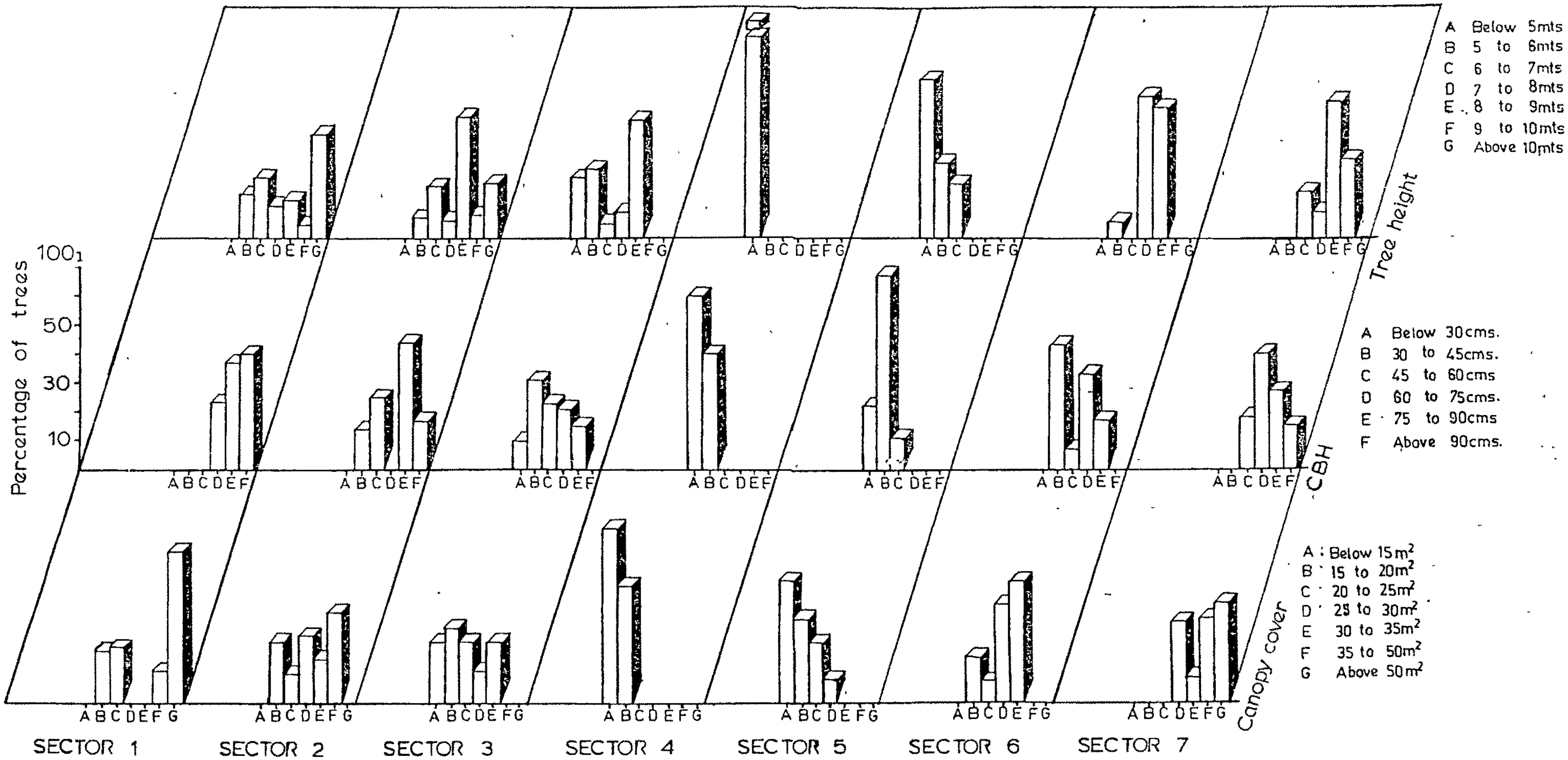
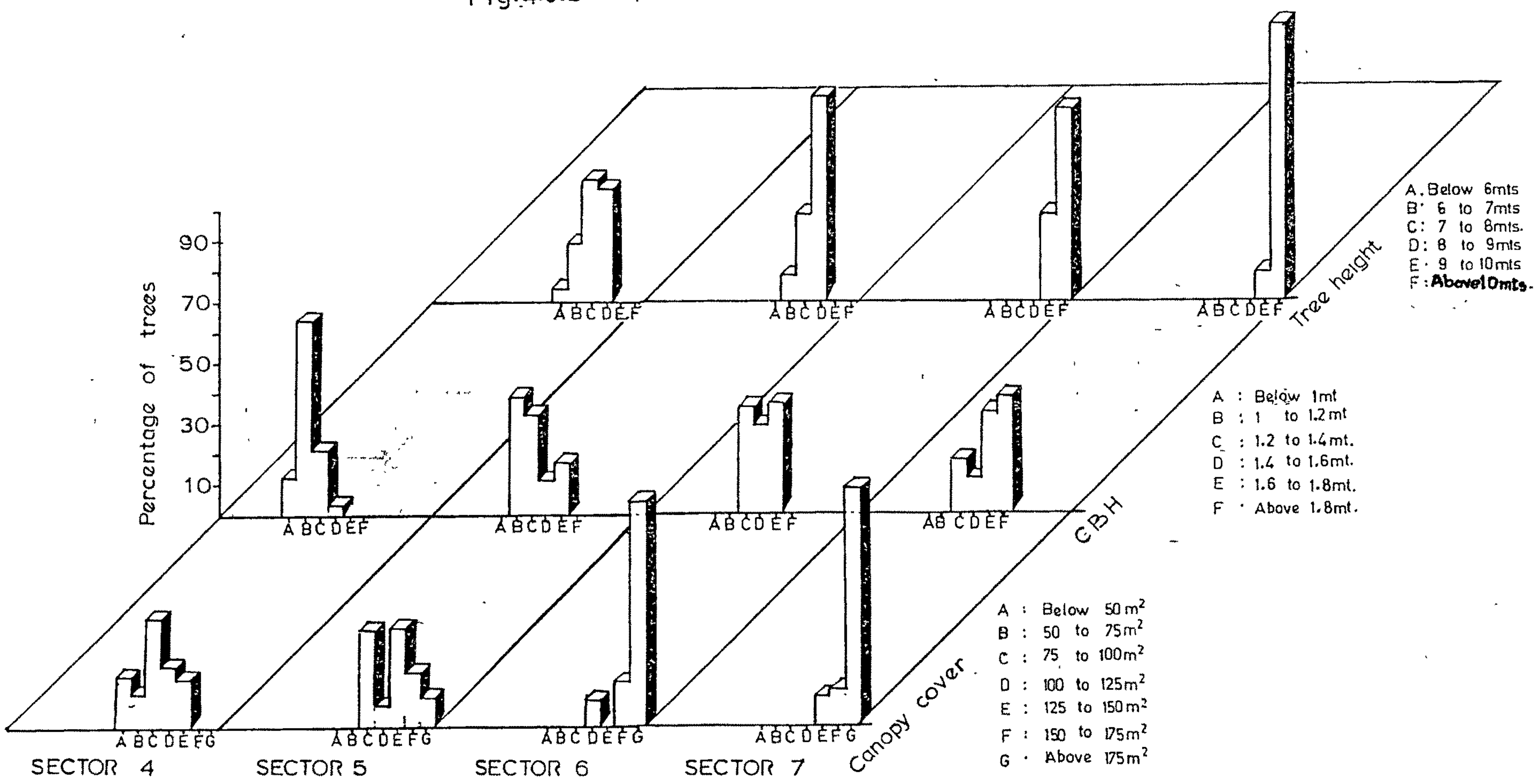


Fig.4.9.2 Impact of air pollution on road side trees *Syzygium cumini* Skeels



Among the seven sectors studied (Fig.4.9.1.) trees growing in sector 4 exhibited poor growth performance. The tree height of Dalbergia sissoo was below 5 mts. (Class A) in this sector. Similarly CBH recorded in 60% of trees was below 30 cm (Class A) and 40% in Class B ( 30 to 45 cm). The canopy cover of all the trees in sector 4 were below $20m^2$ (Class B). Fairly good growth performance was exhibited by the trees growing in the sector 1 and 7 i.e. away from industrial pollution source.

In sector 4, tree height of 63% Syzygium cumini trees was below 8 mts., whereas in sector 6 and 7 tree height ranged above 10 mts. in 63% and 91% of trees respectively. Similar pattern of damage was exhibited in CBH and canopy cover of the tree (Fig.4.9.2.). This also clearly indicates the severe damage to trees in sector 4 due to the combined effect of industrial and autoexhaust pollution. Due to high industrial pollution in sector 4, most of the Dalbergia trees planted have perished except five remaining trees in this sector (Table 10). The quadrat study on D. sissoo revealed the mean density value per quadrat in sector 4 and 5 was 0.33 and 3.7. In the remaining sectors i.e. sector 1, 2, 3, 6 and 7 the mean density value was 34, 29.7, 18.7, 20.3 and 25.7 respectively (Fig.3.4.1.) Syzygium cumini exhibited lesser variations as compared to Dalbergia sissoo. This shows D. sissoo is more sensitive than Syzygium cumini.

4.1.3. FIELD SURVEY OF FRUIT TREES

Growth retardation of trees growing at polluted area was earlier observed by many workers (Garyson,1956, Garsed et al., 1969, Garsed and Rutter, 1984). The major pollutants in the present study area are sulphur dioxide and nitrogen oxides like $NO_2$. It has been earlier reported that $SO_2$ and $NO_2$ in combination may be more toxic to plants than would be predicted by summing their individual effect on growth (Wellburn et al ., 1972, Bennett et al., 1975, Ashenden, 1979a, 1979b, Whitmore, 1985).

4.1.3.1. Effect on morphological parameters:

(i) Height of the tree:

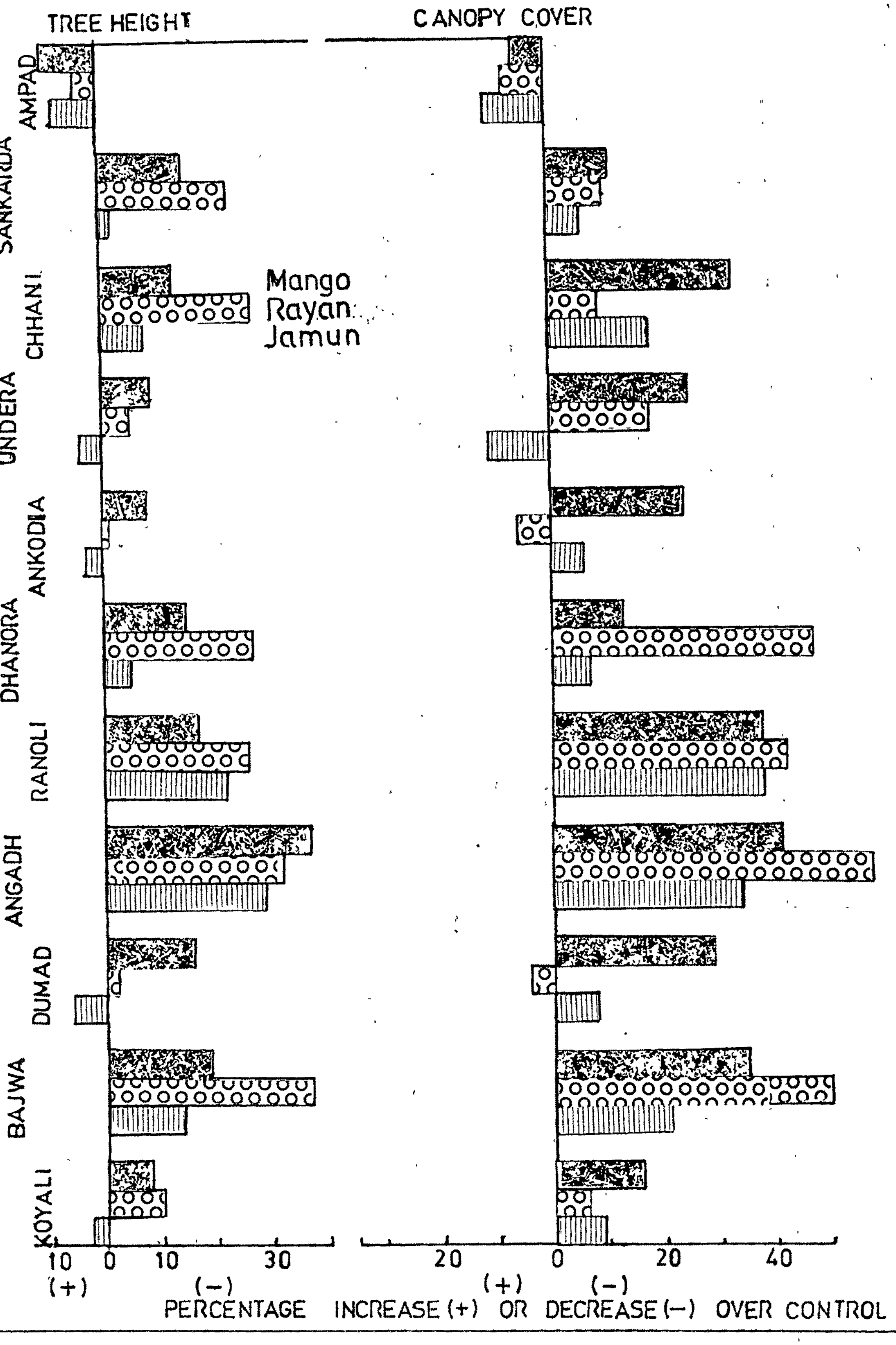
Among the stations observed for the present investigation, trees growing at Angadh, Bajwa and Ranoli was severely damaged. The height of mango and jamun trees were maximum retarded (37% and 29%) at Angadh than control where the mean annual concentration of $SO_2$ , NOx and SPM was 41.1, 51.2 and 207 $\mu g/m^3$ (Table 6), whereas of rayan trees height was 32% less than control at Bajwa, where the average pollutant/s concentration was $SO_2$ 17.9, NOx 30.4 and SPM 336 $\mu g/m^3$. This shows that rayan trees may be more sensitive to some other pollutant/s discharged from fertilizer complex which is the major source of pollution at this station. Among the three tree species studied, height of jamun was comparatively less affected in medium polluted stations like Sankarda, Dumad, Undera, Ankodia etc., (Table 6) where the annual mean pollutant/s concentration of $SO_2$,NOx ranged from 7.5 to 12 µg/m3 and 17 to 30 µg/$m^3$ respectively. At Ampad, height of all the three tree species exhibited least effect, shows the tree growth was similar to control (Fig.4.10.1.).

(ii) Canopy cover:

In mango and rayan, the canopy cover was severely affected at highly polluted stations like * Angadh, Ranoli and Bajwa, where it was 38 to 45% and 41 to 57% less than control respectively (Fig.4.10.1.). In jamun,21 to 38% reduction in canopy cover was recorded at the abovesaid stations. This clearly indicates, that in high pollution zone the canopy of all the species were highly affected. Among them mango, rayan were more severely damaged than jamun. In medium polluted stations like Koyali, Sankarda, Chhani, Ankodia, Undera etc., canopy of mango trees was 10 to 29% less than control. In rayan, the reduction was 5 to 18% at Koyali, Undera, Chhani and Sankarda and canopy was more or less close to control at Dumad and Ankodia. In jamun, 5 to 18% reduction was observed at Ankodia, Sankarda, Koyali, Dumad and Chhani. This shows, in the medium polluted stations canopy of rayan and jamun were comparatively less affected than mango. At low polluted zone Ampad (Table 6) all the

* Stations are arranged in decreasing order of damage, henceforth in the descriptive part.

Fig. 4.10.1 Effect of air pollution on fruit trees



three species exhibited fairly good growth performance as control plants (Fig.4.10.1.).

(iii) Foliar response:

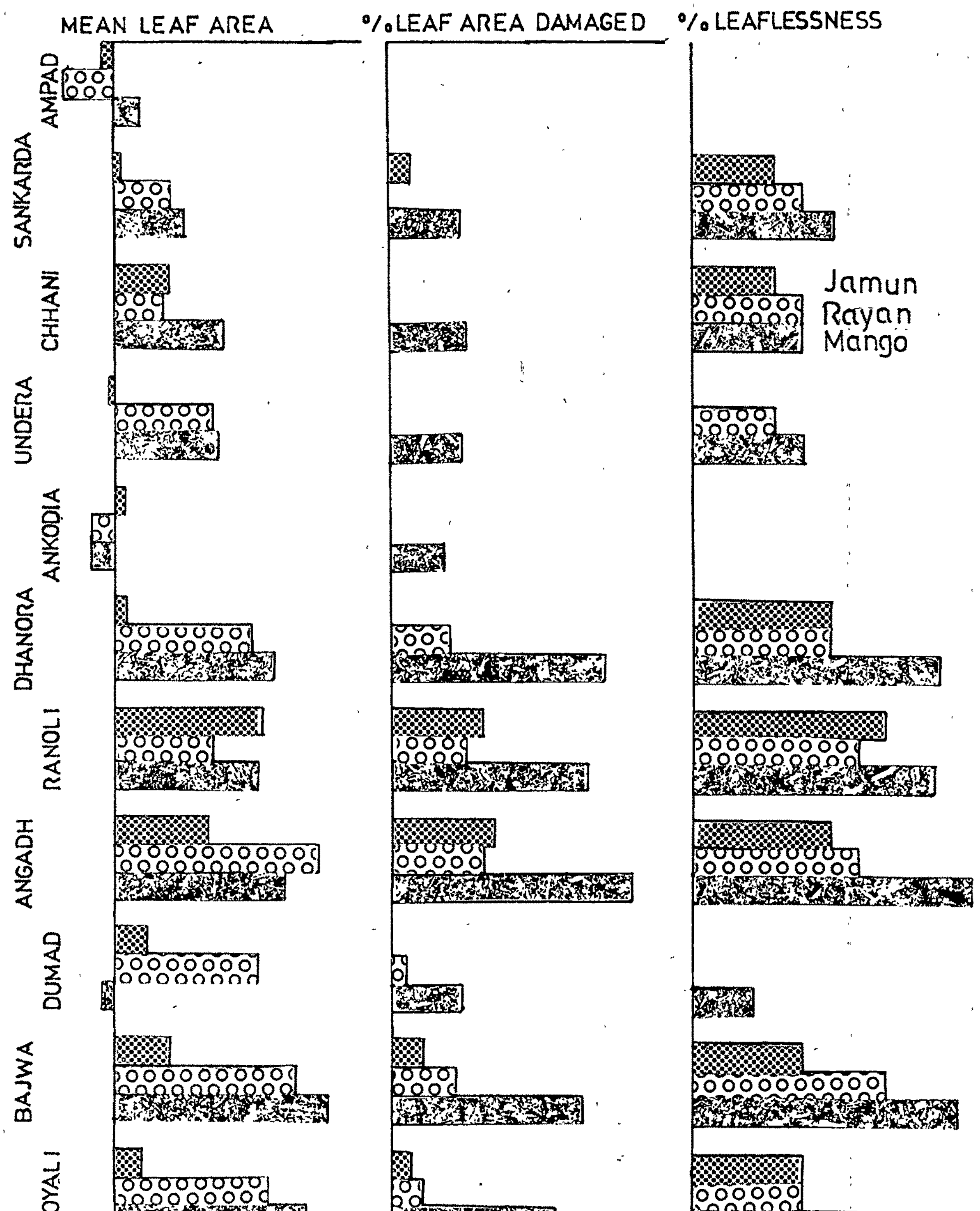
In mango trees growing at Bajwa, Angadh, Ranoli, Dhanora and Koyali, the mean leaf area was 25 to 40% less in comparison to control, whereas in rayan reduction ranged from 17 to 38%. In jamun maximum reduction (27%) was recorded at Ranoli followed by Angadh (17%), whereas at all other stations reduction in mean leaf area was below 11% as compared to control (Fig.4.10.2.). Thus, the mean leaf area of jamun was less affected as compared to other two species. In mango, mean leaf area was very close to control at Dumad, Ankodia and Ampad, whereas in rayan it was close to control at Ampad and Ankodia. In jamun, mean leaf area was more or less close to control at Sankarda, Ankodia, Koyali, Undera, Dumad, Ampad etc. This also indicates that jamun is exhibiting good growth performance than rayan and mango at medium and low polluted stations (Fig.4.10.2.).

The effective photosynthetic leaf area of mango was reduced due to necrosis and chlorosis ( 30 to 45%) at highly polluted stations like Angadh, Ranoli, Bajwa, Dhanora and also at Koyali. In rayan the percentage leaf area damaged ranged from 6 to 17%, whereas in jamun it was between 4 to 19% at abovesaid stations. This clearly indicates that rayan and jamun were exhibiting less visible foliar damage than mango even at highly polluted stations. In mango, at all the remaining stations except Ampad, the percentage leaf area damaged was 10 to 15%, whereas in rayan and jamun no visible foliar damage was observed at most of the medium and low polluted stations like Ankodia, Undera, Chhani, Ampad etc. Thus the pollutants concentration at these stations may not be sufficient to cause acute or visible foliar damage to the rayan and jamun plants. (Fig.4.10.2.).

(iv) Defoliation:

As the foliage gets damaged due to pollution, the carbohydrate production decreases which ultimately leads to premature " starvation " and subsequent abscission of leaves (Dugger and Palmer, 1969). Defoliation due to premature senescence of leaves in trees growing at pollution zones was earlier reported by Chapekar 1972, Prasad et al., 1979, Smith, 1983. In the present study, defoliation in mango trees was observed at all the stations except Ankodia and Ampad. 43 to 52% leaflessness was observed in mango trees growing at high pollution zone i.e. at Angadh, Bajwa, Ranoli and Dhanora, whereas at other stations it was between 10 to 35%. In rayan 25 to 35% leaflessness was recorded at high pollution zone, and 15 to 20% at Koyali, Sankarda, Chhani and Undera. No significant defoliation was observed in rayan at Dumad, Ankodia and Ampad. In jamun 21 to 35%

Fig. 4.10.2: Effect of air pollution on fruit trees



defoliation was recorded at high pollution zone i.e. Ranoli, Angadh, Bajwa and Dhanora. Among the other stations, defoliation (10 to 20%) was recorded at Sankarda, Koyali and Chhani (Fig.4.10.2.). These observation reveal, that in all three species defoliation was more at Angadh, Ranoli, Bajwa and Dhanora which are very close to the pollution sources. At medium and low polluted stations defoliation was comparatively less in rayan and jamun than mango.

4.1.3.2. Effect on fruit yield:

The fruit production in the area under study attained a major setback after the establishment of these industries. Among the three fruit trees under investigation mango is the worst affected one. It is to be emphasized, the present study area especially the high pollution zone was once very popular for mango fruit production. Now, farmers or orchard owners are removing the unproductive trees due to complete failure in fruit production, to be used as timber or fire wood. 25 to 35% of mango trees and 10 to 20% of rayan trees completely stopped fruit production at Angadh, Ranoli, Dhanora and Bajwa.

The failure of fruit production in trees growing at polluted area may be due to reduction in number of pollens transferred to stigma or inhibition of pollen germination on stigmatic surface, where the pH has been altered by air pollutants (Dubay and Murdy, 1983a, 1983b, Hedwig, 1982) or retardation of pollen tube elongation, which is also sensitive to air pollution, results in failure of fertilization (Sülzbach and Pack,1972, Ma et al., 1973,Karnosky, and Stairs,1974, Masura et al., 1976, Murdy and Ragsdale, 1980, Facteau and Rowe,1981, Varshney and Varshney, 1981). The common symptoms observed in the trees growing at pollution zone was senescence of young and mature flowers or dropping of young and immature fruits. This premature fruit or flower fall may be due to the evolution of ethylene in the plant tissues when subjected to air pollution stress(Guttenberger et al., 1979, Helmut et al., 1979, Thomas and Kozlowski,1982). The traces of ethylene in the ambient air, which escapes from petrochemicals during breakdown of naptha, may also induce the premature senescenee of plant parts.

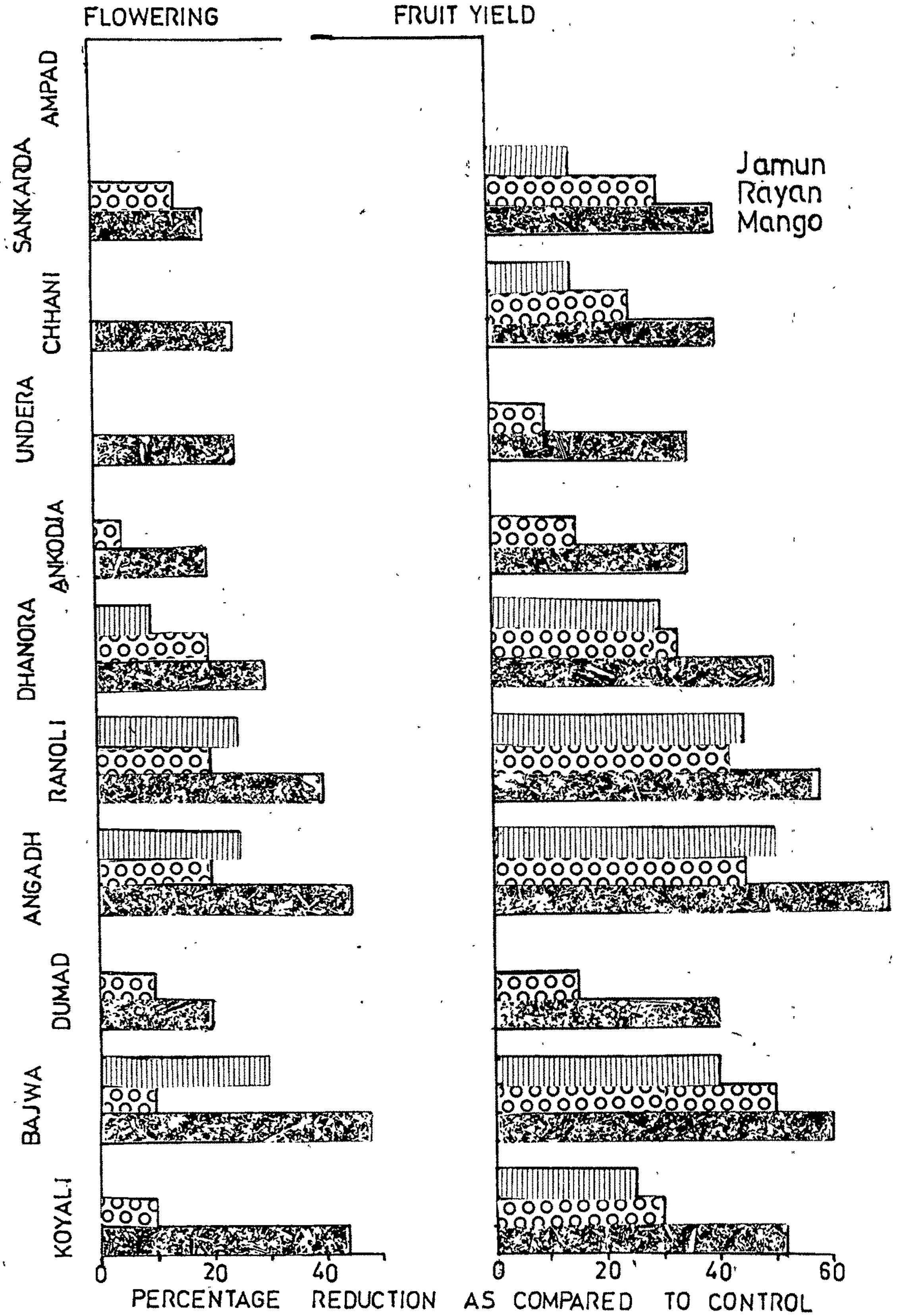
(i) Flowering:

In mango, flowering was 30 to 50% less than control at highly polluted stations like Bajwa, Ranoli, Angadh, Dhanora and also at Koyali. At all medium polluted stations reduction was 20 to 25%. In rayan, flowering was comparatively less affected. Maximum reduction (20%) was recorded at Angadh and 5 to 15% reduction was noticed at all the remaining stations except Chhani, Undera and Ampad. In jamun, reduction in flowering was (10 to 30%) observed only at high air pollution zone. This shows the deleterious effects of air pollution on flowering was comparatively less in rayan and jamun, whereas high in mango (Fig.4.10.3.).

(ii) Fruit production:

In mango, fruit production was highly affected i.e. 50 to 70% reduction was recorded at higher pollution zone (Angadh, Bajwa, Ranoli, and Dhanora). At medium polluted stations like Sankarda, Chhani, Dumad, Ankodia and Undera the reduction was between 35 to 40%. At Ampad, which is low polluted the fruit production was close to control trees. In rayan, at high pollution zone fruit production decreased 37 to 50% as compared to control, whereas it was 10 to 30% at all medium polluted stations. No significant variation was observed in fruit production at Ampad. In jamun 30 to 50% reduction was recorded at high pollution zone. Among the medium polluted stations, 15 to 25% reduction was noticed at Koyali, Sankarda and Chhani. At all remaining stations no significant damage was recorded in jamun fruit production. The observations revealed that, at Angadh, Ranoli, Bajwa and Dhanora fruit yield was highly reduced in all the three fruit species under investigation. This may be due to close vicinity of the pollution source, which resulted higher concentration of pollutants in the ambient air. At medium and low polluted stations like Sankarda, Dumad, Undera, Chhani, Ampad etc., fruit production in rayan and jamun was less affected as compared to mango (Fig.4.10.3.)

Fig. 4.10.3. Effect of air pollution on fruit trees



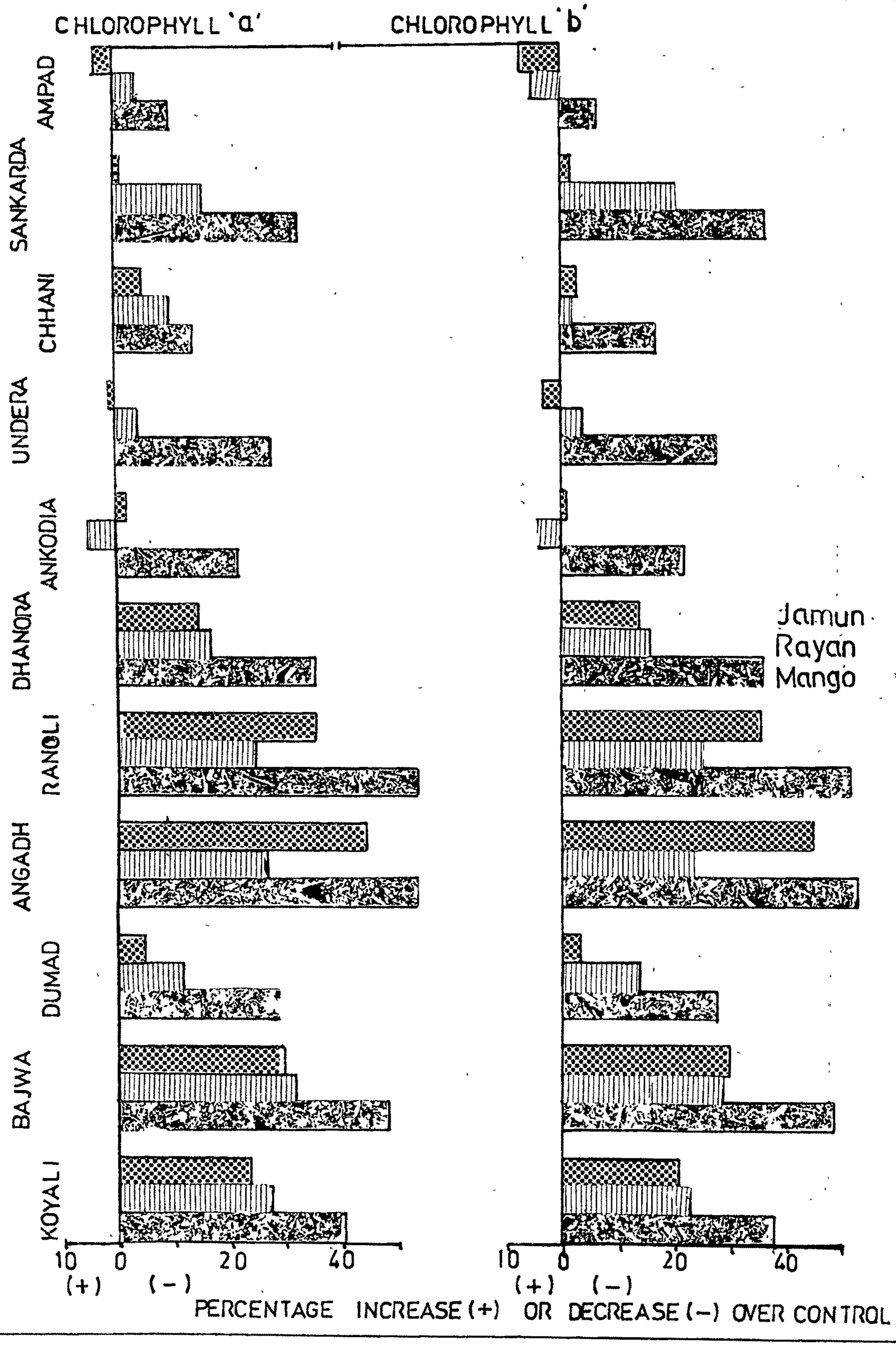
4.1.3.3. Effect on biochemical parameters:

(i) Photosynthetic pigments:

These are the primary site damaged due to air pollution. The chlorophyll destruction due to air pollution has been reported by many workers (Leblanc and Rao,1966, Ricks and Williams,1975, Dubey *et al.*, 1982, Pandey and Rao,1978, Winner and Mooney,1980b, Murray, 1984b).

In the present investigation, high reduction (45 to 55%) of chlorophyll pigments in mango leaves was observed at highly polluted stations like Bajwa, Angadh and Ranoli. Among the medium polluted stations, high reduction in chlorophyll pigments was observed at Koyali (49.6%) and Sankarda (33.3%), whereas at all other stations reduction was between 14 to 29% as compared to control. In rayan, 16 to 32% reduction in chlorophyll pigments was recorded at Angadh, Bajwa, Ranoli, Dhanora and also at Koyali. The reduction was 9 to 16% at all other stations except Ankodia, Undera and Ampad where the chlorophyll pigments were close to control. In jamun chlorophyll pigments decreased 29 to 45% at high pollution zone. This observations revealed that eventhough chlorophyll pigments were severely damaged in all the three species, comparatively percentage reduction was less in rayan than other two species. The lesser destruction of chlorophyll pigments in rayan leaves may be due to the presence of laticiferous cells. This may require further investigation,

Fig. 4.10.4. Effect of air pollution on fruit trees



whether milky latex absorbs the entered pollutants, that gives protection to chlorophyll pigments or it neutralize the effect of acidic pollution. As compared to mango, the chlorophyll pigments of other two species were less affected at medium and low polluted stations (Fig.4.10.4.).

(ii) Foliar protein:

A fundamentally more serious mode of attack of sulphur dioxide is it's ability to cleave disulphide linkage in protein molecules (Puckett et al., 1974). Since the tertiary structure of many enzymes is dependent on the integrity of their disulphide bonds, destruction of these units would deactivate them. Thus, reduction in protein content was observed in plants exposed to air pollution due to increased protein degradation or reduced protein synthesis (Godzik and Linskens,1974, Rudolf and Kreeb,1979). In the present investigation foliar protein content in all three species at the pollution zone was less than control.

In mango, 32 to 43% protein reduction was recorded at highly polluted stations i.e. Angadh, Bajwa, Ranoli etc. At medium polluted stations 14 to 30% reduction was noticed. It was 9.5% less than control at Ampad, which is comparatively less polluted. In rayan, at high pollution zone, protein content decreased 22 to 44%. Eventhough there was no visible foliar damage at Undera, Chhani, Sankarda, Ankodia and Ampad, foliar protein content decreased 9 to 21% as compared to the control. This clearly indicates that the hidden injury in the trees growing at abovesaid stations. In jamun also high reduction ( 27 to 44%) in protein content was recorded at Angadh, Ranoli, Bajwa and Dhanora. In this species also the hidden injury was well reflected by reduced protein content ( 7 to 21%) at medium and low polluted stations (Dumad, Ankodia, Undera, Chhani, Ampad etc.) where no visible damage was observed. (Fig.4.10.5.).

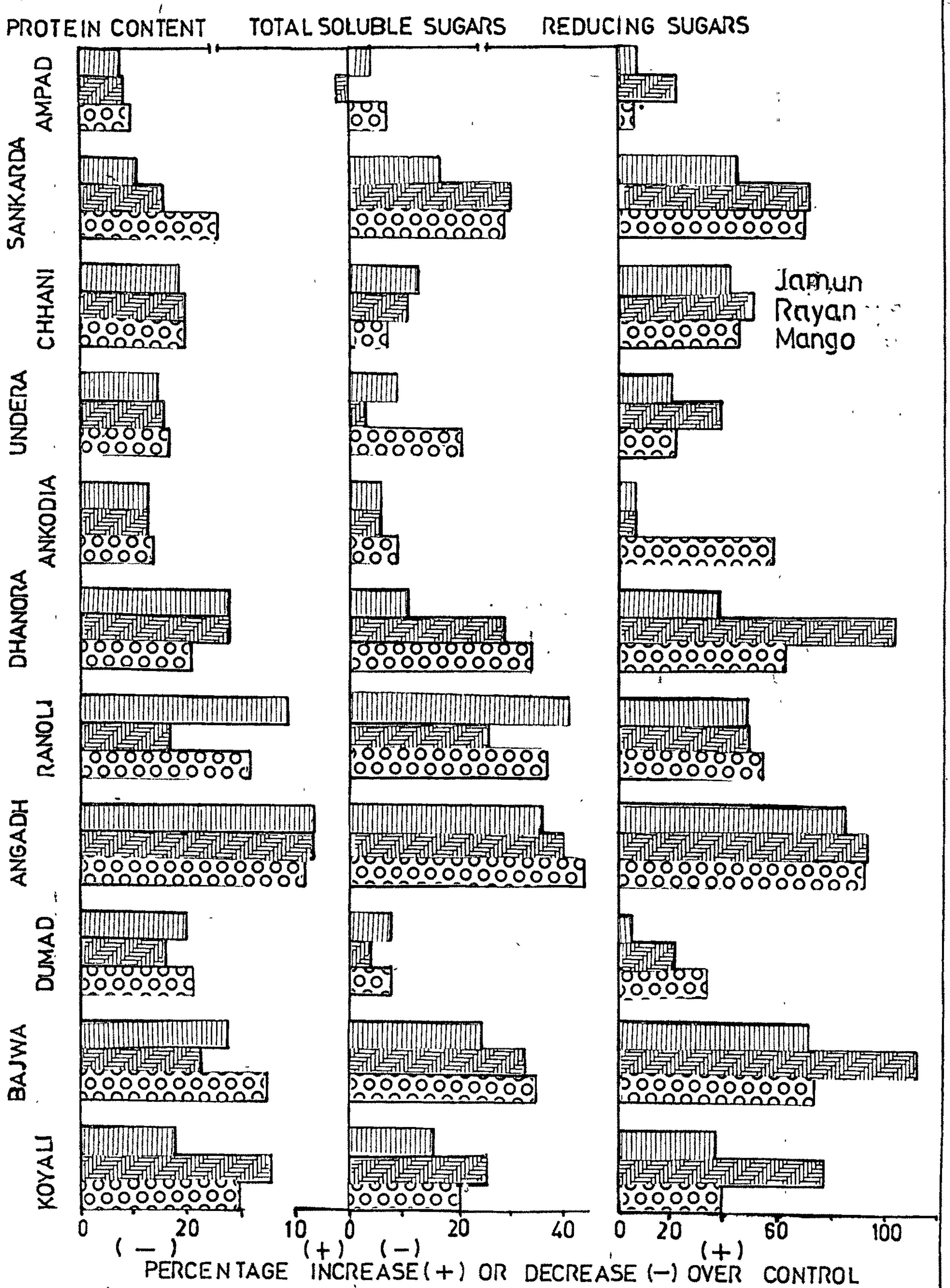
(iii) Foliar sugar content:

In the present investigation, the total soluble sugars decreased in all the three species at all the stations in the pollution zone, whereas reducing sugar content increased in the leaves of all the three species at pollution zone. This suggests that sucrose synthesis might be inhibited by air pollutants (Yang and Miller 1963a, 1963b, Dugger and Palmer, 1969) or partial breakdown of non-reducing sugars into reducing sugars under pollution stress (Malhotra and Sarkar, 1979).

Total soluble sugars: In mango, soluble sugar content reduced 33 to 45% at Angadh, Bajwa, Ranoli and Dhanora. Among the medium polluted stations 20 to 29% reduction was noticed at Koyali, Undera and Sankarda, whereas at all the remaining stations it was 6 to 9% less than control. In rayan, soluble sugar content reducedby 28 to 45% at high pollution zone, i.e. Angadh, Bajwa, Ranoli and Dhanora. Among the medium polluted stations, significant reduction was recorded at Sankarda (30.3%) and Koyali (25.5%), whereas at all other stations reduction was between 4 to 11%. Soluble sugar content was close to control at Ampad. In jamun, 24 to 41% reduction was registered at all the stations in high pollution zone. At all other stations except Ampad, reduction was 5 to 18%. At Ampad sugar content was close to control (Fig.4.10.5.). Thus this observations reveals that at high pollution zone soluble sugar content was drastically reduced in all the three species. Among the medium polluted stations, the percentage reduction in all the three species was comparatively higher at Koyali and Sankarda. As these two stations are comparatively closer to the pollution source, the degree of damage was also higher than at other medium polluted stations.

<u>Reducing sugars</u>: In mango, accumulation of reducing sugars was very high (93.4%) at Angadh, 55 to 75% increase over control was recorded at Bajwa, Dhanora, Sankarda, Ranoli, and Ankodia. At all the remaining stations 22 to 49% increase in reducing sugars was observed except Ampad where it was very close to the control. In rayan reducing sugars increased tremendously (93 to 114% ) over control at highly polluted stations like Angadh, Bajwa and Dhanora (Fig.4.10.5.). Among the medium polluted stations 39 to 78% increase was recorded at Koyali, Sankarda, Chhani and Undera, whereas at remaining

Fig. 4.10.5. Effect of air pollution on fruit trees



stations the percentage increase ranged from 7 to 22%. In jamun, the accumulation of reducing sugars was 42 to 85% over control at Angadh, Bajwa, Ranoli, Chhani and Śankarda. Among the other stations 20 to 40% increase was noticed at Dhanora, Koyali and Undera, whereas at all the remaining stations it was slightly higher (4to 8%) than control (Fig.4.10.5.) These observations reveal that accumulation of reducing sugars was very great at high as well as medium polluted stations. The percentage increase varies from species to species at each stations. In jamun and rayan higher accumulation of reducing sugars was noticed at Sankarda, Undera, Chhani, Ankodia etc., where the plants did not exhibit any visible foliar damage. This clearly shows the hidden injury in the plants is exhibited with disturbance of the normal carbohydrate metabolism (Yang and Miller, 1963a, 1963b, Dugger and Palmer, 1969, Malhotra and Sarkar, 1979).

(iv) Foliar sulphur:

In the present investigation, foliar sulphur content was observed more than control plants in all the three species growing in the pollution zone. The phytotoxicity of sulphur dioxide has been very well described by Thomas and Hendricks, 1950. Treshow (1970) has stated, the total sulphur content of the leaf than control might be expected to provide a measure of the leaf contamination and an index of the amount of air pollution. The uptake of sulphur dioxide and its accumulation as sulphur compounds in plants growing in polluted atmosphere was observed by various investigators (Roberts,1974, Farrar et al., 1977, Keller,1981, Boiko et al., 1985, Landolt and Keller, 1985).

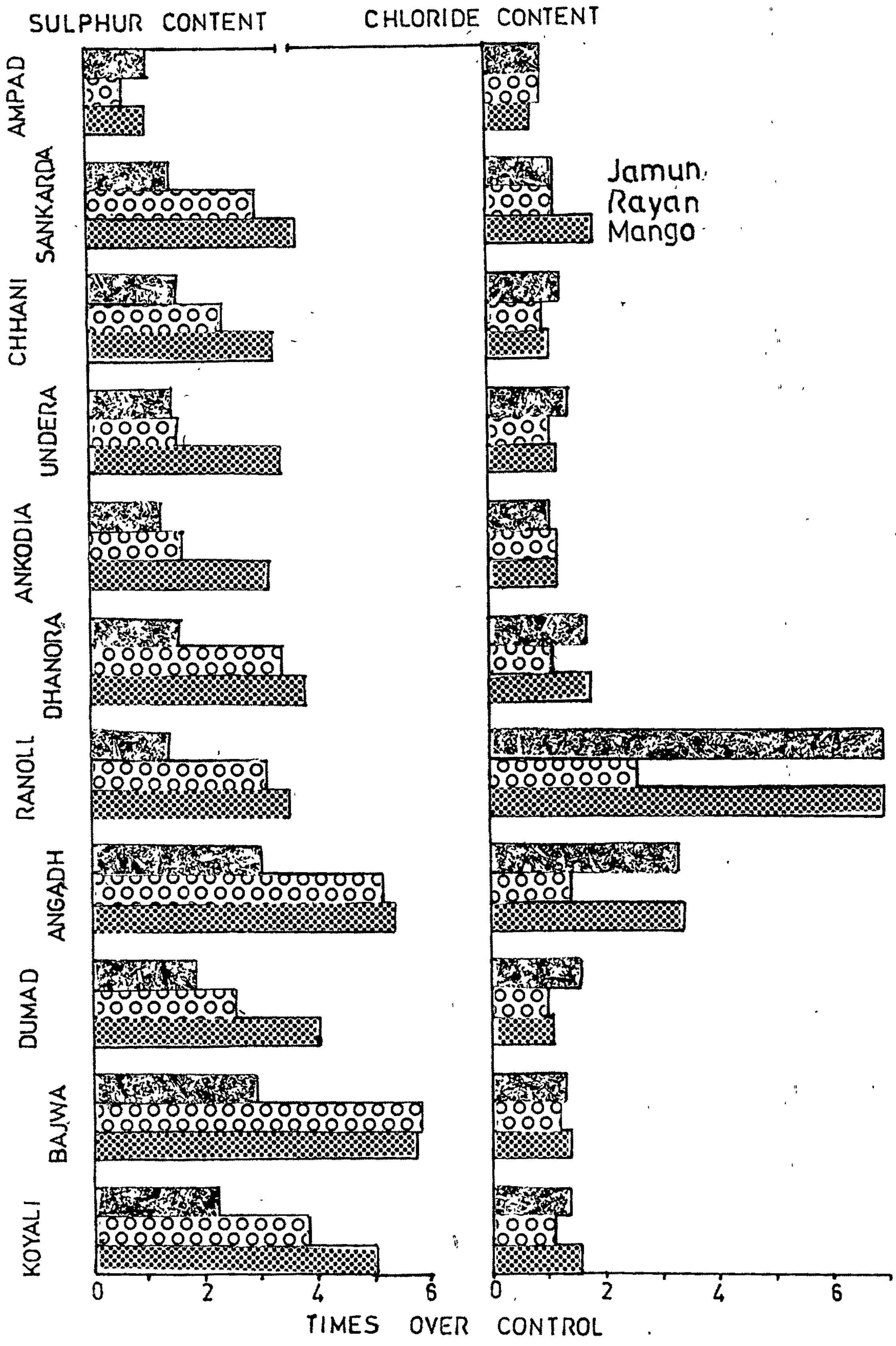
In mango, sulphur content increased 4.97 to 5.66 times over control at Bajwa, Angadh and Koyali. At all the remaining stations except Ampad, the sulphur accumulation was 3.17 to 4.01 times over control. At Ampad, it was close to control. In rayan, the sulphur accumulation was very high at Bajwa (5.76 times over control) and Angadh (5.14 times). At Koyali, Dhanora, Sankarda, Ranoli, Dumad and Chhani it was 2.43 to 3.82 times over control. At other stations sulphur accumulation was 1.07 to 1.66 times over control. In jamun, higher sulphur accumulation was recorded at Angadh (3.01 times) and Bajwa (2.93 times) over control. At all other stations except Ampad, sulphur in the foliar tissues was 1.3 to 2.3 times over control. At Ampad, it was close to the control. (Fig.4.10.6). The observations clearly show that sulphur dioxide is the major pollutant in the study area and it has been reflected as higher accumulation of sulphur in the foliar tissues of all the three species investigated. At Ampad, the sulphur content was more or less close to control in all the three species, indicates that there the ambient air pollutant concentration may also be close to the control station (Table 6). The observations reveal that mango accumulates more sulphur, it was intermediate in rayan and comparatively less in jamun. Higher accumulation of sulphur in mango leaves may be the reason for its higher degree of damage revealed in most of the parameters investigated resulting into very high reduction in fruit yield in high pollution zone.

(v) Foliar chloride:

As the literature regarding chlorine damage to vegetation is meagre, the exact mechanism of its phytotoxicity needs further investigation (Thronton and Setterstorm,1940, Benedict and Breen,1955, Brennan *et al.*, 1965). The common damaging symptoms in broad leaved species are chlorosis which ultimately leads to necrosis (Treshow, 1976).

In mango, foliar chloride content increased 6.94 times over control at Ranoli, followed by Angadh (3.36 times). At Sankarda, Koyali, Dhanora and Bajwa chloride content was 1.37 to 1.88 times over control. At all the remaining stations it was close to the control. In rayan, foliar chloride content was 2.59 times over control at Ranoli and 1.11 to 1.38 times over control was recorded at Angadh, Bajwa, Sankarda, Dhanora and Undera. At all the remaining stations foliar chloride level was close to the control. In jamun also maximum accumulation of chloride (6.91 times) over control was observed at Ranoli, followed by Angadh (3.3 times). At all other stations 1.3 to

Fig. 4.10.6. Effect of air pollution on fruit trees



1.75 times increase was noticed except at Ankodia and Ampad where it was close to the control (Fig.4.10.6.). These observations clearly reflect, that chlorine is a major localized pollutant at Ranoli, where a Alkalies and Chemicals plant is located. Among the other stations significant increase in foliar chloride at Angadh shows the presence of minor sources in the Industrial Estate at Nandesari (Fig.4.10.6.). Among the three species studied, very high accumulation of chloride was recorded in mango and jamun comparatively less in rayan leaves.

The observations indicate that Syzygium, may absorb more chlorine as reflected in high chloride accumulation, than sulphurdioxide. In jamun, damage to morphological and biochemical parameters were also comparatively higher at Ranoli than Bajwa, Dhanora etc., where the sources of sulphur dioxide are present. Thus, jamun may be more sensitive to chlorine pollution singly or combined with other pollutants like $SO_2$, NOx, organic pollutants etc., than sulphur dioxide and nitrogen oxides pollution. Mango may be sensitive to chlorine pollution as same as $SO_2$ and NOx. Rayan exhibited higher sensitivity to $SO_2$ and NOx pollution than chlorine pollution.

4.1.4. SOIL STUDY AT DIFFERENT OBSERVATION STATIONS

It is well known that spil can act as sink for the pollutants like $SO_2$, NOx, carbon monoxide, ethylene, fluoride, etc., (Katz,1949, Abeles et al., 1971 , Innam et al., 1971, Janina et al., 1982). The analysis of soil samples from all the observation stations under investigation did not show much alteration in soil characters except at the highly polluted stations like Angadh, Ranoli etc. Much of the pollutants after settling down in soil get into biogeochemical cycle and are converted to different metabolites in the plant tissues and with the removal of the biomass after the crop harvest are taken away from the pollution site. The soil pH value recorded at Angadh was 5.85 (Table 23). According to Jackson's (1963) classification it is very weak acid soil (5.2 to 6.5), where the sulphate may be the significant salt.

Eventhough Bajwa is considered as highly polluted station, the soil pH was 7.15. This may be due to the deposition of gypsum powder which is also a major pollutant (particulate matter) from the fertilizer complex, located near this station. Thus the gypsum might be neutralizing the soil acidity caused by the acidic gases like $SO_2$, NOx etc. The spil pH recorded at Ranoli (7.92) was towards alkaline range. According to Gupta (1971), the soil pH below 8.5 may be evaluated as normal to most of the crops. Among all the observation stations, the specific conductivity of soil recorded at Ranoli (0.565 mS) was high (Table 23). This shows higher amount of soluble salts in the soil solution. Black (1968) classified such soil as non-saline ones (below 4mS). The soluble chloride content was highest at Ranoli

(2.7 times over control) whereas at other station no significant difference was observed. Soil chloride was slightly higher (1.14 to 1.34 times) than control at Dumad, Angadh, Dhanora, Ampad and Koyali, whereas at remaining stations it was more or less close to the control. So, the effect of higher soil chloride on vegetation cannot be ruled out at Ranoli. At this station, chlorine is the major pollutant emitted from Alkalies and Chemicals plant. This results in higher accumulation of chloride in the foliar tissues as well as in the soil, which ultimately leads to severe damage to the vegetation at this station.

Soil sulphur content recorded at Angadh was 1.82 times over control. Among the other stations, it was slightly higher (1.14 to 1.46 times) than control at Bajwa, Dumad, Ampad, Ankodia, Dhanora and Ranoli, whereas at the remaining stations it was close to control. Thus, soil sulphur content did not show much relation with ambient air pollutants concentration at most of the stations except Angadh(Table 6).

At Angadh, the soil organic matter recorded was 39.0% higher than that of the control, whereas nitrogen content recorded at this station was 17.4% lower than control (Table 23). This may be due to the low mineralization of organic matter because of low pH, which is considered as critical to decomposing as well as nitrogen fixing organisms

(Black,1968, Agrawal *et al.*, 1985b). The nitrogen content recorded at Ranoli, Dhanora and Dumad was 10 to 13% lower than control. Although, NOx is one of the major pollutants, the reaction of soil with NOx was reported slower than reaction with $SO_2$ (Abeles *et al.*, 1971) . The differences in soil characters between control and most of the stations in the pollution zone were not much significant and was not exhibiting any specific trend. So, correlation between the ambient air pollutants concentration and soil nature could not be made.

### 4.1.5. LEAF ANATOMICAL STUDY

#### 4.1.5.1. Impact of air pollution on foliar epidermal traits:

The foliar epidermal study reveals that air pollution induces changes in epidermal traits. In the present study, stomatal frequency, and stomatal index decreased at polluted zones like Angadh, Ranoli, Omkarpura and Bajwa as compared to control. (Table 24, 25 & 26). Similar phenomenon was earlier observed by Sharma,1975, Sharma and Butler, 1973. The decrease in stomatal frequency may be to reduce the entry of toxic gases in the foliar tissues. The decrease in stomatal frequency corresponded with increase in epidermal cells at polluted stations. In mango and rayan leaves, maximum increase (17.5% and 64% respectively) in epidermal cells frequency was recorded at Ranoli, whereas in jamun it was (93.4%) at Omkarpura. The subsidiary cell complex was constant in specimens from control and polluted sites. At all the polluted stations, the three species exhibited a consipicuous decrease in the size of stomatal aperture (Table 24 to 26). In mango, 3 to 5 fold increase in trichome frequency was recorded at the polluted stations (Table 24). The high frequency of trichomes may change the microclimate of the leaves by reducing the leaf temperature, and hence reducing the rate of metabolism. The trichomes may also be helpful to filter the particulate matters which may block the stomatal openings (Garg and Varshney, 1980, Yunus and Ahmad, 1979).

4.1.5.2. <u>Fluorescence study</u>:

Smillie and Nott (1982) used the chlorophyll fluorescence to monitor the salt tolerance in plants. Under stress conditions chlorophyll fluorescence of the leaves decreased significantly (Govindjee *et al*., 1981). In the present study, chlorophyll fluorescence decreased highly in mango leaves at polluted region (Fig.3.5.2.). In jamun leaves it decreased moderately (Fig.3.5.4.), whereas in rayan there was least difference in chlorophyll fluorescence between control and polluted plants (Fig.3.5.3.). These observations also supports that chlorophyll pigments of mango leaves are highly affected by air pollution. Similar observations, i.e. reduced chlorophyll fluorescence in leaves by air pollutants was reported by Schreiber et al., 1978, Shimazaki et al., 1984. The secondary fluorescence of cuticular layer showed, its thickness slightly increased at polluted stations. This may be a mode of resistance in plants to air pollution (Swiecki and Endress, 1982). Riding and Percy (1985) reported that $SO_2$ exposures delayed the wax deposition in elongating needles of *Pinus strobus* in stomatal chamber. This increases their sensitivity to $SO_2$ and acid rain, but no alteration in wax deposition was evident on needles of *Pinus banksiana* even under acute $SO_2$ exposure. Thus the cuticular variation in response to pollution may vary species to species.

## 4.2. FIELD EXPOSURE STUDY

The seasonal response of plants growing at different stations in the pollution zone mainly dependent on the wind direction. In general, stations on the wind ward direction (WWD) to the source of pollution received higher concentration of pollutants.

During monsoon, the experimental stations at Omkarpura, Damapura, Ranoli, Fajalpur, Sankarda and Padamla were on windward side. During this season, the wind direction was mostly (79.2% of days) from south or south-west ( Fig.2.2.4.) Obviously the pollutants concentration was also high at these stations (WWD). The experimental site at Omkarpura, which was located at 0.75 Km. on north - north-east of a fertilizer complex, average seasonal concentration was,* $SO_2$ 21.5, NOx 61.5 and SPM 272 $\mu g/m^3$ (Table 6). The exposure station at Damapura was located 0.7 Km. north-east of Nandesari Industrial Estate also received higher concentration of pollutants for 79.2% of the days during monsoon. The station at Ranoli was located at 0.5 Km. in north-northeast (NNE) direction to Alkalies and Chemicals Limited (GACL) and received higher concentration of chlorine from the plant. The station at Padamla (2.5 Km. NNE to Alkalies and Chemicals Ltd.) received

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*Hence forth the concentration of pollutants in the ambient air is mentioned as seasonal average.

pollutants from GACL and partly from petrochemical complex. The station at Fajalpur was located at 3.5 Km N of Nandesari industrial estate. The station at Sankarda was located 0.6 Km. NW to Universal Dyes stuff and 4.5 Km. NNE of Petrochemical complex and Nandesari industrial estate, and received the seasonal average concentration of $SO_2$ 8.1, NOx 25.8 and SPM 272 $\mu g/m^3$. During monsoon, Bajwa (0.5 Km. S of fertilizer complex) and Koyali (4.0 Km. SW to a fertilizer complex and 0.6 Km. S to a Refinery complex ) were on the leeward direction and received pollutants for a much shorter duration (18.3% of days) during monsoon.

The wind direction changed during winter and the pollutants were carried towards S or SW by N or NE winds (62.5% of the days). The station at Angadh located within 0.5 Km. S to Nandesari industrial estate received higher concentration of pollutants. During this season, Angadh Bajwa and Koyali were on the windward side to the source. All other stations were on the leeward side of their respective pollution source and received comparatively low concentration of pollutants (Table 6).

During summer, wind direction was mostly (56.7% of days) from S or SW and once again the stations like Damapura, Omkarpura, Ranoli, Fajalpur, Sankarda and Padamla were on windward side, whereas the other stations were on the leeward side to the source in most part of the season. (Fig.2.2.4.)

4.2.1. EFFECT ON MORPHOLOGICAL PARAMETERS

(i) Shoot length of the saplings:

The growth of the plants was suppressed when exposed to polluted atmosphere (Constantinidou *et al*., 1976; Ashenden, 1979b, Garsed and Rutter, 1984; Whitmore, 1985, Ayer and Bedi, 1986). Isotopic studies conducted by Garsed and Mochrie 1980, revealed that in $SO_2$ exposed plants incompletely oxidized sulphur compounds like sulphite can enter the phloem and translocated. The accumulation of such compounds in meristem could then affect the growth. Ultimately the plants attain stunted appearance and height is suppressed as compared to the control (Katz, 1949). In the present investigation also the growth of the tree saplings was retarded more when the saplings were at stations in the windward direction to the source.

*Mangifera indica* L. (mango)

The growth rate of mango shoot was retarded 45 to 75% at Omkarpura, Damapura, Fajalpur and Ranoli, which were on windward side during monsoon. An Angadh also (LWD) high retardation (63.5%) was observed due to close vicinity of the source and higher concentration of pollutants prevailed during monsoon ($SO_2$ 30.3, NOx 35.8 and SPM 186 $\mu g/m^3$). At Koyali (LWD), where the plants received pollutants for 18.3% of days, the reduction in growth rate was 31.8% as compared to control.

The turn of winter resulted in change of wind direction. As a result, the saplings at Bajwa and Koyali exposure stations exhibited high percentage reduction in growth rate (85.8 and 74.6% respectively). The plants at Angadh (WWD) were severely damaged and ultimately died due to acute exposure to higher pollutants concentration ($SO_2$ 51.7, NOx 69.5 and SPM 223 $\mu g/m^3$) for a period of 62.5% of days during winter. During winter, the plants growing at Omkarpura, Damapura, Fajalpur, Ranoli, Sankarda etc., (LWD) also exhibited reduction in growth rate (21 to 62%). The percentage reduction in growth rate during winter was more or less close to monsoon at most of the stations except Padamla and Sankarda.

During summer, the plants growing at Omkarpura, Ranoli and Damapura exhibited 62 to 71% reduction in growth rate of shoot, which were exposed for 56.7% of days during this season, At Angadh, Bajwa and Koyali plants showed 36 to 66% reduction in growth rate, eventhough they were in leeward direction (Fig.4.11.1.) Thus, in mango, the growth rate of shoot did not show any significant recovery when the change in wind direction at stations like Omkarpura, Ranoli, Angadh, Bajwa, Damapura and Fajalpur, but slight recovery was observed at other stations. This may be due to the greater sensitivity of mango and close proximity of the pollution source.(Fig.4.11.1.)

Fig. 4.11.1. Field exposure study on *Mangifea indica* L.

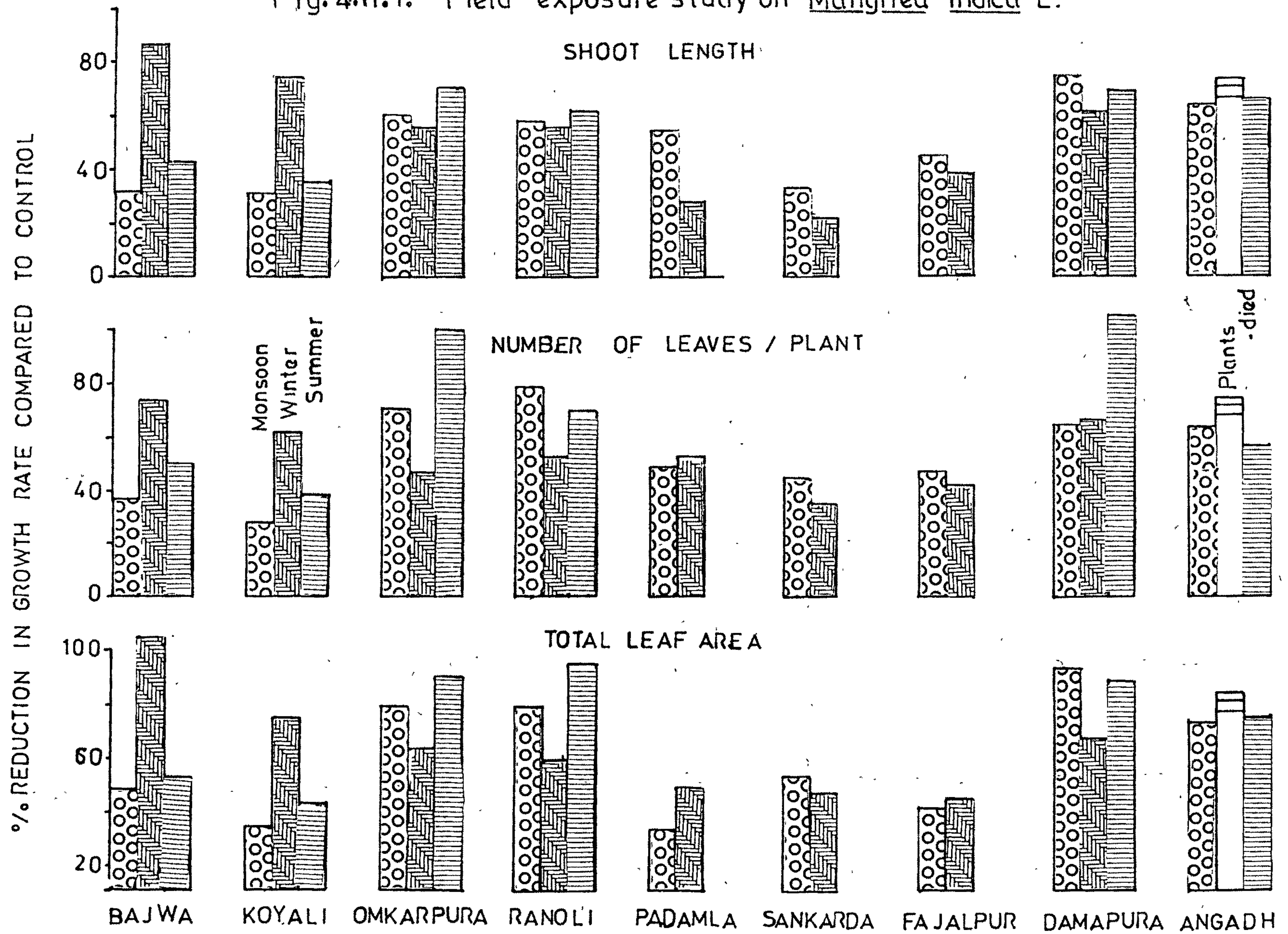


Fig.4.11.2. Field exposure study on *Mangifera indica* L.

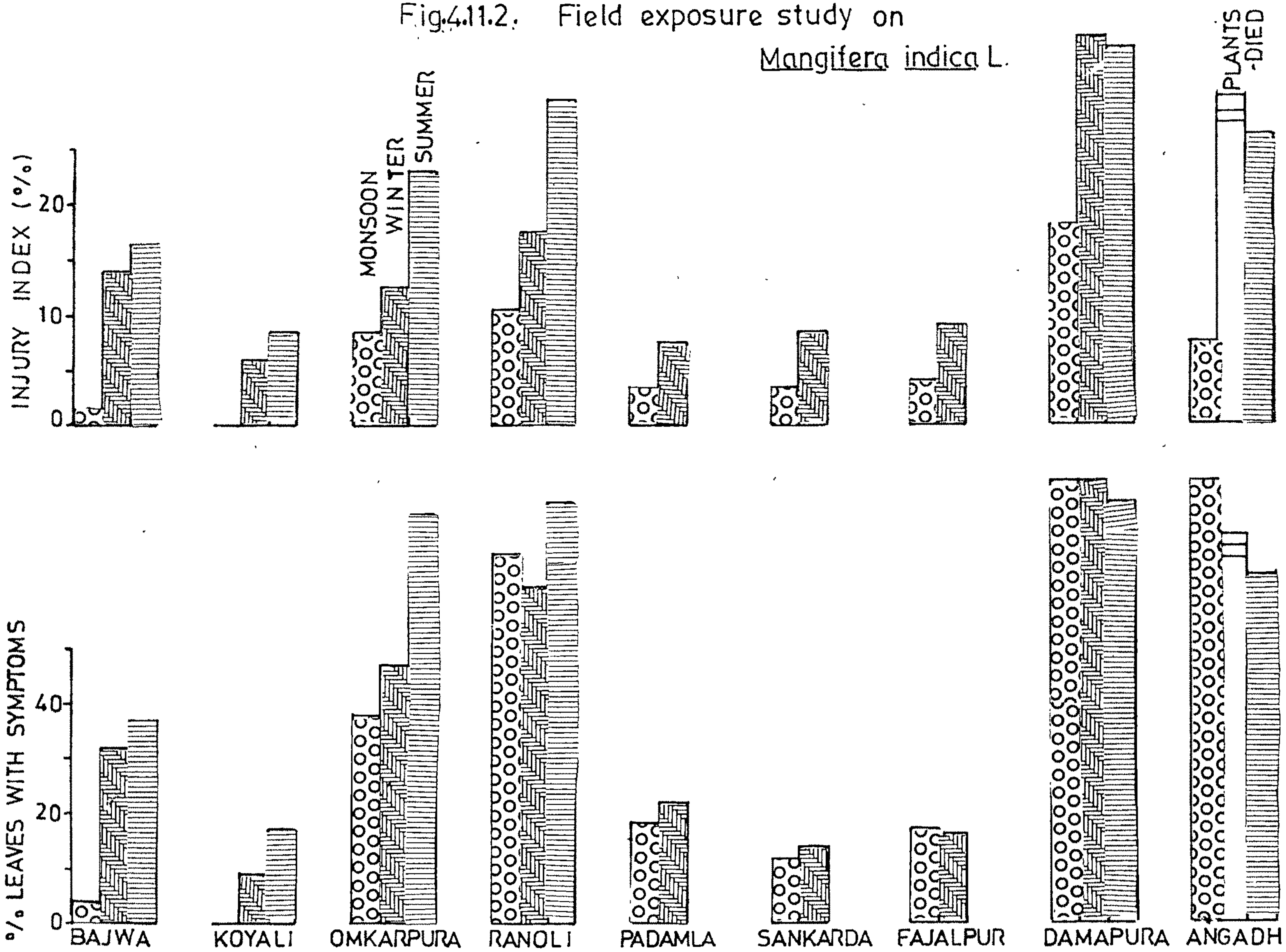


Fig. 4.11.3. Field Exposure Study on *Mangifera indica* L.

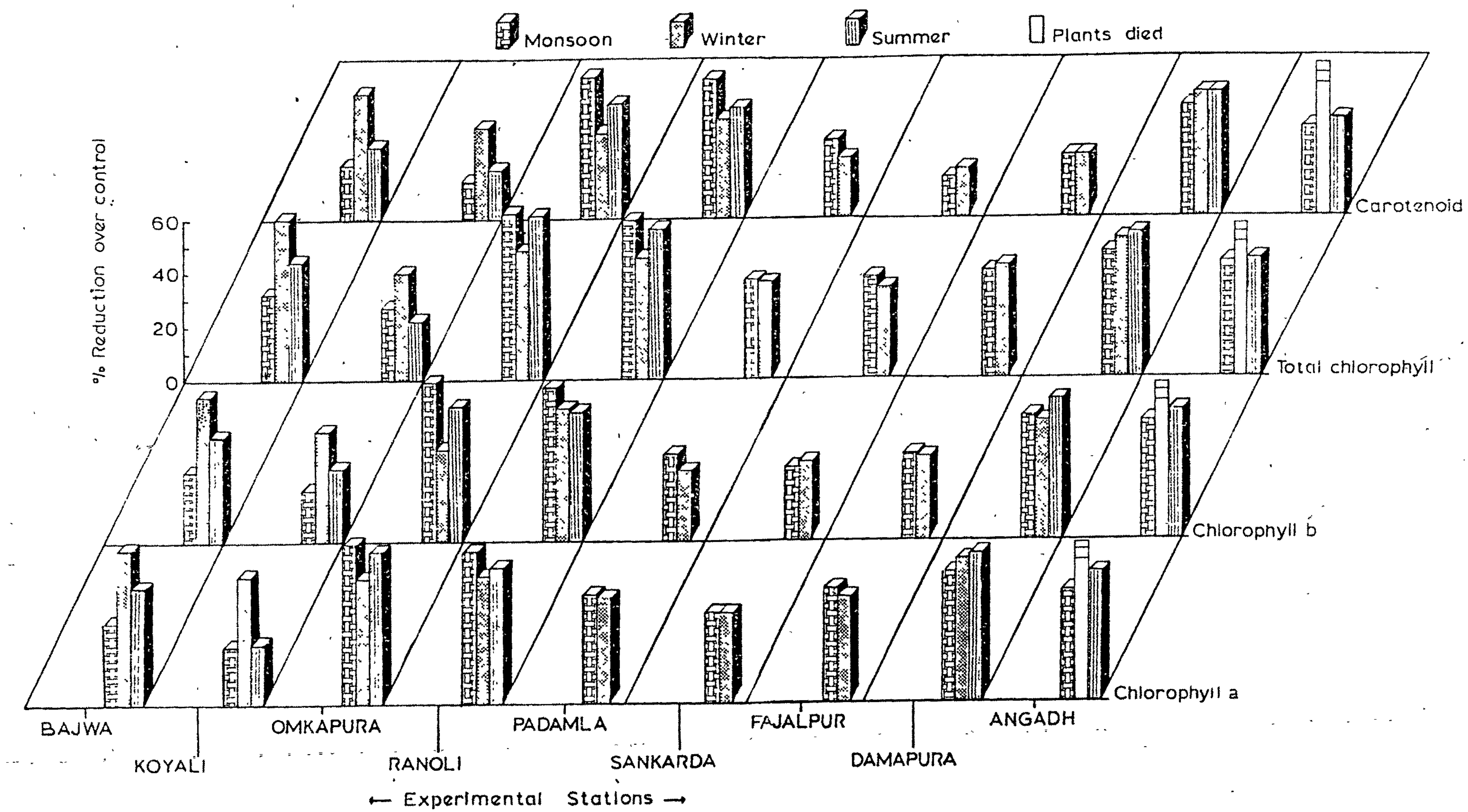


Fig. 4.11.4. Field exposure study on *Mangifera indica* L

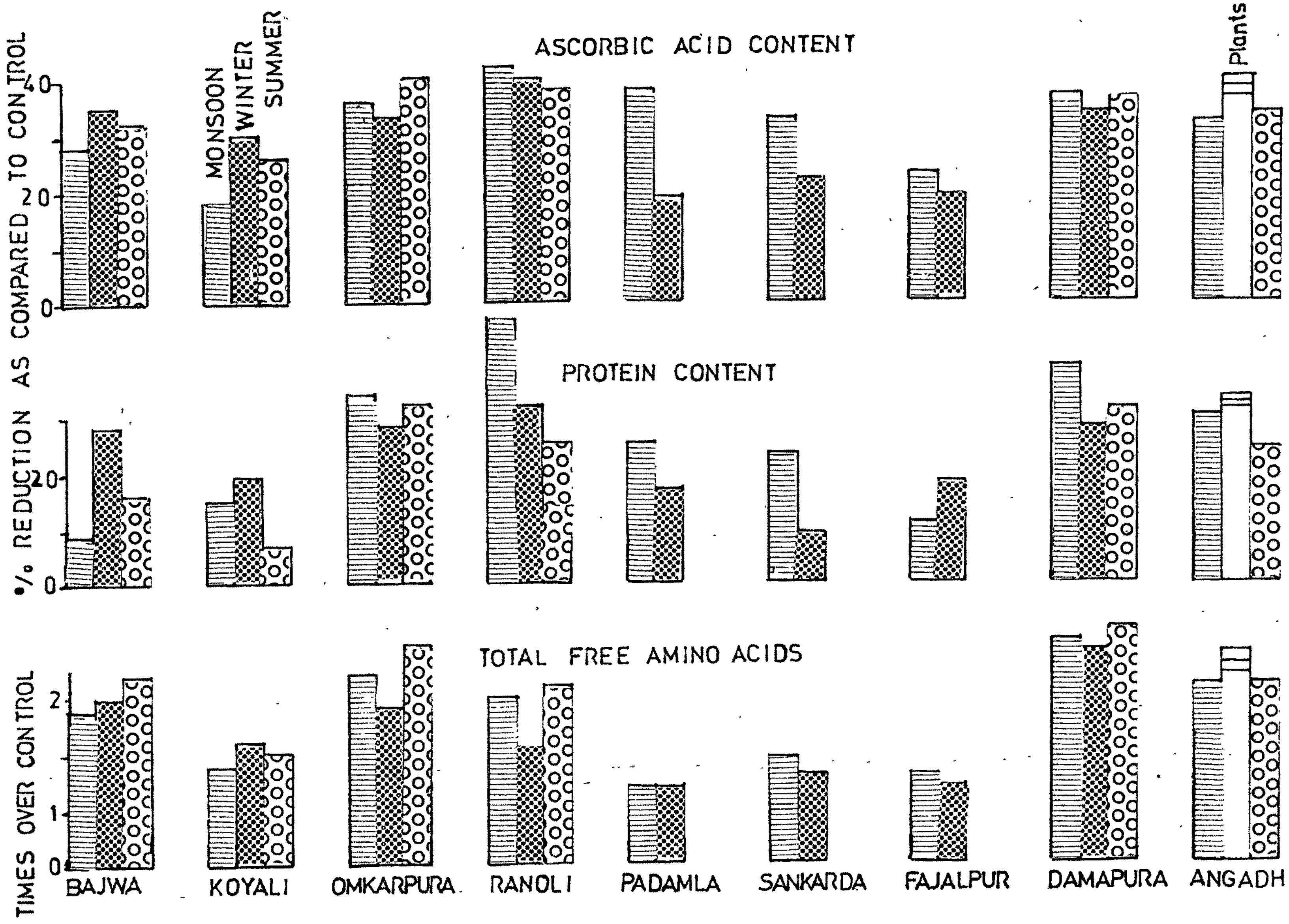
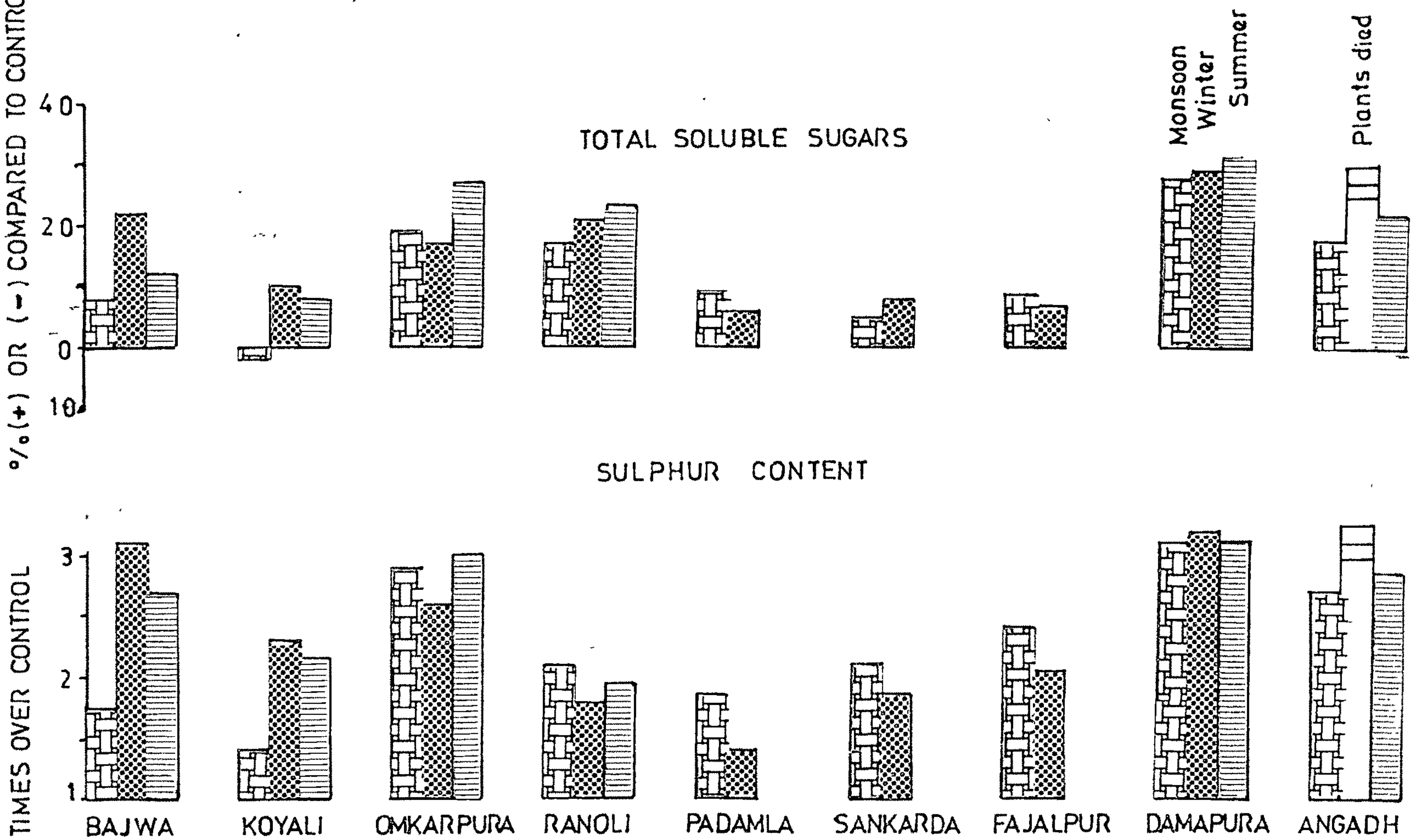


Fig. 4.11.5. Field exposure study on *Mangifera indica* L



*Manilkara hexandra* (Roxb.) Dubard.(rayan)

During monsoon, the growth rate of shoot was reduced from 25 to 46% at Omkarpura, Damapura, Fajalpur and Ranoli (WWD). The plants growing at Bajwa and Angadh were in windward side for 18.3% days and showed 18.9 and 16.7% of reduction respectively. At Koyali the growth rate was slightly higher (8.9%) than control during monsoon. This shows, at this station the plant growth rate may be stimulated at low pollutants concentrations during monsoon.

During winter, higher pollutants concentration ($SO_2$ 38.5, NOx 46.2 and SPM 336 $\mu g/m^3$) at Bajwa heavily damaged the rayan saplings resulting into ultimate death, but the plants at Angadh, eventhough exposed to higher concentrations (51.7, 69.5 and 223 $\mu g/m^3$ respectively) of $SO_2$, NOX and SPM shown 70.6% reduction in shoot growth rate. This reveals that other pollutant/s from the fertilizer complex singly or combined with other pollutants ($SO_2$, NOx etc. ) might be responsible for the fatal damage to rayan. The percentage reduction in shoot growth rate during winter ( 35 to 55%) was more or less close to monsoon observations at Omkarpura and Damapura. The damage to the height of the plants at Sankarda, Padamla, Fajalpur (LWD) was significantly less during winter as compared to monsoon observations. This shows that rayan shoot growth rate could recover in lower concentration of pollutants due to change in wind direction at Sankarda, Padamla and Fajalpur.

During summer, the plants growing at Omkarpura, Ranoli and Damapura (WWD) showed 35 to 56% reduction in growth rate of shoot. At Angadh and Bajwa which were on leeward side of the source for most part of the summer season, the plants exhibited 38.9% and 46.3% reduction. This showed that pollutants concentration at these stations were enough to retard the shoot growth significantly (Fig.4.12.1.)

<u>Syzygium</u> <u>cumini</u> Skeels (jamun)

During monsoon, the plants growing at Damapura, Omkarpura and Ranoli (WWD) showed 59 to 69% retardation in growth rate of shoot, where they were exposed to higher concentrations of pollutants for 79.2% of the days. At Bajwa and Koyali which were in leeward direction, the growth rate was least affected. At Sankarda, Padamla and Fajalpur the reduction ranged from 10 to 14%. This shows that the rate of height retardation of jamun plants occured significantly at maximum polluted stations during this season.

With the change of wind direction during winter, high reduction in the rate of shoot growth at Angadh (63.4%) and

Bajwa (54.3%) were recorded. During winter, the percentage reduction in growth rate was less at all the stations as compared to monsoon observations, except at Ranoli where the recovery was comparatively less. At Sankarda, the growth rate was slightly higher than control, which shows the active growth of the jamun saplings during the favourable spell.

During summer, 60 to 76% reduction in rate of shoot growth was observed at Omkarpura, Ranoli and Damapura(WWD). At Bajwa, Angadh and Koyali, the percentage reduction in growth rate was between 32 to 40%, which was comparatively less than damage during winter (Fig.4.13.1.). This shows, the height increment of jamun saplings was rapid during favourable spell.

(ii) Effect on foliage:

Leaves are the major receiptive part of plant for gases. The number of leaves as well as leaf area of the plant decreases due to pollution stress (Garsed *et al*., 1969, Mudd and Kozlowski, 1975).

*Mangifera indica* L. (mango)

During monsoon, the rate of increase in number of leaves, per plant reduced maximum (78.7%) at Ranoli and 44 to 72% at Omkarpura, Damapura, Fajalpur, Padamla and

Sankarda (WWD) as compared to control. This shows the degree of damage to mango was severe at these stations. At Angadh, which was on leeward side, the number of leaves and total leaf area decreased 63% and 73% respectively. This shows, eventhough the wind direction was only 18.3% of the days towards this station, due to close vicinity of the pollution source, high degree of damage to mango occured.

During winter, at Bajwa (WWD) the number of leaves/plant and total leaf area recorded was 14.6 and 568 $cm^2$ (Table 36), whereas during monsoon it was 12.7 and 596 $cm^2$ (Table 28). This shows, there was an increase in number of leaves, but reduced total leaf area during winter due to early senescence of leaves. At stations in the leeward side of the source, mango saplings exhibited 37 to 67% reduction in rate of increase in number of leaves/plant and 44 to 68% reduction in total leaf area as compared to control. Thus as compared to monsoon observations recovery in rate of increase in number of leaves/plant was observed during winter at most of the stations in leeward side. The total leaf area exhibited high degree of reduction and recovery was comparatively less at most of the stations (LWD) during this season.

During summer, at Omkarpura and Damapura (WWD) the number of leaves recorded (15.1 and 11.5) was less than the winter observations (15.2 and 11.9 respectively). This clearly indicates that the defoliation occured in the saplings due to higher concentration of ambient air pollutants. At Angadh, Bajwa and Koyali the foliar growth (number of leaves/plant and total leaf area) reduced 39 to 76% as compared to control. Eventhough the stations were in lee-ward side the high degree of damage exhibited higher sensitivity of mango to air pollution (Fig.4.11.1.)

Manilkara hexandra (Roxb.) Dubard.(rayan)

During monsoon, reduction in the rate of increase in number of leaves/plant was 27 to 53% at Omkarpura, Damapura, Ranoli and Fajalpur (WWD). During this season, eventhough the pollutants flow was only 18.3% of the days towards Bajwa and Angadh the plants exhibited 26.4% and 37.5% reduction in number of leaves respectively, due to the close vicinity of the source. Comparatively damage to the leaves was less at Koyali (LWD) during monsoon. The total leaf area decreased 54 to 64% at Omkarpura, Ranoli, Damapura and Fajalpur (WWD). At Sankarda, plants exhibited foliar growth more or less close to control plants. This indicates that at this station pollution damage to rayan saplings was much less.

During winter, the flow of pollutants for 62.5% of the days was towards Angadh and Koyali resulted in higher reduction in rate of increase in the number of leaves/plant

(58•8% and 47•10% ) and leaf area (53•6% and 41•3%) respectively. At stations like Damapura and Omkarpura(LWD), the reduction in the number of leaves during winter was more or less close to the monsoon observations, it indicates less recovery at these stations during favourable spell. At other stations at a greater distance from the source in leeward direction, significant recovery in the number of leaves and leaf area in rayan saplings was observed.

During summer, 34 to 54% reduction in the number of leaves was recorded at Damapura, Omkarpura and Ranoli (WWD). Eventhough, the plants at Bajwa and Angadh were on leeward side, the reduction in the number of leaves (39•0 and 43•9%) and total leaf area (61•9 and 47•6%) at respective stations was significantly high. As the stations were close to the source, the damage was also high. At koyali, the plants showed significant recovery in foliar growth. Thus rayan showed significant recovery at Sankarda, Fajalpur, Padamla and Koyali during the favourable spell, whereas at highly polluted stations, closer to the source the recovery was comparatively less (Fig 4.12•1 and 4.12•2•).

<u>Syzygium</u> <u>cumini</u> Skeels (jamun)

During monsoon, reduction in the number of leaves/plant and leaf area was 25 to 59% and 53 to 69% respectively at all the stations in windward side except at Sankarda (13•8%

and 18.6%) . At Angadh (LWD) high damage was refelcted by 43.5% and 56.7% reduction in the number of leaves and leaf area respectively due to close vicinity of the source. At Ranoli, reduction in number of leaves was only 25.5%, but reduction in leaf area was 68.6%. The reduced leaf area in jamun saplings was due to accidental leakage of pollutants resulting into heavy senescence followed by flush of new young leaves during the follow up favourable spell.

During winter, the plants exposed at Angadh exhibited very high damage. The number of leaves and leaf area recorded during winter (17.6 and 492 $cm^2$) was less than monsoon (18.1 and 559 $cm^2$ respectively). This clearly indicates the defoliation occured in the plants due to high concentration of pollutants ($SO_2$ 51.7, NOx 69.5 and SPM 223 $\mu g/m^3$ Table 6) which prevailed during winter. The renewed growth during follow up period was fairly reflected in increase in number of leaves as well as in total leaf area of the plants growing at almost all the stations in the leeward direction except at Ranoli. The reduction in the number of leaves and leaf area at Ranoli was 70.0% and 69.6% respectively. This shows that the damage to jamun increased at this station, eventhough they received pollutants for only 22.5% of days. This revealed that the jamun may be more sensitive to chlorine pollution, which is a major pollutant in the area from Alkalies and Chemicals plant.

During summer, maximum reduction (50.5%) in the number of leaves was recorded at Damapura (WWD). At Ranoli, reduction in the rate of increase in the number of leaves was only 14.6%, but leaf area reduced by 68.6%. The high degree of defoliation followed by new young leaves resulted in decreased leaf area. The plants growing at Angadh, Bajwa and Koyali (LWD) showed significant recovery in growth. Thus, the production of foliage in jamun saplings recovered significantly at all the stations (except Ranoli), at stations on leeward side of the source for a considerable period during the season. (Fig 4.13.1 and 4.13.2.).

(iii) Visible damage and injury index:

Plants subjected to any environmental stress generally exhibit the damage by foliar symptoms (Treshow, 1976). Injury due to air pollutants occurs when absorption of pollutants exceeds the capacity of tissue to oxidize or reduce or respire or translocate the products. If the absorption of $SO_2$ is not very rapid, it is transformed to less toxic sulphate. In cases, where the transformation of $SO_2$ to sulphate is not able to keep pace with the rapid absorption of very toxic $SO_2$ concentration, the sulphite formed results in chlorosis and necrosis. Similarly NOx and chlorine has also been found toxic to plants (Katz, 1949, Darley and Middleton, 1966, Smith, 1983).

Mangifera indica L. (mango)

During monsoon, the exposure of mango saplings to ambient air, resulted in 77 to 100% of leaves with foliar damage at Damapura, Ranoli (WWD) and also at Angadh (LWD). The injury index was higher (18.0%) at Damapura and Ranoli (10.6%), whereas at Angadh it was 7.6%. This shows that at Angadh, eventhough most of the leaves exhibited symptoms, the damaged leaf area was comparatively less. At Omkarpura (WWD) 37.5% of the leaves exhibited the injury index of 8.5%. At all other stations 5 to 17% of leaves showed the injury index of 1 to 5%.

During winter, the change in wind direction increased the injury index at Bajwa(14.4%) and Koyali (6.3%). Plants growing at the stations on the leeward side of the respective pollution sources, received pollutants for 22.5% of the days during winter, but the injury index increased as compared to monsoon observations, i.e. at Damapura (35.4%), Omkarpura (12.8%), Ranoli (17.5%) and at other stations injury index was 6 to 10% (Fig.4.11.2.). This shows inability of this species to recover from the damage during the favourable spell. The concentrations of the pollutants at these stations during winter (Table 6) form additive doses which increased the injury.

During summer, at Omkarpura, Damapura and Ranoli (WWD) 75 to 85% of the leaves showed visible symptoms, Eventhough plants at Angadh were on leeward side, 72.7% of the leaves exhibited an injury index of 26.5%, due to close vicinity of the source. The injury index recorded at Bajwa (16.5%) and Koyali during this season (8.5%) was comparatively higher than winter and monsoon observations. This also indicates that in mango the foliar damage increased due to additive concentrations of pollutants at the stations in leeward direction. (Fig.4.11.2.)

Manilkara hexandra (Roxb.) Dubard.(rayan)

In rayan saplings visible damage was comparatively less. During monsoon, at highly polluted stations like Damapura, Omkarpura (WWD) and Angadh (LWD) 23.8, 15.4 and 17.4% of leaves exhibited visible damage respectively. The extent of pollution at the remaining stations may not be sufficient to cause visible damage to rayan or the presence of latex in the plants may be providing protection to the tissues and preventing disorganisation due to pollution.

During winter, at Angadh (WWD) 23% of the leaves showed injury index of 12.4% . Among other stations, only at Damapura (LWD) 12.4% of the leaves exhibited injury index of 6.3%. Thus the variety of pollutants emitted from the industries at the Nandesari industrial estate may be responsible for the visible damage to the rayan saplings at these two stations.

Fig. 4.12.1. Field exposure study on *Manilkara hexandra* Dubard.

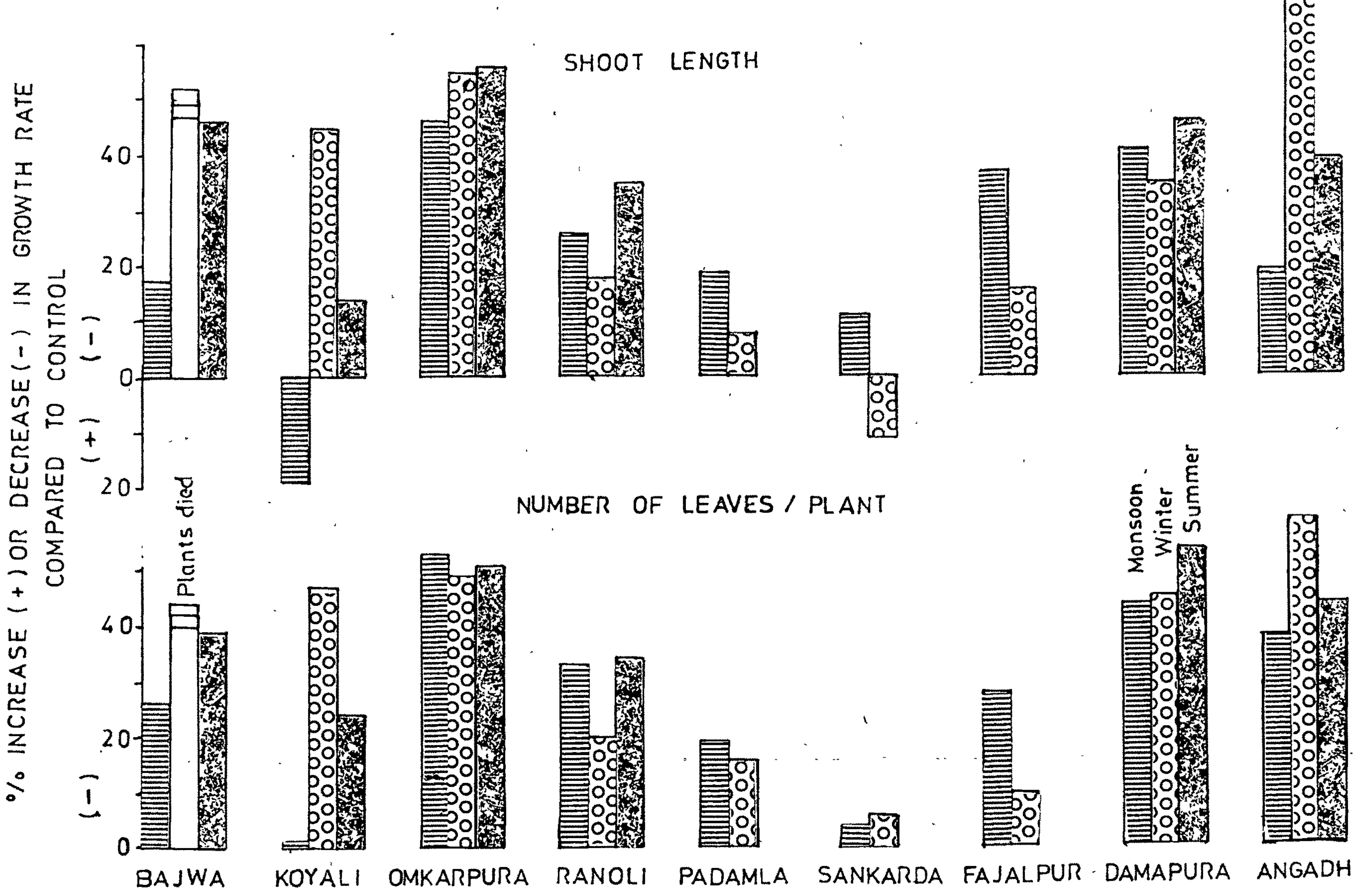


Fig. 4.12.2. Field exposure study on *Manilkara hexandra* Dubard

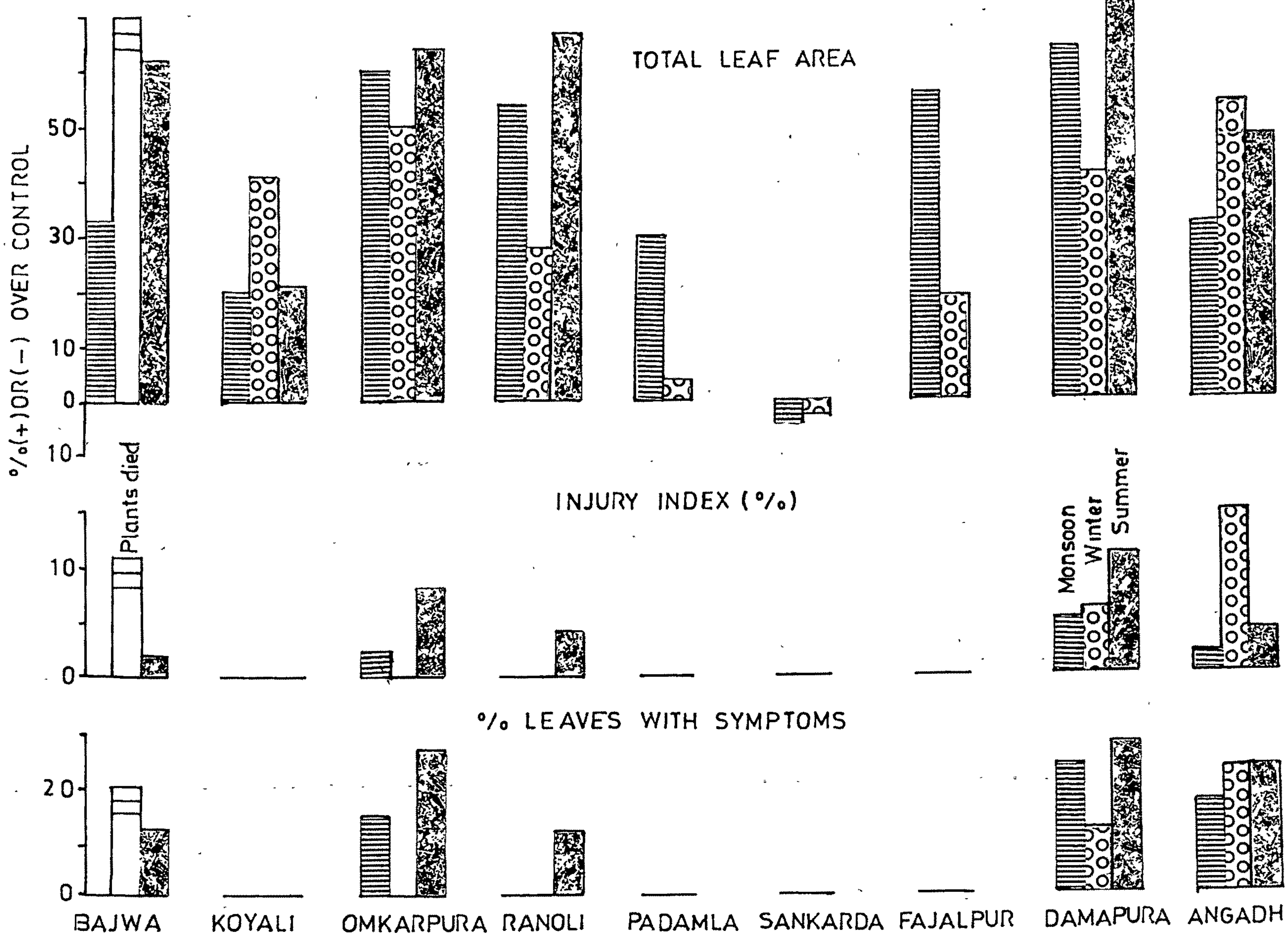


Fig. 4.12.3. Field Exposure Study on *Manilkara hexandra* Dubard.

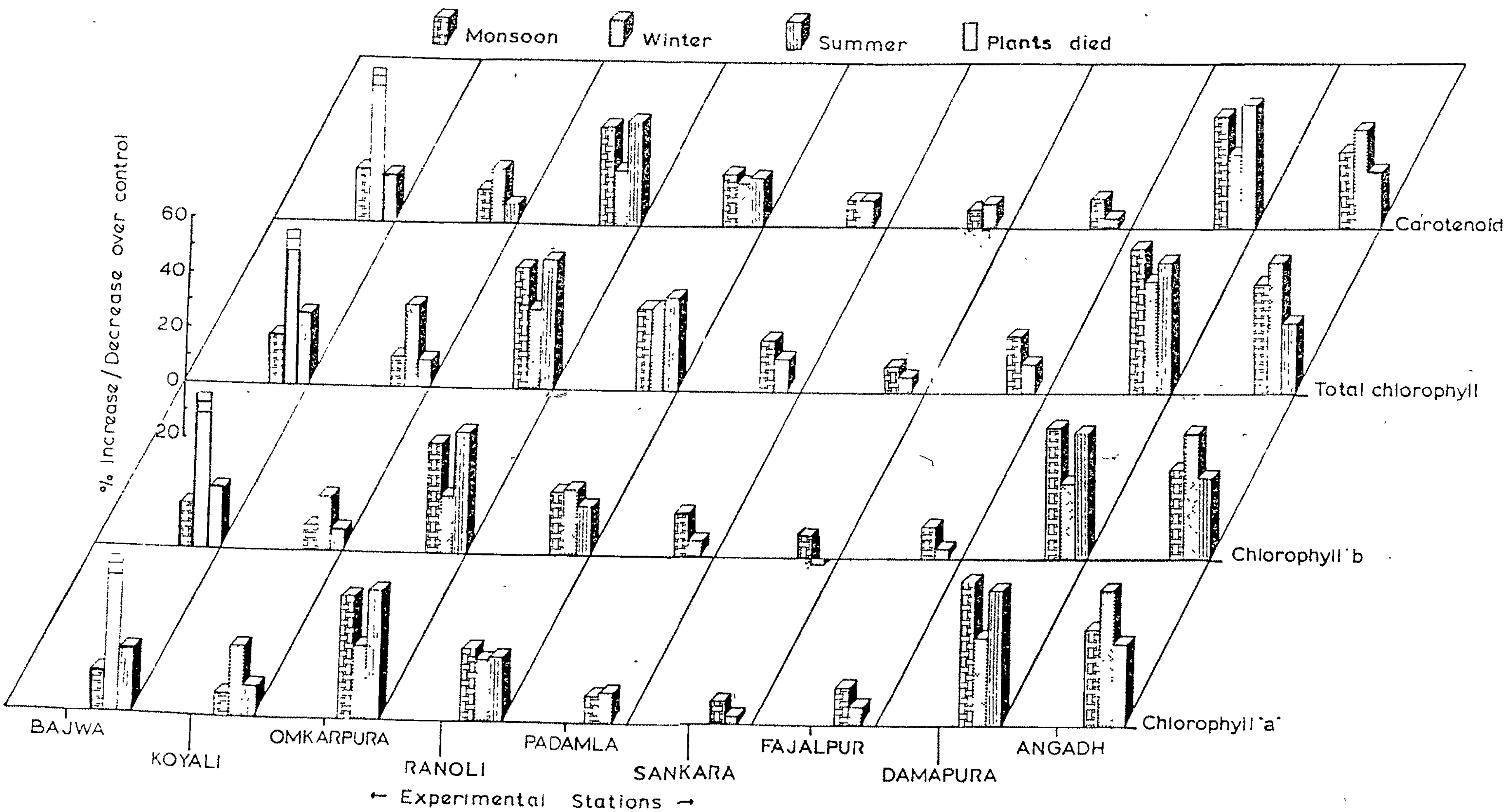


Fig. 4.12.4. Field exposure study on *Manilkara hexandra* Dubard.

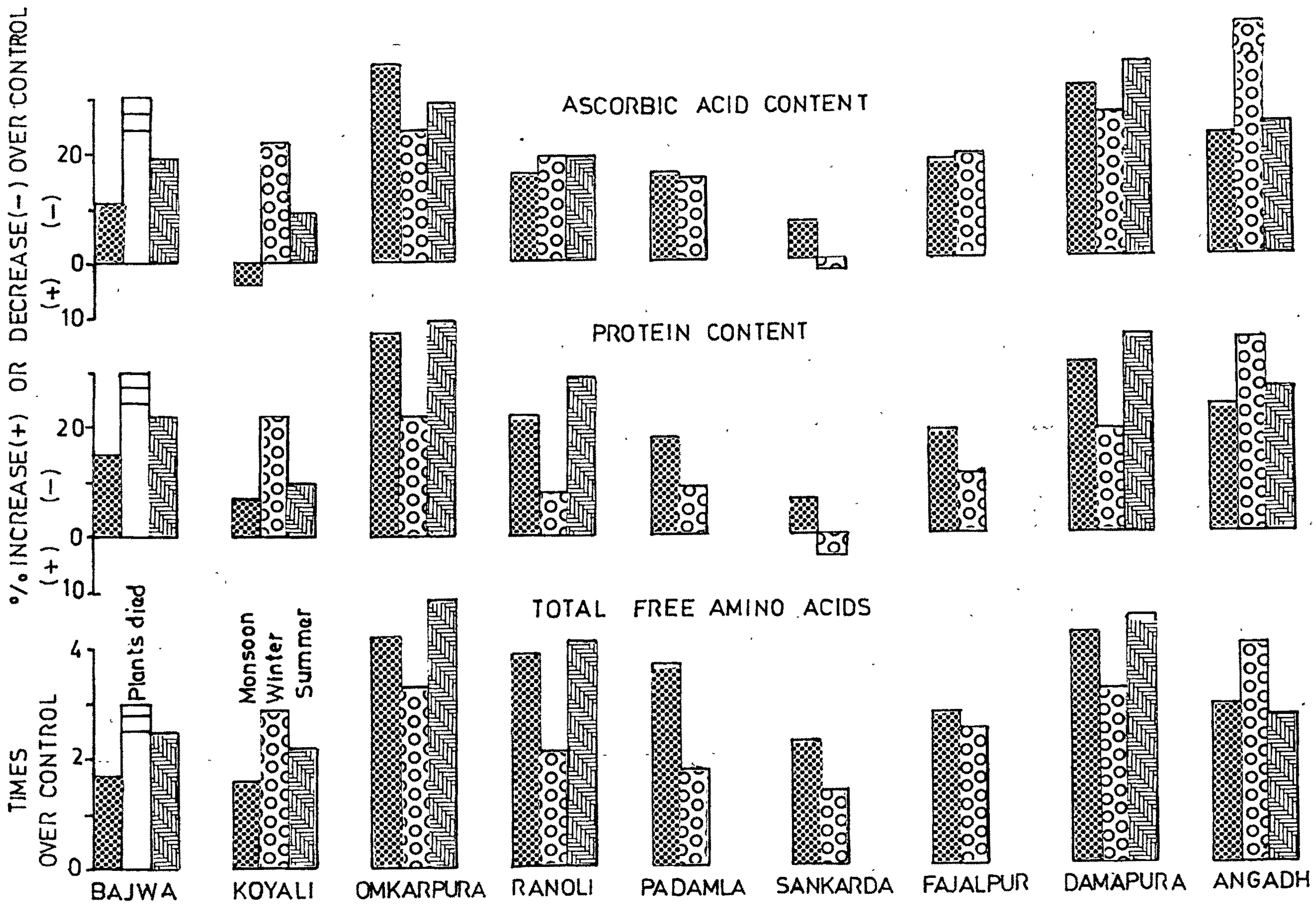
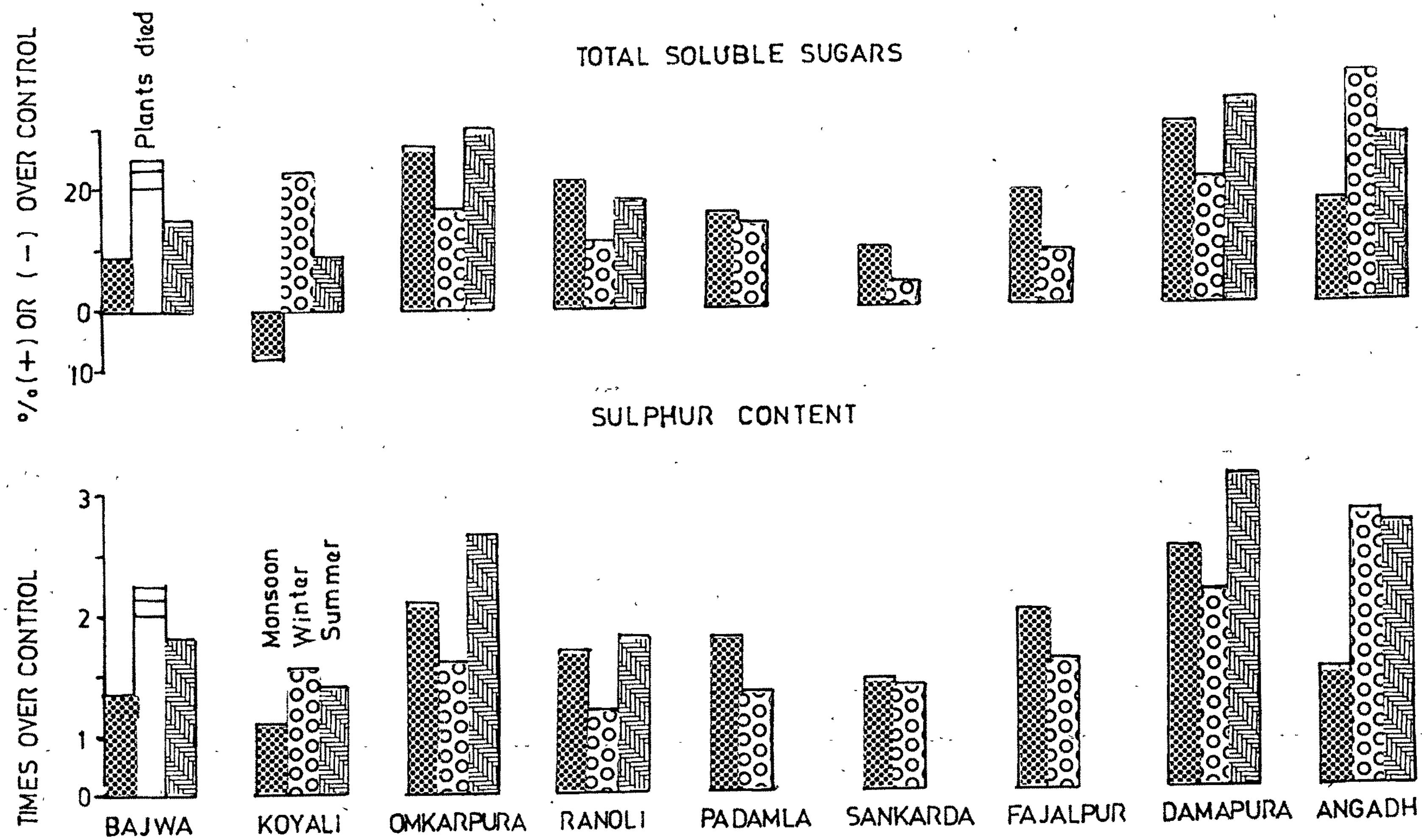


Fig.4.12.5. Field exposure study on *Manilkara hexandra* Dubard.



During summer, 12 to 28% of the leaves showed symptoms at Omkarpura, Damapura, Ranoli (WWD) Angadh and Bajwa (LWD). At Bajwa, eventhough 12.8% of the leaves showed symptoms, the injury index was 1.6% only. No visible damage was recorded at Koyali. Plants growing at Ranoli (WWD) did not show any visible symptoms during monsoon, but during summer exhibited visible damage. This may be due to increase in the rate of metabolism due to rise in ambient air temperature during summer, which induce greater absorption of pollutants. Not only the pollutant level in the ambient air, but climatic conditions also play important role in pollution damage. (Fig.4.12.2.).

Syzygium cumini Skeels (jamun)

During monsoon, mostly at all the stations in windward side of the source (except Sankarda) plants exhibited visible foliar damage (Fig.4.13.2.). Maximum injury index was (10.5%) observed at Ranoli whereas at other stations it was 4 to 7%. Eventhough plants at Angadh were exposed for 18.3% of days, 5.5% of leaves exhibited an injury index of 1.8%.

During winter, the plants at Padamla, Sankarda, Fajalpur and Omkarpura (LWD) did not show any visible foliar damage. This reveals, that damaged leaves were dropped off and it was compensated by number of new leaves as it was well reflected in that parameter i.e. number of leaves/plant. Injury index increased at the stations in the windward direction (Angadh 36%, Bajwa 17% and Koyali 6.4%) during winter. The plants growing at Ranoli, which was mostly on leeward side and received pollutants for 22.5% of days during winter, exhibited an injury index of 11.6% and the leaves with symptoms were 14.8%. As the jamun saplings showed good recovery mostly at all the stations during favourable spell except at Ranoli, it may be considered that jamun may be more sensitive to chlorine pollution which is the major pollutant at this station.

During summer, at all the stations foliar damage was observed. Maximum injury index (38.4%) was recorded at Damapura (WWD) in 58.7% of leaves. At Angadh and Bajwa (LWD) 32.4% and 11.4% of the leaves exhibited an injury index of 29.1% and 9.3% respectively. This may be due to closer vicinity of the source, which resulted in high degree of foliar damage (Fig.4.13.2.).

(iv) Branching:

Among the three species studied, branching was more frequent in jamun at all the experimental stations. In mango and rayan only at few stations, hardly new branching was recorded. The rate of increase in number of branches/plant was also highly influenced by air pollution.

During monsoon, at Koyali (LWD) the rate of branching in jamun saplings was 84.6% higher than control plants. Branching was higher than control at other stations like Omkarpura and Fajalpur (76.9%), Padamla (69.2%) and Ranoli (23.1%). This shows, the suppression of shoot elongation under lesser pollution stress may be inducing more branching that can increase its photosynthetic area and biomass. At Damapura and Angadh, the rate of branching was 26.2% and 23.1% less than control. This may be due to very high concentration of pollutants and close proximity of the source, which suppressed the biomass accumulation by reducing shoot elongation, leaf area as well as branching.

During winter, the rate of increase in number of branches was significantly reduced as compared to monsoon, at stations in the leeward direction i.e. Omkarpura, Ranoli, Sankarda , Fajalpur etc., but there was considerable addition in shoot length, number of leaves and leaf area. During winter, the rate of branching decreased at Bajwa (73.7%), Koyali (63.2%) and Angadh (21.1%) which were on winward side of the source during the most part of this season. Thus the concentration of pollutants at these stations decreased the biomass accumulation by affecting the various morphological and growth parameters. Thus, jamun saplings exhibited various degree of response in the rate of branching depending on the concentrations of pollutants and environmental conditions.

## 4.2.2. EFFECT ON BIOCHEMICAL PARAMETERS

### (i) Photosynthetic pigments:

These are the primary sites damaged by atmospheric pollutants like $SO_2$, NOx etc. (Ricks and Williams, 1975, Santo *et al*., 1979, Hallgren and Gezelius, 1982, Saxe, 1983, Okano *et al*., 1985). Leblanc and Rao (1966) observed that exposure of lichens to $SO_2$ induced the conversion of chlorophyll to phaeophytin. It is well known that lowering the pH of cell sap will cause the loss of $Mg^{++}$ from the chlorophyll molecules to form phaeophytin. The ultra structural studies (Wellburn *et al*., 1972) in the exposed plants revealed, there was a swelling of the granal compartments. Subsequently the chloroplast become swollen, followed by degradation of chloroplast envelope. These deterimental changes leads to reduction in photosynthetic pigments.

In the present investigation, the concentration of photosynthetic pigments in the plants growing in the polluted region was less than that of the control plants. The percentage reduction of chlorophyll *a* and total chlorophyll were more or less close to each other at respective stations. The percentage reduction of chlorophyll *b* and carotenoids was also more or less same at highly polluted stations like Ranoli, Omkarpura, Damapura, Bajwa and Angadh, but comparatively less affected at medium polluted stations like

Fajalpur, Koyali, Sankarda and Padamla. These observations support the earlier view that chlorophyll pigments a and total chlorophyll were more prone to air pollution (Ricks and Williams,1975, Pandey and Rao,1978) than chlorophyll b. Compared to chlorophyll pigments (chlorophyll a, b and total chlorophyll) carotenoids were less affected, shows their less sensitivity to pollutants (Nouchi et al.,1973, Prasad and Rao, 1982). Contrary to this Arndt (1971) reported that carotenoids are more sensitive than chlorophyll pigments.

*Mangifera indica* L. (mango)

During monsoon, at Omkarpura, Ranoli and Damapura (WWD) 46 to 62% reduction in chlorophyll pigments ( chlorophyll a, b and total chlorophyll ) was recorded. At other stations in winward side, 26 to 42% reduction in chlorophyll pigments was registered. During this season, eventhough no visible symptoms were observed at Koyali, (LWD) reduction in chlorophyll pigments was 19 to 27%. This shows that the pollutant concentrations at this station could cause hidden injury in the mango saplings.

During winter, the change in wind direction resulted in increased damage to chlorophyll pigments at Bajwa (53 to 60%) and Koyali (39 to 49%) which were exposed to pollutants for 62.5% of days. At Omkarpura, Ranoli and Damapura

(LWD) the percentage reduction was 33 to 53%. As compared to monsoon observations, slight reduction in degree of damage to the chlorophyll pigments was observed at the stations in the leeward side during winter.

During summer, reduction in chlorophyll pigments was very high (47 to 57%) at Damapura, Omkarpura and Ranoli (WWD). The plants at Bajwa and Angadh also showed high reduction in chlorophyll pigments ( 38 to 49%) (Fig.4.11.3.). This may be due to close vicinity of the source. As compared to winter observations, during summer the degree of damage to chlorophyll pigments slightly decreased at Bajwa and Koyali. Thus in mango slight recovery in chlorophyll pigments was observed during the favourable spell.

*Manilkara hexandra* (Roxb.) Dubard.(rayan)

During monsoon, reduction in chlorophyll pigments was 40 to 52% at Damapura and Omkarpura (WWD), and 30 to 40% at Angadh (LWD). Eventhough no visible symptoms were observed at Ranoli (WWD), the reduction in chlorophyll pigments ( 23 to 31%) clearly indicates the hidden injury in the plants. At other stations also chlorophyll pigments decreased 6 to 21% as compared to control. These observations revealed the hidden injury in rayan at stations where no visible symptoms were recorded.

During winter, the reduction of chlorophyll pigments was 49 to 55% at Angadh (WWD) where the pollutants concentration was also high ($SO_2$ 51.7, NOx 69.5 and SPM 223 $\mu g/m^3$)(Table 6). At Damapura (LWD) the reduction ranged between 28 to 41%. The high reduction may be due to close vicinity of the source. Among other stations, 19 to 31% reduction in chlorophyll pigments was recorded at Koyali (WWD), Omkarpura and Ranoli (LWD). As compared to monsoon observations, the degree of damage to chlorophyll pigments was significantly less during winter at most of the stations in leeward direction to the source.

During summer, 44 to 49% reduction in chlorophyll pigments was recorded at Damapura and Omkarpura (WWD), where the injury index (11.3% and 8.4% respectively) as well as pollutants concentrations was high (Table 6). During summer, eventhough Angadh and Bajwa were on leeward side high damage (21 to 31%) to chlorophyll pigments was recorded due to their closer proximity of the pollution source (Fig.4.12.3.). In rayan, chlorophyll pigments showed recovery during the favourable spell at almost all the stations, but it was very significant at Sankarda, Koyali, Padamla, Fajalpur and Ranoli.

<u>Sysygium</u> <u>cumini</u> Skeels (jamun)

During monsoon, in jamun 46 to 55% reduction in chlorophyll pigments was recorded at Omkarpura, Ranoli and Damapura (WWD) and 22 to 35% reduction at Fajalpur and Padamla (WWD) which received pollutants for 79.2% of days during this season. High damage to chlorophyll pigments was recorded at Bajwa (19 to 23%) and Angadh (37 to 41%) which were on leeward side to the sources. This shows that damage to chlorophyll pigments may occur even the pollutant flow was for 18.3% of days during the season and it may be due to close proximity of the pollution source.

During winter, at Bajwa and Angadh (WWD), reduction in chlorophyll pigments was 43 to 53% as compared to control. Eventhough no visible damage was observed at Omkarpura, Padamla and Fajalpur the hidden injury to plants at these stations was refelcted by 13 to 30% reduction in chlorophyll pigments. At Sankarda, the chlorophyll pigments concentration was very close to control which showed the complete recovery at this station during favourable season.

During summer, jamun plants growing at Omkarpura, Ranoli and Damapura exhibited 38 to 55% reduction in chlorophyll pigments. At Angadh, the percentage reduction ranged from 45 to 48%, whereas at Bajwa and Koyali it was between 10 to 27% as the wind direction was for 35.8% of the days during summer towards these stations (Fig.4.13.3.).

(ii) Foliar ascorbic acid:

Foliar ascorbic acid content in all the three species was observed less than control. Such reduction of ascorbic

Fig. 4.13.1. Field exposure study on *Syzygium cumini* Skeels

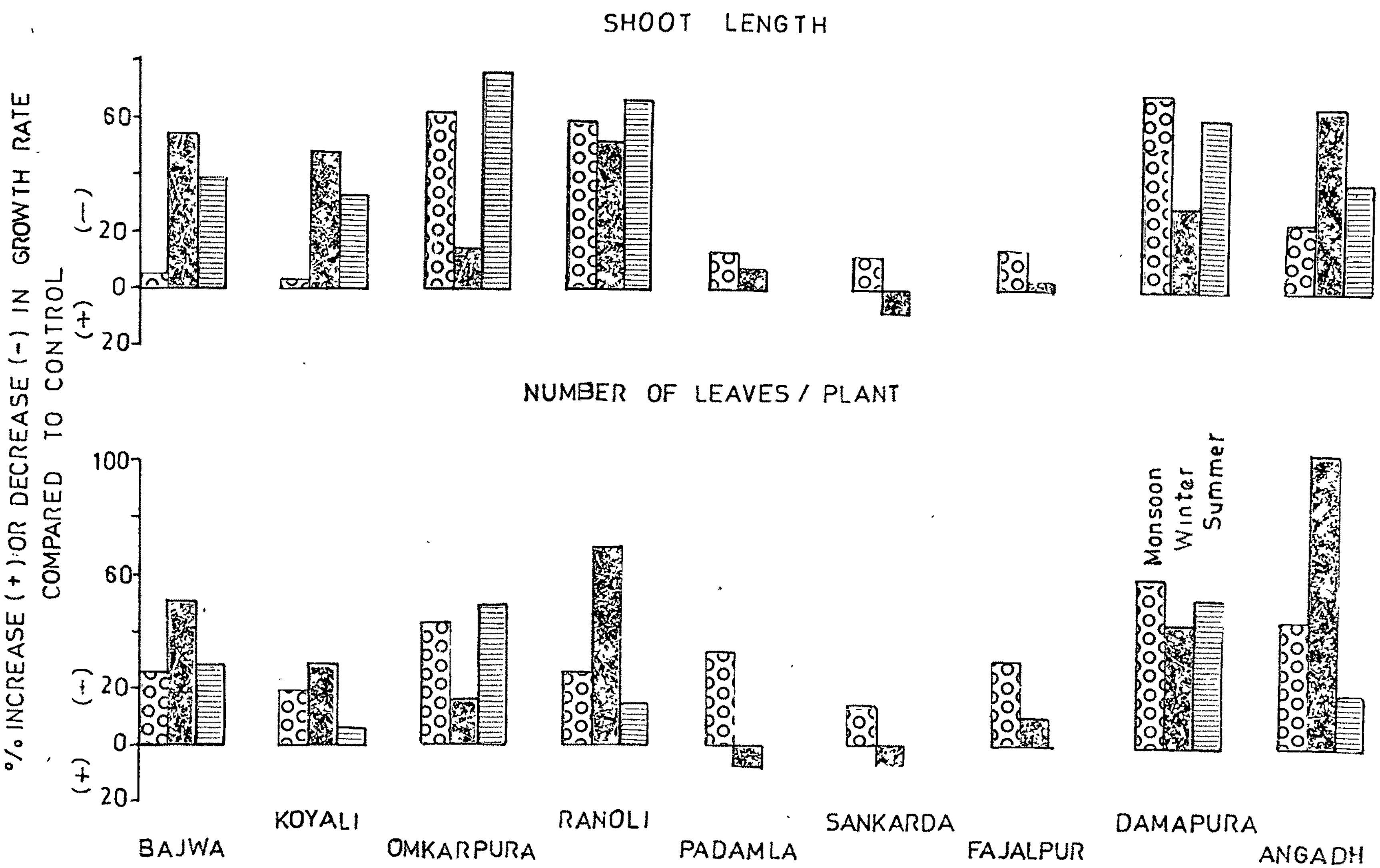


Fig. 4.13.2. Field exposure study on *Syzygium cumini* Skeels

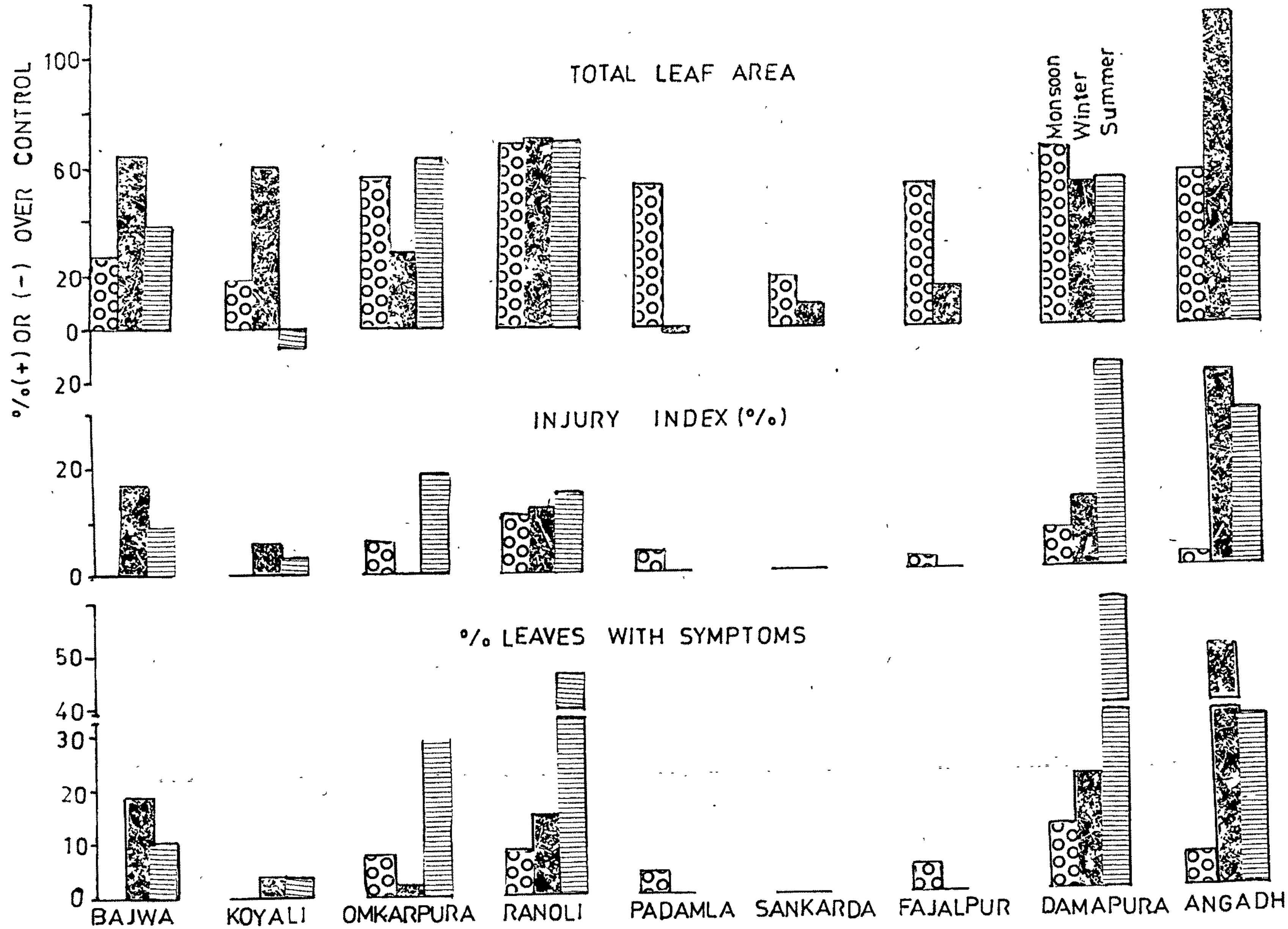


Fig. 4.13.3. Field Exposure Study on *Syzygium cumini* Skeels

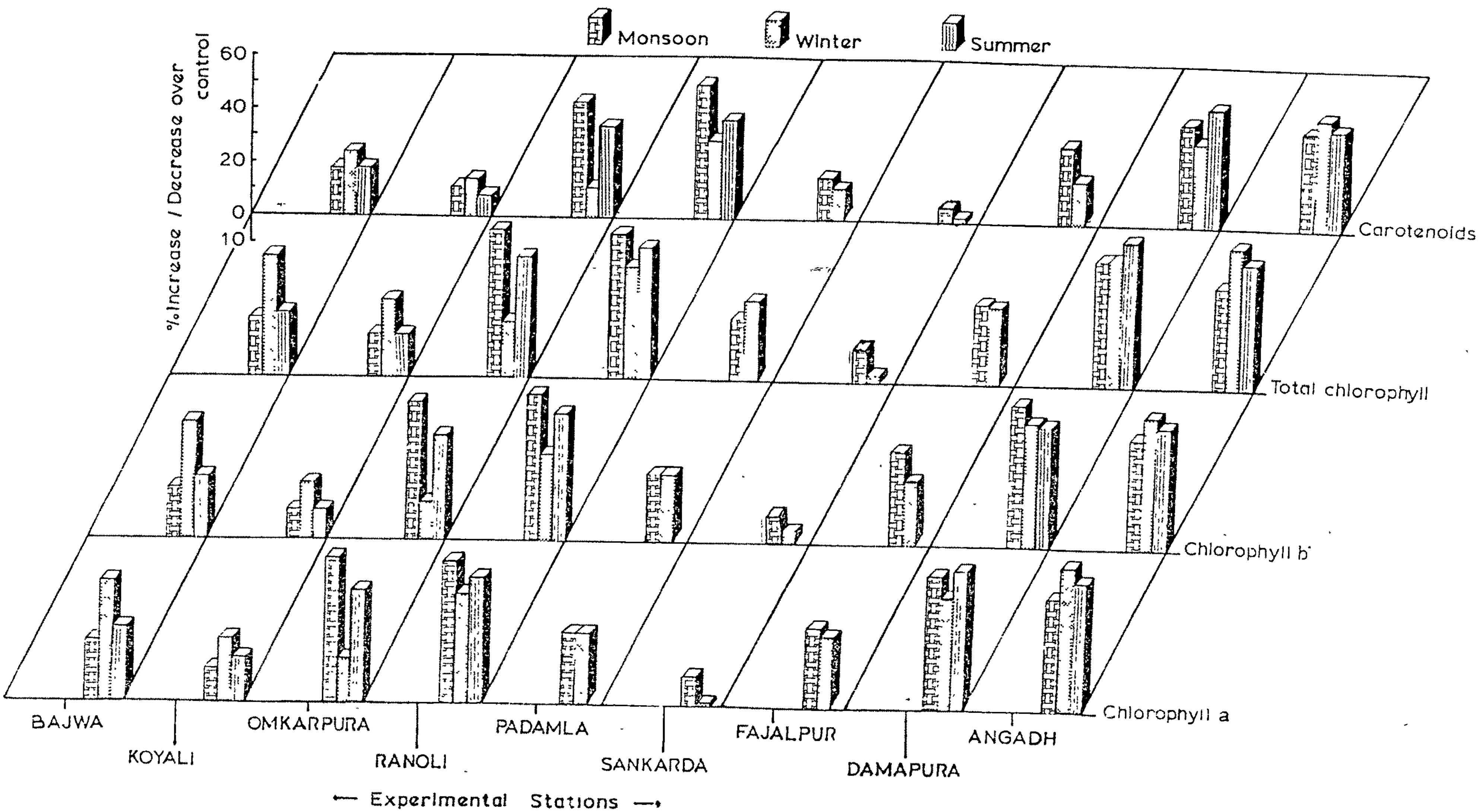


Fig. 4.13.4. Field exposure study on <u>Syzygium cumini</u> Skeels

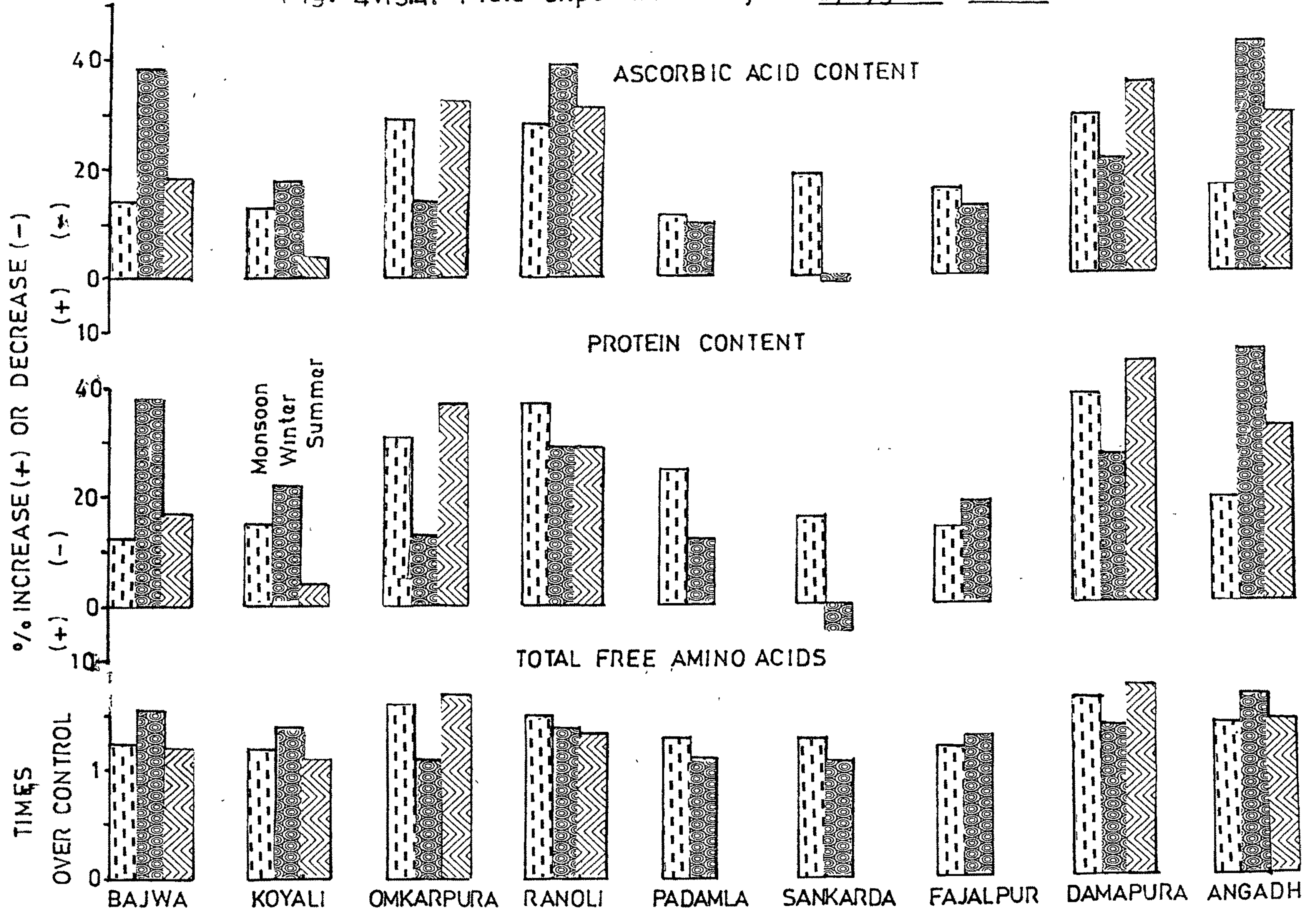
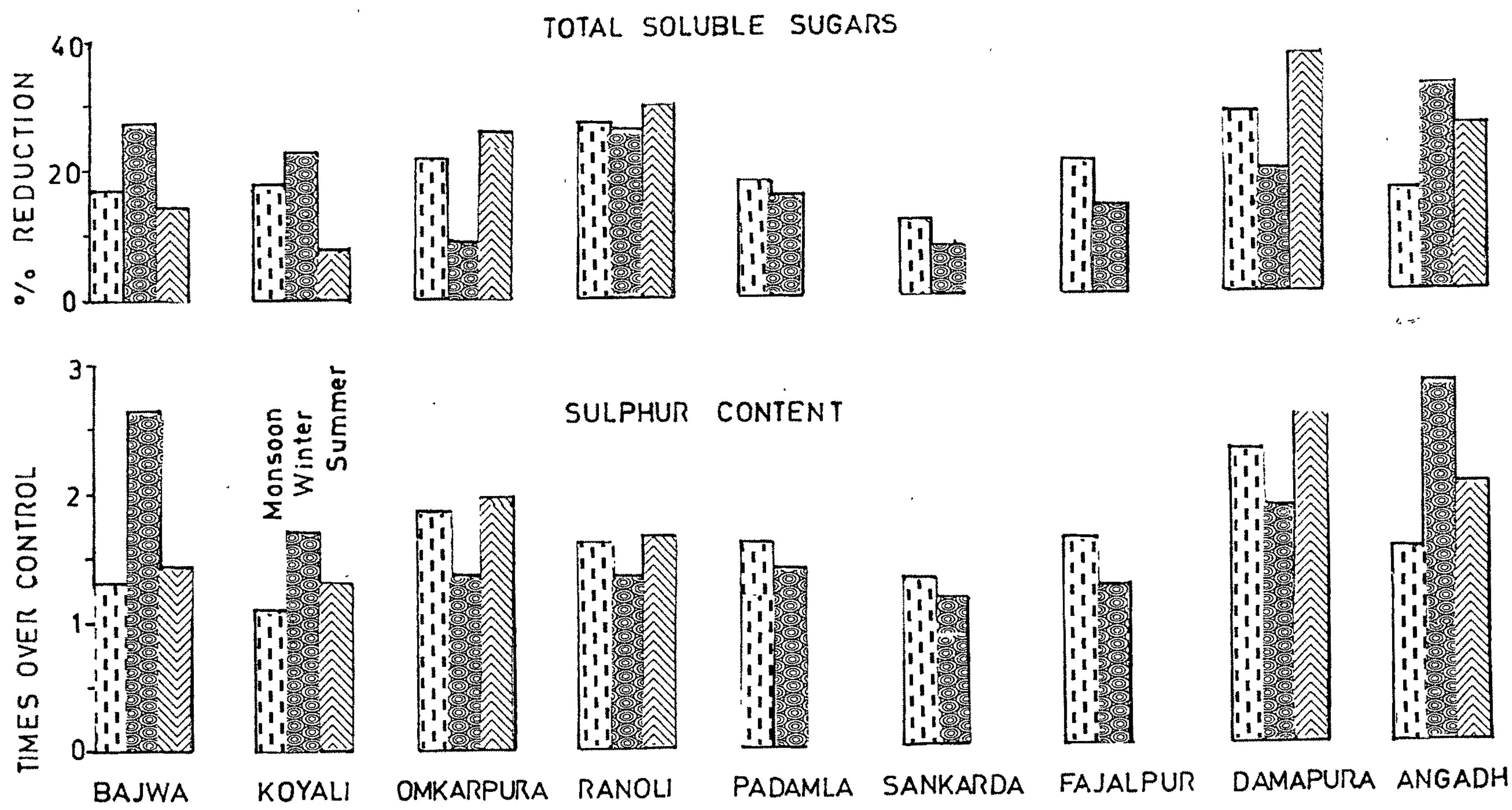


Fig. 4.13.5. Field exposure study on <u>Syzygium</u> <u>cumini</u> Skeels



acid in plants exposed to pollution, may be due to its conversion into dehydroascorbic acid or oxalic acid and other convertible carbohydrates (Hogler and Herman, 1973, Young and Loewus, 1975) or may be the result of oxidizing property of $SO_2$ (Choudhary and Rao, 1977, Keller and Schwager, 1977, Nandi et al., 1981, Varshney and Varshney, 1984b).

Mangifera indica L. (mango):

During monsoon, maximum reduction was noticed at Ranoli (42.1%) and at all other stations in windward direction it ranged ffom 22 to 38%. At Koyali also where the pollutants flow and concentrations were comparatively less due to leeward side, the ascorbic acid level was 18.4% less than control. This shows that even at low pollution concentration the ascorbic acid content was affected in mango saplings.

During winter, ascorbic acid reduction was higher (30 to 35%) at Bajwa and Koyali due to greater flow of pollutants in this direction i.e. for 62.5% of days during winter. During winter the percentage reduction of ascorbic acid content was more or less same as monsoon at highly polluted stations like Omkarpura, Ranoli and Damapura (LWD), whereas at medium polluted stations like Fajalpur, Padamla and Sankarda (LWD) the percentage reduction was comparatively less during winter than monsoon. This shows that in mango leaves ascorbic acid content could recover only slightly at medium polluted stations, but not at highly polluted stations. This may be due to their closer proximity of the pollution source and lesser recovering ability resulting in high degree of damage.

During summer, at Omkarpura, Damapura, Ranoli (WWD) and also at Angadh, the ascorbic acid was highly (34 to 40%) reduced. At Bajwa and Koyali it was 21.9% and 26.2% less than control (Fig.4.11.4.). Compared to winter observations, during summer the degree of damage to ascorbic acid was slightly less at the stations which were on leeward side of the source for the most part of the season.

Manilkara hexandra (Roxb.) Dubard.(rayan):

During monsoon, high damage to ascorbic acid content was recorded at Omkarpura (35.8%) and Damapura (30.6%) due to high concentrations of pollutants at these stations (Table 6). At Koyali, (LWD) ascorbic acid content was close to control. This shows that when the rayan saplings were exposed to low concentration of pollutants or for a shorter duration (18.3% of days) the damage to ascorbic acid was less.

During winter, 42.1% reduction was recorded at Angadh (WWD) which was maximum polluted during this season. The foliar ascorbic acid content of rayan saplings growing at stations on leeward side to the sources of pollution, showed less reduction in its level during winter than monsoon observations. This shows that ascorbic acid considerably increased at these stations when they were in leeward side.

During summer, 28 to 45% reduction in ascorbic acid content was noticed at Omkarpura, Damapura and Ranoli (WWD). At Koyali (LWD) the ascorbic acid level was slightly higher (8.9%) than control. This shows that in rayan ascorbic acid level may increase slightly when exposed to low concentrations of pollutants which may increases its resistant mechanism (Fig.4.12.4.).

Syzygium cumini Skeels (jamun):

During monsoon, high reduction was observed at Omkarpura, Ranoli and Damapura (28 to 30%), where during this season the plants received high concentration of pollutants for 79.2% of the days (Fig. 2.2.4). Eventhough plants growing at Bajwa, Koyali and Sankarda did not show any visible symptoms, the hidden injury was well reflected by reduction ( 11 to 15%) in ascorbic acid.

During winter, the percentage reduction in ascorbic acid was 38 to 41% at Bajwa and Angadh which were on windward side of the pollution source for 62.5% of the days. The ascorbic acid level at all the stations in leeward side of the source except at Ranoli, was comparatively higher during winter than monsoon observations. This reflects the recovery in Jamun plants when the stations are in the leeward side to the pollution source during the major part of the season. At Ranoli (LWD), like monsoon observations, high reduction in ascorbic acid content (39.4%) was recorded during winter also. This may be due to the closer proximity of the source and jamun may be more sensitive to chlorine pollution, which is the major pollutant at this station (Fig.4.13.4.).

(iii)Foliar protein:

The protein content in plants growing at different experimental stations decreased significantly as compared to the control. According to earlier reports most of the damages are mediated via the adverse effects on enzymatic pathways. Sulphur dioxide which is one of the major pollutants, damages the disulphide bonds of protein molecules and disturbs the enzymatic activity (Godzik and Linskens,1974, Puckett et al., 1974, Rudolf and Kreeb, 1979). It was observed that protein content was also reduced at Ranoli where the chlorine is the major pollutant. This may be due to decrease in protein synthesis or by protein hydrolysis (Shevyakova and Leonova, 1975).

*Mangifera indica* L. (mango):

During monsoon high reduction (34 to 48%) in foliar protein was observed at highly polluted stations like Ranoli, Omkarpura and Damapura (WWD). Comparatively less reduction was recorded at Bajwa and Koyali ( 8 to 15%) which were on the leeward side during most part of the season. At Angadh, which was also on leeward side of the source, plants exhibited 30.2% reduction in protein content. Thus the variety of pollutants emitted from the Nandesari industrial estate, which was very close to this station resulted in high degree of damage to foliar protein in mango.

During winter, the percentage reduction in protein content was 28.2 and 18.7 at Bajwa and Koyali (WWD) respectively. At stations in leeward direction to the pollution sources, the percentage reduction in protein content during winter was slightly less than monsoon observations.

During summer, 30 to 40% reduction was observed at Omkarpura, Damapura and Ranoli (WWD). Significant reduction (15 to 25%) was observed at Angadh and Bajwa (LWD) may be due to closer proximity of the pollution sources. At Koyali protein content was slightly less (6.6%) than control. Thus, in mango slight recovery in foliar protein content was observed during the favourable spell (Fig.4.11.4.) .

Manilkara hexandra (Roxb.) Dubard.(rayan):

During monsoon, high reduction in protein content was recorded at Omkarpura (36.7%) and Damapura (31.4%) which were on the windward side to the source during the most part of the season. At Angadh and Bajwa which were on leeward side the protein content reduced 23.1% and 14.5% respectively due to close vicinity of the source.

During winter, foliar protein content significantly recovered or increased at Sankarda, Ranoli, Padamla and Fajalpur (LWD). At Sankarda protein level was more or less close to control. At Ranoli, Padamla and Fajalpur reduction ranged from 8 to 11%, whereas at Omkarpura and Damapura it was 22.2% and 18.6% respectively. This shows, that in rayan, protein content could recover at stations in leeward side, when the pollutants flow towards this direction was comparatively for a shorter period.

During summer, 28 to 46% reduction in protein content was recorded at Omkarpura, Damapura and Ranoli (WWD). At Angadh and Bajwa (LWD) also significant reduction in foliar protein content was recorded (26.1% and 21.8% respectively).

Thus in rayan, foliar protein content showed significant recovery at Sankarda, Padamla, Fajalpur, Koyali and Ranoli, whereas at other stations comparatively lesser recovery was observed during the favourable period (Fig.4.12.4.).

<u>Syzygium</u> <u>cumini</u> Skeels(jamun):

During monsoon, protein content recorded at Damapura, Omkarpura and Ranoli (WWD) was 31 to 39% less than control. At medium polluted stations like (Table 6) Sankarda, Fajalpur and Padamla (WWD) reduction was 14 to 25%. Significant reduction (12 to 20%) in foliar protein content was recorded at Angadh, Bajwa and Koyali (LWD). Thus the pollutants concentrations at these stations was enough to cause significant damage to foliar protein content of jamun saplings.

During winter, very high reduction in foliar protein content was recorded at Angadh (46.4%) and Bajwa (36.6%) which were on windward side to the pollution source for the most part of the season. At Ranoli and Damapura (LWD) also protein content was significantly less (28.6% and 26.7% respectively) than control. During winter, eventhough there was no visible damage at Omkarpura, Padamla and Fajalpur the reduction in protein content ( 12 to 20%) reflected the hidden injury in the plants, when the pollutants flow for 22.5% of days was in this direction during winter.

During summer, maximum reduction (44.1%) in protein content was registered at Damapura and 28 to 33% reduction at Omkarpura, Ranoli and Angadh. These observations clearly reflect that the average pollutants concentrations were also high at these stations. At Koyali, protein content was very close to control, which reflects its recovery from the winter damage as well as lower concentration of pollutants at this station (LWD) during summer could not cause significant damage to the protein content in jamun leaves (Fig 4.13.4.).

(iv) Total free aminoacids:

It is obvious that protein hydrolysis or the inhibition of protein synthesis due to pollution, increased the amount of total free aminoacids in the exposed plant tissues (Godzik and Linskens, 1974, Jager, 1975, 1977, Cowling and Bristow, 1979, Malhotra and Sarkar, 1979, Erickson and Dashek, 1982). Higher accumulation of free aminoacids in foliar tissues of all the three species was observed than control at all the experimental stations.

*Mangifera indica* L. (mango):

During monsoon, high accumulation of free aminoacids over control was ( 2 to 2.5 times) recorded at Damapura, Omkarpura and Ranoli (WWD). Eventhough the plants growing at Angadh and Bajwa were on leeward side to the source for the major part of the season, higher accumulation of aminoacids (2·1 and 1·9 times over control respectively) was noticed due to closer proximity of the source.

During winter, very high accumulation of free amino-acids was recorded at Damapura (2·4 times) and Bajwa (2·0 times over control). Among the other stations, significant increase in free aminoacids content (1·6 to 1·87 times) over control was recorded at Omkarpura, Ranoli (LWD) and Koyali (LWD). Thus, the high accumulation of free aminoacids in mango leaves at Omkarpura, Ranoli and Damapura clearly indicates the high concentration of pollutants at these stations, even if they were in leeward side of the source, This may be due to closer proximity of the source and higher sensitivity of mango to air pollution. At Sankarda, Padamla and Fajalpur (LWD) the free aminoacids content (1·2 to 1·3 times over control) during winter was slightly less than monsoon observations at the respective stations.

During summer, free aminoacids accumulation was 2·1 to 2·6 times over control at Damapura, Omkarpura, Ranoli (WWD) and also at Bajwa and Angadh which were on leeward side to the source during the most part of the season. This high degree of damage at Bajwa and Angadh (LWD) may be due to very close vicinity of the source and higher sensitivity of mango saplings to air pollution (Fig.4.11.4.).

<u>Manilkara</u> <u>hexandra</u> (Roxb.) Dubard.(rayan):

During monsoon, high accumulation of free aminoacids over control (4.2 times) was recorded at Omkarpura and Damapura (WWD), where the pollutants flow (79.2% of days) and their concentrations were high during this season (Table 6). At other stations which were on windward side to the source, the accumulation of free aminoacids was 2.3 to 3.9 times over control. At Bajwa and Koyali (LWD), comparatively less accumulation (1.7 and 1.6 times) was observed as the pollutants flow was only 18.3% days in this direction during monsoon.

During winter, free aminoacids accumulation was very high at Angadh (4.0 times). The free aminoacids level (1.4 to 3.3 times) at all the stations on leeward direction decreased considerably as compared to monsoon observations. This shows, the free aminoacids might be utilised for protein synthesis or the rate of degradation of protein molecules might be reduced due to the recovery phenomenon in the plants during the favourable period.

During summer, very high accumulation ( 4 to 4.9 times) of free aminoacids over control was recorded at Omkarpura, Ranoli and Damapura (WWD). At Angadh, Bajwa and Koyali the accumulation of free aminoacids was (2.2 to 2.7 times) comparatively less, as the stations were on leeward side of the source during the major part of the season (Fig 4.12.4.).

<u>Syzygium cumini</u> Skeels (jamun):

Compared to other two species, free aminoacids accumulation was less in jamun saplings. During monsoon, higher free aminoacids content was recorded at Damapura (1.67) and Omkarpura (1.6 times) where the plants received high concentration of pollutants (Table 6) for 79.2% of the days. At the remaining stations it was from 1.2 to 1.5 times over control.

During winter, free aminoacids content increased (1.3 to 1.7 times) highly at Angadh, Bajwa and Koyali (WWD). Among the stations on the leeward side to the source, aminoacid level was close to the control at Omkarpura, Padamla Sankarda and slightly higher (1.38 times) at Fajalpur. This shows, protein metabolism in jamun saplings was less affected at these stations during winter, as they were exposed to pollutants for 22.5% of days during this season.

During summer, plants growing at Damapura, and Omkarpura (WWD) exhibited greater accumulation (1.76 and 1.7 times) of free aminoacids over control. At Koyali (LWD) it was very close to control. Thus in jamun, the degree of damage to protein metabolism considerably decreased at the stations in leeward side to the source. The recovery phenomenon was significant at Koyali, Sankarda, Padamla, Fajalpur and Omkarpura (Fig.4.13.4).

(v) Total soluble sugars:

The inhibitory mechanism of pollutants like $SO_2$ and NOx on photosynthesis has been well studied by earlier workers. The photosynthetic rate decreases by reducing the activity of ribulose diphosphate carboxylase (RuDPC) and increasing the activity of glucose 6-phosphate dehydrogenase ensymes. The degradation of chlorophyll molecules and the low photosynthetic rate results in less photosynthetic product in plant tissues, (Horsman and Wellburn, 1975, Capron and Mansfield, 1976, Taniyama, 1979, Winner and Mooney, 1980b, Hallgren and Gezelius, 1982, Saxe, 1983). In the present investigation the soulble sugar content was observed less than control plants in the three species at all the experimental exposure stations.

Mangifera indica L. (mango):

During monsoon, the souble sugar content was maximum reduced (27.7%) at Damapura, and the reduction was 16 to 20% at Omkarpura , Ranoli (WWD) and Angadh (LWD). At Koyali, the soluble sugar content was least affected as the wind direction was only for 18.3% of days during this season towards this station.

During winter, higher reduction in foliar sugar content was recorded at Damapura (28·8%), Bajwa (21·6%) and Ranoli (21·1%) as compared to control. During winter, the degree of damage to foliar sugar content was more or less close to monsoon observations at the stations in leeward side. This shows the higher sensitivity of mango, which exhibited insignificant recovery in sugar content during the favourable period.

During summer, plants growing at Damapura (WWD) exhibited higher reduction (31·4%) in sugar content. Among the other stations, 21 to 23% reduction was registered at Omkarpura, Ranoli (WWD) and Angadh (LWD) due to close vicinity of the source (Fig.4.11.5.).

<u>Manilkara</u> <u>hexandra</u> (Roxb.) Dubard.(rayan):

During monsoon, at highly polluted stations like Omkarpura, Ranoli and Damapura (WWD) 21 to 30% reduction in foliar sugar content was recorded. At Koyali (LWD), souble sugar content was slightly higher (7·5%) than control. This may be due to the enhancement of photosynthetic rate in rayan saplings due to resistant mechanism against the comparatively low concentration of pollutants at this station (LWD) during this season.

During winter, high reduction in sugar content was recorded at Angadh (37·8%) and Koyali (24·3%), which were on windward direction for major part of the season (62.5% of the days). During winter, at the stations in leeward side, the percentage reduction in sugar level was comparatively less than monsoon observations.

During summer, high reduction (28 to 35%) in soluble sugars was recorded at Omkarpura, Damapura and Ranoli (WWD). At Koyali the sugar content was more or less close to control. Thus, the degree of damage to foliar sugar content of rayan leaves, was significantly decreased mostly at all the stations during the favourable period (Fig 4.12.5.).

<u>Syzygium</u> <u>cumini</u> Skeels (jamun):

During monsoon, maximum reduction (28.3%) in soluble sugars was recorded at Damapura (WWD) and 21 to 27% reduction was registered at Ranoli, Omkarpura and Fajalpur (WWD). At stations in leeward side to the source i.e. Angadh, Bajwa and Koyali the reduction in foliar sugar content was 15 to 18%. This shows that in jamun the sugar level decreased significantly, where the flow of pollutants towards these stations was comparatively less (18.3% of days during this season).

During winter, 23 to 33% reduction in sugar content was recorded at Bajwa, Angadh and Koyali (WWD), as the plants received pollutants for 62.5% of the days during this season.

At Ranoli and Padamla (LWD) the percentage reduction (26.2% and 16.7% respectively) was more or less close to monsoon observations, whereas at all other stations in leeward side the degree of damage to foliar sugar content during winter was significantly less than monsoon observations.

During summer, at Damapura (WWD) the foliar sugar content was 36.8% less than control. At Bajwa and Koyali (LWD) the reduction was 13.2% and 7.5% respectively (Fig.4.13.5.). Thus, in jamun the degree of damage to foliar sugar content considerably decreased during the favourable spell at most of the stations except Ranoli. This also supports that Jamun may be more sensitive to chlorine pollution where this is the main pollutant and its ambient air concentration is often high.

(vi) Foliar sulphur:

Several workers have observed that in plant tissues, the absorbed $SO_2$ from the ambient air is converted into sulphur compounds like sulphite, sulphate etc. They have established that sulphur accumulation in the plant tissues may be considered for the extent of pollution existing at particular site and also to determine the sensitivity of the plants to sulphur dioxide (Katz,1949, Thomas and Hendricks, 1950, Roberts,1974, Farrar et al., 1977, Keller,1981, Boiko *et al*., 1985, Landolt and Keller, 1985). In the present investigation, sulphur accumulation in the foliar tissues of all three species was recorded higher than control at all the experimental stations. This clearly indicates that sulphur dioxide is the major pollutant at these stations.

*Mangifera indica* L. (mango):

During monsoon, highest sulphur accumulation was recorded in mango saplings at Damapura (3.11 times over control), the $SO_2$ level was also maximum at this station during monsoon. Among other staions in windward side, higher accumulation of sulphur was recorded at Omkarpura (2.9), Fajalpur (2.4) and Ranoli, Padamla and Sankarda (1.87 to 2.1 times over control). Thus the accumulation of sulphur in mango leaves indicates the ambient air $SO_2$ pollution at the respective sttations (Table 6). At Ranoli, mango leaves accumulated sulphur 2.1 times over control. This shows, that at this station although chlorine is the major pollutant from Alkalies and Chemicals industry, sulphur dioxide is also present in the ambient air. At Angadh and Bajwa (LWD) sulphur accumulation was significantly higher (2.3 and 1.76 times) than control. This clearly indicates, the close proximity of the source resulted in higher accumulation of pollutants.

During winter, at stations in leeward direction to the pollution source, the sulphur content in the foliar tissues was 1.4 to 2.63 times over control. During winter, the accumulation of sulphur was slightly less as compared to monsoon observations at the stations in leeward side of the pollution source. At Bajwa and Koyali, foliar sulphur content in the saplings was 3.1 and 2.3 times over control respectively, as these stations were on windward side during most part of the season.

During summer, foliar sulphur accumulation was very high (3.11 times) at Damapura. As the wind direction towards Angadh, Bajwa and Koyali was for 35.8% of the days during summer, the foliar sulphur content was also significantly higher (2.17 to 2.86 times) than control (Fig.4.11.5.). Thus mango exhibited higher accumulation of sulphur at all the stations, even at the stations in leeward side of the pollution source during the most part of the season. This shows the higher sensitivity of mango to air pollution.

This may be due to slow rate of metabolisation of accumulated sulphur during the favourable period or the absorption of $SO_2$ may be faster than its utilization in the plant tissues.

<u>Manilkara</u> <u>hexandra</u> (Roxb.) Dubard.(rayan):

During monsoon, higher sulphur accumulation was recorded at Damapura (2.50 ) and Omkarpura (2.14 times) which were on windward side of the pollution source during the most part of the season. At other stations in the windward side of the source, sulphur content was 1.5 to 2.02 times more than control, but other stations in the leeward side of the source foliar sulphur content was 1.1 to 1.5 times more than control. Thus during monsoon, in rayan sulphur accumulation was comparatively less at the stations in the leeward side of the pollution source.

During winter, foliar sulphur content was very high at Angadh (2.81 times) and Damapura (2.16 times over control). At the stations in the leeward direction i.e. Omkarpura, Fajalpur, Sankarda, Padamla and Ranoli foliar sulphur accumulation ranged from 1.2 to 1.64 times over control. In rayan, the sulphur accumulation was less at the stations in leeward side of the pollution source, as compared to monsoon observations.

During summer maximum (3.1 times) sulphur content was recorded in the rayan saplings growing at Damapura (WWD) followed by Omkarpura (2.64 times). Eventhough, plants growing at Angadh and Bajwa were on leeward side of the source during most part of the season, due to close vicinity of source high accumulation of sulphur (2.71 and 1.79 times respectively ) over control was recorded (Fig 4.12.5.).

Syzygium cumini Skeels (jamun):

During monsoon, sulphur content in the exposed saplings was observed maximum (2·31 times over control) at Damapura (WWD). At other stations in windward side of the pollution source, it was 1·33 to 1·85 times over control. Jamun plant growing at Angadh and Bajwa (LWD) exhibited higher accumulation of sulphur (1·53 and 1·32 times) as these stations were very close to the pollution source. At Koyali (LWD), sulphur level was slightly higher than (1·19 times) control, as the plants received pollutants for a shorter duration (18·3% of days during monsoon).

During winter, higher sulphur accumulation was recorded at Angadh (2·82 times), Bajwa (2·67) and Koyali (1·73 times) over control, as these stations were on windward side of the pollution source during most part of the season. Among the stations in leeward side of the source, sulphur content was very high (1·83 times) at Damapura whereas at other stations it ranged from 1·1· to 1·42 times over control. As compared to monsoon, the accumulation of sulphur during winter was less in the plants growing at leeward side of the pollution source. This shows that jamun might have metabolised the accumulated sulphur at the higher rate which was reflected in lower sulphur accumulation and fairly good growth of plants at these stations during winter.

During summer, at Damapura, Omkarpura and Ranoli (WWD) the foliar sulphur content was 1.68 to 2.6 times over control (Fig.4.13.5.). During summer, foliar sulphur content in the plants growing at Angadh (LWD) was 2.01 times over control. It may be due to its close vicinity to the source, and higher pollutants concentration in the ambient air (Table 6).

This study reveals that mango saplings are highly sensitive to pollution and accumulate more sulphur in the foliar tissues which resulted in high degree of damage to plants. The change in wind direction did not reduce the plant damage at highly polluted stations like Damapura, Angadh, Omkarpura, Bajwa and Ranoli, but slight recovery was observed in the plants growing at Sankarda, Fajalpur, Padamla and Koyali. This was well reflected by the lesser damage to the morphological and biochemical parameters. Thus lesser recovery of mango saplings during favourable spell shows its inability to enhance its metabolic activity, or the prevailing low ambient air pollution concentration at the respective stations (LWD) may be forming additive dose in the foliar tissues.

Comparatively jamun plants recovered more during favourable period and it was well reflected in various morphological and biochemical parameters. Damage to jamun saplings was comparatively more at Ranoli, as well as recovery in morphological growth parameters was less when it was in leeward side to the pollution source. The high degree of damage to jamun at Ranoli shows its sensitivity of major pollutants i.e. chlorine, sulphur dioxide etc.

Eventhough rayan saplings did not show any visible damage at most of the stations (except highly polluted stations like Damapura, Angadh, Omkarpura, Bajwa and Ranoli) the biochemical observations revealed hidden injury in the plant. This species also exhibited different degree of recovery at all the stations during the favourable period, but the recovery phenomenon was very significant depending on the distance and low concentration of pollutants in the ambient air (LWD) at Stations like Sankarda, Fajalpur, Padamla, Koyali and Ranoli.

Thus, rayan is occupying intermediate position in recovery behaviour between mango and jamun. In all the three seasons, plants growing at Damapura and Angadh exhibited high degree of damage even when they were in leeward side of the pollution source. This may be due to their closer proximity of the pollution source and mixture of various pollutants emitted from the industries at the Nandesari Industrial Estate.

## 4.3. ARTIFICIAL FUMIGATION STUDY

The exposure of tree saplings to known concentration of sulphur dioxide showed that normal metabolic pathway in the plant was disturbed by the $SO_2$ exposure. In all the three species under investigation, the concentration of photosynthetic pigments and metabolites like ascorbic acid, protein, sugars etc., were altered in $SO_2$ exposed plants ($C_2$) as compared to their respective unexposed control plants ($C_1$).

### 4.3.1. EFFECT OF SULPHUR DIOXIDE

(i) Foliar response:

According to Katz, 1949, Thomas and Hendricks, 1950, Treshow, 1976, Smith, 1983, the plants subjected to air pollution stress, exhibit damage by visible foliar injury. The sensitive species exhibit the high degree of foliar injury than the resistant species, when exposed to same concentration of pollutant/s (Smith, 1983, Prasad *et al*., 1979, Guderian and Kueppers, 1980, Murray, 1984b). In the present investigation, visible foliar damage was recorded earlier in *Mangifera indica* L. (mango), whereas *Manilkara hexandra* (Roxb.) Dubard (rayan) and *Syzygium cumini* Skeels (jamun) did not show any visible damage upto 60 ppm $h^{-1}$ accumulative $SO_2$ exposure. From this, it can be easily concluded that *Mangifera indica* is highly sensitive to sulphur dioxide than

*Manilkara hexandra* and *Syzygium cumini*.

Tip burning symptoms were observed in mango leaves of $SO_2$ exposed plants ($C_2$) at 90 days. This shows that the exposure of 30 ppm $h^{-1}$ accumulative $SO_2$ induced visible damage in 17.39% leaves. With an increasing number of exposures the foliar damage also increased. After exposing to 60 ppm $h^{-1}$ accumulative $SO_2$ dose, 88.9% of the leaves exhibited the injury index of 38.9%. Thus mango is highly sensitive to sulphur dioxide pollution (Rao, 1972).

(ii) Photosynthetic pigments:

The detrimental effect of sulphur dioxide on photosynthetic pigments has been worked out by many workers (Ricks and Williams, 1975, Santo *et al*., 1979, Dubey *et al*., 1982, Hallgren and Gezelius, 1982, Saxe *et al*., 1983). Lowering of cell sap pH due to sulphur dioxide, resulted in the loss of $Mg^{++}$ from chlorophyll molecules and formed phaeophytin molecules.

In the present study, the chlorophyll pigments gradually decreased in $C_2$ plants with increasing $SO_2$ exposures. After exposing to 60 ppm $h^{-1}$ accumulative $SO_2$ dose, the percentage reduction in chlorophyll *a* and *b* of $C_2$ plants was 43.57% and 46.1% in mango; 26.5% and 27.3% in rayan; 23.7% and 20.9% in jamun respectively as compared to $C_1$ of the respective species. This clearly shows that the chlorophyll pigments are highly damaged in mango as compared to other two species. This also supports the earlier two phases of the present study i.e. field survey and field exposure of the potted saplings, that mango is highly sensitive to pollution, especially to sulphur dioxide.

The carotenoid pigments were also adversely affected by $SO_2$ exposure in all the three species. At 180 days, in $C_2$ plants the carotenoids level declined to 38.57% in mango, 24.3% in rayan and 18.04% in jamun with respect to control ($C_1$). Thus the percentage reduction of carotenoid pigments was comparatively less than that of the chlorophyll pigments. These observations also supports the earlier reports that chlorophyll pigments are highly prone to sulphur dioxide than carotenoids (Nouchi et al., 1973, Prasad and Rao, 1982) (Fig.3.6.1.,3.7.1 and 3.8.1.).

(iii) Ascorbic acid content:

Sulphur dioxide readily diffuses into the leaf and dissolves in the water molecules of mesophyll tissue, forming sulphite which is a highly toxic form of sulphur. Formation of sulphite accompanied by the generation of free oxygen radicals, possibly through a series of reactions (Fridovich and Handler, 1961). In the course of reaction hydroxyl and $H_2O_2$ are also formed (Alscher, 1985). These free radicals are likely to promote the oxidation of ascorbic acid to dehydroascorbic acid. The reduction in ascorbic acid may be due to its conversion into oxalic acid or convertible carbohydrates (Hogler and Herman,1973, Young and Loewus, 1975). The foliar ascorbic acid decreased in the plants, when exposed to $SO_2$ due to oxidizing property of $SO_2$. Such reduction in ascorbic acid content in $SO_2$ exposed plants was reported by Materna,1972, Choudhary and Rao,1977, Keller and Schwager,1977, Nandi et al., 1981, Varshney and Varshney, 1984b.

In the present investigation, the reduction in ascorbic acid due to 60 ppm $h^{-1}$ accumulative $SO_2$ exposure was 29.76% in mango (Fig.3.6.2.), 29.0% in rayan (Fig.3.7.2.) and 29.3% in jamun (Fig.3.8.2.) as compared to $C_1$. Thus the degree of damage to foliar ascorbic acid content was almost similar in all the three species.

(iv) Protein and total free aminoacid content:

It is well known that sulphur dioxide damages the structure of protein molecules by affecting disulphide bonds and also decreases the protein content by inhibiting the protein synthesis (Godzik and Linskens,1974, Rudolf and Kreeb,1979, Malhotra and Sarkar, 1979). This phenomenon leads to increase in free aminoacid content in $SO_2$ exposed plant tissues. Similar observations were recorded in the present investigation also i.e. reduction in protein content amd increase in free aminoacid level with increasing $SO_2$ exposures. This was observed in all the three species under investigation.

Maximum reduction in foliar protein content (32.7%) was recorded in $C_2$ plants of mango (Fig.3.6.3 A) at 180 days, whereas in rayan (Fig.3.7.3A) and jamun (Fig.3.8.3A) the percentage reduction was 24.5 and 27.6 respectively as compared to $C_1$ plants. This also supports that mango is more sensitive to $SO_2$ than rayan and jamun.

In $C_2$ plants of mango, accumulation of free aminoacids was 58.8% (Fig.3.6.3B) higher than $C_1$ at 180 days, whereas in rayan (Fig.3.7.3B) and jamun (Fig.3.8.3B)52.5% and 42.5% increase over $C_1$ was recorded at 180 days. This shows that sulphur dioxide exposure induced rapid accumulation of free aminoacids in foliar tissues of exposed plants.

(v) Soluble sugar content:

The effect of sulphur dioxide on chlorophyll pigments and photosynthetic pathways ultimately reflects in reduced photosynthetic products (Winner and Mooney 1980b, Hallgren and Gezelius 1982, Saxe, 1983).

At 30 days, i.e. after exposing to 10 $ppmh^{-1}$ accumulative dose of $SO_2$, the sugar content was less affected in $C_2$ plants of all the three species. This shows that low concentration of $SO_2$ may have less effect on soluble sugar level but increased number of exposures proved detsrimental to the plants. Among the three species, maximum reduction (31.6%) in sugar content was in $C_2$ plants of mango (Fig.3.6.4A) at 180 days, whereas in rayan (Fig.3.7.4A) and jamun (Fig.3.8.4A) the reduction was 26.8% and 22.1% respectively with respect to unexposed ($C_1$) plants.

(vi) Sulphur content:

The sulphur content in the $SO_2$ exposed plants obviously increased with increasing number of $SO_2$ exposures. This shows that the plants absorb sulphur dioxide and metabolize into different sulphur compounds. The rate of absorbtion and rate of metabolization of absorbed $SO_2$ are the major factors determining the damage to the plant species, but the accumulation of sulphur in the foliar tissues may be considered to determine the sensitivity of the species as well as extent of pollution in the ambient environment (Katz,1949, Roberts, 1974, Farrar et al.,1977, Boiko et al., 1985, Landolt and Keller, 1985).

In the present investigation maximum sulphur content (46.5%) was observed in $C_2$ plants of mango (Fig.3.6.4B)after exposing to 60ppmh$^{-1}$ accumulative $SO_2$ dose, whereas it was 39.2% in rayan (Fig.3.7.4B) and 34.5% in jamun (Fig.3.8.4B)as compared to their respective control ($C_1$) plants. The accumulation of sulphur in all the three species was in close range, but the toxicity was highly reflected in mango and comparatively lesser in the other two species. According to Alscher 1985, the relative degree of tolerance to $SO_2$ which any particular species possess may be due to a more efficient detoxification pathway of $SO_2$. The rapidity with which sulphite was detoxified, is greater in the resistant species (Miller and Xerikos, 1979). This shows that not only the accumulation of sulphur is responsible for the damage, but also the species (mango) may be genetically more sensitive to sulphur dioxide than the other two species.

4.3.2. AMELIORATION OF $SO_2$ EFFECT

Many attempts are being made to minimise the deleterious effects of pollutants like $SO_2$, NOx, $O_3$, HF etc., on vegetation by various nutrient or chemicals as foliar spray or soil treatment (Siegel,1962, Srivastava et al., 1975, Klein and Jager,1976, Cowling and Lockyer,1978, Ayazloo et al., 1980, Pandey and Rao,1980, 1981; Nandi et al., 1981, 1984; Pandey,1982, Olszyk and Tingey,1984, Lee et al., 1985, Rao et al., 1985).

In the present investigation ascorbic acid was employed as an antidote against $SO_2$. Some of the earlier workers used ascorbic acid and its salts against oxidants like Ozone (Freebairn and Taylor,1960, Freebairn,1963) and also against $SO_2$ (Nandi et al., 1981).

According to Bleasdale (1952) the toxicity of $SO_2$ was due to its reducing property which upsets the equilibrium between sulphydryl ions and more oxidised sulphite ions. Ballantyne (1973) suggested that the variations in susceptibility of plants to $SO_2$ were due to difference in sulphite inhibition of phosphorylating activity and when the ratio of oxidized to reduced sulphydryl compounds increased in the presence of $SO_2$ fumigation, extensive foliar damage occured. As ascorbic acid protects the sulphydryl group from oxidation in the plant (Harrer and King, 1941) and able to control the accumulation of sulphydryl group in the plant body within the safe limits, by that it induce the tolerance to $SO_2$ in plants.

In the sulphur dioxide exposed plants, $SO_2$ reduction may lead to the formation of $H_2S$ (Silvius _et al._, 1976), which has been shown to escape from plants fumigated with $SO_2$ (De Cormis,1968b, Hallgren and Fredriksson,1982, Filner _et al._, 1985). The reduction of $SO_2$ into $H_2S$ mediated by ascorbic acid, is likely to afford protection to the plant against $SO_2$ toxicity (Filner _et al._, 1985). Ascorbic acid also scavenges free oxygen radicals during the formation of sulphite (Fridovich and Handler, 1961) and may play important role in overcoming $SO_2$ toxicity (Varshney and Varshney, 1984b).

Ascorbic acid is well known grpwth promotor (Mapson 1958) and it acts via its radicals by creating a reductive atmosphere indispensable for the biosynthesis of macro-molecules and other cell constituents (Chinoy et al.,1974). Some investigators (Murty and Rao 1967, Tomar et al., 1971) reported that ascorbic acid foliar spray of 10 ppm and 20 ppm increased the yield significantly in rice and wheat respectively. Thus ascorbic acid (AA) may reduce the damage caused by the air pollutant/s especially $SO_2$, by inducing the growth or by above said various physiological mechanisms in the plant body. In the present study AA foliar spray was given in two concentrations i.e. 10 µ moles ($T_1$) and 100 µ moles ($T_2$).

4.3.2.1. Mangifera indica L. (mango):

In ascorbic acid treated $T_1$ and $T_2$ saplings, the concentration of photosynthetic pigments,prptein, ascorbic acid, soluble sugar content etc., were close to $C_1$ plants upto 10 ppmh$^{-1}$ accumulative $SO_2$ dose. This shows that ascorbic acid treatment nullified the $SO_2$ effect when the $SO_2$ dose was in low concentration, but in subsequent exposures the metabolites concentration declined gradually as compared to $C_1$.

In mango, 10 µ moles AA treatment ($T_1$) showed fairly good amelioration at all the ages than 100 µ moles ($T_2$)

concentration (Fig.3.6.1. to 3.6.4.). In $T_1$ and $T_2$ plants, after exposing to 60 $ppmh^{-1}$ accumulative $SO_2$ dose, the chlorophyll a (49.3% and 6.6%), chlorophyll b (55.9% and 18.1%), Carotenoids (45.7% and 2.7%), protein (25.0% and 4.1%), soluble sugars (18.5% and 4.8%) etc., were observed higher than $C_2$ plants. These observations clearly shows that 10 µ moles AA treatment was more effective in minimizing the $SO_2$ effect than 100 µ moles AA treatment. In $T_2$ plants fluctuating results were observed i.e. the metabolites concentration was observed more or less close to $C_2$ plants. This shows that 100 µ moles AA treatment may be closer to the toxic level to the mango saplings.

The foliar ascorbic acid content in $T_1$ and $T_2$ plants at 180 days was 25.8% and 5.3% higher than $C_2$ plants. Thus in 100 µ moles AA treated plants the foliar ascorbic acid content was less than 10 µ moles AA treated ones (Fig.3.6.2). Harrer and King (1941), Mapson (1958) reported that at low pH values ascorbic acid gets oxidized to dehydroascorbic acid. Thus, it can be assumed in the present study, the pH of cell sap gets reduced due to high dose of AA (100 µ moles), which resulted in higher oxidation of ascorbic acid in $T_2$ plants than $T_1$ plants.

4.3.2.2. Manilkara hexandra (Roxb.) Dubard.(rayan):

In this species 100 μ moles AA treatment ($T_2$) showed better mitigating effect than 10 μ moles AA treatment ($T_1$).

In rayan, fluctuating results were observed in 10 μ moles AA treatment i.e. the metabolites concentration in $T_1$ plants was observed more or less close to $C_2$ plants (Fig.3.7.1. to3.7.4.). After exposing to 60 $ppmh^{-1}$ accumulative $SO_2$ dose, in $T_1$ plants the metabolites concentration i.e. chlorophyll a (4%) , b (3.9%), carotenoids (3.8%), protein (10.1%) soluble sugars (1.3%) etc., were slightly higher than $C_2$ plants. Thus 10 μ moles AA treatment on rayan saplings exhibited insignificant amelioration.

In $T_2$ plants concentrations of metabolites were always significantly higher than $C_2$ plants at all the ages. The percentage increase in chlorophyll a (19.2%), b (20.8%), carotenoids (17.2%), protein (18.8%), soluble sugars (21.1%) etc., over $C_2$ plants, after exposing to 60 $ppmh^{-1}$ accumulative $SO_2$ dose clearly indicates the diminished $SO_2$ effect on $T_2$ plants due to 100 μ moles AA treatment.

As compared to $SO_2$ unexposed ($C_1$) plants, in $T_2$ plants at(60, 120 and 180 days) reduction in chlorophyll a (2.0%, 13.5% and 12.4%), b (1.8%, 12.4% and 12.2%), protein (4.1%, 11.3% and 10.3%), soluble sugars (1.3%, 10.5% and 12.1%

respectively) etc., was observed. Thus the 100 $\mu$ moles AA concentration is also not optimum level for complete mitigation of the damage caused to rayan saplings due to $SO_2$ exposure. The foliar ascorbic acid in $T_1$ and $T_2$ plants was higher than $C_2$ plants ($SO_2$ exposed and AA untreated), but less than $C_1$ (Fig.3.7.2) plants (neither exposed to $SO_2$ nor treated with AA). Thus, the reduction in AA even in AA treated plants due to $SO_2$ exposure shows the concentrations of AA applied were not sufficient to neutralize the damage caused by $SO_2$ in $T_1$ and $T_2$ plants.

4.3.2.3. Syzygium cumini Skeels (jamun):

In this species also, 100 $\mu$ moles AA treatment, minimized the adverse effect of $SO_2$ more than 10 $\mu$ moles AA treatment (Fig.3.8.1 to 3.8.4.).

10 $\mu$ moles AA treatment, exhibited fluctuating results in jamun plants i.e. more or less close to $C_2$ plants. The chlorophyll a (3.3%), carotenoids (2.4%), ascorbic acid (3.8%), protein (6.5%), soluble sugars (4.2%) etc., were slightly higher than $C_2$ plants after exposure to 60 ppmh$^{-1}$ accumulative $SO_2$ dose. Thus in jamun 10 $\mu$ moles AA treatment exhibited insignificant amelioration of $SO_2$ effect.

In $T_2$ plants, photosynthetic pigments, protein, ascorbic acid contents etc., were higher than $C_2$ plants at all the ages. At 60, 120 and 180 days the amelioration effect was well reflected by higher content of chlorophyll a (4.9%, 5.8% and 16.2%), b (3.2%, 8.8% and 11.8%), ascorbic acid (6.4%, 16.2% and 22.9%), protein (5.6%, 10.5% and 21.1%) , soluble sugars (5.9%, 4.3% and 18.9% respectively) etc., than $C_2$ plants.

The foliar ascorbic acid level in ascorbic acid treated plants ($T_1$ and $T_2$) was higher than $C_2$ plants ($SO_2$ exposed and AA untreated) but less than $SO_2$ unexposed plants ($C_1$). (Fig.3.8.2.) From these observations it can be assumed that the concentrations of AA treatments ( 10 and 100 μmoles) employed in this study were not at optimum level to neutralize the reduction caused by $SO_2$ exposure in jamun saplings.

The foliar sulphur accumulation due to sulphur dioxide exposure was less in ascorbic acid treated plants ( $T_1$ and $T_2$ ) of all the three species as compared to $C_2$ plants. As the ascobic acid mediates the reduction of $SO_2$ into $H_2S$ (Silvius et al., 1976) which has been shown to escape from $SO_2$ exposed plants (De Cormis,1968b), is likely to afford protection to the plants against $SO_2$ toxicity. It has been reported that externally applied AA can induce the growth and biosynthesis of macromolecules (Murty and Rao,1967, Tomar *et al*., 1971, Chinoy *et al*., 1974) . Thus, the accumulated sulphate may be rapidly utilized, reducing the sulphur level in the ascorbic treated and $SO_2$ exposed plants. This study shows that ascorbic acid may be used as an antidote against $SO_2$ damage to the plants. More work is required to establish the optimum dose of AA to reduce maximum damage and to establish cost benefit ratio.