Materials and Methods

MATERIALS AND METHODS

Study area

Geographically the study area falls under the Vadodara Urban Development Area (VUDA), which lies at 73° - 74°10' E longitude, 21° - 23° N latitude, and 30 m above mean sea level. The general topography of the area is plain with little undulations in the North (N) and North-West (NW) directions with the *Mahisagar* and the *Mini* rivers. The study area is intercepted by two small rivers (i.e., *Mini* and *Vishwamitri*), flowing from the N to NW direction Water of these two rivers was potable earlier. Presently they are used as industrial effluent canals. The study area is composed of Vadodara district's industrial zone which lies in NW direction of the Baroda city (Figure.1)

Climatic conditions

The climatic conditions of the study area can be described as 'normal' with no major alterations. Generally the weather remains dry (except during monsoon months) with three marked seasons (viz. Summer, Monsoon and Winter). Meteorological data has been collected from the Meteorological observatory connected to the Physics department of the M S. University of Baroda Temperature during summer remains high the mean ranges from 27.3 - 39 8° C in May, while it goes down to 13.8 - 28.2° C during January. The annual means of low to high temperatures were 21.3 - 33.0° C and 21 4 - 34.2° C for the years 1994-95 and 1995-96 respectively. Average rainfall for the years 1994 and 1995 was 932.2 mm At times, unprecedented precipitations may occur in months like January, April etc. Except during cloudy atmosphere, dry, hot and bright sunny days are prevalent in the study area. Wind flow pattern demarcated seasonally like other climatic factors It flows moderately and maximum average speed reaches upto 8 $km.h^{-1}$ during late summer and early monsoon (i.e. from

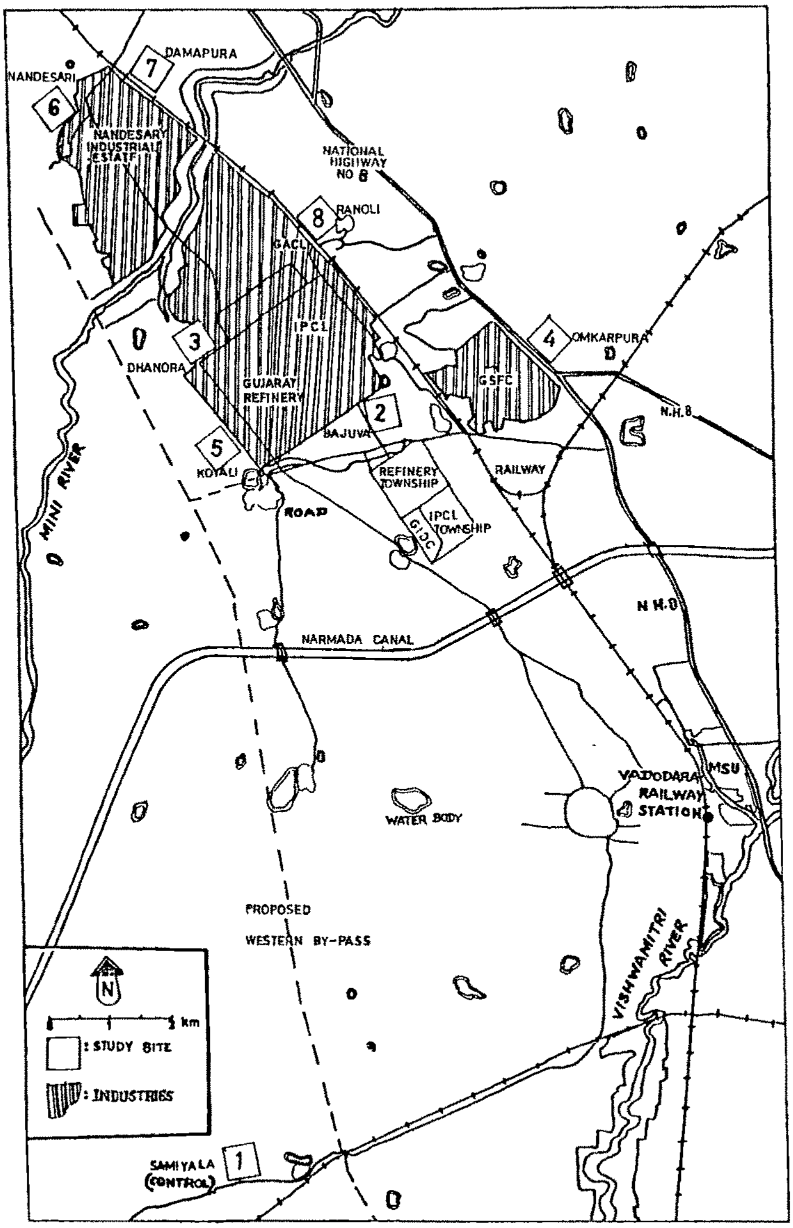

Figure 1 . Map of the study area with sites and major industries.

May to August) from South and South-West directions. Wind, then changes it's route and flows from N and NW, during winter with low speed averaging upto 3 km.h^{-1} (Table 4).

Industries and pollutants

The study area has a large group of industries (≅ 239), running on small to medium scales and polluting heavily (The Nandesari Industrial Estate). Other industrial giants are an oil refinery, a petrochemical complex, a fertilizer company, an alkalis and chemicals unit, a polymer unit, a plastics unit, a glass making unit, a diamines unit and a gas-based power plant. Their chemical products list is wide, and so also the pollutants emitted (Table 5). Common pollutants are oxides of nitrogen, sulphur dioxide, hydrocarbons, ethylene, methane benzene, ammonia, chlorides, fluorides and sulphides of many compounds in gaseous, liquid and solid stages Black soot and carbon dust from the refinery; Silicates, dust of gypsum and other types of particles from the fertilizer and an alkalis and chemical complexes are augmenting the atmospheric impurities. Various dyes, acid vapours and other solid particulates dispersed in the air from the Nandesari industrial units can form different unknown and untested effects under the influence of humidity/rain and sunlight

In addition to this, highway No 8, which passes through the study area with higher traffic density is contributing to the load of pollutants Other activities including extensive farming, houses and roads construction, brick-kilns are supplementing to defile the air at locality levels.

Ambient air quality monitoring

Ambient air quality monitoring data was procured from Gujarat Pollution Control Board (GPCB), Gujarat State Fertilizers Company (GSFC) and Indian Petrochemicals

Corporation Limited (IPCL). It was collected from time to time, coinciding with the sampling periods of trees. Data was combined and presented (Table 6). It was available for three sites in the industrial area and one in control site for sulphur dioxide (SO_2), oxides of nitrogen (NO_x) and suspended particulate matter (SPM)

Soil quality data

Soil samples were collected twice in a year at 5-10 cm depth from all the sites and were analysed at the Soil Testing Department of the Gujarat State Fertilizers Company Limited (Table 7).

SAMPLING PROTOCOL

The study area was divided into different localities. At each locality, a permanent sampling site was selected based on (1) The general vegetation survey (2) damage symptoms (3) wind-flow pattern and (4) industries and pollutants

General vegetation survey

It was conducted at the beginning of the study. Major ground vegetational species and all the woody species were recorded for the entire study area. General vegetation is of dry deciduous forest type. Ground vegetation (except few species) exists for 6 to 8 months, which mainly comes out during rains. It is chiefly composed of *Achyranthus aspera, Blumea obliqua, Boerhavia diffusa, Evolvulus alsinoides, Cucurbita* spp., common grass *Cynadon dactylon* and in wet places *Cyperus* spp. Common shrubs are *Calotropis gigantia* and *Phyllanthus reticulata*. *Acacia nilotica, Azadirachta indica, Holoptelea integrifolia, Moringa pterygosperma* and *Streblus asper* are common trees. In open/waste-lands or where water availability is difficult, there are trees like *Acacia* spp , *Streblus asper, Prosopis juliflora* and *Zizyphus* spp.

Capparis decidua and *Calotropis gigantia* are also present. *Argemone mexicana, Blumea obliqua, Boerhavia diffusa* and *Solanum xanthocarpum* are also present as annuals in open lands.

In the fields, usually tobacco is grown frequently. Wheat, maize, banana, brinjal, potato, cauliflower and onion are also grown. Sometimes cereals like bajra (*Pennisetum typhoides*) and jowar (*Sorghum vulgare*) are cultivated in the fields. Farmers have given up cultivating legumes due to reduced yields around the industrial area, while in control it is grown On the edges of fields, common shrubs like *Euphorbia nivulia* and *Ipomea carnea* are present. They are interspersed with climbers like *Clitoria* spp. and *Cucurbita* spp Trees like *Pithecellobium, Streblus* and *Alangium* are found to be preferred because of their bushy growths (on prunings) to protect the fields. Other trees like *Mangifera, Mimusops* and *Tamarindus* can be found along with *Azadirachta, Holoptelea* and sometimes with *Acacia* and *Anogeissus*.

Invasion by new species is a note-worthy phenomenon; where-in, *Ailanthus excelsa* and *Prosopis juliflora* have started encroaching open drier places. On the other hand, water bodies are trapped in the webs of stolons of exuberantly growing *Eichhornia crassipes* at many places.

Damage symptoms

Damage symptoms like chlorosis and necrosis were recorded on the foliar surfaces at various localities Symptoms were more on evergreens as their leaves persist for longer durations. In deciduous species, leaf longevity was reduced by early leaf fall. Upper sides of the tree canopies were with dried branches. Evergreens have shown two to three marked flush periods. Apical buds died in evergreens and new growth was carried out in form of lateral branches, giving a bushy appearance to the canopies.

Though leaf production was more in evergreen species, reduced leaf longevity has reduced fruit setting in polluted environments.

METHODOLOGY

The growth study was done for 12 tree species (Table 2) It was conducted for eight periods (i e., April-June, 1994 was the 1st and January-March, 1996 was the 8th) for two years (Table 4).

Criteria for selecting the tree species

Trees selected for the study are growing either on the field edges or in the fields (Plate 1A). At some places, they are present in the open-lands. Thus, some of them are close to each other forming a mixed canopy; while others are singly exposed to the nearby industrial complex. At each site, a minimum of 5 to a maximum of 10 individuals for each tree species were selected, based on their approachability for sampling. *Bauhinia* and *Cordia* were less frequent and minimum of 3 individuals for both of them were selected at each site. To attenuate the age differences, trees belonging to similar circumference (CBH) range were selected. It was kept in mind that randomly spread individuals of the selected tree species would present mixed vegetation pattern at a particular site (Figure 2). For these reasons, area of the sites selected for sampling was not less than 500 x 500 m in size.

Quantification of growth pattern

Growth pattern of trees cannot be done the way it is normally carried out for crop plants or annuals. Trees being perennials show continuity in growth for longer periods of time, and any study programme technically cannot be stretched in a similar

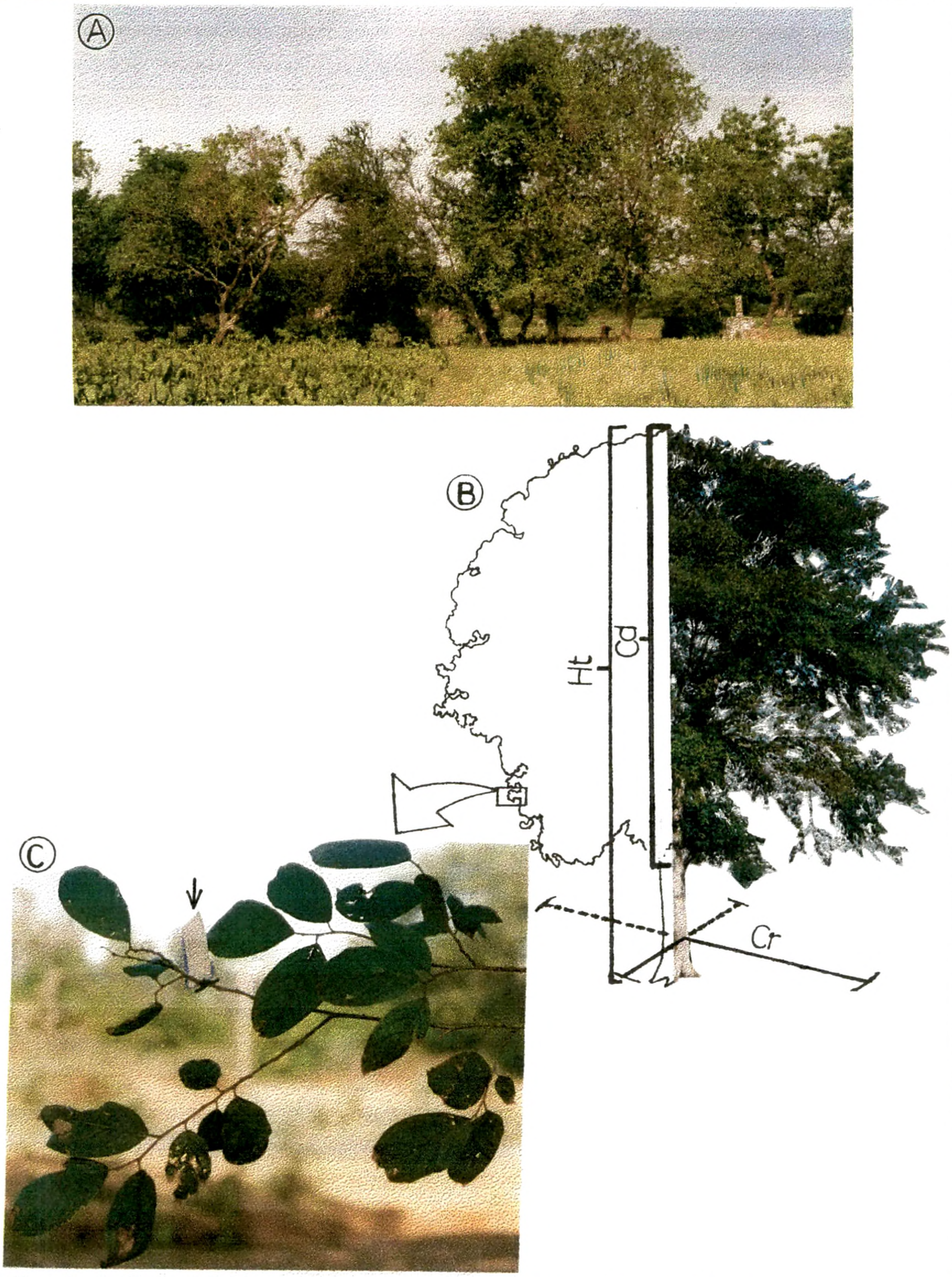

Plate 1 **A**, General field conditions. **B**, Growth parameters measured. **C**, Tagging experiment.

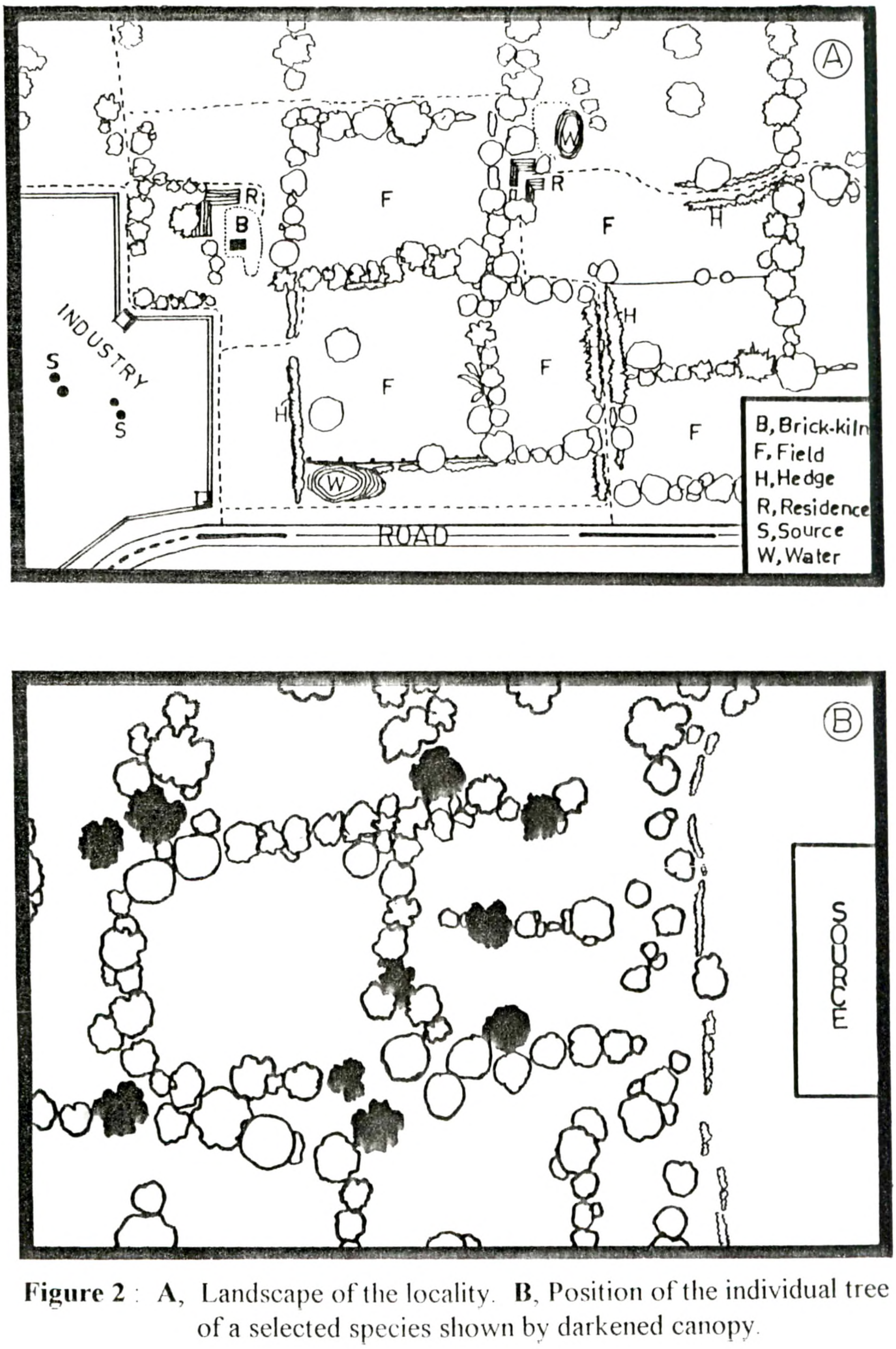

Figure 2 : **A**, Landscape of the locality. **B**, Position of the individual tree of a selected species shown by darkened canopy.

fashion. Growth pattern of a tree can be estimated for smaller time scales with some limitations. It can be monitoring the girth or height of the tree for one or two years. In this study emphasis was laid down to observe the relative variations in the growth pattern of trees over a two year period. To have near realistic estimates, growing branches were monitored regularly for all the trees growing at different sites. Variations in leaf area and biomass were recorded. These were considered as the markers for the growth pattern of trees. Growth pattern observed at control over a two year period was assumed as 100 %. Readings of polluted sites were compared with control. Variations in the observed parameters were used to quantify the growth pattern of trees at different sites.

Growth measurements

The growth measurements like height (Ht), circumference at breast height (CBH), spread or radius of canopy (Cr), and canopy depth (Cd) were taken for the selected trees (Plate 1B). Height was measured by using a multimeter, while circumference of the trunk at breast height and spread of canopy were measured by using a metre tape. Spread of canopy was measured in four opposite directions from the trunk to the end of the crown on the ground. Measured canopy radii were perpendicular to each other. Canopy depth was measured by measuring the height from the ground to the first branching point on the main trunk which was deducted from the total height (Tables 8 to 19). For collecting the samples from the same (selected) individual trees, maps were prepared for all the sites and trees were marked (Figure 2).

Sampling

At each site, sampling was done at an interval of 85 ($\pm$ 5) days by making it four sampling periods each year for two years. During each sampling three young growing twigs were collected from each individual tree canopy. They were positioned in different directions of the crown periphery at a height of 6 to 12 feet from the ground depending on the species. Those samples were brought to the laboratory and washed under running tap water. Starting from the tip of the branch, the first ten fully expanded leaves were separated and their average leaf area (LA), leaf area damage (LD) were measured by using a dot grid made on a transparent sheet. In case of compound-leaved species, leaf area was measured for an average sized pinna. Depending upon the number of pinna per leaf, the leaf area was estimated. Total number of leaflets (LL) were counted (*Moringa* was an exception because of faster withering of leaflets). Internodal length (IL) between 4th to 5th leaf was measured in all the species except in *Azadirachta* and *Mangifera*. These species have leaves in tufts on the tip of the branches, so IL readings were taken between the 6th to 7th leaf number. At the same point from the centre of the internode, girth (G) of the branch was measured by using a vernier callipers. If leaf fall (LF) was seen, then leaf scars present on the branch were measured as the number of fallen leaves. The first ten fully expanded leaves and the branch holdings them were packed separately and oven dried at 70° C for 48 hrs, and weighed. Twig weight (TWt) was calculated by adding leaf weight (LWt) and branch weight (BWt). In case of leaf fall, the left over leaves out of the first ten fully expanded ones were considered for all the selected growth parameters estimations (Table 8-19).

During the reproductive phase, number of flowers on each inflorescence (FL/IN), number of inflorescences on the sampled branch (IN/BR) and similarly, number of fruits per branch (FR/BR) were recorded. Sampling number for growth parameter study was wide and main emphasis was given to vegetative growth only. During sampling, if reproductive phase happened to be coincided then only readings (as mentioned above) pertaining to the tree's reproductive capacity were recorded. Thus, separate sampling was not done for reproductive cycle.

Tagging experiment

During the study, erratic alterations in tree phenology were noticed. To monitor leaf phenology and to identify its impact on growth performances, tagging was done on the young, growing branches depending upon easy approachability (Plate 1C). Trees selected for tagging were *Azadirachta* (from seven), *Holoptelea, Mangifera, Streblus* (from six) and *Tamarindus* from three sites including control. Branches were tagged and at an interval of 65 days, growth was recorded on these branches (Table 20). Number of young and matured leaves, total leaves, total shoot length (i.e., from the marking upto the tip) and leaf fall were recorded for nine months. Data was used to study phenological alterations and estimations of leaf longevity.

Dust deposition

It was done to see the dust holding capacity within different species and at which site the dust deposition was more. It was carried out during the 1st and 3rd periods. Sampled branches (at least 9 for each species, at each site) were brought undisturbed to the laboratory. Care was taken to minimise the loss of deposited dust during the transportation. Leaves and branches were washed in a beaker with a known amount of water. Then that water was filtered through an initially weighed filter paper. These filter papers were oven-dried and the differences between final and initial weights were taken as the amount of dust deposited on the known LA. It was expressed in g m^{-2} (Table 21).

Sulphur accumulation

Sulphur estimation was carried out to see individual tree species' capability to accumulate total sulphur in the leaves and branches. It was measured by turbidity method given by Garrido (1964). Dry powder of the leaves, and branches were weighed and samples were digested in an acid mixture (nitric and perchloric acid in 3:2 ratio). Potassium dichromate was used as a colouring reagent, while barrium chloride was used as a turbidometric reagent. Spectrophotometric readings were read at 420 nm. A standard graph was prepared by using known concentrations of sodium sulphate. Sulphur was estimated for the stem samples of summer and post-monsoons (1st and 3rd periods) while for foliar samples, sulphur was analysed for all the four periods (Table 22).

Calculations and Extrapolations

The means and standard errors ($\pm$ SE) of different growth measurements like tree height, trunk circumference, spread of canopy, canopy depth were calculated. Similarly different growth parameters like internodal length, girth of the branch, leaf area, leaf area damage, leaf fall, and leaflet number (in compound leaved species) were measured. Leaf weight, branch weight, twig weight, flowers per inflorescence and inflorescences, and fruits per branch were also calculated (Tables 8 to 19). Other values expressed based on calculations are, (1) leaf area ratio (LAR) = LA. TWt^{-1} ($cm^2. g^{-1}$), to know how much total biomass is prepared by a particular leaf area (Chiariello *et al.* 1989). (2) Specific leaf area (SLA) LA. LWt^{-1} (cm^2 g^{-1}) which shows ability of a plant to gain leaf biomass with the help of a particular leaf area (Chappelka & Chevone 1992). (3) Leaf weight ratio (LWR) LWt/TWt, to see biomass allocation among leaves and twigs and (4) Leaf to branch weight ratio (LWt/BWt) = LWt. BWt^{-1} (Laurence *et al.* 1994), to see the distribution of biomass among the leaves (source) and the branch (sink). The means and standard errors of different measurements for tagging were also calculated.

Dust deposited on a known leaf area was extrapolated for a unit surface area of 1 m^2, for easy comparison among different tree species and expressed in g m^{-2} (Table 21). Similarly accumulated sulphur in the leaves and branches was expressed in mg g^{-1} of the dry powder (Table 22).