IMPACT OF PARTICULATE POLLUTION ON THE GROWTH AND PHYSIOLOGY OF TREES IN MOIST DECIDUOUS FORESTS

By

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THESIS

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2013

DECLARATION

I hereby declare that this thesis entitled "**Impact of particulate pollution on the growth and physiology of trees in moist deciduous forests**" is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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ANOOB, P.

CONTENTS

LIST OF TABLES

LIST OF TABLES (CONTD)

LIST OF FIGURES

LIST OF FIGURES (CONTD)

LIST OF PLATES

Dedicated to

NAVANEETH, T.P.

(1990-2013)

A mother's loved son, a
sister's caring brother and a
wonderfully jovial friend for
everyone who knew him

INTRODUCTION

INTRODUCTION

Air borne particulates is a complex mixture of organic and inorganic substances of varying size and possess the capacity to enter an organism or plant through numerous ways. The most obvious damage to plant occurs in the leaves. Chlorosis, necrosis and epinasty are some of the major damages caused by air pollutants to plants (Prasad and Choudhury, 1992). The definition of air pollution is broad, and research studies are carried out to include the analysis of the plant responses to a wide range of pollutants released from various anthropogenic sources. The pollutant cement dust and its effect were studied, which is classified as particulate pollutant based on the particle size. Cement dusts which are emitted from the cement factories are considered to be one of the major sources of air pollution that drastically affects the plant growth and development. Cement dust is largely made up of cement-kiln dust. This cement-kiln dust is a by-product from the cement factories and is usually stored as waste in open pit, unlined landfills.

Increased concentration of cement dust pollutants leads to invisible injuries like progressive decline in the physiological process viz. photosynthetic ability and respiration rate of leaves. Also, visible injuries such as closure leaf stomata, a marked reduction in growth and productivity were observed due to the presence of cement dust (Raajasubramanian *et al.*, 2011).

It's a known fact that trees impinge, absorb and accumulate air pollutants to reduce the pollutant level in the air environment by providing enormous leaf area. Plants remove pollutants from air by three processes, namely deposition of particulates, absorption by leaves and aerosols over leaf surface (Prajapati, 2008). But the level at which different tree species provides these services vary among species (Hove et al., 1999).

While being ecologically friendly, the trees may be suffering injuries to its various morphological aspects as well as its physiological processes due to the process of removal of air pollutants. There have been reports that gaseous forms are absorbed by the leaves, while the particulate forms are absorbed through the outer surface of the plants. Affected plants shows some common effects such as decreased chlorophyll, necrosis, and inhibition in photosynthesis and decreasing plant growth (Davison and Blakemore, 1976).

The main species to be studied for the effect of pollution on the growth and physiology is *Tectona grandis* (Teak). Teak is a large deciduous tree with ovate-elliptic to ovate leaves and a very good timber. Due to the glabrous leaves of teak, they possess high potential to trap dust particles.

Teak is found in large numbers near the vicinity of the Malabar cements Ltd., Walayar. The analysis of the morphology and physiology of teak is done extensively by studying various parameters like photosynthesis, transpiration, air pollution tolerance index (APTI) and wood properties. Study of these parameters helps in determining the tolerance level exhibited by Teak for surviving in the drastic conditions available in the area. Malabar cements Ltd was chosen as the area of study because of the nature of the industry, and also to understand if the pollution control measures installed in the factory is having an impact on reducing the particulate pollution emissions.

The APTI values are studied for ten species commonly found in and around the Malabar cements. This helps in understanding to what level these trees are able to cope with its surrounding environmental and anthropogenic conditions. This also gives an insight to how well these select trees are able to tolerate the effects of cement dust pollution, to which they are constantly exposed. APTI is used for comparison of tolerance because of the universal acceptance that just a single factor cannot be used as an indicator of pollution tolerance. APTI is obtained through combination of four factors namely relative water content (RWC), pH of the leaf extract, chlorophyll content of the leaf and ascorbic acid content.

Objectives:

The continuous exposure to cement dust deposition results in damage to the plants and makes them vulnerable to insect and pest attack. Only species which are able to withstand such drastic stress environment can grow and successfully establish in these conditions. This study helps in shedding light on the tree species which are able to survive in cement dust accumulated atmosphere.

The study has been formulated by the following objectives:

1. Study of growth and physiology of *Tectona grandis* under particulate pollution stress
2. Comparison of Air Pollution Tolerance Index of the following moist deciduous tree species
    a. *Tectona grandis* (Teak)
    b. *Terminalia paniculata* (Pullamaruthu)
    c. *Bombax ceiba* (Poola)
    d. *Butea monosperma* (Plash)
    e. *Cassia fistula* (Kanikkonna)
    f. *Anogeissus latifolia* (Mazhukanjiram)
    g. *Pterocarpus marsupium* (Venga)
    h. *Grewia tiliifolia* (Chadachi)
    i. *Terminalia catappa* (Indian almond)
    j. *Artocarpus heterophyllus* (Plavu)
3. Study the effects of particulate pollution on the anatomical properties of *Tectona grandis*

REVIEW OF LITERATURE

REVIEW OF LITERATURE

India is one of the fastest growing economies in the world. This development quite often overlooks the environmental aspects and the stress caused by these activities on the ecology. The pollutants that are released into the atmosphere by different industrial sector had made the environment reach the brink of its carrying capacity in terms of air pollutants nitrous oxide, sulphur di oxide, carbon monoxide as well as carbon di oxide, suspended particles, heavy metals etc. The impacts of such emissions are severe on all the life forms, and their movement into the biosphere by transformation, reaction and modification is responsible for variety of chronic and acute diseases at the local, regional and global scale (Rawat and Banerjee, 1996). Impact on the plant community has been studied worldwide in terms of plant interactions with the environment, since plants are much more sensitive in comparison to other organisms (Abbasi *et al.,* 2004). Air pollutants can directly affect plants through their aerial parts (leaves and stem) or indirectly through the soil by acidification (Steubbing *et al.,* 1989).

Cement industry is the one of the 17 most polluting industries listed by Central Pollution Control Board (CPCB, 2013). During the last decades, the emission of dust from cement factories has been increased alarmingly due to expansion of more cement plants to meet the requirement of cement materials for construction of building. Different cements are composed of different ingredients; many of them contain substances that can be hazardous, like crystalline silica (quartz), lime, gypsum, nickel, cobalt, and chromium compounds (Green, 2004).

In comparison with gaseous air pollutants, most of which are known as being the cause of injury to various types of vegetation, limited studies and relatively little are known about the effects of cement dust pollution on the growth of plants (Iqbal and Shafig, 2001). Cement contains 3-8% aluminium oxide, 0.5-0.6% iron-oxide, 60-70% calcium oxide, 17-25% silicon oxide, 0.1-4% magnesium oxide and 1-3% sulphur trioxide (Ade-Ademilua and Umebese, 2007). Cement dust is composed of Ca, K, Si and Na which often include heavy metals like As, Al, Cd, Pb, Zn, Fe, and Cr. Majority of these elements in excess amounts are potentially harmful to the biotic and abiotic components of the environment (Gbadebe and Bankole, 2007). Farmer (1993) has reported that cement dust pollutants block the stomata, and a reduction in the number of annual crops. Sato et al., (1993) also reported that due to cement dust decreased the productivity and concentration of chlorophyll in a number of crops.

Importance of the study

Plants are very suitable for the detection, monitoring and mitigation of air pollution effects (Singh, 2005). Pollutants can cause injury to leaves, damage the stomata, premature senescence, decrease the photosynthetic activity, disturb membrane permeability and reduce the growth in sensitive plant species (Tiwari et al., 2006). Air pollutants interact with plants and alter their normal functioning. Characteristic morphological injury symptoms develops when plants are exposed to a high concentration of pollutants for a short duration or to chronic levels for relatively longer periods. Although exposure to lower concentrations does not produce any morphological injury symptoms, it will alter the biochemical processes significantly (Iqbal and Shafig, 2001). Air pollution adds an additional stress because it has been shown to increase the sensitivity to pest attack and to modify plant responses to drought (Zunckel *et al.,* 2000).

Toxic compounds such as fluoride, magnesium, lead, zinc, copper, sulphuric acid and hydrochloric acid were found to be emitted by cement manufacturing factories (Iqbal and Shafig, 2001). Plants that are constantly exposed to environmental pollutants will absorb, accumulate and integrate these pollutants into their systems. It's reported that depending on sensitivity level of the plant, plants show visible changes which would include alteration in the biochemical processes or accumulation of certain metabolites (Agbaire and Esiefarienrhe, 2009). Sensitive species are useful as early warning indicators of pollution while tolerant ones help in reducing the overall pollution load, leaving the air moderately free of pollutants (Rao, 1983). It is possible to estimate the overall effect of a large number of pollutants as total pollution by measuring changes in the plants (Agbaire, 2009).

Every plants are sensitive to air pollution. Some can resist fairly high levels of pollution and can be employed as indicators of air pollution (Trivedy and Goel, 1995). Biomonitoring of air pollution has been found to be extremely useful to detect the kind and level of pollutants in air with and without measurement of air pollutants (Prusty et al., 2005). Air quality of that area can be found by studying plant parameters like the presence, absence, abundance, morphology, distribution and chemical characteristics (Dwivedi and Tripathy, 2007).

2.1 Air Pollution Tolerance Index Estimation

APTI is an essential tool for the estimation of the level of tolerance of plants to air pollution stress. Relative water content (RWC), Ascorbic acid (AA) content, Total leaf chlorophyll (TCh), and leaf extract pH are the four physiological and biochemical parameters used for developing an APTI. Plants provide an enormous leaf area for the absorption and accumulation of air pollutants to reduce the pollutant levels in the environment air at varying degrees for different plant species (Escobedo et al., 2008). Air pollutants can directly affect the plants via its leaves or indirectly through soil acidification (Steubing *et al.*, 1989). The various factor of APTI such as ascorbic acid, chlorophyll, leaf pH, and relative water content generally show depletion under stress. Plants, which can resist this depletion, become air pollution resistant (Swami and Chauhan, 2007). When plants are exposed to air borne particulate pollutants, they experiences physiological changes before exhibiting visible damages to leaves (Dohmen *et al.*, 1990). Studies in the past have shown that particulate pollutants have effects on plant parameters like Ascorbic acid content (Hoque *et al.*, 2007), Relative water content (Rao, 1979), Total leaf chlorophyll (Flowers *et al.*, 2007), and pH of the leaf extract (Klumpp *et al.*, 2000). However these separate parameters gave conflicting results for the same species itself. Since one these parameters may show the plant species as sensitive to pollution while another of these parameter may implicate the same plant species as being tolerant to pollution (Han *et al.*, 1995 and Zhou 1996). For the reason that a single parameter fails to provide a clear picture about the tolerance level and pollutant induced changes in the plant species, Air Pollution Tolerance Index

(APTI) based on four parameters has been used to identifying the tolerance level of plant species. The combining of variety of these parameters gives a more reliable result than those of individual parameter (Agbaire, 2009). Air pollution tolerance level is different for each plant and plants do not show a uniform behaviour. Plants with higher index values are tolerant to air pollution and can be used as a filter of sink to mitigate pollution, while plants with lower index value show less tolerance and can be used to indicate levels of air pollution (Chauhan, 2010).

APTI is calculated following the method developed by Singh and Rao (1983). The formula is as follows:

$$APTI = A\ (T+P) \times R/10$$

Where;

A – Ascorbic acid content (mg/g)
T – Total chlorophyll (mg/g)
P – pH of leaf extract
R – Relative water content of leaf

To develop the ranges of APTI values for each category, the mean APTI and their standard deviation are calculated for the selected tree species.

The APTI of a particular geographical area can be used for biomonitoring air quality. The tolerant species and the species having more potential for collecting dust can be used for green belt development in polluted areas (Thakar and Mishra, 2010).

2.1.1 pH of Leaf extract

Adamson (1994) and Mandre (1998) noted that the particles of the cement dust were quite alkaline thus resulting in elevated pH levels which in turn affects the vegetation growth, rate of photosynthesis, respiration, and reduced growth rate. Radhapriya *et al.* (2012) observed that there was an increase in leaf pH in plant species studied with respect to their proximity to cement industries. All the plants collected from areas in and around the factory was found to be highly alkaline in the range of 7.8 to 9.0. High alkalinity is a characteristics of cement dust that contains $CaCO_3$ (Swierez, 2006). Cement dust that are released from the industry settles down on the soil as well as on the leaf surface, which might result in the increase in the alkalinity of the plant species which would otherwise exhibit a neutral pH in a normal environmental conditions (Radhapriya, 2012). Plants with alkaline leaf extract pH exhibits a high level of tolerance to pollution (Agarwal, 1988). High pH may increase the efficiency of conversion of hexose sugar to ascorbic acid (Escobedo. 2008). Low pH showed good correlation with sensitivity to air pollution and the efficiency of photosynthesis was noted to be heavily dependent on pH (Thakar and Mishra, 2010). In plants exposed to industrial emissions, there were almost no or minimal alterations in the leaf extract pH and buffering capacity (Klumpp *et al.*, 2000).

2.1.2 Relative Water Content (RWC)

Relative water content defines the moisture holding capacity of plants under study. RWC helps maintain a plants physiological balance under stress conditions like exposure to particulate air pollution, and thus higher the RWC in a particular species greater is its drought tolerance capacity (Dedio, 1975). Relative water content is associated with protoplasmic permeability in cells and results in the loss of water and dissolved nutrients, causing early senescence of leaves (Agarwal and Tiwari, 1997). The relative water content in a plant body helps in maintaining its physiological balance under stress conditions of air pollution (Dedio, 1975). Variations in the relative water content based on the weather conditions and availability of moisture content in soil. It also depends on maximum humidity. In places where humidity is high, plants are having high moisture too because of less transpiration (Thakar and Mishra, 2010). If the leaves transpiration rate are reduced due to air pollution, plants loses ability to pull water and minerals from roots for biosynthesis. Plants with higher RWC under pollution load was found to be more tolerant to pollutants (Radhapriya *et al.,* 2012). The reduction in photosynthesis appears in the form of reduced plant dry weight as shown in *Cassia fistula* (Raza *et al.,* 1988), *Ficus religiosa* (Tiwari and Bansal, 1996) and *Mangifera indica*

(Agarwal *et al.,* 1991). In *Ficus religiosa,* the leaf dry weight was reported to increase with pollution (Agarwal and Tiwari, 1996).

2.1.3 Ascorbic Acid (AA) Content

Ascorbic acid, commonly known as Vitamin C, is widely distributed in aerobic organisms and is involved in several biological processes. The biological and pharmacological activity, as well as the therapeutic potential of ascorbic acid and its derivatives has been studied extensively (Tripathi *et al.,* 2009). Ascorbic acid is an important reducing agent and plays an important function in cell wall synthesis, defences and cell division (Conklin, 2001). It also plays a vital role in photosynthetic carbon fixation with the reducing power directly proportional to its concentration (Pasqualini *et al.*, 2001). It plays a significant role in light reaction of photosynthesis (Singh and Verma, 2007), activates defense mechanism (Arora *et al.*, 2002), and when exposed to stress condition, it can replace water from light reaction (Singh and Verma, 2007). Ascorbate is known to be an antioxidant molecule which are capable of detoxifying air pollutants (Smirnoff, 1996). Its efficiency as an anti-oxidant may rest on the fact that its monodehydroascorbate radicals relative stability (Smirnoff and Wheeler, 2000). Ascorbic acid being a strong reducing agent as well as a strong anti-oxidant and are generally found to be in higher proportions in tolerant plant species. Tripathi and Gautam (2007) reported pollution load dependent increase in ascorbic acid content of plant species may be due to the increased rate of production of ROS during photo-oxidation process. Total chlorophyll content is related to ascorbic acid content productivity, since ascorbic acid content is concentrated mainly in chloroplasts (Thakar and Mishra, 2010). Air pollution results in a distinct decrease in ascorbic acid contents and an increase in peroxidase activity and thiol concentrations in leaves of the plants affected (Klumpp et al., 2000).

2.1.4 Total Leaf Chlorophyll (TCH)

Chlorophyll is the principle photoreceptor during the light driven process called photosynthesis in which carbohydrates and oxygen are produced by the fixing of atmospheric CO2. Photosynthesis gets inactivated in plants when they are exposed to pollution above physiologically acceptable range. Chlorophyll estimation is an important tool for analysing the effects of pollution on plants as it plays an important role in the plants metabolism and reduction in chlorophyll results in reduced growth of the plant (Joshi and Swami, 2009). Chlorophyll "a" is the molecule found in all plant cells and therefore its concentration is what is reported during chlorophyll analysis (Joshi et al., 2009). Chlorophyll is considered as an index of productivity of plants. Photosynthetic pigments degradation has been widely used as an indicator of air pollution (Ninave *et al.,* 2001). Photosynthetic activity as well as the growth and development of biomass of plants are indicated by its Chlorophyll content. It is known fact that chlorophyll content of plants varies from species to species; depending upon the age of leaf, pollution level as well as with other biotic and abiotic conditions (Katiyar and Dubey, 2001). Chlorophyll a, b and total chlorophyll are found to be in reduced proportions when they are exposed to cement dust pollution than those which are found in controlled conditions (Rahman and Ibrahim, 2012). The shading effects due to deposition of suspended particulate matter on the leaf surface might play a role for this decrease in the concentration of chlorophyll in polluted area. These particles might clog the stomata thus interfering with the gaseous exchange, which results in the increase of leaf temperature which may consequently retard chlorophyll synthesis. Dusted or encrusted leaf surface is responsible for reduced photosynthesis and thus cause reduction in chlorophyll content (Joshi and Swami, 2009). Radhapriya *et al.* (2012) study on selected plants around the cement dust plants recorded that the chlorophyll content in plant species varied with the pollution status. Higher the levels of Suspended Particulate Matter (SPM) and Respirable Suspended Particulate Matter (RSPM), lower were the chlorophyll content recorded. Cement dust decreases the leaf total chlorophyll content and chlorophyll a/chlorophyll b ratio, as a result photosynthetic rate and quantum yield decreases (Rahman and Ibrahim, 2012). Increase in the ratio of Chl a/b is always associated with a change in pigment composition of the photosynthesis apparatus towards a more sun-type like chloroplast which possesses less light harvesting chlorophyll proteins (LHCPs)

(Lichtenthaler, 2000). Garthy (1985) observed that decrease in chlorophyll content was at site affected by heavy pollution whereas sites with low pollution recorded a lower decreases in chlorophyll content. Chlorophyll content gets reduced due to chloroplast damage by incorporation of cement kiln dust over the surfaces of the leaf tissue, as it is responsible for alteration of leaf pH. Because of the high pH of cement results in causing damage to chloroplast (Singh and Srivastra, 2002). Chlorophyll content changes due to the shading effect caused by cement dust and causes damage to photosynthetic apparatus. Reduction of total chlorophyll has been found in leaves of various annuals plants and conifers covered by cement dust (Pandey and Kumar, 1996). Thakar and Mishra (2010) observed that *Tectona grandis, Ficus bengalensis, Polyalthia longifolia, Anacardium occidentale* and *Mangifera indica* showed a total chlorophyll content of more than 15 mg/g under pollution stress.

2.2 Photosynthesis

Photosynthesis is one of the most stress sensitive processes in plant and can be completely inhibited by stress before other symptoms of stress are detected (Berry and Bjorkman, 1980). Net photosynthetic rate is a commonly used indicator of impact of increased air pollutants on tree growth (Woo et al., 2007). Pollutants can cause leaf injury, stomatal damage, premature senescence, decrease photosynthetic activity, disturb membrane permeability and reduce growth and yield in sensitive plant species (Tiwari et al., 2006). Being a principle photosynthetic organ and responsible for the growth and development of the plants, the leaves plays a crucial role in the life cycle of the plant. Therefore rate of photosynthesis in the leaves plays a vital role in the life of the trees. At the leaf level, functional and structural components, which show strong correlations with high growth rate and productivity, include total as well as individual leaf area, internal leaf anatomy and functional traits such as photosynthetic performance (Pellis *et al.,* 2004). Mandre *et al.* (2012) observed in his study on hybrid aspens which were affected by cement dust pollution exhibited a 25% decline in photosynthetic rate compared to unpolluted plants, even though thicker palisade was found in the polluted trees. The palisade cells, containing chloroplasts, are directly responsible for photosynthesis (Pallardy, 2008). This contradiction may be explained by a possible decreasing of the concentration of chlorophylls and chloroplasts in leaves of trees growing in alkaline soils influenced by cement dust pollution as established for conifers as well as deciduous trees by earlier studies (Nanos and Ilias, 2007). Hand dusting cement-kiln dust at rates of 0.5 to 3.0 g m^{-2} on green bean [*Phaseolus vulgaris* (L.)] leaves reduced photosynthesis up to 73%. The decrease in net photosynthesis rates soon after dust application may have been caused by blocking of the stomata on the top leaf surface or the amount of radiation available for photosynthesis due to the absorption or reflection of the dust coatings. Photosynthesis rates returned to normal as new leaves appeared and coated leaves expanded, reducing the concentration on the dusted leaves (Armbrust, 1986). Reduction in photosynthesis rates affects the biomass assimilation in terms of reduced specific leaf area and plant height (Kamlakar, 1992). Many research works have indicated that the photosynthetic rate would decrease after the dust cover because of the shading, plugging of the stomata, increase of leaf temperature and change of the leaf surface pH (Farmer, 1993; Hirano *et al.,* 1994). Contrary to this, Hiraro *et al.* (1994) found the photosynthetic rate of the dusted leaf was greater than that of the control at air temperatures below 25° C and was less above 30° C. It was explained that the dark coloured dust increased leaf temperature and consequently increased the photosynthetic rate at lower temperatures but deceased at higher temperature. Cement dust deposited over the surfaces of the leaf in interfere with absorption of light quantity, this in turn cause reduction in photosynthesis (Sirohi and Singh, 1991)

2.3 Transpiration

The loss of excess water in form of vapour from various parts of the plant like leaf, stem, flower and even root is known as transpiration. There are three types of transpiration; they are stomatal, cuticular and lenticular. Transpirational water loss from the plant through stomata accounts for about 90% in normal cases. Tranpiration is a very important physiological process that helps in cooling of plant body, to reduce the excess water and in promotion of upward movement of water through xylem. Thus internal or external factors affecting the rate of transpiration will also affect growth and physiology of the plant.

The rate of transpiration is directly related to the opening and closing of the stomata. Light intensity, temperature, wind speed, relative humidity, soil water, CO_2 concentration etc. regulates the rate of transpiration indirectly. The rate of transpiration varies from plant to plant. Rate of transpiration is determined by the efficiency of opening and closing processes of the stomata of individual plant species (Abdulrahaman & Oladele, 2009). Hirano *et al.* (1994) observed an increase in transpiration of plants species covered by dust while Scheffer *et al.* (1961) observed a contrary result, as it was observed that plants exhibited decreased transpiration with increased dust load. Hirano *et al.* (1994) proposed increase in leaf temperature raised the vapour pressure deficit in intercellular spaces and so made the difference in water vapour pressure between intercellular space and the surrounding air. Thus the dusted leaves have higher transpiration rates. The transpiration rates tends to show higher values in the degraded site (Ozturk *et al.*, 2010).

Particulate pollutants inhaled by leaves blocks the stomatal opening and caused mechanical injury to the guard cells. For efficient transpiration to take place, general freshness of leaf is of outmost importance which is lacking in particulate polluted. These pollutants leads to external foliar anomalies, which results in overall decline in transpiration efficiency of the stands affected by particulate pollutants (Saha and Padhy, 2012). Ambient level of air pollution affects stomatal conductance, photosynthesis and root morphology of young beech (Taylor and Davies, 1990).

2.4 Leaf area parameters

Pollution leads to the reductions in leaf area and leaf number, which may be due to decreased leaf production rate and enhanced senescence. The reduced leaf area result in reduced absorbed radiations and subsequently in reduced photosynthetic rate (Tiwari et al., 2006). Reduction of leaf area and petiole length was observed in plants under pollution stress conditions (Dineva, 2004 and Tiwari et al., 2006). Borka (1980) observed a reduction of about 4-5 % in the height of *Helianthus annuus* when exposed to cement dust pollution as compared to those growing in normal conditions after 130 days of observation. Salama *et al.* (2011) observed reduction in leaf area when *Datura innoxia* were exposed to cement dust pollution. Uysal *et al.* (2012) observed that the leaf area increased with increase in cement kiln dust content up to 60 g kiln dust/ kilogram of soil, but declined after 75 g/ kg. The study by Wagh *et al.* (2006) revealed that there was a decrease in leaf area in all plant species, growing at sites with heavy vehicular traffic, as compared to areas where vehicular traffic were low. Several laboratory and field experiments conducted with cultivated (Davis, 1980) and field studies of native plants displayed reduction in leaf area (Rao, 1977) owing to air pollution. Byers *et al.* (1992) linked the decrease in leaf area to the reduced photosynthesis activity of plants exposed to air pollutants. Leaf area index or LAI is defined as the single-side leaf area per unit ground area and is a dimensionless number. The importance of LAI stems from the relationships which have been recognized between it and a range of ecological processes like rates of photosynthesis, transpiration and evapotranspiration by McNaughton and Jarvis (1983) and Pierce and Running (1988). Measurements of LAI have been used to predict future growth and yield (Kaufmann *et al.*, 1982) and to monitor changes in canopy structure due to pollution and climate change (Waring 1985, Gholz *et al.*, 1991). The ability to estimate leaf area index is therefore a valuable tool in modelling the ecological processes occurring within a forest and in predicting ecosystem responses.

2.5 Dust accumulation

Wind movements suspends large quantities of dust in the atmosphere that tends to settle down back to earth's surface and are deposited on leaf surface when the wind velocity decreases (Armbrust, 1986). Dust pollutants contribute to about 40% of total air pollution problems in India (Chauhan and Sanjeev, 2008). Dust accumulation on the leaf surface provokes severe damages to the photosynthetic apparatus (Santosh and Tripathi, 2008). The most apparent effect due to deposition of dust on numerous plant species has found to be leaf damage (Naidoo and Chirkoot, 2004). Heath and Castillo (1988) reported that leaf injury is due to diverse altercations at the sub cellular level. Various studies have shown that main detrimental effect of dust at subcellular level is photosystem damage (Santhosh and Tripathi, 2008). Species with high dust-carrying capacity is useful in cleaning air but are less likely to survive well in the area with frequent dust storm. On the other hand species with low dust-carrying capacity are advantageous to survive in areas with frequent dust pollution (Chen Xiong-Wen, 2001). Pollutants gets accumulated in plants when they are exposed to it and they assimilate it at the rate depending upon their assimilation capacity. When plants are exposed to highly polluted condition, where the rate of accumulation exceeds the rate of assimilation, then accumulation of pollutants starts inside the plants (Aerts, 1990). Deciduous plants are affected more by air pollution than evergreen plants (Dwivedi and Sashi, 2012). The deciduous plants gets rid of the total accumulated pollutants through leaf fall and the new leaves sprout in its place which are free from any pollutant. While evergreen plants have the mechanism for leaf fall throughout the year, it helps in maintaining a more or less equilibrium with respect to accumulation of the pollutant in the leaves, with little fluctuation. This mechanism helps in self-protecting the evergreen plants from reaching the threshold level of accumulated pollutants (Dwivedi and Sashi, 2012). Sharma (1992) observed that the dust collection efficiency depends on the various factors like canopy, tree height, leaf surface, leaf geometry, cuticular thickness and petiole length. Thakar and Mishra (2010) observed that the most excellent collector of the dust is *Calotropis gigantean* because of it thick oily cuticle on leaves and short pedicle along with *Tectona grandis, Ficus religiosa, Delonix regia, Buchania lanzen, Mangifera indica, Tabernaemontana divarieata* and *Annona squamosa*. Depression in the middle of the leaf found in *Ailanthus excelsa, Psidium guajava, Madhuca indica* and *Ficus glomerata* are excellent in dust accumulation because of their depression in middle of the leaves. Whereas *Acacia arabica, Dalbergia sisoo* and *Tamarindus indica* have less dust accumulation potential because of their smooth leaf surface, long petiole, tall height of the tree (Thakar and Mishra, 2010). Trees with high dust collecting potential have the potential to solve the problems of particulate air pollution to a great extent (Dwivedi and Tripathy, 2007). Dust deposition reduces diffusive resistance of the leaves and also increases the temperature of leaf making the tree more likely to be susceptible to drought (Farmer, 1993).

2.6 Morphology and growth

Plants shows a decrease in plant growth due to cement dust treatment which might be contributed to the presence of different toxic pollutants in cement dust (Iqbal and Shafig, 2001). Decreased plant height of plants exposed to cement dust may be due to the decrease in phytomass, net primary production and chlorophyll content in response to the cement dusts (Iqbal and Shafig, 2001). Harmful substances which is present in the cement dust plays vital role to retard the growth of plant. The effect of cement kiln dust on the growth of mustard was studied by Uma and Rao (1993) which reveals that the growth of mustard was gradually decreased with increase in cement dust deposition due to the presence of harmful substances. Salama *et al.*(2011) observed that the air pollution around the cement factory area have a significant effect on the morphological parameters of plants exposed to it which result in significant reduction in plants height, leaf area, leaf number, fresh and dry weights of shoot and root systems of *Datura innoxia*. These reductions are attributed to the cement factory emissions which contain toxic gases and cause air pollution. The level of reduction of these morphological factors increases with decreasing distances from the cement factory. Water content of leaves (mg/ cm^2 leaf area) decreases with respect to increasing cement kiln dust (Uysal *et al.*, 2012). Klumpp *et al.* (2000) observed that growth analysis of seedlings exposed to pollution demonstrated that a change of the relationship between above-ground and below-ground plant parts was the most obvious effect of air pollution and soil contamination. Even species considered resistant to air pollution, suffers metabolic disturbances by the quality of ambient air and soil present around the plant. The declining vigour of sensitive trees to pollution results from reductions in needle longevity, size, increased respiratory activity, and altered translocation patterns which are induced by chronic air pollution stress (McLaughlin *et al.*, 1982).

2.7 Water potential

The hydraulic system within intact plants acts as a true continuum. Water will move from the soil into the plant, through the plant and into the atmosphere in response to a water potential gradient. Water flows along a gradient of decreasing water potential. Water potential is measured in units of negative pressure such as bars or Mega Pascals (MPa). Free water is defined to have a potential of zero. Water that contains solutes will have a negative potential and it will attract free water across a semi permeable membrane. When water is held by force as the case may be in the pores of soil, the water potential is determined by the force which is required to move this water to a state of free water. This is also the case for water held in the plant (Blum, 2011).

The industrial pollution of forest communities results in strong differentiation of woody plants by the vitality status. It is usually determined by visual traits such as crown shape, life span, degree of leaf damage etc. The differentiation is also manifested in changes of different functional parameters of the plants too (Poschenrieder *et al.*, 1989; Lyanguzova and Efimova, 2005). Plant water uptake is one of the most informative parameters reflecting plant vital activity, because of its strong dependence on environmental conditions and plant properties (Larcher, 2003). The leaf water potential is also a very universal parameter determining the water status of plants. It is both an indirect descriptor of the water deficit in the plants and the driving force for plant water uptake (Hinckley *et al.*, 1978).

Industrial pollution influences directly and indirectly all components of water conducting system of the trees. This influence increases by decreasing the tree vitality status. It also results in reduction of water transport conductivity in different parts of tree xylem (Sazonova and Olchev, 2010). Sazonova and Olchev (2010) also proposed that this in turn may generate a higher water deficit and a degradation of tree vitality status. Misbalance in the water transport system may lead to high variability of water potential for periods with rapid changes of weather conditions.

2.8 Anatomical property of wood

Local pollution sources are known to cause growth reduction of forest around them and were already identified by Pollanschütz (1971). Anatomical alterations of the woody cells were reported by Kartusch and Halbwachs (1985). Wood of trees affected by pollution is much different from that of unaffected trees (Fruhwald, 1986). Between stands, the vessel frequency were found to be higher in *Eucalyptus tereticornis* affected by cement dust pollution than those located in the control stand (Varghese and Sivaramakrishna, 1991). A similar trend is reported in *Fagus sylvatica* (Kurjatko *et al.,* 1990) and *Alnus glutinosa* (Kartusch and Halbwachs, 1985).

Within a stand the fibre length, shows an increase in the centrifugal direction while vessel element length does not vary significantly within a stand (Varghese and Sivaramakrishna, 1991). Vessel diameter, vessel frequency, fibre lumen width and fibre wall thickness tend to vary significantly within a stand (Varghese and Sivaramakrishna, 1991). Similar trends were also reported by Shiokura *et al.* (1985) in *Leucaena leucocephala*. Increase in fibre length in the centrifugal direction are reported for many hardwood species (Zobel and Van Buijkanen, 1989).

Many research works have been done on the effect of air pollution affecting the wood properties, but majority studies have been done on coniferous species. A 48.3% reduction was observed in wood formation affected by pollution, and a significant reduction in vessel width and fibre length was observed in *Dalbergia sissoo* while vessel length and fibre width remained unaffected (Ghouse *et al.*, 1984). Grill *et al.* (1979) observed that the vessels, tracheids and fibres are shortened in broadleaved species and in ring porous wood the number of vessels are reduced.

Safdari *et al.* (2012) observed that the frequency of rays of *Pinus eldarica located* in the polluted site are higher compared to those located in unpolluted site. Also fibre length, fibre wall thickness and fibre lumen size of these trees are more in unpolluted site than in polluted sites. In general he concludes that the air pollution impact on the width of the tree ring can reduce wood quality as well.

Zimmerman (1983) emphasised that it is the vessels and not the vessel elements that are the operating units of conduction. The increase in frequency of vessels is associated with decrease in vessel diameter (Varghese and Sivaramkrishna, 1991). A similar situation is found in *Alnus glutinosa* (Kartush and Halbwachs, 1985), *Fagus sylvatica* (Jurjatko *et al.*, 1990) and *Leucaena leucocephala* (Shiokura *et al.*, 1985).

Rao *et al.* (1966) observed that factors other than growth rate are of great importance in determining the proportion of tissue in teak. Varghese *et al.* (2000) observed that fibre traits were very stable and not influenced by either latitude, site or ecotype effects while vessel dimensions were more influenced by individual edaphic effects than latitudinal or ecotype effect in teak. Bamber *et al.* (1982) observed such a trend in *Eucalyptus grandis* where fast growth affected the physiologically active cells but not the fibres that offer mechanical strength. The trend may differ with species as in the case of *Leucaena leucocephal* (Shiokura *et al.*, 1985) where faster grown trees had longer fibres and vessel elements.

Fibre lumen and wall thickness responds differently to the growing conditions as reported in four species of eucalyptus (Wilkes and Abbott, 1983) where larger trees had greater wall thickness, but not fibre diameter leading to greater Runkel ratios. Plants with primitive features have low F/V ratio (fibre length to vessel element length) and average dicotyledons has a ratio around 2.0 (Carlquist, 1988). Trees with specialised wood have higher values as reported by Varghese and Shivaramakrishna (1996) in *Casuarina equisetifolia.* Higher values of F/V observed in teak may be an adaptation for long fibres (Varghese *et al.*, 2000). A gain in F/V length ratio is a sign of increasing mechanical strength of trees (Carlquist, 1975).

The Runkel Ratio is a microscopic extension of the wood density, in this the wall thickness and lumen width are the basic factors used in their determination. Therefore, runkel ratio should not be expected to provide much more basic information than the measured wood density (Horn, 1978). Higher runkel ratio fibres are stiffer, less flexible and form bulkier paper of lower bonded areas than lower runkel ratio fibre (Ververis *et al.*, 2004). The average fibre length and runkel ratio are important parameters for paper making purpose. High average fibre length and low runkel ratio result in good pulp strength properties (Shakhes *et al.*, 2011).

The increased vessel frequency together with their decreased dimensions under pollution stress influences the vulnerability and mesomorphic ratios of the affected trees (Carlquist, 1977). It is difficult to have substantial evidence of the actual pollution-caused water stress, particularly when it needs to be traced along the life time of a tree under conditions of environmental pollution. In such cases, the study of ratios of vulnerability and mesomorphy across the tree trunk may be of great help. Its also suggested that low values of vulnerability ratio could be interpreted as high redundancy of vessels, indicating an increased capability of the given tree species to withstand water stress, whereas declined values of mesomorphic ratio could be regarded as a change in a given species from mesomorphy to xeromorphy (Carlquist, 1977).

MATERIALS AND METHODS

MATERIALS AND METHODS

3.1. Location

The study was carried out in the Walayar range, Palakkad under the Eastern Circle. Random sampling was done near the Malabar cement premises at 10°51' N 76°50' E, which was the affected area by particulate pollution, mainly cement dust from the Malabar cements factory (Fig. 1). The control plot at Vattapara was taken at 10°49' N 76°48' E, about 5 km away from this area, which was used as a reference for understanding the degree to which the trees are affected by the particulate pollution and the tolerance levels of different species that are studied. In this area trees of moist deciduous nature were randomly selected for taking the readings and sample collections. The readings for the estimation of Air Pollution Tolerance Index (APTI) are carried out season wise during winter, summer and monsoon. Physiological parameters like photosynthesis, transpiration, water potential were studied for *Tectona grandis*, the most prominent species found near the cement factory. The wood properties of *Tectona grandis* were studied from the discs collected from a plantation established in 1939, located within the Malabar cements staff quarters.

3.2. Methodology

3.2.1. Relative leaf water content (RWC)

Relative water content of the leaves were carried out following the method described by Singh (1977), and was calculated with the formula:

$$RWC = [(FW - DW) / (TW - DW)] \times 100$$

FW = Fresh weight, DW = dry weight, and TW = turgid weight.

Fresh weight was obtained by weighing the fresh leaves. The leaves were then immersed in water over night, blotted dry and then weighed to get the turgid weight. Next, the leaves were dried overnight in an oven at 70°C and reweighed to obtain the dry weight.

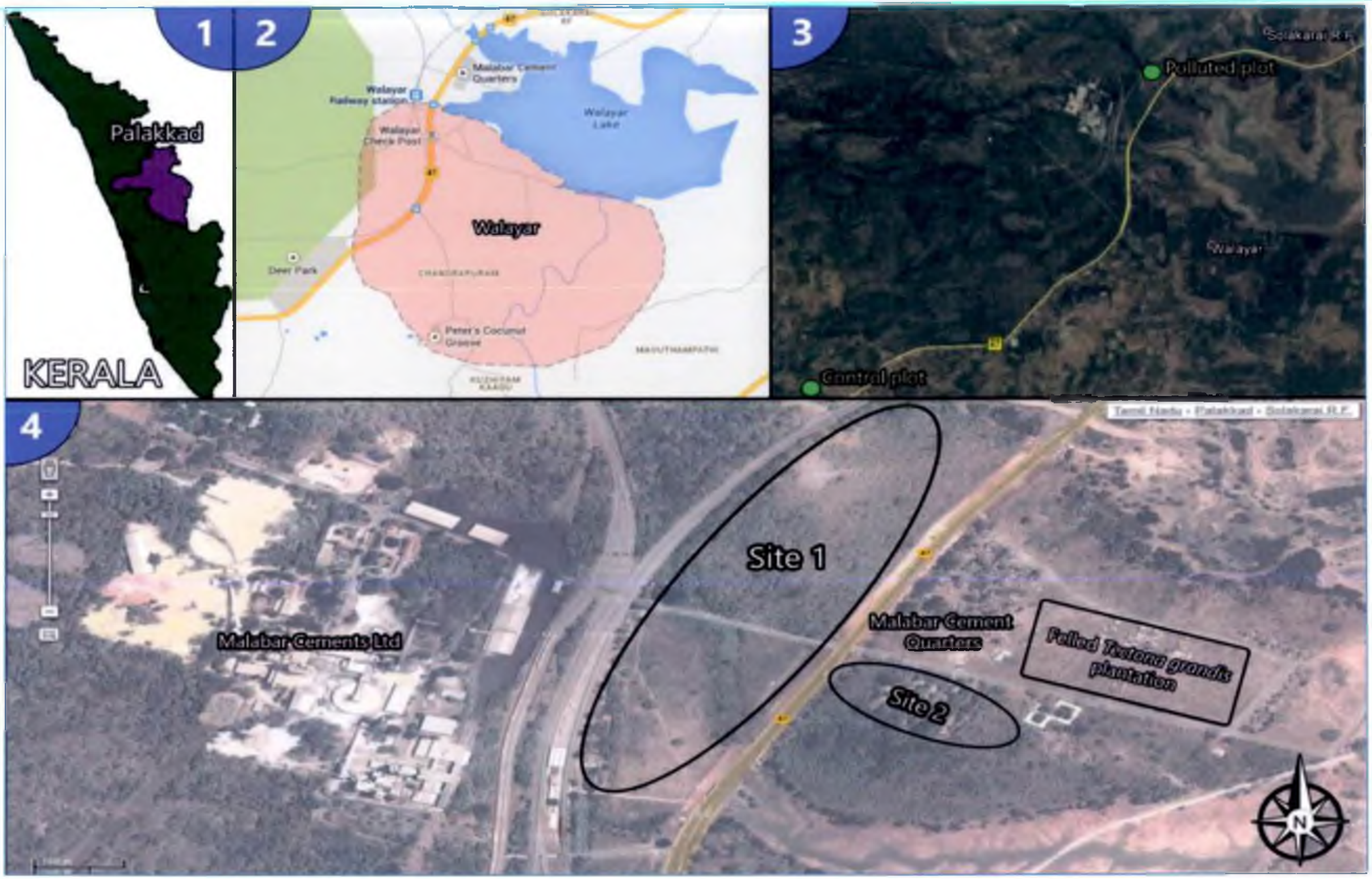

Fig. 1. Location of study; 1. Map of Kerala, 2. Map of Walayar, 3. Location of polluted and control plot, 4. Location of polluted plot near Malabar cements Ltd., and location of *Tectona grandis* plantation from where disks were collected

3.2.2. Total chlorophyll content (TCH)

The chlorophyll content of the leaf samples was estimated using the method described by Arnon (1949). Leaf sample weighing 250 mg is macerated with 10 ml of 80 % acetone using a pestle and mortar and the extract is centrifuged at 3000 rpm for 10 minutes. The supernatant solution is transferred into a 25 ml volumetric flask and made up to 25 ml using acetone. Then the colour intensity of the green pigment is read at 645nm and 663nm for chlorophyll a and chlorophyll b content respectively. Calculations were made using the formula below:

Chlorophyll a = 12.7 (Absorbance at 663) - 2.69 (Absorbance at 645) x **V**/1000**W** mg/g

Chlorophyll b = 22.9 (Absorbance at 645) – 4.68 (Absorbance at 663) x **V**/1000**W** mg/g

Total Chlorophyll = [(8.022 x Absorbance at 663) + (20.2 x Absorbance at 645)] x **V**/1000**W** mg/g

V - Total volume of the chlorophyll solution (25ml)

W - Weight of the tissue extracts (0.25g)

The chlorophyll content of the leaf sample is expressed as **mg/g** of fresh leaf.

3.2.3. pH of Leaf extract

Five grams of the fresh leaves was homogenized in 10 ml deionised water. This was then filtered and the pH of leaf extracted determined after calibrating pH meter with buffer solution of pH 4 and pH 7.

3.2.4. Ascorbic acid (AA) content analysis

Ascorbic acid content was estimated using the method prescribed by Sadasivam and Manickam (1996). Three solutions are prepared forehand for the estimation of ascorbic acid content in the leaf sample.

I. Bromine water: Dissolve 1 – 2 drops of liquor bromine was dissolved in 100 ml cool water.

II. Ascorbic acid stock standard solution: 100 mg ascorbic acid was dissolved in 100 ml of 4% oxalic acid solution in a standard flask.

III. Working standard: 10 ml of the stock solution was diluted to 100 ml with 4% oxalic acid. The concentration of the working standard was 100 μg/ml.

Extraction: 0.5 g of sample material was grinded using a pestle and mortar in 10 ml 4% oxalic acid solution. The supernatant was collected after centrifugation at 10,000 rpm.

The aliquot was transferred to a conical flask and added bromine water drop wise with constant mixing to remove the enolic hydrogen atoms in the ascorbic acid. When the extract turned orange yellow due to excess bromine, it was expelled by blowing in air. It was then made up to a known volume (25 ml) with 4% oxalic acid solution.

The 10 ml of standard stock solution similarly was converted into dehydro form by bromination. Then it was diluted to 100 ml with 4% oxalic acid for the working standard (100μg/ml).

Procedure:

Working standards of 0.1 – 1.0 ml (10 - 100μg) was pipetted out into a series of test tubes. Similarly 1ml aliquot of brominated sample extract was pipetted out into another series of test tubes. The volume was made up to 3ml by adding distilled water in all the test tubes. DNPH reagent of 1 ml, followed by 1- 2 drops of thiourea was added to each tube. A blank was set but with water in place of ascorbic acid solution. The contents of the test tube was mixed thoroughly and incubated at 37°C for three hours. After incubation, the orange – red osazone crystals formed was dissolved by adding 7 ml of 80% sulphuric acid. The absorbance was measured at 540nm wavelength. Ascorbic acid concentration versus absorbance graph was plotted and ascorbic acid content in the sample was calculated.

Plate. 1. Spectrophotometer for estimation of chlorophyll and ascorbic acid content

Plate. 2. pH meter for measuring pH of leaf samples

3.2.5. APTI determination

The air pollution tolerance indices of ten common plants were determined following the method of Singh and Rao (1983). The formula of APTI is given as

$$\mathbf{APTI} = [\mathrm{A}\ (\mathrm{T+P}) + \mathrm{R}]/10$$

Where,

A - Ascorbic acid content (mg/g)
T - Total chlorophyll (mg/g)
P - pH of leaf extract
R - Relative water content of leaf (%)

After calculating the individual APTI values, they are divided and graded into four grades of air pollution tolerance (Liu and Ding , 2008) as tolerant (T/ grade I), moderately tolerant (MT/ grade II), intermediate (I/ grade III) and sensitive (S). The tolerance grades were identified according to the following criteria:

1. Tolerant: APTI > mean APTI + SD
2. Moderately tolerant: mean APTI < APTI <mean APTI + SD
3. Intermediate: mean APTI – SD < APTI < mean APTI
4. Sensitive: APTI < mean APTI – SD

3.2.6. Dust accumulation

The dust load on the leaf surface were measured following the methodology described by Prusty *et al.* (2005). Leaves of each species were placed in beakers separately and washed thoroughly by hairbrush with distilled water. The dusty water were kept in a petri dish and brought to the laboratory and completely evaporated in an oven at 100°C and weighed with an electronic balance to record the total dust quantity trapped.

$$W = (W_2 - W_1)/\ n$$

Where,

W_1 – Initial weight of the petri dish without dust
W_2 – Final weight of petri dish with dust
n – Total area of the leaf (cm^2)

3.2.7. Rate of dust accumulation

The rate of dust accumulation is calculated between the intervals of the three seasons studied. The accumulation rate was calculated on average per month basis.

$$\text{Rate of dust accumulation} = [\{(DA_1+DA_2)/2\} \text{ x } (t_2-t_1)]/\text{month}$$

Where,

DA_1 – Dust accumulated at time (t_1)
DA_2 – Dust accumulated at time (t_2)

3.2.8. Leaf surface area

The leaves collected for dust accumulation after cleaning were used for measuring the leaf area. It was first measured by plotting the leaf over the graph paper, then were cross checked using leaf area meter and were expressed in cm^2.

3.2.9. Leaf area index (LAI)

Leaf area index value is total leaf area divided by total canopy cover and includes layering of canopies. The leaf area index were measured with the aid of canopy analyser (LAI 2000). The readings were taken during the three seasons, i.e. winter, summer and monsoon. Estimation of LAI through canopy analyser is an indirect method, but is of non-destructive in usage.

3.2.10. Leaf area duration (LAD)

Leaf area duration or LAD values are calculated using the formula given by Power *et al.* (1967). LAD were calculated with the values taken during winter, summer and monsoon in both the control and polluted plot.

$$LAD = [(LAI_1+LAI_2)/2] \text{ x } (t_2-t_1)$$

Where,

LAI_1-Leaf area index at time (t_1)

LAI_2-Leaf area index at time (t_2)

3.2.11. Water potential

The water potential of the *Tecona grandis* leaves were measured with the aid of pressure bomb apparatus. The readings were taken during the early morning hours from both the polluted and control plots. The leaf were cut from the trees with a shaving blade and transferred to plastic bag, and kept inside the pressure bomb and pressure was applied gradually inside the chamber. The readings were taken as soon as the leaf were collected in order to avoid errors due to loss of water through the cut ends. The unit of the water potential measured were recorded in 'MPa'.

3.2.12 Photosynthesis and transpiration

The photosynthesis and transpiration of the trees located at the polluted and the control plots were recorded. Infra-red gas analyser (IRGA) was the instrument used for the measurement of both these values. Stomatal conductance is the value taken for understanding the transpiration taking place in the trees. The unit of measurement for both photosynthesis and transpiration is $\mu mol\ m^{-2}\ s^{-1}$.

3.2.13. Anatomical properties of *Tectona grandis*

a. Microtomy

Wood specimens of size 1.0 cm^3, representing three radial positions viz., middle, pith and periphery were made out from the samples used for anatomical studies. The specimens were then softened by keeping in water bath (Rotex water bath) at 100^o C for 20 minutes. Cross and tangential sections of 10-15 μm thickness were prepared using a Leica sliding microtome (Leica SM 2000 R).

b. Maceration

Maceration of wood samples was done using Jeffrey's method (Sass, 1971). For maceration, Jeffrey's solution was used and it is prepared by mixing equal volumes of 10 percent potassium dichromate and 10 percent nitric acid.

Plate. 3. Pressure bomb apparatus for measuring water potential

Plate. 4. Measuring photosynthesis and transpiration with the aid of IRGA

Radial chips of wood shavings were taken from the 1 cm^3 wood blocks separately from three radial positions viz., pith, middle and periphery. These chips were boiled in the maceration fluid for 15-20 minutes so that the individual fibres were separated. Then these test tubes were kept for 5-10 so that the fibres settled at the bottom. The solution was discarded and the resultant material was thoroughly washed in distilled water until traces of acid were removed. The samples were stained using saffranin and mounted on temporary slides using glycerine as the mountant.

c. Staining procedure

Permanent slides of transverse and tangential sections were stained using the procedure outlined by Johansen (1940). Sections were stained using saffranin and later washed through a series of alcohol solutions at different concentrations (70 %, 90 % and 95 %) to ensure complete dehydration. They were subsequently dipped in acetone followed by xylene and finally mounted in DPX mountant to prepare the permanent slides.

d. Image Analysis

Microscopic examination and quantification of sections was undertaken using an Image Analyser (Labomed-Digi 2). It consists of a microscope, digital camera and PC (Personal computer). The digital camera provides digitized images which are analyzed by the computer software (Labomed DigiPro-2). The software provides several classes of measurements like length, diameter, area and count.

e. Observations

From the macerated fibres, fibre length, fibre diameter, fibre wall thickness and fibre lumen diameter for teak were measured using the Image Analyzer. Each measurement was repeated five times for all the above characters at each radial position, viz., pith, middle and periphery and is expressed in micrometers (µm). Tangential longitudinal sections (T.L.S) were used to measure ray height (µm), ray frequency and ray width (µm), whereas transverse sections (T.S) were used to determine vessel frequency, vessel diameter and vessel area. Vessel frequency (vessels per mm^2) was determined by counting the number of vessels in randomly selected fields of the section with the help of the image analysis software, Labomed-Digi 2 and was expressed as number per millimeter (mm). For each character, observations were taken from all the three radial positions in the transverse sections.

The vessel vulnerability and mesomorphy was worked out by the following formula (Carlquist, 1977):

$$\text{Vessel vulnerability} = \frac{\text{Vessel diameter}}{\text{Vessel frequency per mm}^2}$$

$$\text{Vessel mesomorphy} = \text{Vessel vulnerability x Vessel element length}$$

Criteria important in pulp and papermaking were derived from the data obtained using the following equation (Yáñez-Espinosa *et al.*, 2004):

$$\text{Ratio Runkel} = \frac{\text{2 x Fibre wall thickness (FWT)}}{\text{Fibre lumen diameter (FLD)}}$$

3.2.14. Statistical analysis

Data obtained were subjected to statistical analysis using SPSS (v20) and MSTAT-C. The tests used for the study included ANOVA with post hoc testing using Duncan's multiple range tests (DMRT) and t-test.

RESULTS

RESULTS

The study on "Impact of particulate pollution on the growth and physiology of trees in moist deciduous forests" was carried out during the period of 2012-2013, at Walayar, Palakkad, Kerala, India.

4.1 Air pollution tolerance index (APTI)

4.1.1 Chlorophyll content of leaf samples

4.1.1.1 Total chlorophyll content (TCH)

The chlorophyll content of the leaf samples were calculated through the process of spectrophotometry. The results for total chlorophyll content during winter (Table. 1), summer (Table. 2) and monsoon (Table. 3) are given in this section. On statistical analysis of the TCH for the ten species studied were significantly different between the species as well as between the statuses of the plot for winter, summer and monsoon. The higher values were in the control plots than the polluted in all the three seasons. It was also seen that TCH differed among the species in all the three seasons. *Cassia fistula* had the highest TCH during winter (2.61 mg/ g), *Artocarpus heterophyllus* during summer (1.86 mg/ g) and *Butea monosperma* during monsoon (1.89 mg/ g). The TCH values ranged between 2.61-0.78 during winter, 1.86-0.7 during summer and 1.89-0.85 during monsoon. The TCH were higher during winter than the other two seasons.

Table 1. Total chlorophyll content of leaf extracts among different species between polluted and control during winter

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	1.27	2.73	2^{q}
2	*Terminalia paniculata*	0.67	1.33	0.1^{n}
3	*Bombax ceiba*	0.38	1.17	0.78^{m}
4	*Butea monosperma*	2.74	2.02	2.38^{s}
5	*Cassia fistula*	2.16	3.06	2.61^{t}
6	*Anogeissus latifolia*	2.29	2.02	2.15^{r}
7	*Pterocarpus marsupium*	2.30	1.37	1.83^{p}
8	*Grewia tiliifolia*	1.54	1.79	1.66^{o}
9	*Terminalia catappa*	2.59	1.54	2.06^{q}
10	*Artocarpus heterophyllus*	1.31	2.48	1.9^{p}
	Mean	1.72^{x}	1.95^{y}	

Values with the same superscript do not differ significantly between themselves

Table 2. Total chlorophyll content of leaf extracts among different species between polluted and control during summer

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	0.50	2.12	1.31^{q}
2	*Terminalia paniculata*	0.72	1.34	1.03^{o}
3	*Bombax ceiba*	0.38	1.07	0.7^{m}
4	*Butea monosperma*	0.88	1.93	1.4^{r}
5	*Cassia fistula*	0.99	1.14	1.06^{p}
6	*Anogeissus latifolia*	0.91	1.10	1^{n}
7	*Pterocarpus marsupium*	1.91	1.09	1.5^{s}
8	*Grewia tiliifolia*	1.51	1.49	1.5^{s}
9	*Terminalia catappa*	1.80	1.50	1.65^{t}
10	*Artocarpus heterophyllus*	1.55	2.17	1.86^{u}
	Mean	1.11^{x}	1.49^{y}	

Values with the same superscript do not differ significantly between themselves

Table 3. Total chlorophyll content of leaf extracts among different species between polluted and control during monsoon

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	0.87	1.59	1.23^{n}
2	*Terminalia paniculata*	1.00	1.47	1.24^{n}
3	*Bombax ceiba*	0.92	0.79	0.85^{m}
4	*Butea monosperma*	1.54f	2.24	1.89^{s}
5	*Cassia fistula*	1.34	1.14	1.24^{n}
6	*Anogeissus latifolia*	1.67	0.94	1.31^{o}
7	*Pterocarpus marsupium*	1.74	1.20	1.47^{p}
8	*Grewia tiliifolia*	1.14	1.50g	1.32^{o}
9	*Terminalia catappa*	1.21	1.91	1.56^{r}
10	*Artocarpus heterophyllus*	1.06	1.98	1.52^{q}
	Mean	1.25^{x}	1.47^{y}	

Values with the same superscript do not differ significantly between themselves

4.1.1.2 Chlorophyll 'a' content

The results of chlorophyll 'a' content during winter (Table. 4), summer (Table. 5) and monsoon (Table. 6) is given in this section. On statistical analysis, the chlorophyll 'a' content were significantly different for different species as well as for statuses during winter, summer and monsoon. The values for chlorophyll 'a' were higher in the control plots than the polluted plots during summer and monsoon, while during winter season, the chlorophyll 'a' content were higher in the polluted area. The chlorophyll 'a' content was highest in *Cassia fistula* (1.66 mg/ g) during winter, *Artocarpus heterophyllus* (0.99 mg/ g) during summer and *Butea monosperma* (1.23 mg/ g) during monsoon season. The values for chlorophyll 'a' values ranged between 1.66-0.43 during winter, 0.99-.38 during summer and 1.23-0.57 during monsoon. The chlorophyll 'a' values were higher in winter than the other two seasons.

Table 4. Chlorophyll 'a' content of leaf extracts among different species between polluted and control during winter

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	0.83	1.91	1.37^{r}
2	*Terminalia paniculata*	0.47	0.93	0.7^{n}
3	*Bombax ceiba*	0.19	0.67	0.43^{m}
4	*Butea monosperma*	1.96	1.21	1.58^{s}
5	*Cassia fistula*	1.61	1.72	1.66^{t}
6	*Anogeissus latifolia*	1.64	1.48	1.56^{s}
7	*Pterocarpus marsupium*	1.72	0.83	1.27^{q}
8	*Grewia tiliifolia*	1.08	0.94	1.01^{o}
9	*Terminalia catappa*	1.82	0.48	1.15^{p}
10	*Artocarpus heterophyllus*	0.97	1.08	1.02^{o}
	Mean	1.23^{x}	1.12^{y}	

Values with the same superscript do not differ significantly between themselves

Table 5. Chlorophyll 'a' content of leaf extracts among different species between polluted and control during summer

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	0.25	1.08	0.67^{o}
2	*Terminalia paniculata*	0.51	0.92	0.71^{p}
3	*Bombax ceiba*	0.19	0.56	0.38^{m}
4	*Butea monosperma*	0.52	1.14	0.83^{s}
5	*Cassia fistula*	0.45	0.70	0.57^{n}
6	*Anogeissus latifolia*	0.68	0.69	0.68^{o}
7	*Pterocarpus marsupium*	1.26	0.59	0.92^{s}
8	*Grewia tiliifolia*	0.66	0.82	0.74^{q}
9	*Terminalia catappa*	1.13	0.47	0.8^{r}
10	*Artocarpus heterophyllus*	0.95	1.04	0.99^{u}
	Mean	0.66^{x}	0.8^{y}	

Values with the same superscript do not differ significantly between themselves

Table 6. Chlorophyll 'a' content of leaf extracts among different species between polluted and control during monsoon

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	0.50	1.18	0.84^{q}
2	*Terminalia paniculata*	0.36	1.05	0.71^{o}
3	*Bombax ceiba*	0.54	0.53	0.53^{m}
4	*Butea monosperma*	0.86	1.61	1.23^{s}
5	*Cassia fistula*	0.53	0.76	0.64^{n}
6	*Anogeissus latifolia*	1.21	0.64	0.92^{r}
7	*Pterocarpus marsupium*	0.87	0.72	0.79^{p}
8	*Grewia tiliifolia*	0.39	0.76	0.57^{m}
9	*Terminalia catappa*	0.54	1.16	$0,85^{q}$
10	*Artocarpus heterophyllus*	0.29	1.03	0.66^{n}
	Mean	0.61^{x}	0.94^{y}	

Values with the same superscript do not differ significantly between themselves

4.1.1. Chlorophyll 'b' content

The results for chlorophyll 'b' content is recorded for winter (Table. 7), summer (Table. 8) and monsoon (Table. 9) in this section. On statistical analysis, chlorophyll 'b' content were significantly different between the species as well as between the statuses during winter, summer and monsoon. The chlorophyll 'b' content was highest in the control plots during winter and summer, while it was higher in the polluted plot during the monsoon period. The chlorophyll 'b' content was highest in *Cassia fistula* (0.95 mg/ g) during winter, *Artocarpus heterophyllus* were highest during summer (0.86 mg/ g) and monsoon (0.86 mg/ g). The chlorophyll 'b' values ranged between 0.95-0.3 during winter, 0.86-0.32 during summer and 0.86-0.32 during monsoon. The chlorophyll 'b' value was higher during winter than the other two seasons.

Table 7. Chlorophyll 'b' content of leaf extracts among different species between polluted and control during winter

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	0.44	0.82	0.63^{n}
2	*Terminalia paniculata*	0.20	0.39	0.3^{m}
3	*Bombax ceiba*	0.19	0.50	0.34^{m}
4	*Butea monosperma*	0.78	0.81	0.8^{o}
5	*Cassia fistula*	0.55	1.34	0.95^{p}
6	*Anogeissus latifolia*	0.65	0.54	0.6^{n}
7	*Pterocarpus marsupium*	0.58	0.55	0.56^{n}
8	*Grewia tiliifolia*	0.46	0.85	0.65^{n}
9	*Terminalia catappa*	0.76	1.06	0.91^{p}
10	*Artocarpus heterophyllus*	0.34	1.41	0.87^{op}
	Mean	0.50^{x}	0.83^{y}	

Values with the same superscript do not differ significantly between themselves

Table 8. Chlorophyll 'b' content of leaf extracts among different species between polluted and control during summer

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	0.25	1.04	0.64^{q}
2	*Terminalia paniculata*	0.22	0.41	0.32^{m}
3	*Bombax ceiba*	0.19	0.51	0.35^{n}
4	*Butea monosperma*	0.36	0.79	0.57^{p}
5	*Cassia fistula*	0.54	0.44	0.49^{o}
6	*Anogeissus latifolia*	0.23	0.41	0.32^{m}
7	*Pterocarpus marsupium*	0.65	0.51	0.58^{p}
8	*Grewia tiliifolia*	0.85	0.67	0.76^{r}
9	*Terminalia catappa*	0.67	1.03	0.85^{s}
10	*Artocarpus heterophyllus*	0.60	1.13	0.86^{s}
	Mean	0.46^{x}	0.69^{y}	

Values with the same superscript do not differ significantly between themselves

Table 9. Chlorophyll 'b' content of leaf extracts among different species between polluted and control during monsoon

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	0.37	0.41	0.39^{n}
2	*Terminalia paniculata*	0.64	0.42	0.53^{o}
3	*Bombax ceiba*	0.38	0.26	0.32^{m}
4	*Butea monosperma*	0.68	0.63	0.65^{q}
5	*Cassia fistula*	0.82	0.37	0.59^{p}
6	*Anogeissus latifolia*	0.47	0.29	0.38^{n}
7	*Pterocarpus marsupium*	0.87	0.48	0.67^{q}
8	*Grewia tiliifolia*	0.75	0.74	0.74^{s}
9	*Terminalia catappa*	0.67	0.74	0.71^{r}
10	*Artocarpus heterophyllus*	0.77	0.95	0.86^{t}
	Mean	0.64^{x}	0.53^{y}	

Values with the same superscript do not differ significantly between themselves

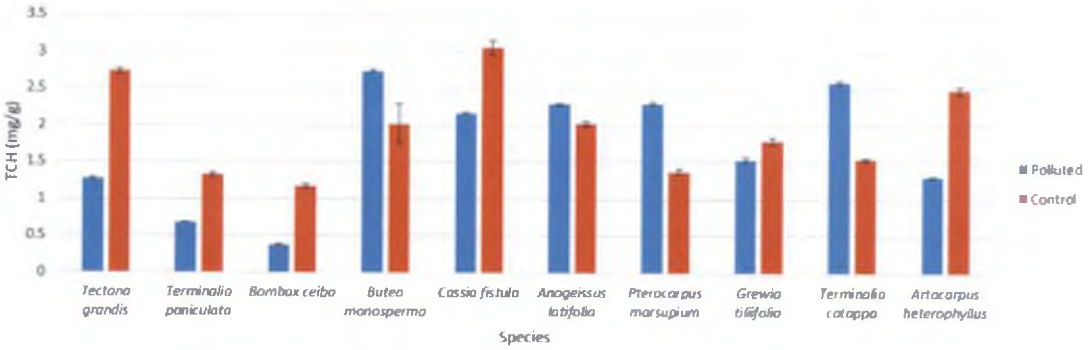

Fig. 2. Total chlorophyll content of leaf extract among different species between polluted and control during winter

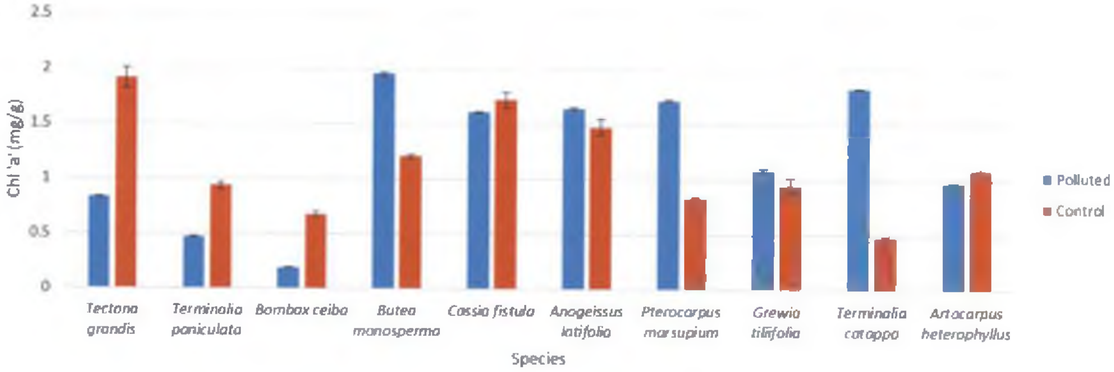

Fig. 3. Chlorophyll 'a' content of leaf extract among different species between polluted and control during winter

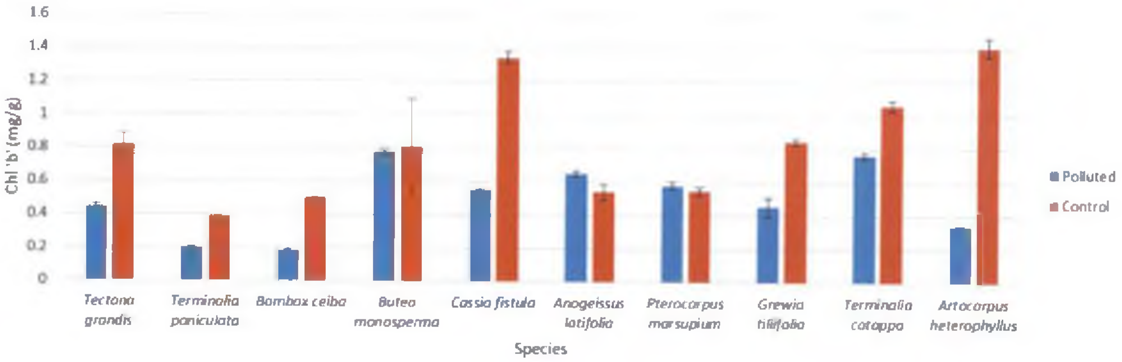

Fig. 4. Chlorophyll 'b' content of leaf extract among different species between polluted and control during winter

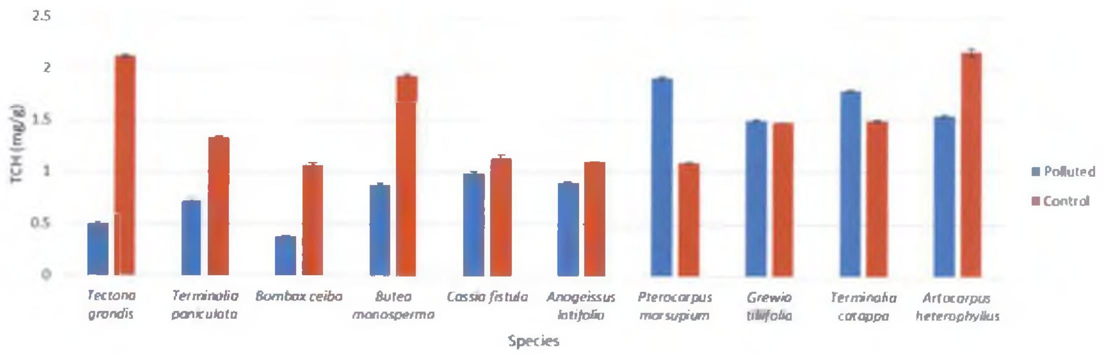

Fig. 5. Total chlorophyll content of leaf extract among different species between polluted and control during summer

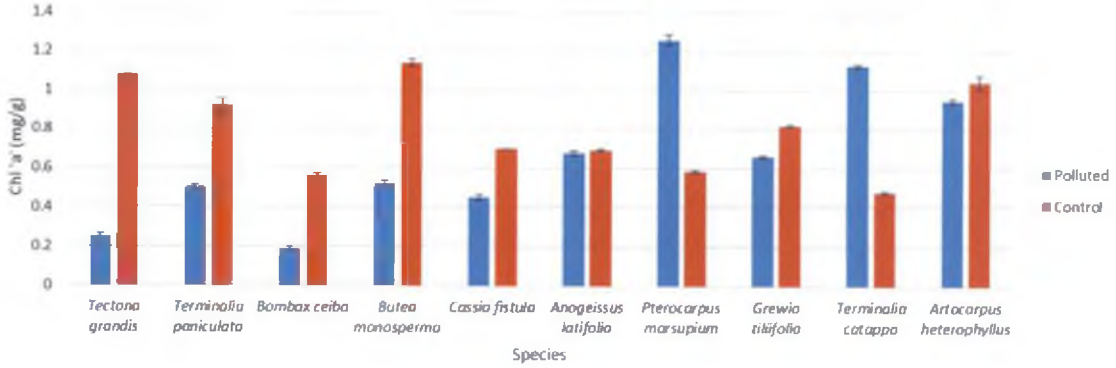

Fig. 6. Chlorophyll 'a' content of leaf extract among different species between polluted and control during summer

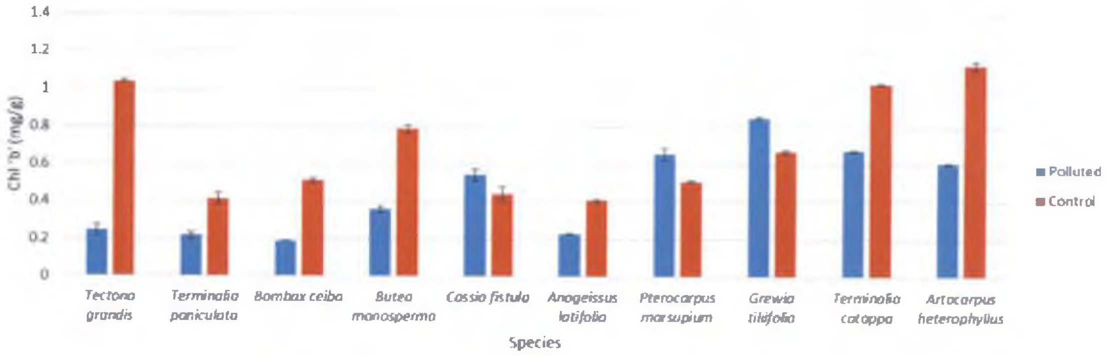

Fig. 7. Chlorophyll 'b' content of leaf extract among different species between polluted and control during summer

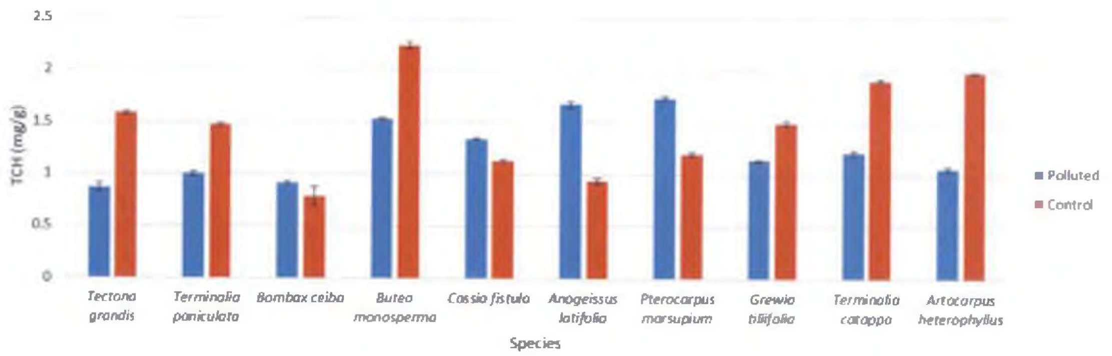

Fig. 8. Total chlorophyll content of leaf extract among different species between polluted and control during monsoon

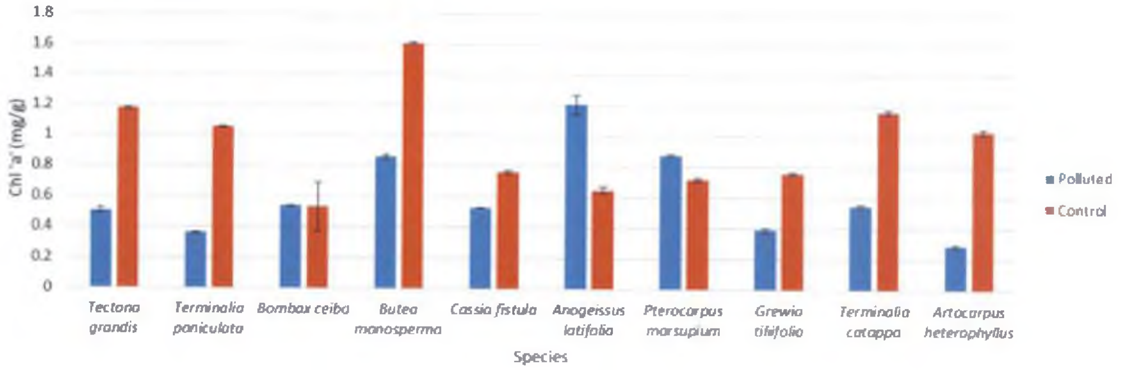

Fig. 9. Chlorophyll 'a' content of leaf extract among different species between polluted and control during monsoon

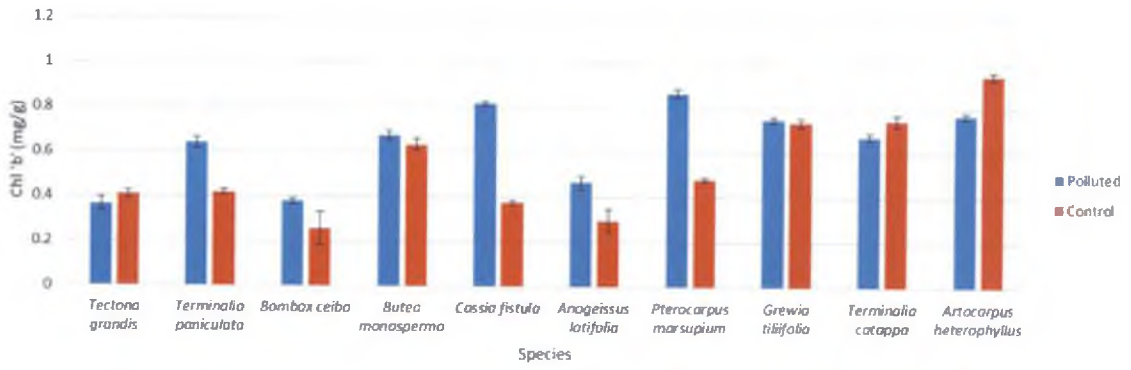

Fig. 10. Chlorophyll 'b' content of leaf extract among different species between polluted and control during monsoon

4.1.2 Ascorbic acid content (AAC) of leaf samples

Ascorbic acid of the leaf extracts were estimated using the method prescribed by Sadasivam and Manickam (1996). The results of ascorbic acid for the different species studied during winter (Table. 10), summer (Table. 11) and monsoon (Table. 12) are given in this section. The results from statistical analysis reveals that the ascorbic acid content were significantly different between species as well as between statuses during winter, summer and monsoon. The ascorbic acid content were highest in the control plots than the polluted plots during summer and monsoon, while it was higher in the polluted plot than the control during winter season. The highest value of ascorbic acid was observed in *Terminalia paniculata* (0.076 mg/ g) during winter, Pterocarpus marsupium (0.09 mg/ g) during summer and *Artocarpus heterophyllus* (0.083 mg/ g) during monsoon. The ascorbic acid content ranged between 0.076-0.049 during winter, 0.09-0.042 during summer and 0.083-0.055 during monsoon season. The values of ascorbic acid was higher during summer than the other two seasons.

Table 10. Ascorbic acid content of leaf extracts among different species between polluted and control during winter

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	0.081	0.056	0.068^{o}
2	*Terminalia paniculata*	0.072	0.081	0.076^{p}
3	*Bombax ceiba*	0.048	0.051	0.049^{m}
4	*Butea monosperma*	0.085	0.059	0.072^{op}
5	*Cassia fistula*	0.070	0.070	0.07^{op}
6	*Anogeissus latifolia*	0.062	0.054	0.058^{n}
7	*Pterocarpus marsupium*	0.071	0.068	0.07^{op}
8	*Grewia tiliifolia*	0.070	0.074	0.072^{op}
9	*Terminalia catappa*	0.060	0.045	0.52^{mn}
10	*Artocarpus heterophyllus*	0.093	0.037	0.065^{o}
	Mean	0.071^{x}	0.06^{y}	

Values with the same superscript do not differ significantly between themselves

Table 11. Ascorbic acid content of leaf extracts among different species between polluted and control during summer

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	0.043	0.040	0.042^{m}
2	*Terminalia paniculata*	0.069	0.080	0.074^{no}
3	*Bombax ceiba*	0.035	0.052	0.044^{m}
4	*Butea monosperma*	0.055	0.060	0.057^{mn}
5	*Cassia fistula*	0.062	0.085	0.07^{no}
6	*Anogeissus latifolia*	0.053	0.058	0.056^{mn}
7	*Pterocarpus marsupium*	0.059	0.122	0.09^{o}
8	*Grewia tiliifolia*	0.031	0.073	0.052^{mn}
9	*Terminalia catappa*	0.041	0.042	0.042^{m}
10	*Artocarpus heterophyllus*	0.078	0.043	0.06^{mn}
	Mean	0.053^{x}	0.066^{y}	

Values with the same superscript do not differ significantly between themselves

Table 12. Ascorbic acid content of leaf extracts among different species between polluted and control during monsoon

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	0.047	0.064	0.055^{m}
2	*Terminalia paniculata*	0.055	0.079	0.067^{op}
3	*Bombax ceiba*	0.052	0.068	0.06^{n}
4	*Butea monosperma*	0.072	0.076	0.074^{r}
5	*Cassia fistula*	0.072	0.065	0.068^{p}
6	*Anogeissus latifolia*	0.063	0.086	0.074^{r}
7	*Pterocarpus marsupium*	0.072	0.071	0.071^{q}
8	*Grewia tiliifolia*	0.064	0.092	0.079^{s}
9	*Terminalia catappa*	0.064	0.067	0.066^{o}
10	*Artocarpus heterophyllus*	0.071	0.095	0.083^{t}
	Mean	0.063^{x}	0.073^{y}	

Values with the same superscript do not differ significantly between themselves

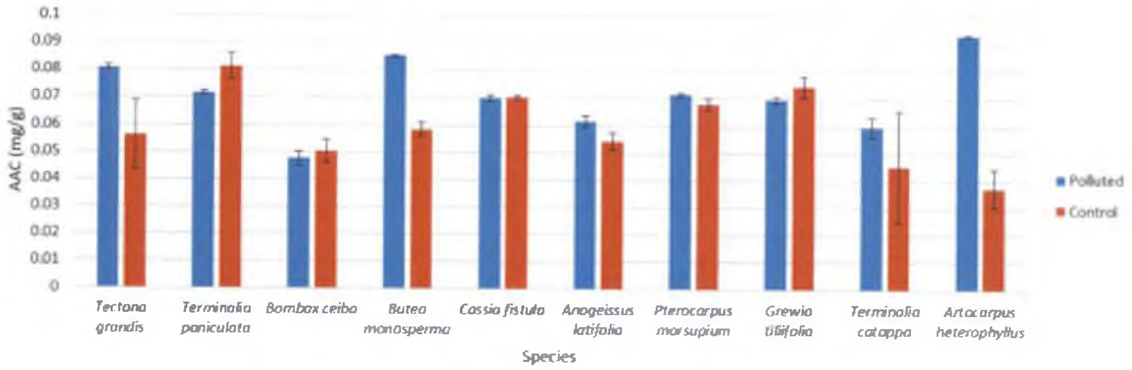

Fig. 11. Ascorbic acid content of leaf extract among different species between polluted and control during winter

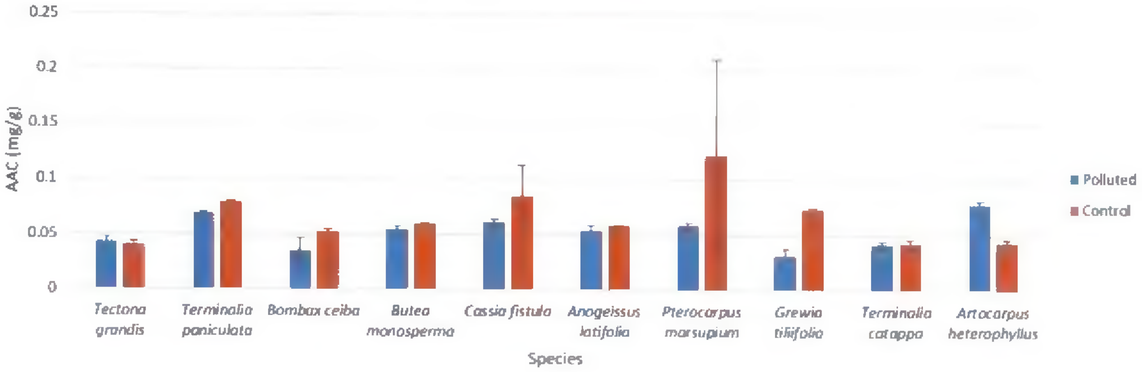

Fig. 12. Ascorbic acid content of leaf extract among different species between polluted and control during summer

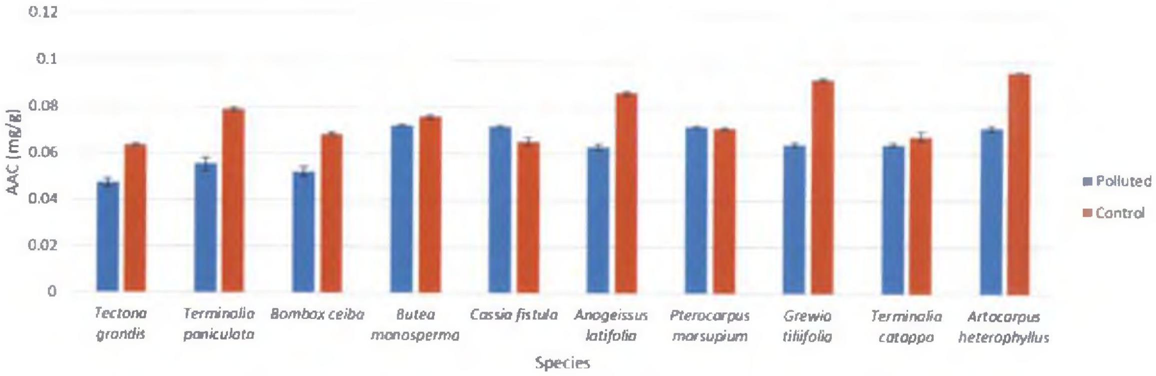

Fig. 13. Ascorbic acid content of leaf extract among different species between polluted and control during monsoon

4.1.3 Relative water content of leaf samples

The method based on the fresh weight, dry weight and turgid weight as described by Singh (1977) were used for the estimation of the relative water content (RWC) of the leaf samples. The results for RWC during winter (Table. 13), summer (Table. 14) and monsoon (Table. 15) are given in this section. On statistical analysis, RWC were found to be significantly different between species and statuses during winter and summer. RWC was significant for the species as well as the interaction between species and status, but were not significant between statuses during monsoon season. The relative water content was higher in the control plot than polluted during all the three seasons. The RWC was highest in *Anogeissus latifolia* during winter (89.96%) and summer (88.25%), while it was the highest in *Tectona grandis* (85.68%) during monsoon season. The RWC ranged between 89.96-52.69 during winter, 88.25-66.89 during summer and 85.68-57.8 during monsoon season. The RWC were higher during winter than during summer and monsoon seasons.

Table 13. Relative water content of leaf samples among different species between polluted and control during winter

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	49.06	74.24	61.65^{n}
2	*Terminalia paniculata*	78.58	88.65	83.61^{r}
3	*Bombax ceiba*	78.04	64.31	71.17^{p}
4	*Butea monosperma*	96.12	79.82	87.97^{s}
5	*Cassia fistula*	74.07	73.44	73.75^{q}
6	*Anogeissus latifolia*	81.54	98.38	89.96^{s}
7	*Pterocarpus marsupium*	38.18	67.20f	52.69^{m}
8	*Grewia tiliifolia*	70.45	68.04	69.25^{op}
9	*Terminalia catappa*	85.95	79.25	82.6^{r}
10	*Artocarpus heterophyllus*	55.17	80.78	67.97^{o}
	Mean	70.72^{x}	77.41^{y}	

Values with the same superscript do not differ significantly between themselves

Table 14. Relative water content of leaf samples among different species between polluted and control during summer

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	80.03	80.44	80.23^{q}
2	*Terminalia paniculata*	80.68	88.51	84.59^{r}
3	*Bombax ceiba*	83.00	70.12	76.56^{p}
4	*Butea monosperma*	89.01	81.36	85.19^{r}
5	*Cassia fistula*	77.01	70.65	73.83^{no}
6	*Anogeissus latifolia*	78.55	97.96	88.25^{s}
7	*Pterocarpus marsupium*	78.50	71.59	75.04^{op}
8	*Grewia tiliifolia*	66.66	67.12	66.89^{m}
9	*Terminalia catappa*	82.61	81.00	81.81^{q}
10	*Artocarpus heterophyllus*	63.27	82.40	72.83^{n}
	Mean	77.93^{x}	79.11^{y}	

Values with the same superscript do not differ significantly between themselves

Table 15. Relative water content of leaf samples among different species between polluted and control during monsoon

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	88.85	82.51	85.68^{q}
2	*Terminalia paniculata*	73.12	88.52	80.82^{opq}
3	*Bombax ceiba*	71.13	78.95	75.04^{n}
4	*Butea monosperma*	73.88	82.57	78.22^{no}
5	*Cassia fistula*	79.56	42.50	61.03^{m}
6	*Anogeissus latifolia*	77.87	90.28	84.07^{pq}
7	*Pterocarpus marsupium*	54.87	59.90	57.38^{m}
8	*Grewia tiliifolia*	80.19	79.33	79.76^{nop}
9	*Terminalia catappa*	82.67	81.69	82.18^{opq}
10	*Artocarpus heterophyllus*	73.23	84.52	78.87^{nop}
	Mean	75.54^{x}	77.08^{x}	

Values with the same superscript do not differ significantly between themselves

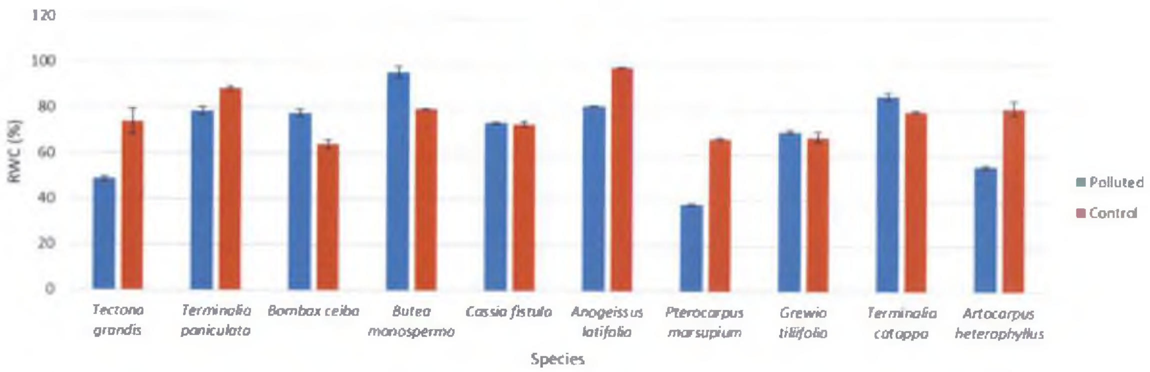

Fig. 14. Relative water content of leaf extract among different species between polluted and control during winter

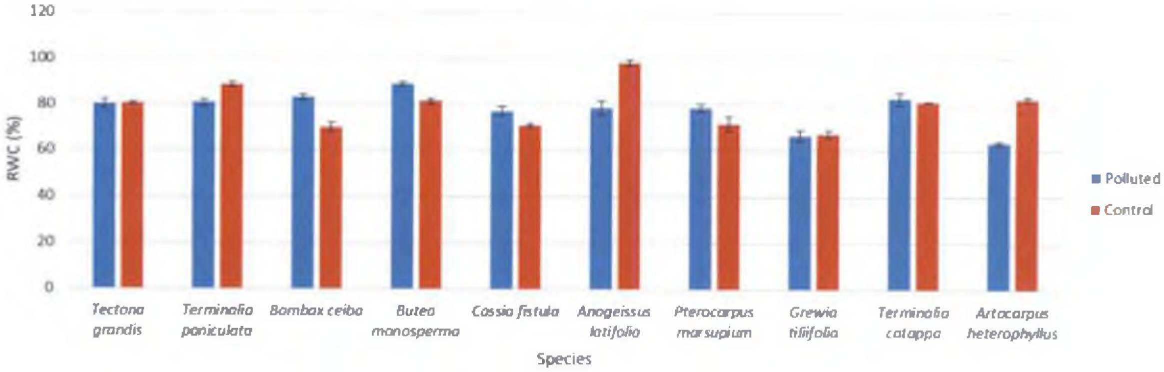

Fig. 15. Relative water content of leaf extract among different species between polluted and control during summer

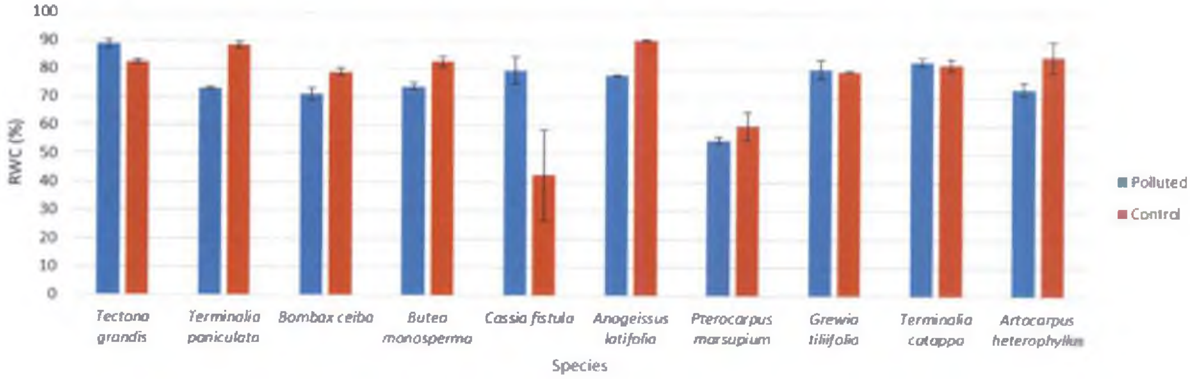

Fig. 16. Relative water content of leaf extract among different species between polluted and control during monsoon

4.1.4 The pH of leaf samples

The pH of the leaf samples were estimated with the aid of a pH meter. The results of pH during winter (Table. 16), summer (Table. 17) and monsoon (Table. 18) are given in this section. Uncharacteristically of plants exposed to cement dust pollution that are alkaline in nature, the pH of none of the species were alkaline, since none of the samples pH crossed 7, the mark of neutrality. Nevertheless pH were higher in species exposed to cement dust than those growing far away from the cement factory. On statistical analysis, pH were significantly different between the species as well as between statuses during winter, summer and monsoon. The values of pH was higher in polluted plot during all the three seasons. The highest pH values was in *Butea monosperma* (6.13) during winter, while it was highest in *Tectona grandis* during summer (6.21) and monsoon (6.44). The values of pH ranged between 6.13-4.3 during winter, 6.21-4.05 during summer and 6.44-4.04 during monsoon. The value of pH was thus higher during monsoon than the other two seasons.

Table 16. pH of leaf extract among different species between polluted and control during winter

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	6.09	5.59	5.84^{p}
2	*Terminalia paniculata*	5.50	4.54	5.02^{n}
3	*Bombax ceiba*	5.46	5.66	5.56^{o}
4	*Butea monosperma*	6.74	5.53	6.13^{q}
5	*Cassia fistula*	6.02	5.66	5.84^{p}
6	*Anogeissus latifolia*	4.76	3.85	4.3^{m}
7	*Pterocarpus marsupium*	5.33	5.37	5.35^{o}
8	*Grewia tiliifolia*	5.67	5.42	5.54^{o}
9	*Terminalia catappa*	4.38	4.33	4.35^{m}
10	*Artocarpus heterophyllus*	5.84	3.98	4.91^{n}
	Mean	5.58^{x}	4.99^{y}	

Values with the same superscript do not differ significantly between themselves

Table 17. pH of leaf extract among different species between polluted and control during summer

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	6.74	5.68	6.21^{q}
2	*Terminalia paniculata*	5.46	4.49	4.97^{o}
3	*Bombax ceiba*	5.62	5.63	5.62^{p}
4	*Butea monosperma*	6.76	5.53	6.15^{q}
5	*Cassia fistula*	6.43	5.69	6.06^{q}
6	*Anogeissus latifolia*	4.20	3.91	4.05^{m}
7	*Pterocarpus marsupium*	5.55	5.48	5.51^{p}
8	*Grewia tiliifolia*	4.58	5.33	4.95^{o}
9	*Terminalia catappa*	4.49	4.50	4.49^{n}
10	*Artocarpus heterophyllus*	5.36	4.02	4.69^{n}
	Mean	5.52^{x}	5.02^{y}	

Values with the same superscript do not differ significantly between themselves

Table 18. pH of leaf extract among different species between polluted and control during monsoon

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	6.31	6.58	6.44^{s}
2	*Terminalia paniculata*	4.98	4.50	4.74^{o}
3	*Bombax ceiba*	5.76	5.03	5.39^{p}
4	*Butea monosperma*	6.87	5.75	6.31^{s}
5	*Cassia fistula*	6.55	5.24	5.9^{r}
6	*Anogeissus latifolia*	4.61	3.47	4.04^{m}
7	*Pterocarpus marsupium*	5.63	5.15	5.39^{p}
8	*Grewia tiliifolia*	6.16	5.35	5.76^{q}
9	*Terminalia catappa*	4.74	4.28	4.51^{n}
10	*Artocarpus heterophyllus*	5.51	3.71	4.61^{no}
	Mean	5.71^{x}	4.91^{y}	

Values with the same superscript do not differ significantly between themselves

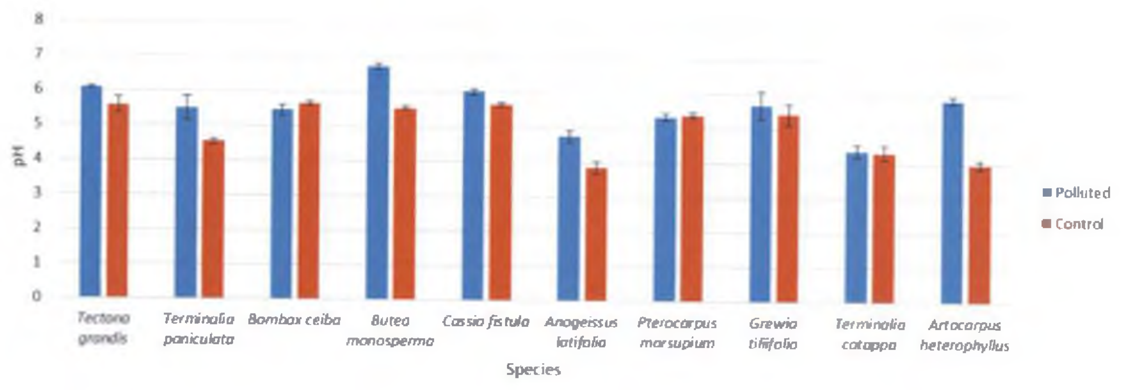

Fig. 17. pH of leaf samples among different species between polluted and control during winter

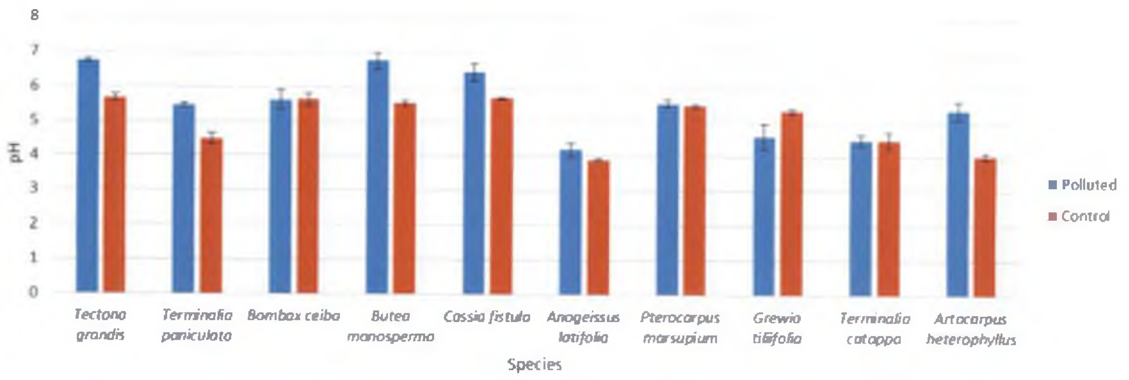

Fig. 18. pH of leaf samples among different species between polluted and control during summer

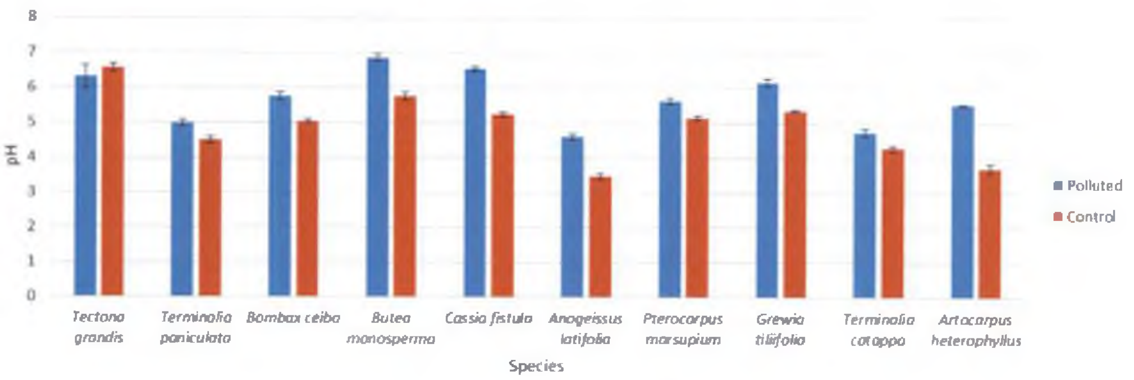

Fig. 19. pH of leaf samples among different species between polluted and control during monsoon

4.1.5 Air pollution tolerance index (APTI)

This index is based on total chlorophyll content, ascorbic acid content, relative water content and pH of the leaf samples. The air pollution tolerance indices of the ten species under consideration were carried out by the method described by Singh and Rao (1983). The results of APTI during winter (Table. 19), summer (Table. 20) and monsoon (Table. 21) are discussed in this section. On statistical analysis, APTI during winter and monsoon were significantly different between species, statuses as well as the interaction between species and status. But during summer, it was significant between species as well as between statuses, but was not significant between statuses and species. The values of APTI was higher in control plots than the polluted during summer and monsoon, while it was higher in the polluted plot during winter. The APTI was the highest in *Butea monosperma* during winter (5.64) and monsoon (4.74), while it was highest in *Pterocarpus marsupium* (4.55) during summer. The values of APTI ranged between 5.64-2.2 during winter, 4.55-2.09 during summer and 4.74-2.8 during monsoon. The APTI was higher during winter than during summer and monsoon seasons.

After the estimation of APTI of the ten species, they were graded into four tolerance classes (Liu and Ding, 2008). The species with higher tolerance in the polluted area were given priority than those in control plots. After grading, it is evident (Table. 22) that *Butea monosperma* was the most tolerant to the particulate pollution, followed by *Cassia fistula*. The most sensitive species were found to be *Bombax ceiba* and *Terminalia catappa*. *Tectona grandis* fell in the intermediate tolerance category according to this classification.

Table 19. Air pollution tolerance index (APTI) among different species between polluted and control during winter

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	2.91	3.45	3.18^{op}
2	*Terminalia paniculata*	3.48	4.23	3.85^{r}
3	*Bombax ceiba*	2.17	2.22	2.2^{m}
4	*Butea monosperma*	7.76	3.53	5.64^{t}
5	*Cassia fistula*	4.25	4.50	4.38^{s}
6	*Anogeissus latifolia*	3.55	3.13	3.34^{pq}
7	*Pterocarpus marsupium*	2.08	3.09	2.58^{n}
8	*Grewia tiliifolia*	3.54	3.65	3.6^{qr}
9	*Terminalia catappa*	3.58	2.09	2.83^{no}
10	*Artocarpus heterophyllus*	3.67	1.95	2.81^{no}
	Mean	3.7^{x}	3.18^{y}	

Values with the same superscript do not differ significantly between themselves

Table 20. Air pollution tolerance index (APTI) among different species between polluted and control during summer

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	2.50^{bcde}	2.54	2.52^{mn}
2	*Terminalia paniculata*	3.43	4.10	3.76^{op}
3	*Bombax ceiba*	1.74	2.47	2.1^{m}
4	*Butea monosperma*	3.74	3.63	3.69^{nop}
5	*Cassia fistula*	3.54	4.07	3.81^{op}
6	*Anogeissus latifolia*	2.14	2.86	2.5^{mn}
7	*Pterocarpus marsupium*	3.43	5.68	4.55^{p}
8	*Grewia tiliifolia*	1.28	3.35	2.31^{m}
9	*Terminalia catappa*	2.15	2.05	2.09^{m}
10	*Artocarpus heterophyllus*	3.39	2.21	2.8^{mno}
	Mean	2.73^{x}	3.3^{y}	

Values with the same superscript do not differ significantly between themselves

Table 21. Air pollution tolerance index (APTI) among different species between polluted and control during monsoon

Sl No.	Species	Polluted	Control	Mean
1	*Tectona grandis*	3.01	4.28	3.65^{o}
2	*Terminalia paniculata*	2.42	4.18	3.3^{n}
3	*Bombax ceiba*	2.48	3.14	2.81^{m}
4	*Butea monosperma*	4.48	5.00	4.74^{r}
5	*Cassia fistula*	4.50	1.76	3.13^{n}
6	*Anogeissus latifolia*	3.07	3.43	3.25^{n}
7	*Pterocarpus marsupium*	2.90	2.69	2.8^{m}
8	*Grewia tiliifolia*	3.73	5.00	4.36^{q}
9	*Terminalia catappa*	3.15	3.41	3.28^{n}
10	*Artocarpus heterophyllus*	3.43	4.59	4.01^{p}
	Mean	3.32^{x}	3.75^{y}	

Values with the same superscript do not differ significantly between themselves

Table 22. Tress graded according to APTI values in descending order

Sl No.	Species	Polluted			Control		
		Winter	Summer	Monsoon	Winter	Summer	Monsoon
1	*Butea monosperma*	T	MT	T	MT	MT	T
2	*Cassia fistula*	MT	MT	T	MT	T	S
3	*Terminalia paniculata*	MT	MT	S	MT	T	MT
4	*Grewia tiliifolia*	MT	S	MT	MT	MT	T
5	*Pterocarpus marsupium*	S	MT	I	I	T	I
6	*Artocarpus heterophyllus*	MT	MT	I	S	I	T
7	*Tectona grandis*	I	I	I	MT	I	MT
8	*Anogeissus latifolia*	MT	I	I	I	I	I
9	*Terminalia catappa*	MT	I	I	S	I	I
10	*Bombax ceiba*	I	S	I	MT	I	I

*T – tolerant, MT – moderately tolerant, I – Intermediate, and S – sensitive.

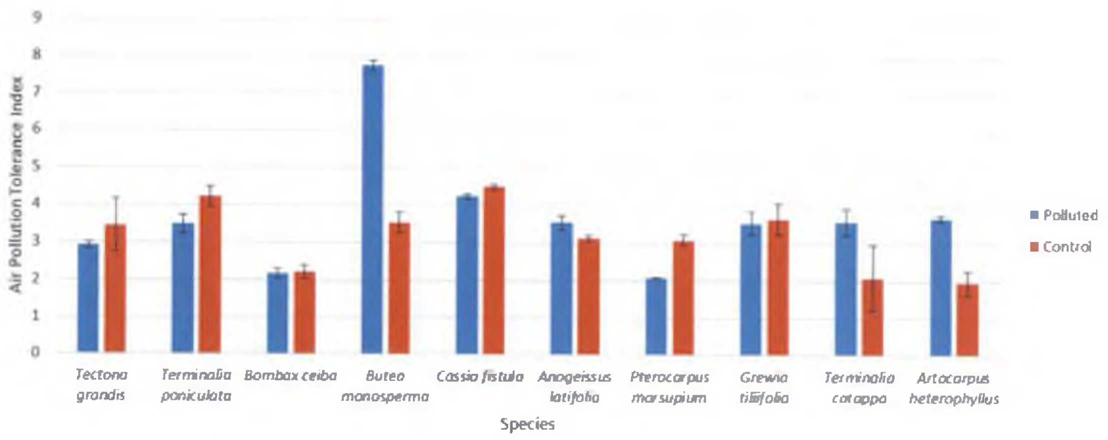

Fig 20. APTI among different species between polluted and control during winter

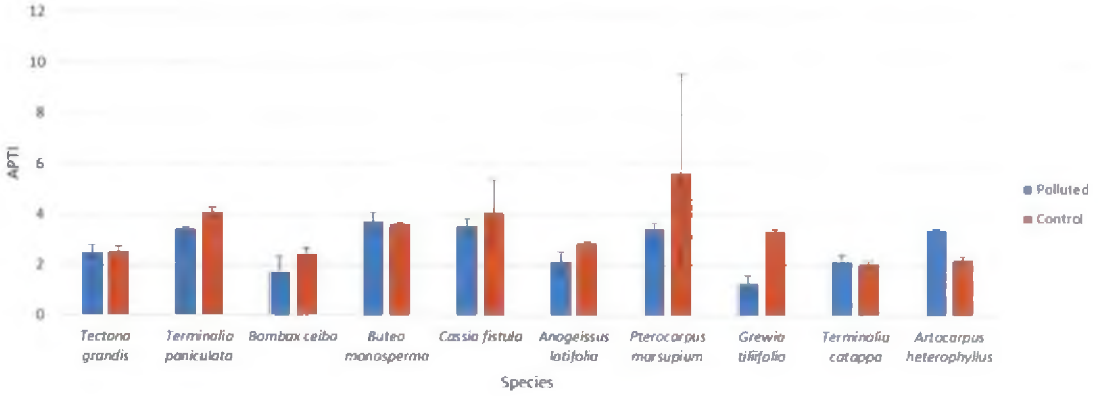

Fig. 21. APTI among different species between polluted and control during summer

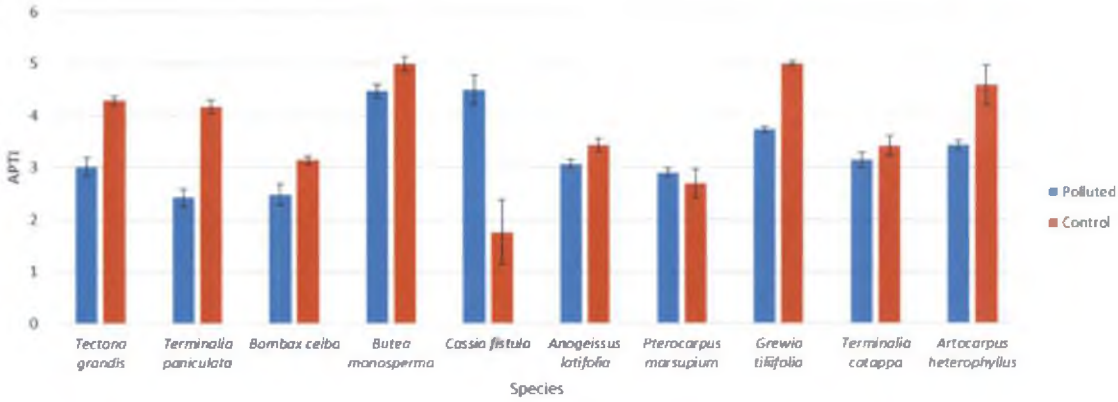

Fig. 22. APTI among different species between polluted and control during monsoon

4.2 Morphological parameters of teak

The morphological parameters like height and girth were measured at both the plots. The height measurement were taken using Haga's altimeter and the girth at breast height using a measuring tape. The mean height and girth of the teak trees in polluted plot were observed to be comparatively lesser than those located away from the pollution load as can be observed from the (Table. 23). The mean height of *T. grandis* for the control plots were 16.5 m in comparison to that of 9.7 m in trees exposed to cement dust pollution. While the mean girth of the trees in control plot were 101.6 cm in comparison to 50.2 cm in the polluted plot (Table. 23). After statistical analysis, it was confirmed that both the variation in height and girth difference in the controlled as well as polluted conditions were significantly different.

4.3 Dust accumulation on leaf surface

The dust accumulation on the leaf surface of *Tectona grandis* at both the sites were carried out according to the methodology described by Prusty *et al.* (2005). According to the (Fig. 23), it is evident that the leaves of *Tectona grandis* were under severe dust load in the polluted area in comparison to the control plots. During winter, the dust load in polluted plot were 0.2045 mg/ cm^2 while in control plot it were 0.0344 mg/ cm^2. In summer, the dust accumulated on the leaf surface of *T. grandis* were 0.2994 mg/ cm^2 while in the control plot its 0.0367 mg/ cm^2. The load during monsoon in polluted plot were 0.0123 mg/ cm^2 and in control plot it were recorded to be 0.0026 mg/ cm^2 (Table. 24). On statistical analysis, it was found that the dust load was significantly different between polluted and control plots and between seasons.

4.4 Rate of dust accumulation

The rate of dust accumulation were studied between the intervals of the seasons studied, i.e. between winter and summer (Dec-March) and then between summer and monsoon (March-June). The rate of accumulation during Dec-March for the polluted plot (0.7307 mg/month) were significantly higher than control plots

(0.1032 mg/month) (Table. 25). The dust accumulation rate for the period March-June in polluted plot (0.5144 mg/month) were significantly different than the control plot (0.0649 mg/month).

Table 23. Height and girth of *Tectona grandis* in polluted and control plots

	Polluted	Control
Height* (m)	9.7 (3.3)	16.5 (1.65)
Girth* (cm)	50.2 (29.16)	101.6 (24.31)

*Significantly different at 0.05 levels

Table 24. Dust accumulation on the leaf surface of *Tectona grandis* during three season in the polluted and control plot

	Polluted (mg/cm^2)	Control (mg/cm^2)	Mean (mg/cm^2)
Winter*	0.2045 (0.00005)	0.0344 (0.000008)	0.1195^b
Summer*	0.2994 (0.00006)	0.0367 (0.000009)	0.1681^c
Monsoon*	0.0123 (0.000008)	0.0026 (0.000002)	0.0074^a

*Significantly different at 0.05 levels

Values with the same superscript does not differ between themselves

Table 25. Rate of dust accumulation on *Tectona grandis* leaf surface

	Polluted (mg/month)	Control (mg/month)	Mean
Dec – March*	0.7307 (0.12)	0.1032 (0.02)	0.4169
March – June*	0.5144 (0.1)	0.0649 (0.01)	0.2896

*Significant at 0.05 levels

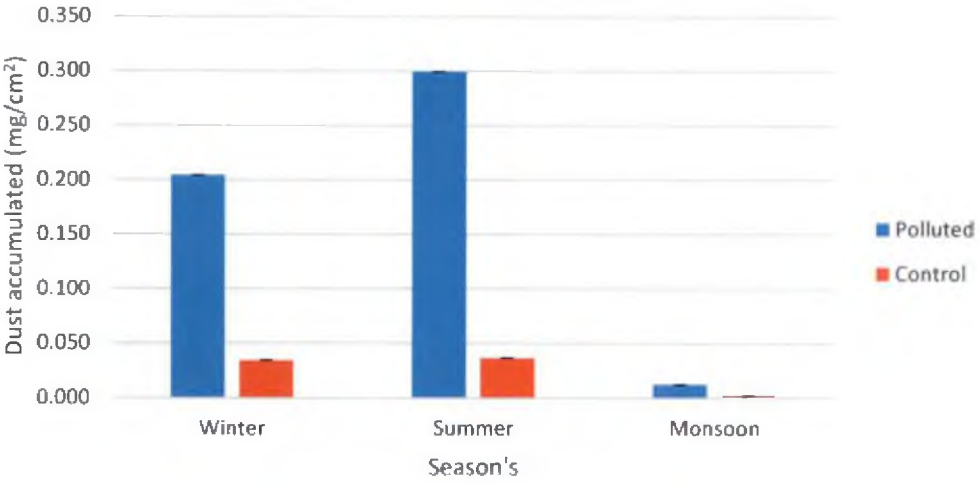

Fig. 23. Dust accumulation on *Tectona grandis* leaf surface during three season

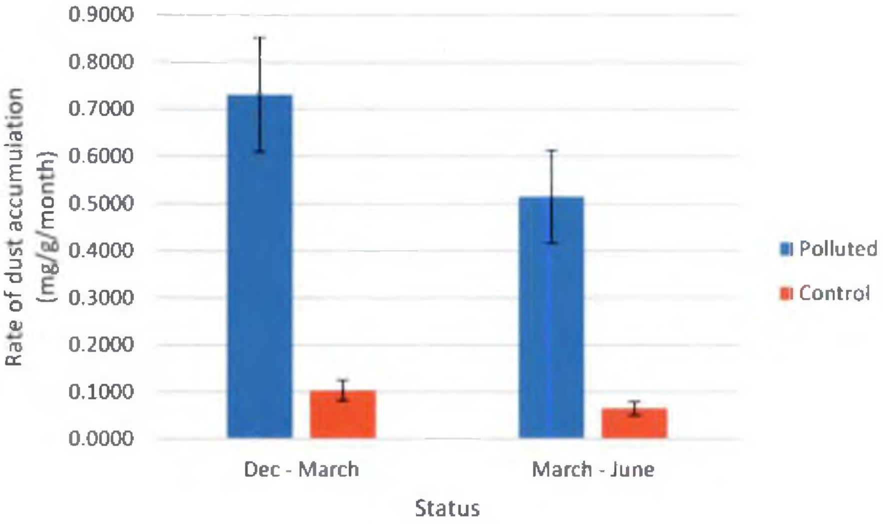

Fig. 24. Rate of dust accumulation on the leaf surface of *Tectona grandis*

4.5 Leaf surface area

The leaf surface area were measured during all the three seasons, and found that the leaf surface area were higher in control plot compared to polluted plot irrespective of the seasons (Fig. 25). The leaf surface area during winter in the polluted plots were 304.62 cm^2 in comparison to 352.24 cm^2 in the control plots. The leaf surface area were 281.84 cm^2 in the polluted site in comparison to 366.43 cm^2 in the control plots during summer season. The leaf surface area during monsoon in the polluted plot were recorded at 353.03 cm^2 in comparison to 455.61 cm^2 in the control plots (Table. 26).

The highest leaf surface area for *Tectona grandis* were during monsoon (404.32 cm^2) followed by winter (328.43 cm^2) and summer season (324.14 cm^2). However the leaf surface area were not significantly different between summer and winter seasons, though it differed significantly with monsoon readings (Table. 26). Leaf surface area were significant at 5% levels for the status of the plot as well as the season.

4.6 Leaf area index (LAI)

The leaf area index of *Tectona grandis* during winter, summer and monsoon were taken using canopy analyser at both the plots. The LAI were found to be the highest in the control plots compared to those exposed to pollution dust from the factory (Fig. 27). The LAI during winter in the polluted site were 0.68 and 1.53 in the control plot (Table. 27). The LAI in the polluted plot were 0.62 and control plot were 1.48 during summer season. While during monsoon period, the LAI in the polluted plot were 0.76 and in the control plot it was 1.89.

On statistical analysis LAI were significant at 5% for the status, season and the combination of the both. Also LAI during summer (1.048) and winter (1.106) differed significantly at 5% with those of monsoon (1.324) season which was the highest among the three seasons.

4.7 Leaf area duration (LAD)

The leaf area duration (LAD) of *Tectona grandis* were observed between winter and summer (Dec-March), and between summer and monsoon (March-June). The no. of days between Dec 14, 2012 and March11, 2013 were 87 days, and the no. of days between March 11, 2013 and June 17, 2013 were 98 days. The LAD for Dec-March in the polluted plot were 56.51 and 130.89 in the control plot (Table. 28). While for the period March-June, the LAD for the polluted plot were 67.42 and for the control plot it was 165.03.

On statistical analysis, there was significant difference in both the LAD between polluted and control plots, with the LAD being significantly lower in polluted compared to the control plots (Table. 28). The LAD during March-June (93.7) were significantly higher than the LAD during Dec-March (116.22). It was observed that the leaf fall in the polluted plot commences as early as mid-November, especially in typical moist deciduous trees like *Bombax ceiba* and *Tectona grandis*, while in the control plots trees shed their leaves as late as mid-December. Also the new flushes of leaves comes up in the polluted plot only by April, which is one and a half month late in comparison to trees in the control plot.

4.8 Plant water status of *Tectona grandis*

The water potential of *Tectona grandis* were recorded with the aid of pressure bomb apparatus. The water potential were recorded to be the highest during summer in the polluted site, while the water potential were lowest during monsoon in the polluted site. The water potential during summer in the polluted site is 2.68 MPa and 1.79 MPa in the control site (Table. 29). The water potential in polluted site is recorded at 0.25 MPa and in control site its 0.35 MPa during monsoon season.

On statistical analysis of the water potential, there were significant difference between the water potential at the polluted site in comparison to control plots during summer as well as during monsoon. The water potential during summer (2.3 MPa) is significantly higher than during monsoon (0.3 MPa).

Table 26. Leaf surface area of *Tectona grandis* during three seasons

	Polluted (cm^2)	Control (cm^2)	Mean
Winter*	304.62 (30.48)	352.24 (38.89)	328.43a
Summer*	281.84 (20.16)	366.43 (47.27)	324.14a
Monsoon*	353.03 (41.27)	455.61 (136.26)	404.32b

*Significant at 0.05 levels

Values with the same superscript do not differ significantly between themselves

Table 27. Leaf area index (LAI) of *Tectona grandis* during three seasons

	Polluted	Control	Mean
Winter*	0.68 (0.08)	1.53 (0.11)	1.106^{a}
Summer*	0.62 (0.08)	1.48 (0.08)	1.048^{a}
Monsoon*	0.76 (0.09)	1.89 (0.08)	1.324^{b}

*Significant at 0.05 levels

Values with the same superscript do not differ significantly between themselves

Table 28. Leaf area duration (LAD) of *Tectona grandis* during the periods between the seasons

	Polluted	Control	Mean
Dec-March*	56.51 (6)	130.89 (6.67)	93.7
March-June*	67.42 (6.76)	165.03 (5.94)	116.22

*Significant at 0.05 levels

Table 29. Water potential of *Tectona grandis* during summer and monsoon

	Polluted (MPa)	Control (MPa)	Mean
Summer*	2.68 (0.17)	1.79 (0.03)	2.3
Monsoon*	0.25 (0.1)	0.35 (0.06)	0.3

*Significant at 0.05 levels

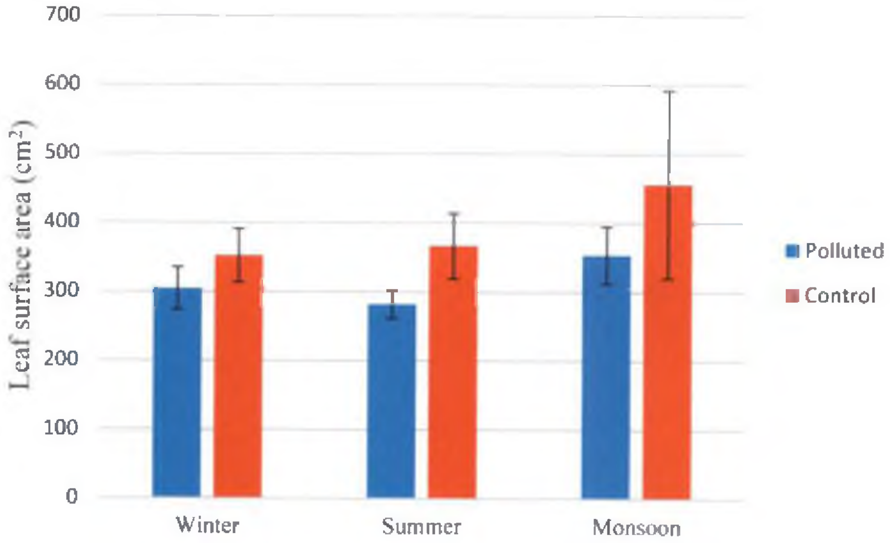

Fig. 25. Leaf surface area of *Tectona grandis* during three seasons

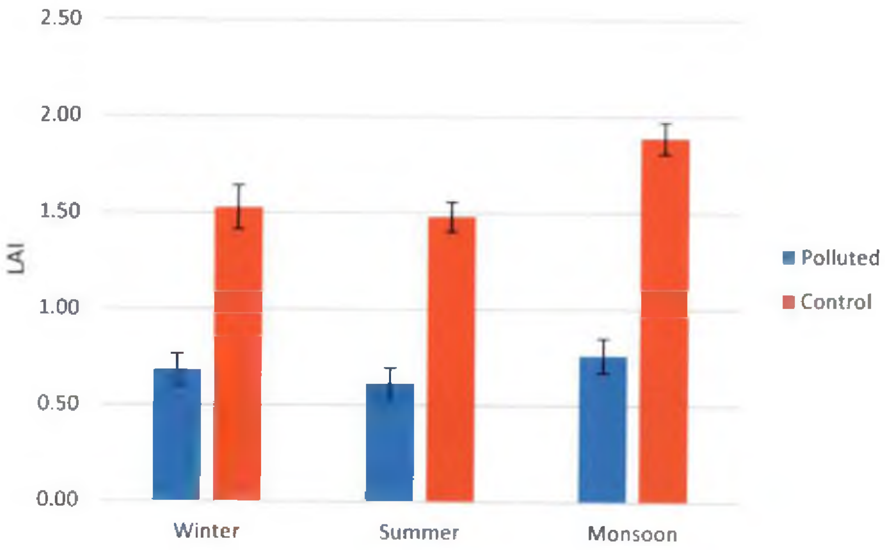

Fig. 26. LAI of *Tectona grandis* during three seasons

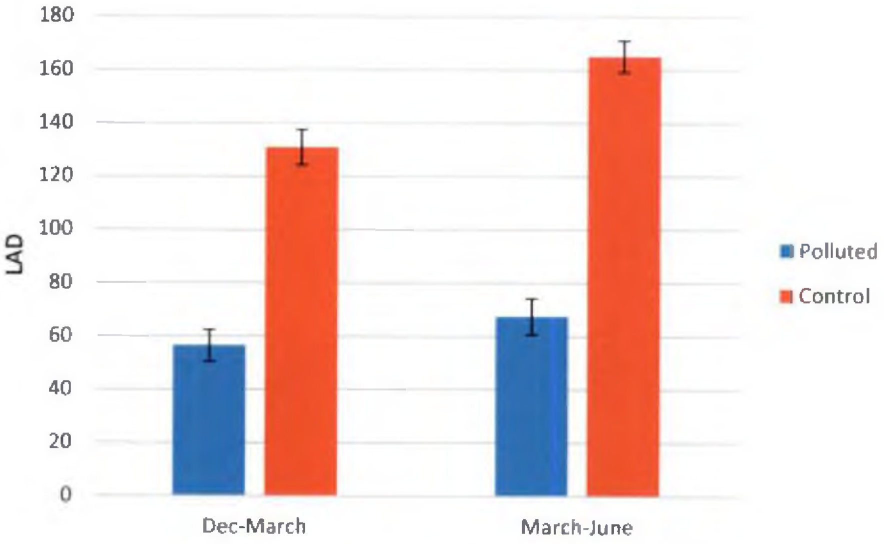

Fig. 27. Leaf area duration (LAD) of *Tectona grandis* during periods between the seasons

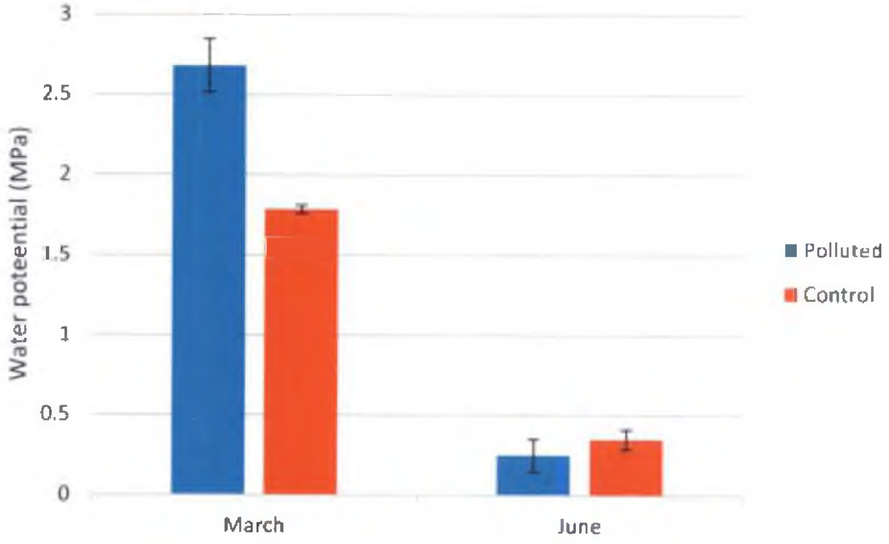

Fig. 28. Water potential of *Tectona grandis* during summer and monsoon seasons

4.9. Photosynthesis

The photosynthesis taking place in *Tectona grandis* was measured with IRGA, during the early morning hours. The results indicate that the photosynthesis taking place in the trees located in the polluted region is significantly lower in the polluted plots (4 µmol m^{-2} s^{-1}) in comparison to control plots (8.7 µmol m^{-2} s^{-1}) during summer season. Photosynthesis was highest in control plot (7.3 µmol m^{-2} s^{-1}) in comparison to polluted plot (3.7 µmol m^{-2} s^{-1}) during monsoon season.

Table. 30. Comparison of photosynthesis of *Tectona grandis* in the polluted plot and control plot

	Polluted (µmol m^{-2} s^{-1})	Control (µmol m^{-2} s^{-1})	Mean
Summer*	4.0	8.7	6.35
Monsoon*	3.7	7.3	5.5

*Significant at 0.05 levels

4.10. Transpiration

The transpiration in *Tectona grandis* was measured based on the stomatal conductance with the aid IRGA. Stomatal conductance is the measure of the rate of passage of carbon dioxide entering or water vapour escaping through the stomata of a leaf. The stomatal conductance is significantly higher for *T. grandis* in control (0.292 µmol m^{-2} s^{-1}) plot than in the polluted plot (0.045 µmol m^{-2} s^{-1}) during summer. The stomatal conductance during monsoon was highest in polluted plot (5.23 µmol m^{-2} s^{-1}) in comparison to control plot (0.42 µmol m^{-2} s^{-1}).

Table. 31. Comparison of stomatal conductance of *Tectona grandis* in the polluted plot and control plot

	Polluted (µmol m^{-2} s^{-1})	Control (µmol m^{-2} s^{-1})	Mean
Summer*	0.045	0.292	0.17
Monsoon*	5.23	0.42	2.82

*Significant at 0.05 levels

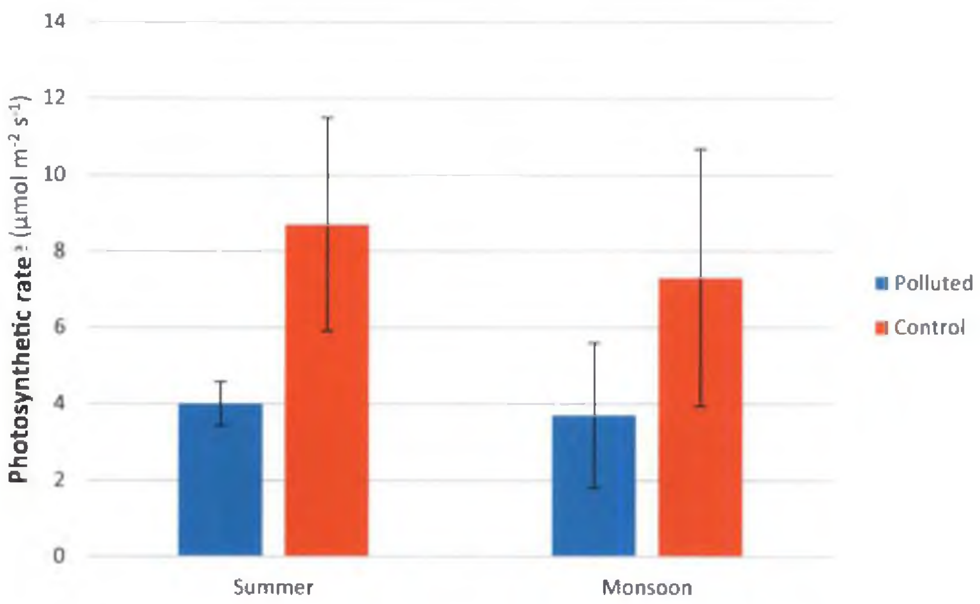

Fig. 29. Photosynthesis of *Tectona grandis* during summer and monsoon seasons

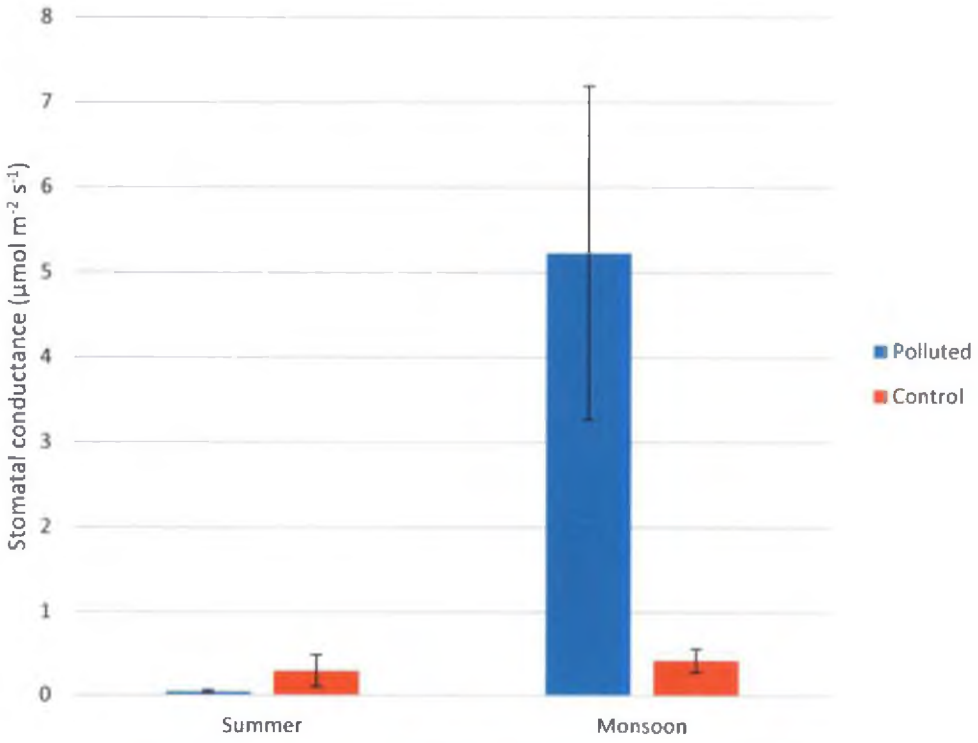

Fig. 30. Transpiration of *Tectona grandis* during summer and monsoon seasons

4.11. Wood anatomical properties of *Tectona grandis*

4.11.1. Comparison with fast grown *Tectona grandis* at Nilambur

The vessel and ray elements of *Tectona* grandis in Walayar (63 years old) were compared with 47 year old teak at Nilambur (Anish, 2013). The vessel and ray parameters were statistically analysed at the pith, middle and periphery (Table. 32) of the *Tectona grandis* disk. Also overall comparison of these parameters were done between the disks of Walayar and Nilambur teak (Table. 33). The vessel and ray characters of Walayar teak was statistically analysed, and only ray width and ray frequencies varied with radial positions. The ray width at periphery (68 μm) was significantly higher than those in the pith (47 μm) and middle positions (50 μm). While the ray frequency at pith (17/mm^2) was significantly higher than those in middle (8/mm^2) and periphery (6/mm^2) positions.

The overall comparison of the vessel and ray characteristics of Walayar and Nilambur teak revealed that only the frequencies of vessel (9/mm^2 at Walayar and 4/mm^2 at Nilambur) and ray (11/mm^2 at Walayar and 4/mm^2 at Nilambur) differed significantly between the two based on their standard deviations, while the remaining characters did not show any significant difference (Table. 35).

4.11.2. Comparison with sixty year old *Tectona grandis*

The fibre and vessel characteristics of *Tectona grandis* of Walayar were compared with Nilambur (Varghese *et al.*, 2000). The fibre length (1359 μm at Walayar and 1472 μm at Nilambur), fibre lumen diameter (11 μm at Walayar and 14 μm at Nilambur) and fibre wall thickness (3.9 μm at Walayar and 5.2 μm at Nilambur) of Walayar were lower in comparison to Nilambur (Table. 34). While fibre width (26 μm at Walayar and 24.3 μm at Nilambur) and vessel diameter (219 μm at Walayar and 199 μm at Nilambur) of Walayar were higher in comparison to Nilambur. The anatomical index of runkel ratio were higher in Walayar teak (0.95) than in Nilambur teak (0.82). On statistical analysis of *Tectona grandis* of Walayar, it showed no significant difference in the fibre and vessel characteristics radially across the disk from pith to periphery (Table. 35).

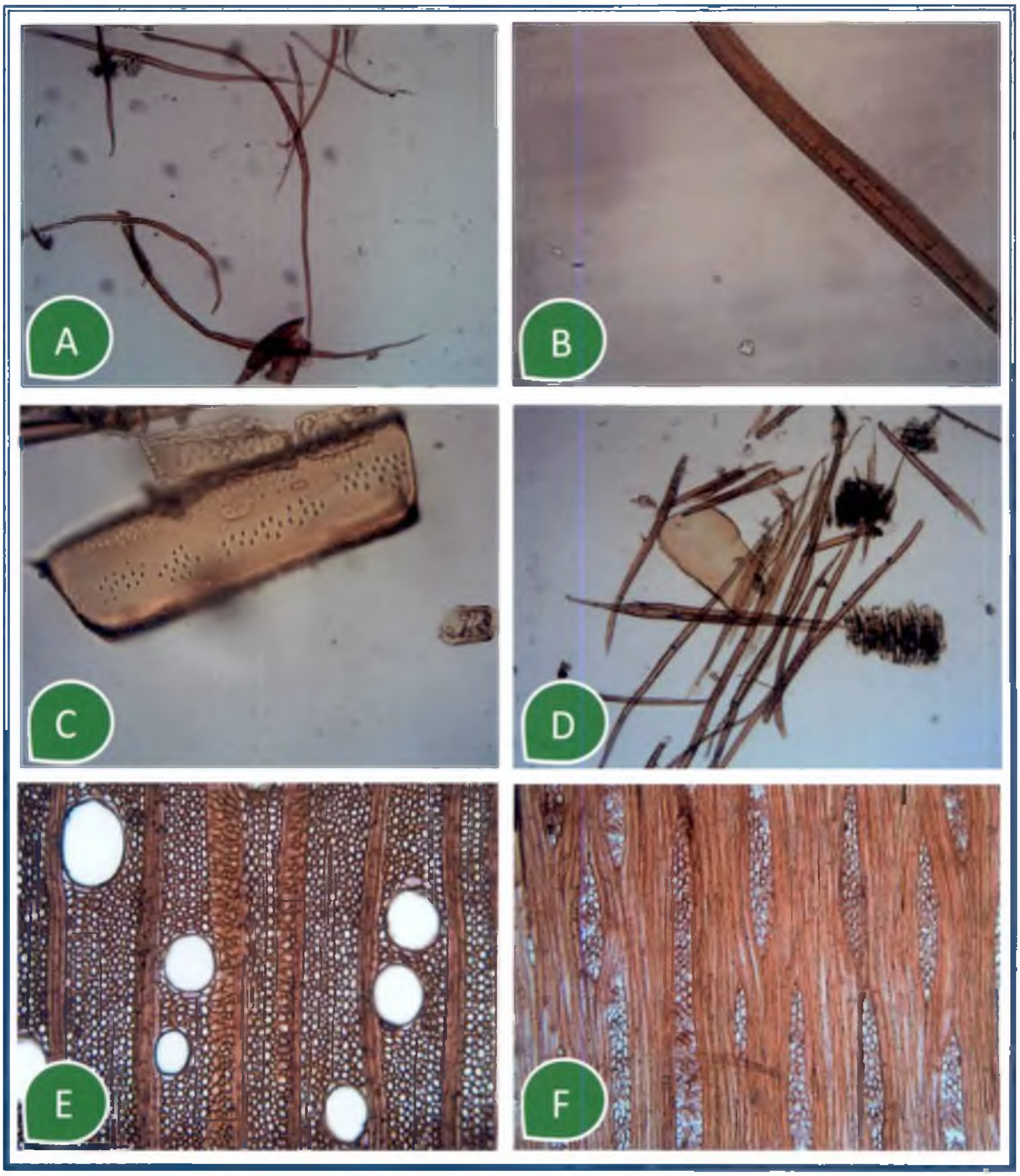

Plate. 5. Photos taken through image analyser: (A) Fibre (10x) isolated by maceration, (B) Fibre lumen and wall (40x) obtained by maceration, (C) Vessel element (40x) obtained by maceration, (D) Size comparison of vessel element and fibre (10x) obtained through maceration, (E) Transverse section (40x) taken through sliding microtome, (F) Tangential section (40x) taken using sliding microtome

Table. 32. Comparison of vessel and ray characteristics at pith, middle and periphery portion of the disk of Walayar

Region	Vessel diameter (µm)	Vessel area (µm^2)	Vessel frequency (no./mm^2)	Ray height (µm)	Ray width (µm)	Ray frequency (no./mm^2)
Pith	223.75 (44.18)	43196.5719 (9921)	11 (3.99)	549.25 (118.36)	47^{a} (5.9)	17^{b} (2.72)
Middle	215.5 (59.05)	48399.05 (10087.01)	8 (2.92)	525.05 (101.25)	50^{a} (6.06)	8^{a} (3.35)
Periphery	216.75 (69.84)	57573.2094 (30010.89)	9 (3.77)	835.25 (357.22)	68^{b} (8.03)	6^{a} (1.12)

Table. 33. Overall comparison of vessel and ray characteristics of Walayar with Nilambur teak (Anish, 2013)

	Vessel diameter (µm)	Vessel area (µm^2)	Vessel frequency (no./mm^2)	Ray height (µm)	Ray width (µm)	Ray frequency (no./mm^2)
Walayar	218.67 (54.42)	49722.94 (18771.45)	9 (3.68)	636.52 (254.27)	55 (11.45)	11 (5.35)
Nilambur	206.02 (61.03)	50990.13 (22665.69)	4 (1.36)	542.75 (99.9)	48.83 (12.88)	4 (1.13)

Table. 34. Comparison of vessel and fibre characteristics of Walayar with Nilambur teak (Varghese *et al.*, 2000)

Location	Fibre length (µm)	Vessel element length (µm)	Vessel diameter (µm)	Fibre width (µm)	Fibre lumen diameter (µm)	Fibre wall thickness (µm)	Runkel Ratio	F/V ratio
Walayar	1359	390	219	26	11	3.9	0.95	2.4
Nilambur	1472	324	199	24.3	14	5.2	0.82	4.6

Table 35. Comparison of vessel and fibre characteristics at the pith, middle and periphery of Walayar teak

Radial position	Fibre length (µm)	Vessel element length (µm)	Vessel diameter (µm)	Fibre width (µm)	Fibre lumen diameter (µm)	Fibre wall thickness (µm)	Runkel Ratio	F/V ratio
Pith	1547.82 (450.74)	393.8 (44.96)	223.57 (39.8)	24.48 (4.93)	10.14 (4.19)	3.72 (1.45)	0.99 (0.91)	3.3 (1.18)
Middle	1091.56 (714.77)	381.69 (100.79)	215.95 (55.01)	26.11 (7.42)	12.11 (5.21)	3.45 (2.86)	0.60 (0.44)	2.78 (2.62)
Periphery	1436.35 (784.46)	403.29 (76.09)	217.58 (66.13)	26.69 (5.32)	10.18 (4.5)	4.46 (1.93)	1.25 (1.35)	2.84 (2.37)

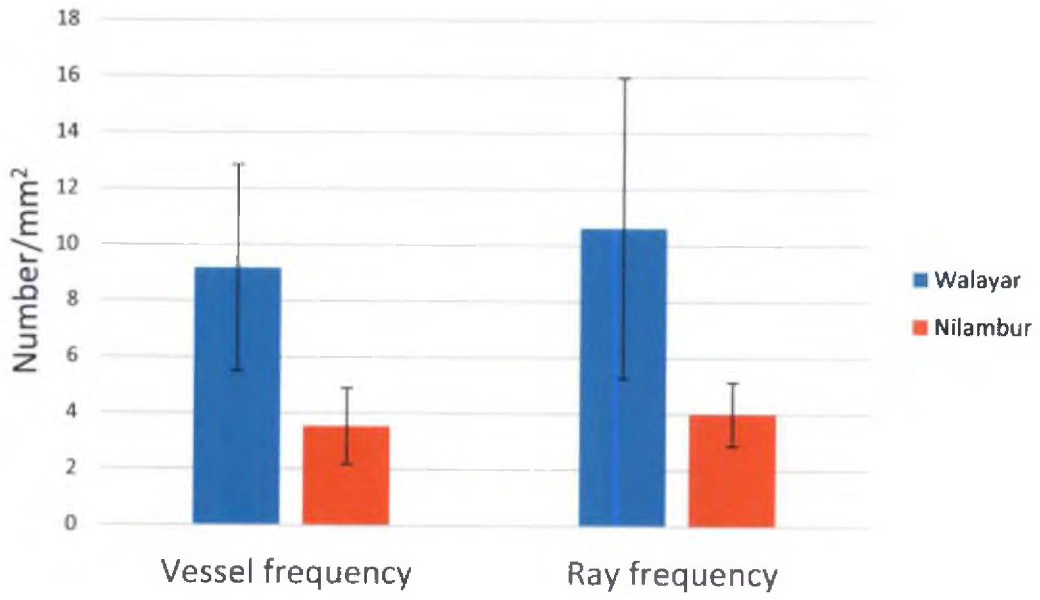

Fig. 31. Comparison of vessel and ray frequencies of Walayar and Nilambur teak

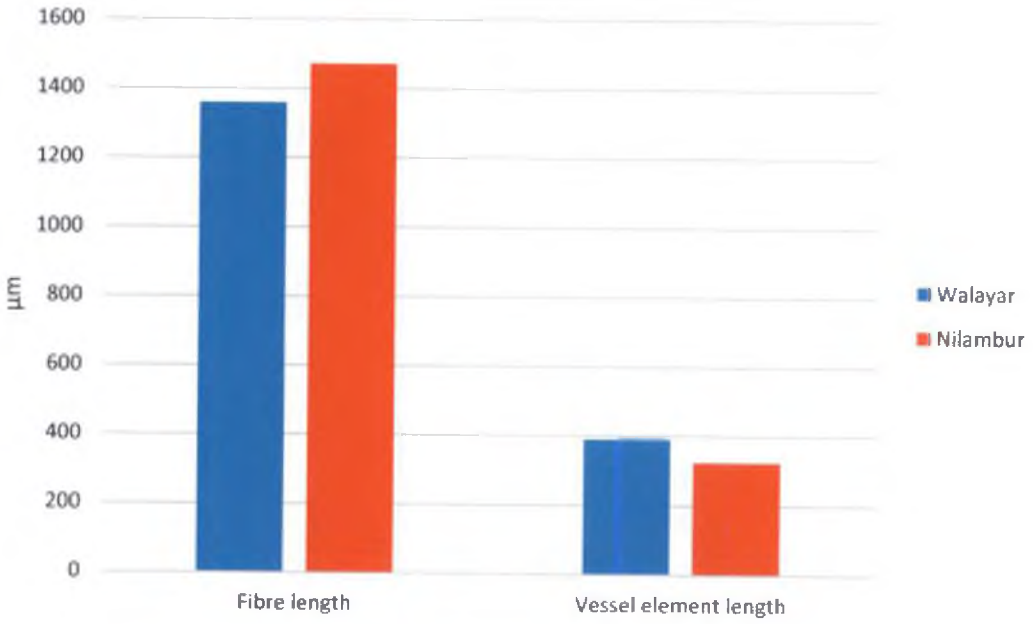

Fig. 32. Comparison of fibre and vessel element length of Walayar and Nilambur teak

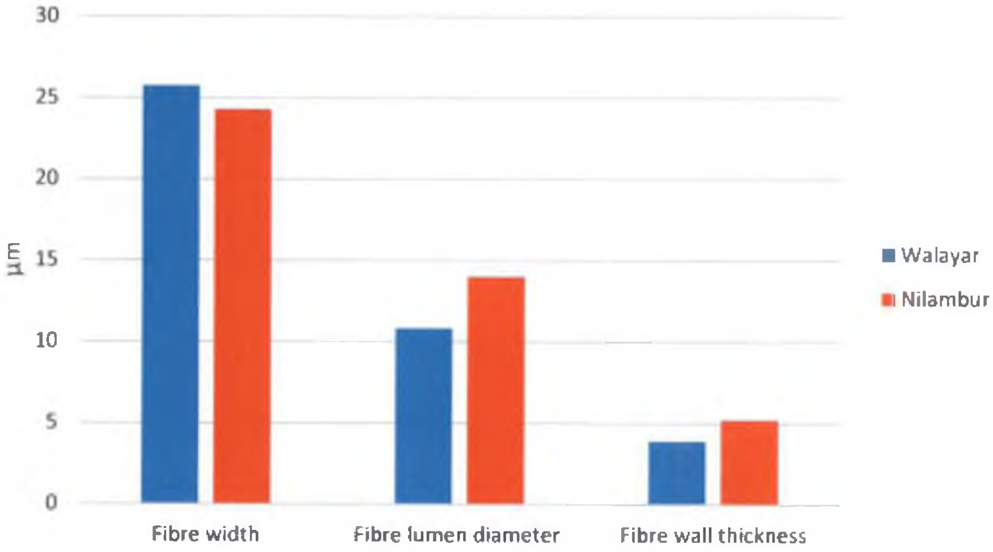

Fig. 33. Comparison of fibre characteristics of Walayar and Nilambur teak

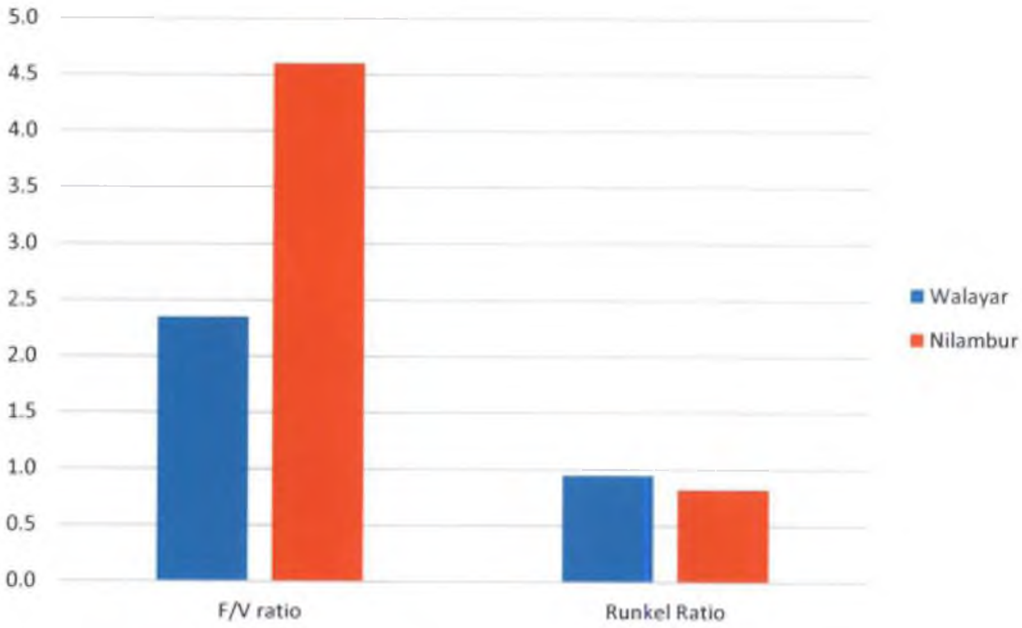

Fig. 34. Comparison of anatomical ratios of Walayar and Nilambur teak

4.11.3. Vessel mesomorphy

The values of vessel mesomorphy and vessel vulnerability was measured for *Tectona grandis* of Walayar using the formula given by Carlquist (1977). The values for vessel vulnerability was 22.7, 28.96 and 29.59 at radial positions of pith, middle and periphery respectively. The values of vessel mesomorphy was 8995.40, 1147.83 and 11996.8 at radial positions of pith, middle and periphery of the samples disks. No significant difference was observed for vessel mesomorphy as well as for vessel vulnerability with change in radial positions.

Table 36. Vessel vulnerability and vessel mesomorphy at the pith, middle and periphery of Walayar teak

Radial position	Vessel vulnerability	Vessel mesomorphy
Pith	22.7 (11.10)	8995.40 (4688.9)
Middle	28.96 (11.80)	1147.83 (627.92)
Periphery	29.59 (9.95)	11996.8 (4605.53)

DISCUSSION

DISCUSSION

This study was carried out to study the air pollution tolerance of some moist deciduous species when exposed to particulate pollution and also to study the growth and physiology of *Tectona grandis* when subjected to pollution stress. The results of the study are discussed in this chapter.

5.1. Effect of particulate pollution on growth and physiology of *Tectona grandis*

5.1.1. Morphology

The morphology of trees at both control and the polluted differed greatly even though both plantations were established at the same time. The overall growth was visibly stunted in the polluted, while those in the control were much better off. From Table. 23, it is evident that the height and girth of *Tectona grandis* in the polluted plot differed significantly from those in control plots. The declining vigour of sensitive trees to pollution has been reported due to reductions in needle longevity, size, increased respiratory activity, and altered translocation patterns which are induced by chronic air pollution stress (McLaughlin *et al.*, 1982). Pollutants can cause leaf injury, stomatal damage, premature senescence, decrease photosynthetic activity, disturb membrane permeability and reduce growth and yield in sensitive plant species (Tiwari et al., 2006). Almost all these symptoms was observed in *T. grandis* in this study when exposed to particulate pollution. Reduction in photosynthesis rates affects the biomass assimilation in terms of reduced specific leaf area and plant height (Kamlakar, 1992).

5.1.2. Seasonal changes

It was observed that leaf shedding during winter was earlier in trees located close to the pollution core i.e., near the Malabar Cements in comparison to those in the control plot. The deciduous trees under particulate pollution from the cement factory seems to start shedding their leaf as early as mid-November, especially in case of species like *Bombax ceiba and Tectona grandis*. While leaf shedding started as late as mid-December in case of the same species in the control site. Also the

Plate. 6. Early setting of leaves in the control plot (February, 2013)

Plate. 7. Delayed setting of leaves in polluted plot (February, 2013)

setting of new flushes of leaves were delayed in the polluted site (Plate. 7.) than in the control plots (Plate. 6.) by 45 days. This characteristic thus drastically reduces the active growing season for trees growing in the polluted region as compared those which came up in stress free environment. This can be one of the reasons for the difference in volume of the teak trees growing in these two sites (Table. 23). Klumpp *et al.* (2000) observed that growth analysis of seedlings exposed to pollution demonstrated that a change of the relationship between above-ground and below-ground plant parts was the most obvious effect of air pollution and soil contamination. The quality of the ambient air and soil present around the plant affects even the species which are resistant to air pollution. The reduced LAD (Fig. 27) in the polluted plot in comparison to the control plot plays a direct role in the retarded growth of *Tectona grandis* when exposed to particulate pollution. Tiwari *et al.* (2006) observed that pollution leads to the reductions in leaf area and leaf number, which may be due to decreased leaf production rate and enhanced senescence. The reduced leaf area result in reduced absorbed radiations and subsequently in reduced photosynthetic rate.

5.1.3. Dust load, leaf parameters and water potential

The data were collected for dust accumulation in *Tectona grandis* during winter, summer and monsoon in polluted as well as non-polluted plots. The dust load were found to be highest during summer season, followed by winter season and the least being during monsoon. The dust load were least when not exposed to the particulate pollutants. The reason for high dust load during summer is due to the prolonged exposure without much precipitation and reduced leaf area of *Tectona grandis* during summer as evident from (Fig. 25). But the dust load were significantly low during monsoon season in both plots, the reason being that the dust attached to the leaf surface were continuously removed by rainfall in the region. This has resulted in an increased leaf area during monsoon season in comparison to both winter and summer seasons. The effect of dust load can be seen on the APTI of *Tectona grandis* as well as on its components when the dust loads varied with seasons. The values of APTI were least during summer when the dust load were the highest. Also the dust load impacted negatively on chlorophyll content and ascorbic acid content, while it had a positive effect on the pH. The leaf area index (LAI) were significantly high in control plots in comparison to polluted plots. When exposed to particulate pollution, the LAI was low during summer season and high during the monsoon season.

Leaf texture of *Tectona. grandis* is rough and hairy leading to greater dust accumulation as compared to the other three species which have comparatively smooth leaf texture. The leaf area of *Tectona grandis* were the greatest compared to other species in the area. Charturvedi *et al.* (2012) observed a decline in leaf area by 9%, Chlorophyll content by 26%, and photosynthetic rate by 49% in *Tectona grandis* due to the effect of dust load, suggesting that this species is not suitable for the site having high dust loads. According to Shrivastava and Sharma (2007), *Tectona grandis* falls in the medium range as far as dust capture level potential of the trees are concerned, while *Cassia fistula, Bombax ceiba, Butea monosperma* and *Terminalia catappa* falls in high dust capture potential category. In this study, it was observed that *Bombax ceiba* and *Terminalia catappa* are sensitive to particulate pollution along with *Tectona grandis*, thus having high dust capture capacity for these species means high susceptibility to particulate pollutant atmosphere. Thus they are best avoided in such areas, while *Butea monosperma* is ideal for planting along these areas because of its high tolerance to particulate pollutants and also possess high potential for trapping of the ambient pollutants. *Cassia fistula* is also a good option for growing in these areas for particulate pollution mitigation, and it also has been reported to be used as a good indicator species for cement dust pollution by Varshney (1985). The tolerant species and the species having more potential for collecting dust can be used for green belt development in polluted areas (Thakar and Mishra, 2010).

The water potential of *T. grandis* were significantly higher with a water potential of 2.68 MPa in polluted plot compared to 1.79 MPa in the control plots during summer. But the water potential tended to be very low during monsoon season in both the plots (Table. 29). The higher water potential observed during summer in the polluted plot corresponds with the high dust load on the leaf surface (Table. 24), while the lower water potential during monsoon corresponds with the low dust load during that season. Also the trees will be under drought stress during summer season than during monsoon, this can cause the relatively higher water potential during summer than in monsoon, in addition to the pollution stress. The water potential of *T. grandis* may be influenced by the particulate pollution. Sazonova and Olchey (2010) observed that industrial pollution affects the water conducting systems of the trees and that in turn may also cause variability in water potential of the affected trees.

5.1.4. Photosynthesis and Transpiration

The photosynthesis of *T. grandis* is lower when exposed to particulate pollution than when growing in pollution stress free conditions (Table. 30). This is similar to the observations made by Mandre *et al.* (2012) in his study on hybrid aspens which when affected by cement dust pollution exhibited a 25% decline in photosynthetic rate compared to unpolluted plants, even though thicker palisade was found in the polluted trees. The palisade cells, containing chloroplasts, are directly responsible for photosynthesis (Pallardy, 2008). This contradiction may be explained by a possible decreasing of the concentration of chlorophylls (Table. 1-3) and chloroplasts in leaves of trees growing in alkaline soils influenced by cement dust pollution as established for conifers as well as deciduous trees by earlier studies (Nanos and Ilias, 2007). Also cement dust deposited over the surfaces of the leaf in interfere with absorption of light quantity, this in turn cause reduction in photosynthesis (Sirohi and Singh, 1991). Thus particulate pollution load leads to the decrease in the photosynthesis of the trees affected.

Ambient levels of air pollution affects stomatal conductance and photosynthesis of young beech (Taylor and Davies, 1990). The transpiration was observed to be significantly reduced in the polluted plot than the control plot for *Tectona grandis* during summer (Fig. 30). Rate of transpiration is determined by the efficiency of opening and closing processes of the stomata of individual plant species

(Abdulrahaman & Oladele, 2009). Particulate pollutants inhaled by leaves blocks the stomatal opening and caused mechanical injury to the guard cells. For efficient transpiration to take place, general freshness of leaf is critical which is lacking in particulate polluted site. These pollutants leads to external foliar anomalies, which results in overall decline in transpiration efficiency of the stands affected by particulate pollutants (Saha and Padhy, 2012). Thus the particulate pollution dust is responsible for the reduced transpiration in affected trees during summer season.

But during monsoon season, when the effect of particulate pollution is the least it was found that transpiration was significantly high in polluted plot in comparison to control plot. During this period, factors other than particulate pollution may be affecting the transpiration of *Tectona grandis*. According to Wang *et al.* (2011), atmospheric pollutants had minor effects on transpiration, while majority of variance in transpiration was by the joint effects of heat and water variables.

5.1.5. Wood anatomical properties of *Tectona grandis*

5.1.5.1. Comparison with fast grown *Tectona grandis*

The vessel and ray characteristics were recorded through sectioning of the Walayar teak and were compared with *Tectona grandis* (47 year old) grown at Nilambur (Anish, 2013). Based on the standard deviations of vessel and ray characteristics, it was found that vessel frequency and ray frequency were significantly higher in Walayar teak in comparison to Nilambur teak (Table. 33). Safdari *et al.* (2012) found that the frequency of the rays were higher in polluted sites compared to unpolluted sites similar to the results obtained in this study (Table. 33). Relatively more number of vessels with less lumen diameter are the characteristic feature of the vessels of trees growing under pollution stress (Rao *et al.*, 2004). In the present study higher vessel frequency was found in Walayar teak which are exposed to pollution than the Nilambur teak growing in normal conditions, but there were no significant difference based on their standard deviations in the vessel diameter between the two populations of *Tectona grandis*. Kurjatko *et al.* (1990) observed that the proportion of vessels were higher when exposed to pollution stress which is similar to this study, but contradictorily he observed that vessel diameters were reduced when exposed to pollution unlike the present study in which the vessel diameter of the pollution stressed teak is higher than those of Nilambur. From Table. 32, a general trend was observed in the ray frequency as it decreased from the pith towards the periphery in Walayar teak. The changes found in the vessel and ray frequencies can be attributed to the effect of deposition of cement dust on the teak trees growing in the Walayar region.

5.1.5.2. Comparison with sixty year old *Tectona grandis*

The details about fibre characteristics and anatomical indices were recorded through the method of maceration and were compared with the results of the 60 year old Nilambur teak by Varghese *et al.* (2000) (Table. 34). On comparison of fibre characteristics of Walayar teak with those of Nilambur teak recorded by Varghese *et al.* (2000), it was found that fibre length, fibre wall thickness, and fibre lumen diameter were reduced in the Walayar teak than those of Nilambur. Ghouse *et al.* (1984) observed a reduction in fibre length when trees were exposed to pollution. While a similar trend was observed by Safdari *et al.* (2012), who recorded that the fibre length, wall thickness and fibre lumen size of *Pinus eldarica* of unpolluted site were more than the polluted and semi-polluted plots. They concluded that air pollution impact on tree ring width can reduce wood quality as well. Vessel element length was higher in Walayar teak than in Nilambur teak (Fig. 32). Short vessel elements are more resistant to collapse and deformation (Carlquist, 1977) and thus more useful from safety point of view (Zimmerman, 1983). Thus Walayar teak exhibits undesirable characteristics when under particulate pollution stress than unaffected Nilambur teak.

The runkel ratio were found to be higher in Walayar teak in comparison to those in Nilambur (Fig. 34). Higher runkel ratio fibres are stiffer, less flexible and form bulkier paper of lower bonded areas than lower runkel ratio fibre (Ververis *et al.*, 2004). High average fibre length and low runkel ratio result in good pulp strength properties (Shakhes *et al.*, 2011). But the average fibre length of Walayar teak subjected to particulate pollution were found to be lower than those in Nilambur, and also exhibited comparatively higher runkel ratio. So the particulate pollution at Walayar might be the reason for the higher runkel ratios compared to Nilambur teak. The F/V ratio of Walayar teak was lower in comparison to Nilambur teak (Fig. 34). According to Carlquist (1975), gain in F/V length ratio is a sign of increasing mechanical strength of trees. Thus it can be concluded that Walayar teak affected by particulate pollution possess lower mechanical strength than unaffected Nilambur teak.

According to Turnbull (1965), stresses in trees arise because of a shortening of the stem as it grows in diameter which imposes compression on the inner wood. In other words, stresses arise as a result of shortening of fibre length and increase in diameter. If so, then the reverse must also be true, i.e. fibre length reduces and fibre width increases as a result of stress on the plant. This is similar to the results obtained in this study, the fibre length is reduced and wider fibre was observed in Walayar teak in comparison to Nilambur teak (Fig. 32-33).

The vulnerability ratio and the mesomorphic ratio in the polluted samples tends to be reduced since early stages of wood increment under polluted condition (Gupta and Iqbal, 2005). Though mesomorphy and vulnerability was measured for Walayar teak, no comparisons could be made with unaffected teak due to lack of literature as well as samples. There was no significant difference for vessel mesomorphy as well as vulnerability across the radial positions of the samples disks (Table.36).

5.2. Air pollution tolerance index of important moist deciduous forest species

5.2.1. Chlorophyll content

Total chlorophyll content (Table 1) was found to be highest in *Butea monosperma* (2.74 mg/ g) located near to Malabar cements during winter but it dropped steeply during summer (0.88 mg/ g). This was followed by *Terminalia catappa* and *Pterocarpus marsupium* with values of 2.59 mg/ g and 2.30 mg/ g respectively during winter when exposed to particulate pollution. The lowest total chlorophyll content were recorded in *Bombax ceiba* (0.38 mg/ g) during summer and winter.

This was followed by *Tectona grandis* and *Terminalia paniculata* with total chlorophyll content of 0.05 mg /g during summer and 0.67 mg/ g during winter respectively.

The proportion of chlorophyll 'a' (Table. 4-6) were higher than chlorophyll 'b' (Table. 7-9) for all the species studied irrespective season or pollution status of the area. Another interesting observation recorded was that the chlorophyll 'a' content was found to be higher in some species growing in polluted area than control plot during winter season (Table. 4) while chlorophyll 'b' was higher in polluted plot than control plot during monsoon season (Table 9).

The total chlorophyll content were least during summer season (1.11 mg/ g) in the polluted plots (Table. 2), and the highest content being during winter periods (Table. 1). The total chlorophyll content during monsoon season (Table. 3) were lower than that of winter. The reason for this may be due to the younger flushes of leaves growing back on the trees after remaining leaf less during major part of summer season.

The total chlorophyll content (Table. 2), chlorophyll 'a' (Table. 5) and chlorophyll 'b' content (Table. 8) were observed to be the least during summer in six out of ten species studied. This can be contributed to the higher dust loads observed during summer than any other seasons (Table. 24). Chlorophyll a, b and total chlorophyll are found to be in reduced proportions when they are exposed to cement dust pollution than those which are found in controlled conditions (Rahman and Ibrahim, 2012).

The general trend observed in the chlorophyll content was that the total chlorophyll content were reduced when exposed to cement dust pollution irrespective of season (Fig 2, 5, 8). The exceptions to this rule being *Pterocarpus marsupium* and *Terminalia catappa*. *Pterocarpus marsupium* of the polluted site expressed consistently higher total chlorophyll content than those growing in normal stress free conditions (Table. 1-3). While *Terminalia catappa* had higher chlorophyll (Table. 24) content only when the dust load were the highest (summer and winter), but during periods of low dust pollution (monsoon season) the chlorophyll content were lower in the polluted plot than in the control plots (Table 1).

Teak exhibited consistently low chlorophyll content throughout the seasons in pollution affected areas than those located at the control plots (Table. 1-3). A similar trend was observed by Joshi and Swami (2009) in teak trees located at an area polluted by automobile exhaust which had total chlorophyll content at a reduced quantity of about 23% compared to those in control areas. It was also observed that there was a reduction of about 17% and 32% for chlorophyll 'a' and chlorophyll 'b' content respectively in teak trees exposed to pollution than those in unaffected by pollution. This is true for *Tectona grandis* in this study as the chlorophyll content were lowest during summer (Table. 2) when the dust load was the highest (Table. 24). *Bombax ceiba* tended to be better off during monsoon season (Fig. 8) than during winter (Fig. 2) and summer seasons (Fig. 5), because of the fact that the dust on the leaf surfaces are washed away by rainfall and thus the photosynthetic systems are not damaged seriously. Chlorophyll is considered as an index of productivity of plants. Photosynthetic pigments degradation has been widely used as an indicator of air pollution (Ninave *et al.*, 2001). According to Joshi and Swami (2009), the shading effects due to deposition of suspended particulate matter on the leaf surface might play a role for the decrease in the concentration of chlorophyll in polluted area. These particles might clog the stomata thus interfering with the gaseous exchange, which results in the increase of leaf temperature which may consequently retard chlorophyll synthesis. Dusted or encrusted leaf surface is responsible for reduced photosynthesis and thus cause reduction in chlorophyll content (Joshi and Swami, 2009).

5.2.2. The pH of leaf extract

The overall observed values for the leaves concerning with pH were on the lower side i.e. were acidic in nature. The pH of leaf extracts of none of the species studied went past the mark of 7. Limestone and cement dusts, with pH values of 9 or higher, may cause direct injury to leaf tissues or indirect injury through alteration of soil pH (Auerbach *et al.*, 1997). But Klumpp *et al.* (2000) observed that in plants exposed to industrial emissions, there were almost no or minimal alterations in the leaf extract pH and buffering capacity. Also one other reason for this reduced pH can be attributable to the installation of the pollution control devices inside the factory which might have led to reduction in the particulate pollution from the factory. Highest values of pH was exhibited by *Butea monosperma* (Fig. 17-19) during all the seasons followed by *Tectona grandis* and *Cassia fistula* when exposed to cement dust pollution. Almost all the trees expressed higher pH value when exposed to cement dust pollution than those located far away in the control plots. The highest pH expressed in non-polluted region was by *Tectona grandis* during all the seasons when studies were carried out.

Terminalia catappa and *Anogeissus latifolia* expressed low pH even after being exposed to cement dust pollution. Lowest pH in the control plots were exhibited by *Anogeissus latifolia* with a pH of 3.85 in winter, 3.91 in summer and 3.47 during monsoon, followed by *Terminalia catappa* and *Terminalia paniculata*. It can be observed from (Fig. 17-19) that the low pH level is positively correlated with chlorophyll content in all the species, with chlorophyll content being on the lower side (Fig. 2-8) with none of the species going beyond 3.5 mg/ g of total chlorophyll content. Plants with low pH shows good correlation with sensitivity to air pollution and the efficiency of photosynthesis are heavily dependent on pH. Photosynthesis reduces in plants with low pH (Thakar and Mishra, 2010). That is, as the pH of the plant lowers, so does the photosynthetic activity of the plant.

5.2.3. Ascorbic acid content

Ascorbic acid is a stress reducing factor and a strong anti-oxidant and is generally higher in tolerant plant species (Radhapriya *et al.*, 2012). It was found that *Artocarpus heterphyllus* (0.093 mg/ g), and *Butea monosperma* (0.085 mg/ g) exhibited the highest ascorbic acid content during winter in the polluted plot (Table. 10). While *Bombax ceiba* (0.048 mg/ g) expressed comparatively lower value, followed by *Terminalia catappa* (0.060 mg/ g) and *Anogeissus latifolia* (0.062 mg/ g). But overall the differences between species based on ascorbic acid content were not very stark.

During summer (Table. 11) *Artocarpus heterophyllus* exhibited highest value (0.078 mg/ g) in the cement dust polluted area while *Pterocarpus marsupium* expressed exceptionally high ascorbic acid content (0.122 mg/ g) in the control plots, followed by *Cassia fistula* (0.085 mg/ g) and *Terminalia paniculata* (0.080 mg/ g). The lowest were recorded in *Grewia tiliifolia* (0.031 mg/ g) and *Bombax ceiba* (0.035 mg/ g).

In the monsoon period (Table. 12), ascorbic acid tended to be lower in all the trees studied at polluted site compared to their counterparts in the control plots. Highest values were exhibited by *Butea monosperma* (0.072 mg/ g), *Cassia fistula* (0.072 mg/ g), *Pterocarpus marsupium* (0.072 mg/ g) and *Artocarpus heterophyllus* (0.071 mg/ g) in the cement dust polluted area, with only *Cassia fistula* and *Pterocarpus marsupium* having slightly higher content than their counterparts in the control plots. The lowest quantity was found to be *Tectona grandis* (0.047 mg/ g) and *Bombax ceiba* (0.052 mg/ g) located in the polluted region.

Air pollution results in a distinct decrease in ascorbic acid contents and an increase in peroxidase activity and thiol concentrations in leaves of the plants affected (Klumpp *et al.*, 2000). This might be the reason for the reduced ascorbic acid content (Table. 11) during summer season, due to the increased air pollution with increased dust load (Table. 24).

It is interesting to note that *Tectona grandis* and *Artocarpus heterophyllus* exhibited high ascorbic acid content (Table. 11) during periods of high dust deposition (winter and summer) while it's reduced during the periods of lowest stress by cement dust pollution i.e. during the monsoon period. Ascorbic acid being a stress reducing factor, may be of higher content in these species during severe stress conditions to help cope up with the surrounding pollution and survive in the area. Tripathi and Gautam (2007) reported pollution load dependent increase in ascorbic acid content of plant species may be due to the increased rate of production of ROS during photo-oxidation process. Photo-oxidation usually occur when plants are exposed to stress. The light-dependent generation of active oxygen species is termed photooxidative stress. Oxidative damage arises in the presence of high light principally when there is additional stress factor like pollution (Foyer *et al.*, 1994). Air pollutants produce reactive oxygen species (ROS), which adversely affect biochemical processes of plants and reduce their tolerance capacity to other stresses also. Ascorbate is known to be an antioxidant molecule which are capable of detoxifying air pollutants (Smirnoff, 1996). Ascorbic acid is an integral weapon in the defence against ROS (Rai *et al.*, 2011). Thus species in which ROS is produced due to the effect of pollution, also produces ascorbic acid as a form of defence within the plant.

Total chlorophyll content is related to ascorbic acid content productivity, since ascorbic acid content is concentrated mainly in chloroplasts (Thakar and Mishra, 2010). This trend can be found in this study also, with the total chlorophyll of the species (Fig. 2, 5 and 8) correspondingly increasing or decreasing with change in ascorbic acid content (Fig. 11, 12 and 13).

5.2.4. Relative water content

The relative water content were highest in *Butea monosperma* (96.12%), *Terminalia catappa* (85.95%) and *Anogeissus latifolia* (81.54%) during the winter season (Table. 13) in the polluted area and highest in *Anogeissus latifolia* (98.38%) and *Terminalia paniculata* (88.65%) in the control plots. *Pterocarpus marsupium* (38.18%) exhibited lowest relative water content followed by *Tectona grandis* (49.06%) and *Artocarpus heterophyllus* (55.17%) in the polluted regions, while *Bombax ceiba* (64.31%), *Pterocarpus marsupium* (67.20%) and *Grewia tiliifolia* (68.04%) were the lowest in the non-polluted region.

In summer (Table. 14), relative water content of *Butea monosperma* (89.01%), *Bombax ceiba* (83%) and *Terminalia catappa* (80.68%) were highest in the polluted area while *Anogeissus latifolia* (97.96), *Terminalia paniculata* (88.51%) and *Butea monosperma* (81.36%) were the highest in the control plots. The lowest relative water content were found in *Artocarpus heterophyllus* (63.27%) and *Grewia tiliifolia* (66.66%) in the polluted regions around the Malabar cements area.

During monsoon season (Table. 15), *Tectona grandis* (88.85%) in the polluted region and *Anogeissus latifolia* (90.28%) in the non-polluted region exhibited the highest RWC. Interestingly *Cassia fistula* in the polluted region exhibited a higher value of 80% compared to non-polluted region's value of 42%. Relative water content were above 70% for almost all the species studied except for *Pterocarpus marsupium* and *Cassia fistula*.

Overall it was found that the trees growing in the polluted conditions exhibited high relative water content all throughout the seasons, with exceptions of *Tectona grandis*, *Pterocarpus marsupium* and *Artocarpus heterophyllus* during winter (Table. 13), *Artocarpus heterophyllus* and *Grewia tiliifolia* during summer (Table. 14) and *Pterocarpus marsupium* during monsoon season (Table. 15). High water content within the trees helps to maintain its physiological balance under stress condition due to being exposed to air pollution when the transpiration rates are usually high. Thus high relative water content favours drought resistance in plants. If the leaf transpiration rate reduces because of the air pollution, plant cannot live well due to the inability to pull water up from the roots for photosynthesis (Sadeghian and Mortazaienezhad, 2012)

5.2.5. Air pollution tolerance index (APTI)

Air pollution tolerance index was done for all the ten species during three seasons viz. winter (Table. 19), summer (Table. 20) and monsoon (Table. 21). From the APTI grading (Table. 22) it's evident that *Butea monosperma* is the most tolerant of the ten species studied, followed by *Cassia fistula* and *Terminalia paniculata*. During winter *Butea monosperma* exhibited very high APTI value of 7.76 compared to others not only during winter but for all seasons. *Bombax ceiba* is the most sensitive species in this study followed by *Terminalia catappa*, *Anogeissus latifolia* and *Tectona grandis*, in that order (Table. 22).

The low tolerance level of *Bombax ceiba* was in accordance with the observations of Varshney (1985), thus very suitable for being used as an indicator species. As it was indicated by Chauhan (2010) that plants with low APTI values can be used to indicate air pollution levels in an area. *Tectona grandis* which is established in the area in the form of plantations, was one of the sensitive species to pollution. Varshney (1985) also observed a similar trend in teak and classified it as a sensitive species. This was further supported by Krishnayya (1997) who also found *Tectona grandis* to be sensitive to pollution. Varshney (1985) also indicated that *Tectona grandis* is a very good indicator of combination of pollutants.

Cassia fistula fell in the category of tolerant species based on its performance during all the seasons and was one of the most tolerant species in this study when exposed to particulate pollution stress. *Cassia fistula* had moderate tolerance during winter and summer season, while it expressed highest APTI values in monsoon when exposed to cement dust pollution. Varshney (1985) found *Cassia fistula* to be a tolerant to pollution which was supported by Raza *et al.* (1991) who also observed a similar characteristic for *Cassia fistula. Cassia fistula* is considered as a good indicator of cement dust pollution (Varshney, 1985).

Terminalia catappa was observed to be moderately tolerant when exposed to cement dust pollution during winter. While during summer and monsoon it expressed an intermediate APTI in the polluted plot. But according to APTI grading, *Terminalia catappa* is the second most sensitive species in this study which contradicts with the results of Krishnayya (1997) who observed that *Terminalia catappa* to be tolerant when exposed to air pollution stress.

Lakshmi *et al.* (2008) recorded APTI values of 4.57 and 6.42 for *Cassia fistula* and *Artocarpus heterophyllus,* which were similar to the values obtained by these same species in this study. In this study, *Cassia fistula* exhibited a value of 4.50 during monsoon under pollution stress conditions, while an maximum APTI value of exhibited by *Artocarpus heterophyllus* were 4.59 during monsoon period in the unpolluted plot. But most species exhibited markedly different APTI values during different seasons. This observation stresses that studies of tolerance index of tree species are affected to a great extent by the weather conditions also, and its index will vary with the surrounding environmental factors. Thus it's important to study the APTI of a species over different time periods to have a better understanding of air pollution tolerance character of the species. For example *Grewia tiliifolia* exhibits moderate tolerance during winter and monsoon periods while during summer, when there is an additional stress of drought this species was found to be sensitive.

Based on the APTI gradation values for the trees, it were found that some species were found to be more sensitive when not exposed to pollution stress than those exposed to pollution. Such a trend was observed in *Artocarpus heterophyllus* and *Terminalia catappa,* both of which exhibited sensitivity during winter while when exposed to pollution, they expressed moderate tolerance (Table. 22). *Cassia fistula* also tended to be sensitive during monsoon even though it expressed high tolerance while exposed to pollution stress (Table. 22). This may be due to the fact that the trees in the polluted areas were well adapted to the adverse habitat and thus show high tolerance levels compared to those located in non-polluted areas (Radhapriya *et al.*, 2012).

The APTI value is the least during summer, followed by winter and monsoon. The reason for such lower tolerance during summer can be the exposure to the pollutants for longer periods than other seasons without much of a precipitation to remove the load. The high amount of dust on these leaves also made some species sensitive during the summer season (Table. 24). The reason for monsoon having higher APTI than winter periods can be due to the fact that the trees are exposed to lower dust load during monsoon than other seasons, since the dust are washed off by rainfall during this period.

Conclusion

The study revealed that there was significant changes in *Tectona grandis* when they are exposed to particulate pollution stress. The effects of particulate matter was observed in the morphological, physiological and anatomical properties of *Tectona grandis*. There was clear evidence that the changes observed both on the physiology and anatomy of *T. grandis*, were more or less affected by particulate pollution than anything else, since the control samples were growing in a minimal stress conditions.

On estimation of tolerance levels of different species when affected by particulate pollution, Butea monosperma and Cassia fistula was more tolerant than Tectona grandis which is grown extensively in the form of plantations in the area. While species like Bombax ceiba and Terminalia catappa was found to be sensitive to such pollution constraints. Selection of trees based on such analysis helps in identifying the best suitable trees for a given location, since APTI factors in the stress factors present in the area. Thus species that are resistive to such stress factors may be planted in order for it to survive and flourish in the region. Also such analysis can help in pointing out sensitive species which can then be later used as an indicator of degradation of the site of interest. Planting of resistive species of economic or ecological values also confirms its chances of survival as well as remediation of the region.

SUMMARY

SUMMARY

The objective of the study was to analyse the effect of particulate pollution effect on the Air pollution tolerance index (APTI) of the most prominent species of Walayar, near the Malabar cements Ltd., and also to study the growth and physiology of *Tectona grandis* under particulate pollution stress and also to investigate the anatomical properties of teak wood.

The salient findings of the study are given below:

1. The pH of the leaf samples of all the trees studied were in the acidic range, with the maximum mean value during monsoon season in the polluted plot (5.71).

2. *Butea monosperma* had the maximum pH of 6.87 followed by *Tectona grandis* with a pH of 6.74.

3. The low pH of the leaf samples resulted in low chlorophyll content in the trees studied, with the total chlorophyll higher in the control plot than the polluted plots.

4. The ascorbic acid content was highest in the control plots during summer and monsoon, while it was higher in the polluted plot during winter season.

5. The relative water content was the highest when the stress due to particulate pollution was highest during summer than during winter and monsoon seasons.

6. *Butea monosperma* was the most tolerant to particulate pollution stress followed by *Cassia fistula* and *Terminalia paniculata.*

7. *Bombax ceiba* was the most sensitive species to particulate pollution stress followed by *Terminalia catappa* and *Anogeissus latifolia.*

8. *Tectona grandis* which is found abundantly near the Malabar cements Ltd., falls in the sensitive category.

9. The height and girth of *Tectona grandis* is affected negatively by pollution stress.

10. The mean rate of dust accumulation is higher during December-March (0.4169 mg/month) than during March-June (0.2896 mg/month).

11. Leaf size and LAI is affected negatively in *Tectona grandis* when they exposed to cement dust pollution.

12. The mean LAD is lower during December-March (93.7) than during March-June (116.22) with lower LAD in the polluted plots.

13. Water potential of *Tectona grandis* is negatively affected by cement dust deposition with the mean water potential higher during summer (2.3 MPa) than monsoon season (0.3 MPa).

14. The vessel and ray frequency is significantly higher in the Walayar teak than Nilambur teak.

15. The mean fibre length is reduced in stressed teak of Walayar than those in Nilambur, but the fibre width is more in stressed teak.

16. The photosynthesis in *Tectona grandis* is higher in control plots (8.7 μmol m^{-2} s^{-1}) than when exposed to particulate pollution stress (4 μmol m^{-2} s^{-1}).

17. Transpiration of *Tectona grandis* is reduced in polluted plots (0.045 μmol m^{-2} s^{-1})than in control plots (0.292 μmol m^{-2} s^{-1}).

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APPENDICES

APPENDICES

I. Results of ANOVA for height and girth of *Tectona grandis*

		Sum of Squares	df	Mean Square	F	Sig.
Height (m)	Between Groups	231.200	1	231.200	33.945	.000
	Within Groups	122.600	18	6.811		
	Total	353.800	19			
Girth (cm)	Between Groups	13209.800	1	13209.800	18.330	.000
	Within Groups	12972.000	18	720.667		
	Total	26181.800	19			

II. Results of Univariate analysis of variance of leaf size/ leaf surface area of *Tectona grandis*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	181112.809[a]	5	36222.562	8.573	.000
Intercept	7446776.481	1	7446776.481	1762.369	.000
Status	91878.805	1	91878.805	21.744	.000
season	81383.272	2	40691.636	9.630	.000
status * season	7850.732	2	3925.366	.929	.401
Error	228173.538	54	4225.436		
Total	7856062.828	60			
Corrected Total	409286.347	59			

a. R Squared = .443 (Adjusted R Squared = .391)

III. Results of Univariate analysis of variance for LAI of *Tectona grandis*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	14.520[a]	5	2.904	334.008	.000
Intercept	80.643	1	80.643	9275.259	.000
status	13.424	1	13.424	1543.945	.000
season	.847	2	.424	48.715	.000
status * season	.249	2	.125	14.333	.000
Error	.469	54	.009		
Total	95.633	60			
Corrected Total	14.990	59			

a. R Squared = .969 (Adjusted R Squared = .966)

IV. Results of Univariate analysis of variance of dust accumulated on *Tectona grandis*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7.616E-007[a]	5	1.523E-007	154.961	.000
Intercept	5.802E-007	1	5.802E-007	590.222	.000
status	3.263E-007	1	3.263E-007	331.968	.000
season	2.714E-007	2	1.357E-007	138.056	.000
status * season	1.639E-007	2	8.195E-008	83.363	.000
Error	5.308E-008	54	9.830E-010		
Total	1.395E-006	60			
Corrected Total	8.147E-007	59			

a. R Squared = .935 (Adjusted R Squared = .929)

V. Results of T-Test for rate of dust accumulation on *Tectona grandis*

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Dec-March	Equal variances assumed	14.418	.001	16.112	18	.000	.627562004000	.038949020825	.545733147704	.709390860296
	Equal variances not assumed			16.112	9.590	.000	.627562004000	.038949020825	.540272715785	.714851292215
March-June	Equal variances assumed	8.972	.008	14.319	18	.000	.449480643200	.031390806942.	.383531005035	.515430281365
	Equal variances not assumed			14.319	9.412	.000	.449480643200	.031390806942	.378941045505	.520020240895

VI. Results of T-Test for leaf area duration (LAD) of *Tectona grandis*

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
December-March	Equal variances assumed	.126	.727	-26.207	18	.000	-74.3850000	2.8383727	-80.3481997	-68.4218003
	Equal variances not assumed			-26.207	17.804	.000	-74.3850000	2.8383727	-80.3529078	-68.4170922
March-June	Equal variances assumed	.633	.437	-34.286	18	.000	-97.6080000	2.8468770	-103.5890667	-91.6269333
	Equal variances not assumed			-34.286	17.707	.000	-97.6080000	2.8468770	-103.5961689	-91.6198311

VII. Results of T-Test for water potential of *Tectona grandis*

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Summer	Equal variances assumed	10.499	.023	8.967	5	.000	8.93333	.99622	6.37248	11.49419
	Equal variances not assumed			10.532	3.180	.001	8.93333	.84820	6.31829	11.54837
Monsoon	Equal variances assumed	1.410	.250	-2.627	18	.017	-.99000	.37690	-1.78184	-.19816
	Equal variances not assumed			-2.627	14.793	.019	-.99000	.37690	-1.79433	-.18567

VIII. Results of T-Test for photosynthesis of *Tectona grandis*

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Summer	Equal variances assumed	11.207	.002	-8.203	48	.000	-4.68240	.57084	-5.83015	-3.53465
	Equal variances not assumed			-8.203	25.997	.000	-4.68240	.57084	-5.85579	-3.50901
Monsoon	Equal variances assumed	4.394	.043	-4.066	37	.000	-3.64262	.89577	-5.45762	-1.82762
	Equal variances not assumed			-4.237	32.319	.000	-3.64262	.85980	-5.39331	-1.89193

IX. Results of T-Test for transpiration of *Tectona grandis*

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Summer	Equal variances assumed	41.440	.000	-5.901	40	.000	-.24634	.04174	-.33071	-.16197
	Equal variances not assumed			-5.901	20.366	.000	-.24634	.04174	-.33332	-.15936
Monsoon	Equal variances assumed	19.346	.000	11.211	39	.000	4.81200	.42922	3.94381	5.68019
	Equal variances not assumed			10.937	19.188	.000	4.81200	.43999	3.89169	5.73231

X. Results of ANOVA for vessel and ray characters at pith, middle and periphery positions (radial positions) of *Tectona grandis* of Walayar

		Sum of Squares	df	Mean Square	F	Sig.
Vessel diameter	Between Groups	200.258	2	100.129	.029	.971
	Within Groups	41133.675	12	3427.806		
	Total	41333.933	14			
Vessel area	Between Groups	529849586.491	2	264924793.246	.722	.506
	Within Groups	4403270108.414	12	366939175.701		
	Total	4933119694.905	14			
Vessel frequency	Between Groups	33.114	2	16.557	1.276	.314
	Within Groups	155.680	12	12.973		
	Total	188.794	14			
Ray height	Between Groups	297545.308	2	148772.654	2.939	.091
	Within Groups	607398.375	12	50616.531		
	Total	904943.683	14			
Ray width	Between Groups	1290.000	2	645.000	14.047	.001
	Within Groups	551.000	12	45.917		
	Total	1841.000	14			
Ray frequency	Between Groups	330.231	2	165.116	25.799	.000
	Within Groups	76.801	12	6.400		
	Total	407.033	14			

XI. Results of ANOVA for fibre and vessel characters at pith, middle and periphery positions (radial positions) of *Tectona grandis* of Walayar

		Sum of Squares	df	Mean Square	F	Sig.
Fibre length	Between Groups	1697348.251	2	848674.126	1.915	.160
	Within Groups	18612037.088	42	443143.740		
	Total	20309385.340	44			
Vessel element length	Between Groups	2204.362	2	1102.181	.147	.864
	Within Groups	164726.998	22	7487.591		
	Total	166931.360	24			
Fibre width	Between Groups	39.326	2	19.663	.548	.582
	Within Groups	1507.552	42	35.894		
	Total	1546.877	44			
Lumen width (fibre lumen diameter)	Between Groups	38.139	2	19.069	.881	.422
	Within Groups	909.114	42	21.646		
	Total	947.253	44			
Fibre wall thickness	Between Groups	8.200	2	4.100	.878	.423
	Within Groups	196.121	42	4.670		
	Total	204.321	44			
F/V ratio	Between Groups	1.013	2	.507	.092	.913
	Within Groups	121.256	22	5.512		
	Total	122.270	24			
Runkel Ratio	Between Groups	3.243	2	1.622	1.708	.194
	Within Groups	39.881	42	.950		
	Total	43.124	44			

XII. Results of ANOVA for vessel mesomorphy and vessel vulnerability of *Tectona grandis* of Walayar

		Sum of Squares	df	Mean Square	F	Sig.
Vessel vulnerability	Between Groups	169.961	2	84.980	.678	.518
	Within Groups	2757.125	22	125.324		
	Total	2927.086	24			
Vessel mesomorphy	Between Groups	28532913.280	2	14266456.640	.461	.637
	Within Groups	680652597.246	22	30938754.420		
	Total	709185510.526	24			

XIII. Results of Univariate analysis for total chlorophyll content during winter season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	29.566[a]	19	1.556	320.528	.000
Intercept	202.695	1	202.695	41751.316	.000
Status	.771	1	.771	158.806	.000
Species	17.598	9	1.955	402.758	.000
Status * Species	11.197	9	1.244	256.267	.000
Error	.194	40	.005		
Total	232.456	60			
Corrected Total	29.760	59			

a. R Squared = .993 (Adjusted R Squared = .990)

XIV. Results of Univariate analysis for total chlorophyll content during summer season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	15.098[a]	19	.795	2691.431	.000
Intercept	102.154	1	102.154	345992.775	.000
Status	2.165	1	2.165	7333.809	.000
Species	6.417	9	.713	2415.006	.000
Status * Species	6.516	9	.724	2452.036	.000
Error	.012	40	.000		
Total	117.264	60			
Corrected Total	15.110	59			

a. R Squared = .999 (Adjusted R Squared = .999)

XV. Results of Univariate analysis for total chlorophyll content during monsoon season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	9.364[a]	19	.493	594.064	.000
Intercept	111.280	1	111.280	134128.896	.000
Status	.761	1	.761	917.459	.000
Species	3.991	9	.443	534.453	.000
Status * Species	4.613	9	.513	617.742	.000
Error	.033	40	.001		
Total	120.677	60			
Corrected Total	9.398	59			

a. R Squared = .996 (Adjusted R Squared = .995)

XVI. Results of Univariate analysis for chlorophyll ‘a’ content during winter season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	15.840[a]	19	.834	596.910	.000
Intercept	83.061	1	83.061	59472.009	.000
Status	.162	1	.162	115.730	.000
Species	8.567	9	.952	681.530	.000
Status * Species	7.111	9	.790	565.755	.000
Error	.056	40	.001		
Total	98.956	60			
Corrected Total	15.895	59			

a. R Squared = .996 (Adjusted R Squared = .995)

XVII. Results of Univariate analysis for chlorophyll ‘a’ content during summer season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5.201[a]	19	.274	1098.557	.000
Intercept	32.027	1	32.027	128537.312	.000
Status	.308	1	.308	1237.924	.000
Species	1.662	9	.185	741.260	.000
Status * Species	3.230	9	.359	1440.369	.000
Error	.010	40	.000		
Total	37.238	60			
Corrected Total	5.211	59			

a. R Squared = .998 (Adjusted R Squared = .997)

XVIII. Results of Univariate analysis for chlorophyll 'a' content during monsoon season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6.706[a]	19	.353	225.419	.000
Intercept	36.212	1	36.212	23128.180	.000
Status	1.689	1	1.689	1078.990	.000
Species	2.262	9	.251	160.554	.000
Status * Species	2.754	9	.306	195.444	.000
Error	.063	40	.002		
Total	42.980	60			
Corrected Total	6.768	59			

a. R Squared = .991 (Adjusted R Squared = .986)

XIX. Results of Univariate analysis for chlorophyll 'b' content during winter season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6.155[a]	19	.324	65.444	.000
Intercept	26.272	1	26.272	5307.192	.000
Status	1.640	1	1.640	331.305	.000
Species	2.731	9	.303	61.298	.000
Status * Species	1.784	9	.198	40.049	.000
Error	.198	40	.005		
Total	32.625	60			
Corrected Total	6.353	59			

a. R Squared = .969 (Adjusted R Squared = .954)

XX. Results of Univariate analysis for chlorophyll 'b' content during summer season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4.506[a]	19	.237	685.993	.000
Intercept	19.801	1	19.801	57276.751	.000
Status	.840	1	.840	2429.799	.000
Species	2.332	9	.259	749.533	.000
Status * Species	1.334	9	.148	428.696	.000
Error	.014	40	.000		
Total	24.321	60			
Corrected Total	4.520	59			

a. R Squared = .997 (Adjusted R Squared = .995)

XXI. Results of Univariate analysis for chlorophyll 'b' content during monsoon season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.410[a]	19	.127	168.710	.000
Intercept	20.551	1	20.551	27335.127	.000
Status	.183	1	.183	243.072	.000
Species	1.692	9	.188	250.115	.000
Status * Species	.535	9	.059	79.042	.000
Error	.030	40	.001		
Total	22.991	60			
Corrected Total	2.440	59			

a. R Squared = .988 (Adjusted R Squared = .982)

XXII. Results of Univariate analysis for ascorbic acid content during winter season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.012[a]	19	.001	16.754	.000
Intercept	.256	1	.256	6973.136	.000
Status	.002	1	.002	53.753	.000
Species	.004	9	.000	13.553	.000
Status * Species	.005	9	.001	15.843	.000
Error	.001	40	.000036755		
Total	.269	60			
Corrected Total	.013	59			

a. R Squared = .888 (Adjusted R Squared = .835)

XXIII. Results of Univariate analysis for ascorbic acid content during summer season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.026[a]	19	.001	3.116	.001
Intercept	.209	1	.209	482.921	.000
Species	.014	9	.002	3.531	.003
Status	.003	1	.003	5.893	.020
Species * Status	.009	9	.001	2.392	.028
Error	.017	40	.000		
Total	.252	60			
Corrected Total	.043	59			

a. R Squared = .597 (Adjusted R Squared = .405)

XXIV. Results of Univariate analysis for ascorbic acid content during monsoon season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.008[a]	19	.000	277.700	.000
Intercept	.292	1	.292	185777.627	.000
Species	.004	9	.000	259.791	.000
Status	.003	1	.003	1652.203	.000
Species * Status	.002	9	.000	142.885	.000
Error	6.287E-005	40	.000001572		
Total	.300	60			
Corrected Total	.008	59			

a. R Squared = .992 (Adjusted R Squared = .989)

XXV. Results of Univariate analysis for relative water content during winter season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	12273.328[a]	19	645.965	179.957	.000
Intercept	329129.547	1	329129.547	91691.274	.000
Species	7739.790	9	859.977	239.578	.000
Status	672.189	1	672.189	187.263	.000
Species * Status	3861.349	9	429.039	119.525	.000
Error	143.582	40	3.590		
Total	341546.457	60			
Corrected Total	12416.909	59			

a. R Squared = .988 (Adjusted R Squared = .983)

XXVI. Results of Univariate analysis for relative water content during summer season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4051.511[a]	19	213.237	67.608	.000
Intercept	369958.797	1	369958.797	117296.556	.000
Species	2372.288	9	263.588	83.571	.000
Status	20.935	1	20.935	6.637	.014
Species * Status	1658.288	9	184.254	58.418	.000
Error	126.162	40	3.154		
Total	374136.470	60			
Corrected Total	4177.673	59			

a. R Squared = .970 (Adjusted R Squared = .955)

XXVII. Results of Univariate analysis for relative water content during monsoon season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	8052.970[a]	19	423.841	22.605	.000
Intercept	349361.936	1	349361.936	18632.927	.000
Species	4909.252	9	545.472	29.092	.000
Status	35.577	1	35.577	1.897	.176
Species * Status	3108.141	9	345.349	18.419	.000
Error	749.988	40	18.750		
Total	358164.894	60			
Corrected Total	8802.958	59			

a. R Squared = .915 (Adjusted R Squared = .874)

XXVIII. Results of Univariate analysis for pH during winter season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	31.944[a]	19	1.681	52.251	.000
Intercept	1676.085	1	1676.085	52090.073	.000
Species	21.159	9	2.351	73.066	.000
Status	5.163	1	5.163	160.448	.000
Species * Status	5.622	9	.625	19.414	.000
Error	1.287	40	.032		
Total	1709.316	60			
Corrected Total	33.231	59			

a. R Squared = .961 (Adjusted R Squared = .943)

XXIX. Results of Univariate analysis for pH during summer season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	40.287[a]	19	2.120	64.912	.000
Intercept	1667.534	1	1667.534	51049.552	.000
Species	30.430	9	3.381	103.509	.000
Status	3.665	1	3.665	112.214	.000
Species * Status	6.191	9	.688	21.059	.000
Error	1.307	40	.033		
Total	1709.127	60			
Corrected Total	41.593	59			

a. R Squared = .969 (Adjusted R Squared = .954)

XXX. Results of Univariate analysis for pH during monsoon season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	49.610[a]	19	2.611	191.659	.000
Intercept	1691.447	1	1691.447	124158.117	.000
Species	35.469	9	3.941	289.282	.000
Status	9.720	1	9.720	713.509	.000
Species * Status	4.420	9	.491	36.052	.000
Error	.545	40	.014		
Total	1741.602	60			
Corrected Total	50.154	59			

a. R Squared = .989 (Adjusted R Squared = .984)

XXXI. Results of Univariate analysis for APTI during winter season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	92.038[a]	19	4.844	44.814	.000
Intercept	710.719	1	710.719	6575.084	.000
Status	3.992	1	3.992	36.929	.000
Species	54.246	9	6.027	55.760	.000
Status * Species	33.801	9	3.756	34.745	.000
Error	4.324	40	.108		
Total	807.081	60			
Corrected Total	96.362	59			

a. R Squared = .955 (Adjusted R Squared = .934)

XXXII. Results of Univariate analysis for APTI during summer season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	59.103[a]	19	3.111	3.373	.001
Intercept	545.364	1	545.364	591.385	.000
Status	4.735	1	4.735	5.134	.029
Species	40.378	9	4.486	4.865	.000
Status * Species	13.990	9	1.554	1.686	.125
Error	36.887	40	.922		
Total	641.354	60			
Corrected Total	95.990	59			

a. R Squared = .616 (Adjusted R Squared = .433)

XXXIII. Results of Univariate analysis for APTI during monsoon season

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	47.039[a]	19	2.476	52.045	.000
Intercept	748.455	1	748.455	15734.241	.000
Status	2.787	1	2.787	58.592	.000
Species	22.868	9	2.541	53.416	.000
Status * Species	21.383	9	2.376	49.947	.000
Error	1.903	40	.048		
Total	797.396	60			
Corrected Total	48.941	59			

a. R Squared = .961 (Adjusted R Squared = .943)

XXXIV. Mean of total chlorophyll content of leaf extracts across three seasons

Sl No.	Species	Winter		Summer		Monsoon	
		Polluted	Control	Polluted	Control	Polluted	Control
1	*Tectona grandis*	1.27^{ij}	2.73^{b}	0.50^{s}	2.12^{b}	0.87^{o}	1.59^{f}
2	*Terminalia paniculata*	0.67^{k}	1.33^{i}	0.72^{r}	1.34^{j}	1.00^{m}	1.47^{h}
3	*Bombax ceiba*	0.38^{l}	1.17^{j}	0.38^{t}	1.07^{n}	0.92^{no}	0.79^{p}
4	*Butea monosperma*	2.74^{b}	2.02^{f}	0.88^{q}	1.93^{c}	$1.54f^{g}$	2.24^{a}
5	*Cassia fistula*	2.16^{e}	3.06^{a}	0.99^{o}	1.14^{k}	1.34^{i}	1.14^{k}
6	*Anogeissus latifolia*	2.29^{d}	2.02^{f}	0.91^{p}	1.10^{l}	1.67^{e}	0.94^{n}
7	*Pterocarpus marsupium*	2.30^{d}	1.37^{i}	1.91^{d}	1.09^{m}	1.74^{d}	1.20^{j}
8	*Grewia tiliifolia*	1.54^{h}	1.79^{g}	1.51^{g}	1.49^{i}	1.14^{k}	$1.50g^{h}$
9	*Terminalia catappa*	2.59^{c}	1.54^{h}	1.80^{e}	1.50^{h}	1.21^{j}	1.91^{c}
10	*Artocarpus heterophyllus*	1.31^{i}	2.48^{c}	1.55^{f}	2.17^{a}	1.06^{l}	1.98^{b}

Values with the same superscript do not differ significantly between themselves during a season

XXXV. Mean of chlorophyll 'a' content of leaf extracts across three seasons

Sl No.	Species	Winter		Summer		Monsoon	
		Polluted	Control	Polluted	Control	Polluted	Control
1	*Tectona grandis*	0.83^{i}	1.91^{a}	0.25^{s}	1.08^{p}	0.50^{g}	1.18^{b}
2	*Terminalia paniculata*	0.47^{k}	0.93^{h}	0.51^{p}	0.92^{g}	0.36^{hi}	1.05^{c}
3	*Bombax ceiba*	0.19^{l}	0.67^{j}	0.19^{t}	0.56^{n}	0.54^{g}	0.53^{g}
4	*Butea monosperma*	1.96^{a}	1.21^{f}	0.52^{o}	1.14^{b}	0.86^{d}	1.61^{a}
5	*Cassia fistula*	1.61^{d}	1.72^{c}	0.45^{r}	0.70^{i}	0.53^{g}	0.76^{e}
6	*Anogeissus latifolia*	1.64^{c}	1.48^{e}	0.68^{k}	0.69^{j}	1.21^{b}	0.64^{f}
7	*Pterocarpus marsupium*	1.72^{c}	0.83^{i}	1.26^{a}	0.59^{m}	0.87^{d}	0.72^{e}
8	*Grewia tiliifolia*	1.08^{g}	0.94^{h}	0.66^{l}	0.82^{h}	0.39^{h}	0.76^{e}
9	*Terminalia catappa*	1.82^{b}	0.48^{k}	1.13^{c}	0.47^{q}	0.54^{g}	1.16^{b}
10	*Artocarpus heterophyllus*	0.97^{h}	1.08^{g}	0.95^{f}	1.04^{e}	0.29^{i}	1.03^{c}

Values with the same superscript do not differ significantly between themselves during a season

XXXVI. Mean of chlorophyll ‘b’ content of leaf extracts across three seasons

Sl No.	Species	Winter		Summer		Monsoon	
		Polluted	Control	Polluted	Control	Polluted	Control
1	*Tectona grandis*	0.44^{cgi}	0.82^{c}	0.25^{n}	1.04^{b}	0.37^{ef}	0.41^{ef}
2	*Terminalia paniculata*	0.20^{j}	0.39^{hi}	0.22^{p}	0.41^{l}	0.64^{cd}	0.42^{ef}
3	*Bombax ceiba*	0.19^{j}	0.50^{fgh}	0.19^{q}	0.51^{j}	0.38^{ef}	0.26^{f}
4	*Butea monosperma*	0.78^{c}	0.81^{c}	0.36^{m}	0.79^{e}	0.68^{c}	0.63^{cd}
5	*Cassia fistula*	0.55^{efg}	1.34^{a}	0.54^{i}	0.44^{k}	0.82^{abc}	0.37^{ef}
6	*Anogeissus latifolia*	0.65^{de}	0.54^{efg}	0.23^{o}	0.41^{l}	0.47^{de}	0.29^{ef}
7	*Pterocarpus marsupium*	0.58^{ef}	0.55^{efg}	0.65^{g}	0.51^{j}	0.87^{ab}	0.48^{de}
8	*Grewia tiliifolia*	0.46^{fghi}	0.85^{c}	0.85^{d}	0.67^{f}	0.75^{bc}	0.74^{bc}
9	*Terminalia catappa*	0.76^{cd}	1.06^{b}	0.67^{f}	1.03^{c}	0.67^{c}	0.74^{bc}
10	*Artocarpus heterophyllus*	0.34^{i}	1.41^{a}	0.60^{h}	1.13^{a}	0.77^{bc}	0.95^{a}

Values with the same superscript do not differ significantly between themselves during a season

XXXVII. Mean of ascorbic acid content of leaf extracts across three seasons

Sl No.	Species	Winter		Summer		Monsoon	
		Polluted	Control	Polluted	Control	Polluted	Control
1	*Tectona grandis*	0.081^{bc}	0.056^{hi}	0.043^{l}	0.040^{n}	0.047^{l}	0.064^{hi}
2	*Terminalia paniculata*	0.072^{cde}	0.081^{bc}	0.069^{f}	0.080^{c}	0.055^{j}	0.079^{d}
3	*Bombax ceiba*	0.048^{ij}	0.051^{hij}	0.035^{o}	0.052^{k}	0.052^{k}	0.068^{g}
4	*Butea monosperma*	0.085^{ab}	0.059^{gh}	0.055^{j}	0.060^{h}	0.072^{f}	0.076^{e}
5	*Cassia fistula*	0.070^{cdefg}	0.070^{cdefg}	0.062^{g}	0.085^{b}	0.072^{f}	0.065^{h}
6	*Anogeissus latifolia*	0.062^{efgh}	0.054^{hij}	0.053^{k}	0.058^{i}	0.063^{i}	0.086^{c}
7	*Pterocarpus marsupium*	0.071^{cdef}	0.068^{defg}	0.059^{hi}	0.122^{a}	0.072^{f}	0.071^{f}
8	*Grewia tiliifolia*	0.070^{cdefg}	0.074^{cd}	0.031^{p}	0.073^{e}	0.064^{hi}	0.092^{b}
9	*Terminalia catappa*	0.060^{fgh}	0.045^{jk}	0.041^{mn}	0.042^{lm}	0.064^{hi}	0.067^{g}
10	*Artocarpus heterophyllus*	0.093^{a}	0.037^{k}	0.078^{d}	0.043^{l}	0.071^{f}	0.095^{a}

Values with the same superscript do not differ significantly between themselves during a season

XXXVIII. Mean of relative water content of leaf extracts across three seasons

Sl No.	Species	Winter		Summer		Monsoon	
		Polluted	Control	Polluted	Control	Polluted	Control
1	*Tectona grandis*	49.06^{i}	74.24^{d}	80.03^{cde}	80.44^{cd}	88.85^{ab}	82.51^{abc}
2	*Terminalia paniculata*	78.58^{c}	88.65^{b}	80.68^{cd}	88.51^{b}	73.12^{ef}	88.52^{ab}
3	*Bombax ceiba*	78.04^{c}	64.31^{g}	83.00^{c}	70.12^{f}	71.13^{f}	78.95^{cdef}
4	*Butea monosperma*	96.12^{a}	79.82^{c}	89.01^{b}	81.36^{cd}	73.88^{def}	82.57^{abc}
5	*Cassia fistula*	74.07^{d}	73.44^{de}	77.01^{e}	70.65^{f}	79.56^{cde}	42.50^{h}
6	*Anogeissus latifolia*	81.54^{c}	98.38^{a}	78.55^{de}	97.96^{a}	77.87^{cdef}	90.28^{a}
7	*Pterocarpus marsupium*	38.18^{j}	67.20f^{g}	78.50^{de}	71.59^{f}	54.87^{g}	59.90^{g}
8	*Grewia tiliifolia*	70.45e^{f}	68.04^{f}	66.66^{g}	67.12^{g}	80.19^{cde}	79.33^{cde}
9	*Terminalia catappa*	85.95^{b}	79.25^{c}	82.61^{c}	81.00^{cd}	82.67^{abc}	81.69^{bcd}
10	*Artocarpus heterophyllus*	55.17^{h}	80.78^{c}	63.27^{h}	82.40^{c}	73.23^{ef}	84.52a^{bc}

Values with the same superscript do not differ significantly between themselves during a season

XXXIX. Mean of pH of leaf extracts across three seasons

Sl No.	Species	Winter		Summer		Monsoon	
		Polluted	Control	Polluted	Control	Polluted	Control
1	*Tectona grandis*	6.09^{b}	5.59^{cd}	6.74^{a}	5.68^{c}	6.31^{c}	6.58^{b}
2	*Terminalia paniculata*	5.50^{d}	4.54^{ef}	5.46^{cd}	4.49^{ef}	4.98^{h}	4.50^{j}
3	*Bombax ceiba*	5.46^{d}	5.66^{cd}	5.62^{cd}	5.63^{cd}	5.76^{d}	5.03^{h}
4	*Butea monosperma*	6.74^{a}	5.53^{cd}	6.76^{a}	5.53^{cd}	6.87^{a}	5.75^{d}
5	*Cassia fistula*	6.02^{b}	5.66^{cd}	6.43^{b}	5.69^{c}	6.55^{b}	5.24^{g}
6	*Anogeissus latifolia*	4.76^{e}	3.85^{g}	4.20^{fg}	3.91^{g}	4.61^{ij}	3.47^{m}
7	*Pterocarpus marsupium*	5.33^{d}	5.37^{d}	5.55^{cd}	5.48^{cd}	5.63^{de}	5.15^{gh}
8	*Grewia tiliifolia*	5.67^{cd}	5.42^{d}	4.58^{e}	5.33^{d}	6.16^{c}	5.35^{fg}
9	*Terminalia catappa*	4.38^{f}	4.33^{f}	4.49^{ef}	4.50^{ef}	4.74^{i}	4.28^{k}
10	*Artocarpus heterophyllus*	5.84^{bc}	3.98^{g}	5.36^{cd}	4.02^{g}	5.51^{ef}	3.71^{l}

Values with the same superscript do not differ significantly between themselves during a season

XL. Mean of APTI across three seasons

Sl No.	Species	Winter		Summer		Monsoon	
		Polluted	Control	Polluted	Control	Polluted	Control
1	*Tectona grandis*	2.91^{d}	3.45^{cd}	2.50^{bcde}	2.54^{bcde}	3.01^{fgh}	4.28^{bc}
2	*Terminalia paniculata*	3.48^{cd}	4.23^{b}	3.43^{bcd}	4.10^{ab}	2.42^{i}	4.18^{c}
3	*Bombax ceiba*	2.17^{e}	2.22^{e}	1.74^{de}	2.47^{bcde}	2.48^{i}	3.14^{efg}
4	*Butea monosperma*	7.76^{a}	3.53^{c}	3.74^{bc}	3.63^{bcd}	4.48^{bc}	5.00^{a}
5	*Cassia fistula*	4.25^{b}	4.50^{b}	3.54^{bcd}	4.07^{ab}	4.50^{bc}	1.76^{j}
6	*Anogeissus latifolia*	3.55^{c}	3.13^{cd}	2.14^{cde}	2.86^{bcde}	3.07^{efgh}	3.43^{de}
7	*Pterocarpus marsupium*	2.08^{e}	3.09^{cd}	3.43^{bcd}	5.68^{a}	2.90^{gh}	2.69^{hi}
8	*Grewia tiliifolia*	3.54^{c}	3.65^{c}	1.28^{e}	3.35^{bcd}	3.73^{d}	5.00^{a}
9	*Terminalia catappa*	3.58^{a}	2.09^{e}	2.15^{cde}	2.05^{cde}	3.15^{efg}	3.41^{def}
10	*Artocarpus heterophyllus*	3.67^{c}	1.95^{e}	3.39^{bcd}	2.21^{bcde}	3.43^{de}	4.59^{b}

Values with the same superscript do not differ significantly between themselves during a season

IMPACT OF PARTICULATE POLLUTION ON THE GROWTH AND PHYSIOLOGY OF TREES IN MOIST DECIDUOUS FORESTS

By

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ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the
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ABSTRACT

The research work on 'Impacts of particulate pollution on the growth and physiology of trees in moist deciduous forests' was carried out in the vicinity of Malabar cements Ltd., from August 2012 to June 2013.

The objective of the research was to study the growth and physiology of *Tectona grandis* under the stress caused by the particulate pollution caused by deposition of cement dust and also to compare the air pollution tolerance index of important moist deciduous forest species found in the region to identify the trees least affected by particulate pollution. The results indicated a reduction in chlorophyll content and ascorbic acid content in species sensitive to particulate pollutants. *Butea monosperma* was the most tolerant to particulate pollution stress, followed by *Cassia fistula*, *Terminalia paniculata* and *Grewia tiliifolia*. Species like *Bombax ceiba, Terminalia catappa* and *Anogeissus latifolia* was sensitive to particulate pollution. While *Tectona grandis*, which is predominantly found planted in the region fell in the category of intermediate tolerance.

Tectona grandis found abundantly in the area due to many plantations setup in the region, is only having intermediate tolerance to the particulate pollutants. Various physiological parameters of *Tectona grandis* like chlorophyll content, LAI, LAD, water potential, photosynthesis, transpiration and leaf surface area was found affected by the deposition of particulate pollutants. Changes in the wood anatomical properties was also found when they were compared to those grown in relatively healthier environments of Nilambur. There was a significant increase in the vessel frequency, ray frequency and fibre width, while fibre length was reduced in *Tectona grandis* at Walayar.