AIR POLLUTION TOLERANCE INDEX OF SOME FODDER PLANT SPECIES AROUND SONAPUR CEMENT FACTORY IN DANG, WESTERN NEPAL

A THESIS

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BY

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DECLARATION

I. "Kalpana Basnet" hereby declare that the work enclosed here is entirely my own, except where states otherwise by reference or acknowledgement and has not been published or submitted elsewhere, in whole or in part for the requirement for any other degree or professional qualification. Any literature, data or works done by others are cited within this thesis has been given due acknowledgement and listed in the reference section.

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RECCOMMENDATION

This is to recommend that the thesis entitled **"Air pollution tolerance index of some fodder plant species around Sonapur cement factory in Dang, Western Nepal"** is carried out by "Kalpana Basnet" under our supervision. The entire work is based on original scientific investigations and has not been submitted for any other degree in any institutions. We therefore, recommend this proposal to be accepted for Master Degree in Botany.

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LIST OF ACRONYMS AND ABBREVIATIONS

AA	Ascorbic acid content
API	Anticipated performance index
APTI	Air pollution tolerance index
ANOVA	Analysis of variance
CO	Carbon monoxide
CO_2	Carbon dioxide
DMSO	Dimethyl sulfoxide
EDTA	Ethylene diamine tetra acetic acid
EPI	Environmental Performance Index
HEI	Health effect institute
IHEM	Institute for health matrices evaluation
Km	Kilometre
Ltd.	Limited
NH_3	Ammonia
$NMVOC_s$	Non- methane volatile organic compounds
NO_x	Nitrogen oxides
NO_2	Nitrogen dioxide
NS	Nepal standard
OPC	Ordinary Portland cement
pH	Potentiality of hydrogen
PM	Particulate matter
Pvt.	Private
ROS	Reactive oxygen species

RWC	Relative water content
SLA	Specific Leaf Area
SO_2	Sulphur dioxide
TChl	Total chlorophyll content
TPD	Tons per day
UNEP	United Nations Environment Program
VOCs	Volatile organic compounds
WHO	World Health Organization
Fig.	Figure
et al.,	And others
mg	Milligram
ml	*Milliliter*
nm	Nanometer
g	Gram
%	Per cent
µm	*Micrometer*

ABSTRACT

The study aims to find out the air pollution tolerant index of some fodder plant species around the Sonapur cement factory in Dang, Nepal. Commonly available and dominant five fodder plant species (*Melia azedarach*, *Leucaena leucocephala, Garuga pinnata, Dalbergia sissoo*, *Bambusa nutans*) were selected from three different distances i.e. (0-300) m, (300-600) m, (600-1000) m at four directions (east, west, north and south). Matured leaf samples were collected for the biochemical studies of air pollution tolerance index (APTI). The APTI values of different plant leaves were calculated considering the biochemical parameters like relative water content (RWC), total leaf chlorophyll content (TChl), leaf extract pH and ascorbic acid (AA). Additionally, specific leaf area (SLA) was also measured. The correlation of SLA with APTI and different biochemical parameters were also calculated. The highest APTI value of the studied plants ranged from twelve to sixteen, indicating their moderate tolerance to air pollution. The APTI values of fodder plants increased significantly ($p=0.05$) at the distance near the factory at (0-300) m. Among them the highest APTI was found in *L. leucocephala* and was followed by *G. pinnata* in the east direction, *M. azedarach* in north direction, *D. sissoo* in south direction and *B. nutans* in west direction. The value of SLA, total chlorophyll content and pH decreased whereas relative water content and ascorbic acid increased near the cement factory in most of studied plants. SLA of studied plants showed significantly negative correlation ($p<0.05$) with APTI. This study recommends plants like *L. leucocephala, G. pinnata, Melia azedarach, D. sissoo, B. nutans*, which scored high APTI value at different directions, for further plantation around the cement factory.

Keywords: Ascorbic acid, leaf extract pH, relative water content, specific leaf area, total leaf chlorophyll content.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1. Background

Air is the most essential natural resource for life sustaining. Clean air is crucial for the proper growth and development of all organisms. However, it has become highly polluted as a result of urbanization and industrialization (Abbaslou *et al.*, 2017; Masoudi *et al.*, 2017). The combination of air with chemical, physical, or biological elements that defines the natural properties of the atmosphere and any alternation in its natural quality is referred to as air pollution (WHO/UNEP, 1992). Sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), particulate matter (PM 10 with a diameter of 10 m or less and PM 2.5 with a diameter of 2.5 m or less), non-methane volatile organic compounds (NMVOCs), ozone, and ammonia (NH_3) are the major airborne pollutants in urban areas (Pradhan *et al.*, 2012). Some pollutants are emitted directly (primary pollutants), while others (secondary pollutants such as ozone and secondary particles) are generated in the atmosphere from emitted precursors. Air pollution is a challenging topic, and the entire world has to deal with the consequences of it. It has a negative impact on environmental elements that are directly or indirectly related to human health (Gautam *et al.*, 2020). These air toxicants have the potential to cause respiratory problems, eye irritation, skin illnesses, and allergies in humans. A toxic amount of pollution is present in 92% of the world's population, resulting in 7 million deaths annually (HEI/IHME, 2019). The quality of urban life and the sustainability of the urban ecology are seriously threatened by pollution that exceeds an ecosystem's ability to withstand it (UNEP, 2002). According to the World Health Organization, nine out of every ten people breathe polluted air. Ambient air pollution is expected to cause 4.2 million deaths per year from stroke and heart disease (WHO, 2020). According to the Environmental Performance Index (EPI), Nepal's air quality would have ranked worst among 180 countries in 2020 (EPI, 2018).

Air pollution is also harmful to biodiversity and the natural climate system. Air contaminants, whether gaseous or particle, have been shown to affect plants (Singh, 2005). Air quality in dry regions is negatively impacted by numerous gaseous and particle pollutants suspended in the air (Ahmad *et al.*, 2019). Pollutants are only deposited by wet or dry deposition. Wet deposition is less significant since toxins in the atmosphere are washed away, even from the leaf surface. However, the dry deposition procedure exposes the material to the environment for a longer period of time (Reinert, 1984). As plants are constantly exposed to the environment, they absorb, store, and integrate contaminants on their foliar surfaces, causing apparent alterations based on their sensitivity level (Trivedi, 2001). In general, the leaf surface acts as a place for dust to accumulate, generating stress on the leaf surface. Heavy concentrations of dust pollutants affect the morphology and internal structure of leaves (Gostin, 2009). The stresses on the leaf surface may be responsible for plant growth and development. Some of the measures used to understand leaf stress are leaf size and specific leaf area. It has also been noted that when plants are exposed to air pollution, they undergo physiological changes before displaying observable harm to their leaves (Dohmen *et al.*, 1990; Tripathi and Gautam, 2007). Plants growing in industrial regions are exposed to a variety of pollutants, including NO_2, SO_2, CO, heavy metals, benzene, smoke, dust, and soot particles. Plant leaves have a huge surface area for absorbing and accumulating air pollutants, and thus serve as an environmental sink (Liu and Ding, 2008). These air pollutants may disrupt the physiological processes of plants, influencing growth, stomata conductance, and even photosynthesis (Pandey and Kumar, 1996). A large load of dust particles alters the morphology and internal structure of leaves (Gostin, 2009). Plants exposed to cement dust pollution had significantly shorter shoot length, total leaf area, and dry weight, according to Ademilua *et al.* (2008). Reduction in growth parameters due to impacts on physiological process have been speculated because of the cumulative effects of the pollutants (Schutzki and Cregg, 2007). There are various methods for reducing atmospheric pollution, but one of the natural ways of cleaning the environment is by the absorption of gaseous and some particle contaminants through leaves (Varshney, 1985). The response of plants to pollution absorption can be utilized to evaluate air quality in an economical and sustainable manner (Rai *et al.*, 2013).

Many industries in Nepal are sources of air pollutants. The cement business is one of the 17 most polluting industries, according to the Central Pollution Control Board. The most serious environmental effect is the emission of dust and gases (Nawaz *et al.*, 2019). Cement industries are considered as a major source of greenhouse gas emission and are contributors of extremely large amount of dust (Ghada *et al.*, 2016; Magiera *et al.*, 2013). They are potential anthropogenic sources of air pollution which may harm to humans as well as flora. Cement dust is a localized problem in the vicinity of a cement factory for air pollution. The manufacture of cement has emerged as a potential hazard to the natural environment and living beings (Miegeria *et al.*, 2013). Dust particles are discharged into the air from limestone mines, coal yards, and cement clinkers, as well as dust from various processes such as crushing and clinkerization (Chapagain and Dhakal, 2011). Cement production requires a large amount of energy, and plenty of fly ash and dust is generated during storage, milling, packing, and transportation (Dubey, 2013). The production of cement dust has emerged as a potential concern to the natural environment and organisms (Miegra *et al*., 2013). Despite the negative impacts of cement dust on plants, some remain resistant to cement dust pollution. This could be related to genetic make-up or biochemical/anatomical changes during stressful situations (Erdal and Demirtas, 2010). Dust deposition on plant leaves seems to be common in factories because plants are stationary and regularly exposed to harmful chemicals from the surrounding environment (Lohe *et al.,* 2015). Cement dust has a significant impact on plant physiology and morphology, including plant height, leaf area, chlorophyll and carotenoids reduction, non-reducing and total carbohydrates, protein, and total lipid content (Salama *et al*., 2011). Cement dust accumulation is typical on plants growing near cement factories, and this dust covering limits plant growth (Oblisami *et al.,* 1978). Dust deposition on leaves causes physiological disturbance in vegetation, resulting in a decrease in chlorophyll content and photosynthetic activity (Pandey and Kumar, 1996). Thus, the plants surrounding the cement industry with high pollution exposure can not only be recommended as dust tolerant, but can also be employed for bio monitoring (Radhapriya *et al*., 2012).

Plants are an essential component of our ecosystem, and trees and shrubs, as long-lived components of the landscape, play an important role in improving environmental conditions. Plants behave differently and absorb/resist different pollutants (Ahmad *et al*., 2019). Trees and shrubs are vital components of various plant habits because they purify air, water, and soil while also beautifying urban and industrial areas (Ghafari *et al*., 2020). Cultivation of trees and shrubs can serve to be an effective and economical device for the removal of air pollutants. Krzeminska *et al*., (2006) suggested plantation of resistant and fast-growing trees and shrubs to withstand and mitigate the increasing air pollution.

Plants are perfect for detecting, monitoring, and mitigating the effects of air pollution (Singh, 2005). Plant species differ in their level of sensitivity and tolerance (Khan and Abbasi, 2001). Bio-monitoring of air pollution, with or without measurements, has been shown to be highly useful in identifying the kind and concentration of contaminants in the air (Prusty *et al.*, 2005). Setala *et al*., (2013) suggested that nearly one third of the pollutants in air is reduced by plants when compared to areas with no vegetation. As all plants do not have same level of tolerance to air pollution, it is very essential to measure their tolerance level. For this, Air pollution tolerance index (APTI) is measured using four biochemical parameters like

Ascorbic acid, total chlorophyll content, relative water content and pH of the leaves extract (Liu and Ding, 2008). Variation in biochemical variables in leaves is used as a biological marker of air pollution for the early detection of stress or physiological damage based on visible injury indicators (Tripathi *et al*., 2009). Based on APTI value, Padmavathi *et al*., (2013) categorized plants as sensitive (1 –11), intermediate (12 –16) and tolerant (≥ 17).

1.2. Justification of the study

Dang valley lies in Lumbini province of the inner terai at Midwestern Nepal. It is the second largest valley of Asia surrounded by Shivalik Hills and Mahabharat Range. There are seven cement factories in Dang district in which four are in running phase namely Sonapur Cement Industry, Ghorahi Cement Industry, Arun Cement Pvt. Ltd. and Samrat Cement Company Pvt. Ltd. and other three are in construction phase. Among them Sonapur Cement Industry and Ghorahi Cement Industry are located 17 km apart. Sonapur Cement Industry lies in Tulsipur Sub- Metropolitan 18, Dudhras Dang. It was established in 2007 A.D. and has the capacity to produce 1200 tons or 22000 sacks of cement per day. The villages like Dharmpur and Haspuruwa lie in north side of the factory, Baghausi and Dhadagajeri are in the south, Manikapur and Beljhundi in west, Kartikya and Ranibari community forests lies in eastern side of this factory. The cement dusts are harmful to human beings as well as plants (Chapagain and Dhakal, 2011). Plants play important role to reduce air pollution near the cement factory. Long term exposure of the plants to cement dust may cause physiological upset. It is not known if the plants near and surrounding the factory have faced any such physiological abnormalities. That’s why it is very important to investigate if the air pollutants have any adverse effects on plant physiology and have reduce their availability. Different plant species have their own physiological adjustment to fight against air pollutants, and hence some are tolerant, and some are sensitive. Hence, to understand this, APTI of fodder plant species have done for the present study. It was not known which fodder plant species are more tolerant or sensitive to air pollution. And it was also not known if the cement dusts from the cement factories have caused any physiological damage to these plants. Plants play important role to reduce air pollution near the cement factory. Plants have different ability to remove and tolerate pollutants. Tolerant plants can help to improve polluted environment and clean up man-made air pollution. Therefore, it is an urgent need to understand if the plants around cement factory pollution are tolerant or sensitive.

1.3. Research questions

i. Which species are more sensitive and acts as bio indicator for air pollution?

ii. Which species are tolerant and can be planted in industrial sites?

1.4. Research Objectives

The general objective of the study is to compare air pollution tolerance index of different fodder plant species and the specific objectives are:

i. To measure the biochemical parameters relative water content, leaf extract pH, ascorbic acid and total chlorophyll content for calculation of air pollution tolerance index.
ii. To measure specific leaf area and its correlation with different biochemical parameters.

1.5. Limitations

i. Dust load on leaves could not be measured due to frequent rainfall.
ii. Due to time and resource constraints only five fodder plants were selected for the study.

CHAPTER 2: LITERATURE REVIEW

Air pollution tolerance index is the numerical value used to access the ability of plants to withstand air pollution. Many works related to APTI has been conducted by different authors in world wide. The APTI of 99 plants were calculated by (Dwivedi and Tripathi, 2007) around coal-fired (brick) industries in India and categorized them as sensitive or resistant. Among them was found to be most resistant and *Lepidium sativum* was recorded as the most sensitive plant. *Ricinus communis* showed uniform distribution at all the polluted sites but *Lepidium sativum* was found only at the less polluted sites. The APTI of selected plant species around the Otorogun gas plant in delta state in Nigeria was studied by Agbaire and Esiefarienrhe, (2009). Plants were randomly selected for APTI measurements from the nearby areas of the station. Among selected plants *Emilia sonchifolia, Manihot esculenta* and *Elaesis guineensis* were most tolerant species. Similarly, Tripathi *et al*., (2009) investigated APTI of 10 trees in Moradabad city, India from residential, industrial and commercial area. According to observed APTI value, *Ficus rumphii* showed highest value at a residential site, *Holoptele integrifolia* at commercial and industrial site. But *Cassia siamea* showed lowest APTI at all three sites considering as sensitive tree species.

The tolerance for various plant species based on APTI values and heavy metal concentration was assessed by Begum and Harikrishna, (2010) and reported that *Ficus religiosa, Azadirachta indica,* and *Pongamia pinnata* were the most tolerant plants in south Bengaluru's industrial areas. But other species tested had low APTI scores and were considered as sensitive. The vegetation around a Himal cement factory and the impact of dust pollution on crop productivity in Kathmandu valley was studied by Chapagain and Dhakal, (2011). They have reported significantly low productivity of wheat; maize and mustard growing in the fields up to 1.5 km around the factory in comparison to the fields that were at 3-4 km distance. But the productivity of rice was least affected. The APTI of 10 plant species from the urban areas were studied and among them *Psidium guajava, Swietenia mahagoni, Magnifera indica, Ficus benghalensis* and *Polyanthia longifolia* had the highest APTI value (Mondal *et al*., 2011). The most tolerant plant species, according to APTI value, can be advantageous for greenbelt development. Similarly, the biochemical changes in *Azadirachata indica, Magnifera indica, Delonix regia,* and *Cassia fistula* in Nagpur, India at industrial, commercial, and residential sectors was estimated for APTI (Thawale *et al*., 2011). In this study, the four biochemical properties of the selected plant species were demonstrated to change in response to air pollution.

APTI of plant species in an Indian cement industry was evaluated by Radhapriya *et al*., (2012). The APTI results have been studied applying physiological and biological variables. All plant species near the cement industry, according to the study, were much more susceptible to air pollution than plant species in control areas. Approximately 37% of the plant species studied have been categorized as air pollution resistant based on the observed APTI value. *M. indica, Bougainvillea species,* and *Psidium guajava* were the plant species with high APTI values, whereas 33% of the species like *Thevetia neriifolia*, *Saraca indica, Phyllanthus emblica,* and *Cercocarpus ledifolius* had low APTI values. APTI of plant species growing in the vicinity of cement in India was studied by Babu *et al*., (2013) and found shrubs like *Cassia auriculata* and *Bougainvillea spectabilis* and trees of *Aeglemarmelos* as a suitable plant species which can be used as sink towards air pollutants. Similarly, the effects of cement dust on physiology of selected trees at cement nagger; India was studied by Rai *et al.,* (2013) emphasized on assessing APTI from six common roadside plant species growing along India's industrial and non-industrial areas. APTI levels were observed to be greater in industrial site plant samples than in non-industrial site plant samples. Based on APTI, *Ficus bengalensis* was shown to be tolerant in industrial sites while *Magnifera indica* was found to be tolerant in non-industrial sites. Plant species with little changes in APTI values were *M. indica* and *Bougainvillea.* Panigrahi *et al*., (2014) studied the biochemical parameters and APTI of ten plant species. According to the study, *Magnifera indica* had the highest APTI score of 20.80, considered as most tolerant plant species followed by *Bougainvillea spectabilis* (20.32), *Nerium indicum* (18.94), *Azadirachta indica* (18.73), and *Caltropis procera* (18.10).

The APTI of 15 plant species growing in Rohtak, Haryana, at residential, university, and industrial areas were investigated by Dhankar *et al.,* (2015) and reported the highest APTI results in industrial sites. In terms of longevity, *Eucalyptus obliqua* and *Ficus virens* shown that they are the most suited plant species for greenbelt regions and are suggested for air pollution control. Gholanmi *et al.,* (2016) evaluated the APTI in affected areas of six plant species present in the Ahvaz region. *Myrtus* has the greatest APTI and has been determined to be resistant to plant pollution and *Prosopis* has the lowest APTI and has been suggested as sensitive plant to air pollution according to the study. Gupta *et al*., (2016) assessed the APTI and anticipated performance index (API) of four selected species, *Terminalia arjuna*, *Morus alba*, *Dalbergia sissoo*, and *Polyathia longifolia*, in Delhi, India, to investigate their tolerance to air pollution and green belt development. The physiological and biological characteristics were investigated in order to determine the APTI values. Their findings revealed that the APTI values for the four selected species are sensitive and can be used as indicators of biology. Kanwar *et al*., (2016), studied different plant species in Kathmandu valley and investigated that *Prunus persica, Populus deltoides*, and *Grevillea robusta* have the highest APTI values and suggested for the roadside plantation. The sensitive species like *Pyrus pyrifolia, Celtis australis,* and *Punica granatum* were suggested for bio-indicators purpose.

APTI of four roadside gymnosperms (*Cedrus deodara*, *Pinus roxburghii, Araucaria bidwillii* and *Thuja orientiales)*, from Kathmandu were reported by Hamal and Chettri, (2017). High APTI values were found in all four species, indicating tolerance to air pollution. Ter *et al.*, (2020) revealed that *Ficus elastica*, *Ficus auriculata*, *Ficus religiosa*, *Ficus benghalensis*, *Cinnamomum camphora* and *Grevillea robusta* are the most tolerant tree species and can be employed for urban green belt development. *Phyllanthus emblica* and *Schima wallichii* are both highly sensitive to air pollution and can be used as bio indicators. Mohamed *et al.*, (2017) studied 23 natural plant species in six different locations at industrial area of Palestine. Among which five plant species were found in all locations. Based on the APTI, *Polygonium equisetiforme* was more tolerant at all locations. *Marrubium vulgare* was considered as most sensitive plant species. Zouari *et al*., (2018) have evaluated APTI of four different plant species around polluted and unpolluted industrial site in Sfax, Tunisia. The results, from their study revealed that among four plant species *Olea europaea* and *Phoenix dactylifera* are the most tolerant species with 20.09 and 17.10 APTI value respectively and can be planted in polluted sites for controlling air pollution and improvement of air quality. *Ficus caria* and *Morus alba* are the most sensitive ones with APTI 8.87 and 7.49 respectively, suggested as bio-indicator.

The APTI value of different plant species were studied by Dhyani *et al*., (2019). The most tolerant species include *Bougainvillea glabra* and *Duranta repens*, which have high APTI values. *Lantana camera* and *Ricinus communis* were the sensitive species, and they can be employed as bio-indicators of air quality. Manjunath and Reddy, (2019) studied six plant species commonly growing in polluted and non- polluted regions of Bengaluru. Lowest APTI was recorded in *Ocimum sanctum* in both regions and can be used in bio-monitoring. Whereas higher APTI was recorded in *Vica rosea* and *Baugainvillea spectabilis* and can be used in heavily polluted urban environments to restore green urban ecosystem. Nawaz *et al.*, (2019) and reported that the APTI is high in *Ficus benghalenis, F. religiosa. Terminilia catappa, Leucanea leucocephala* and *Mangifera indica,* hence suggested to develop the green belts using these trees speciallyto raise the water tables around the cement industries. Oyedeji *et al.,* (2019) studied three plant species *Terminilia catappa, Anacardium occidentale* and *Tectona grandis.* They show higher index at control site than at polluted site. The study has recommended that these plants can be used in developing green belts in city centers, mainly in extremely polluted areas, surrounding the factories. An investigation was carried out by Uka *et al*., (2019) on some selected road side tree species in Ghana as experimental sites and KNUST campus as control site. The biochemical studies have revealed that reduction in TChl content and pH whereas increase in AA, RWC in severely polluted roadsides. It was concluded that *Magnifera indica, Ficus platyphylla* and *Terminalia cattapa* can be doing few measure of air cleaning functions while *Polyalthia longifolia* was poor and unsuitable as a pollution sink. Shrestha *et al*., (2021) have studied APTI of nine plant species for the selection of vegetation traffic barriers in Kathmandu valley. Considering both APTI and dust capturing potential, *Cinnamomum camphora, Nerium oleander* and *Albizia julibrissin* were found to be the most suitable species for the road side plantation. Timilisna *et al*., (2022) studied APTI of 13 different plant species from the experimental site or polluted site and from control site. Their studies concluded that Ascorbic acid and relative water content provided greater tolerance than other parameters. All the plants were sensitive to air pollutants and thus were effective indicators of air pollution along major roadsides of Kathmandu valley. Bui *et al*., (2022) calculated the APTI of 12 plant species at both sites in Korea that is from roadside and urban forest. The APTI of the roadside plant species was higher than that of the plant from the urban forest. Among 12 plant species *Acer palmatum, A. buergerianum* and *Pinus densiflora* had high APTI values. Plants such as *Zelkova scrrata* and *Metasequoia glyptostroboides* with low APTI plants can be used as an indicator of air pollution.

2.1. Relative Water Content (RWC)

Plants having a high water content are beneficial for combating the negative impacts of air pollution and maintaining ecological balance (Kuddus *et al*., 2011). Plants with low water content, on the opposite hand, may limit transpiration rate, causing leaf damage to take water from the roots (Chouhan *et al*., 2012). The plant species growing at polluted sites has high RWC than in non-polluted sites and further increases the drought and stress tolerance in plants (Mohamed *et al*., 2015). Rathaore *et al*., (2018) suggested that plants having more relative water content on polluted condition can be tolerant to pollution. Zouri *et al*., (2018) explained that reduction in leaf relative water content of plant species growing at the polluted areas have reduction in transpiration rate due to which plants loses ability to raise water from the root to the leaves. Ghafari *et al.*, (2020) investigated that *Yucca filamentosa* in the marginal site had the highest APTI among all studied species due to difference in water content of the leaf it reflects the impact of air pollution and the sensitivity of the plants. To deal with this difficult and to survive in stress condition it is necessary for the plant to maintain the water content of their tissues.

2.2. Total chlorophyll content (TChl)

Air pollutants enters and reaches the leaf tissue through the opening of guard cells, causing partial denaturation of the chloroplast and a decrease in pigment concentration in the cells of contaminated leaves (Tripathi and Gautam, 2007). The effect of cement dust on certain physical and biological parameters of *Sesamum indicum* plant was analyzed by Kumar *et al.*, (2015) and found decrease in the amount of total chlorophyll content in the polluted site in comparison to that of the control site. Reduction in total chlorophyll content in different plant species growing in the polluted site compared to the unpolluted one was reported by Zouari *et al.,* (2018). Afterward Chaudhary and Rathore, (2019) also reported reduction in photosynthetic pigments varies with the nature of leaves of selected plant species and their sensitivity to air pollutants. Dhyani *et al.*, (2019) observed that total chlorophyll concentration may decline due to dust deposition on plant leaves, which prevents gas exchange or light intensity, both of which limit photosynthesis and metabolism.

2.3. Leaf extract pH

Acidic plants were more susceptible than with basic plants (Mohamad *et al.*, 2015). According to Kaur and Nagpal, (2017), in the presence of an acidic pollutant, the leaf pH decreases, and the rate of decrease is greater in sensitive plants than in tolerant plant species. Sumangala, (2018) observed that all the plant species collected from the site exhibited of pH towards acidic side from 4 to 6. Zouri *et al.*, (2018) reported that the leaves pH measured in *Olea europaea* and and *Phonenix dactylifera* plants from both polluted and control sites was to be same whereas the leaves pH in *Ficus caria* and *Morus alba* plants from the industrial area dropped significantly.

2.4. Ascorbic acid (AA)

The increased rate of production of reactive oxygen species (ROS) during photo oxidation process increases the ascorbic acid content in the plants of polluted areas (Tripathi and Gautam, 2007). Gupta and Durohit, (2015) analyzed that ascorbic acid is an important metabolite which activates the resistance mechanism under pollution stress in plants. Sumangala, (2018) found significantly variation in Ascorbic acid across the 46 plant species that were studied. AA was generally higher in tolerant species. According to Zouri *et al*., (2018) the ascorbic acid of studied plants showed decrease in polluted sites than unpolluted areas but high contents in industrial site than control ones. Further, Chaudhary and Rathore, (2019) studied the impact of dust on leaf physiology of urban trees and observed that ascorbic acid content significantly increased in the leaves at polluted sites during all seasons.

2.5. Specific leaf area (SLA)

The variability of specific leaf area and other leaf traits, the relationship between them was studied by Wilson *et al*., (1999) and analyzed that specific leaf area was found to suffer from a number of drawbacks which was influenced by leaf thickness in between variables. Meziane and Shiplely, (2001) studied relationship between specific leaf area, leaf nitrogen and leaf gas exchange where specific leaf area directly affects both leaf nitrogen both leaf nitrogen levels and net photosynthetic rates. Specific leaf area and leaf area – leaf mass relationship in oil palm plantation was studied by Awal *et al*., (2004) in Malaysia. The SLA was plotted on frond number and found decreased systematically with time as the frond mature. Borowiak and Filder, 2014 studied specific leaf area and relative water content of Italian rye grass leaves which were exposed to heavy metals and revealed that leaf thickness increased due to increased heavy metals concentrations in ambient air, but relative water content decreased. Greenwood *et al*., (2017), reviewed tree mortality across biomes either promoted due to drought intensity, lower wood density and higher specific leaf area and found that tree species with denser wood and lower specific area showed lower mortality responses.

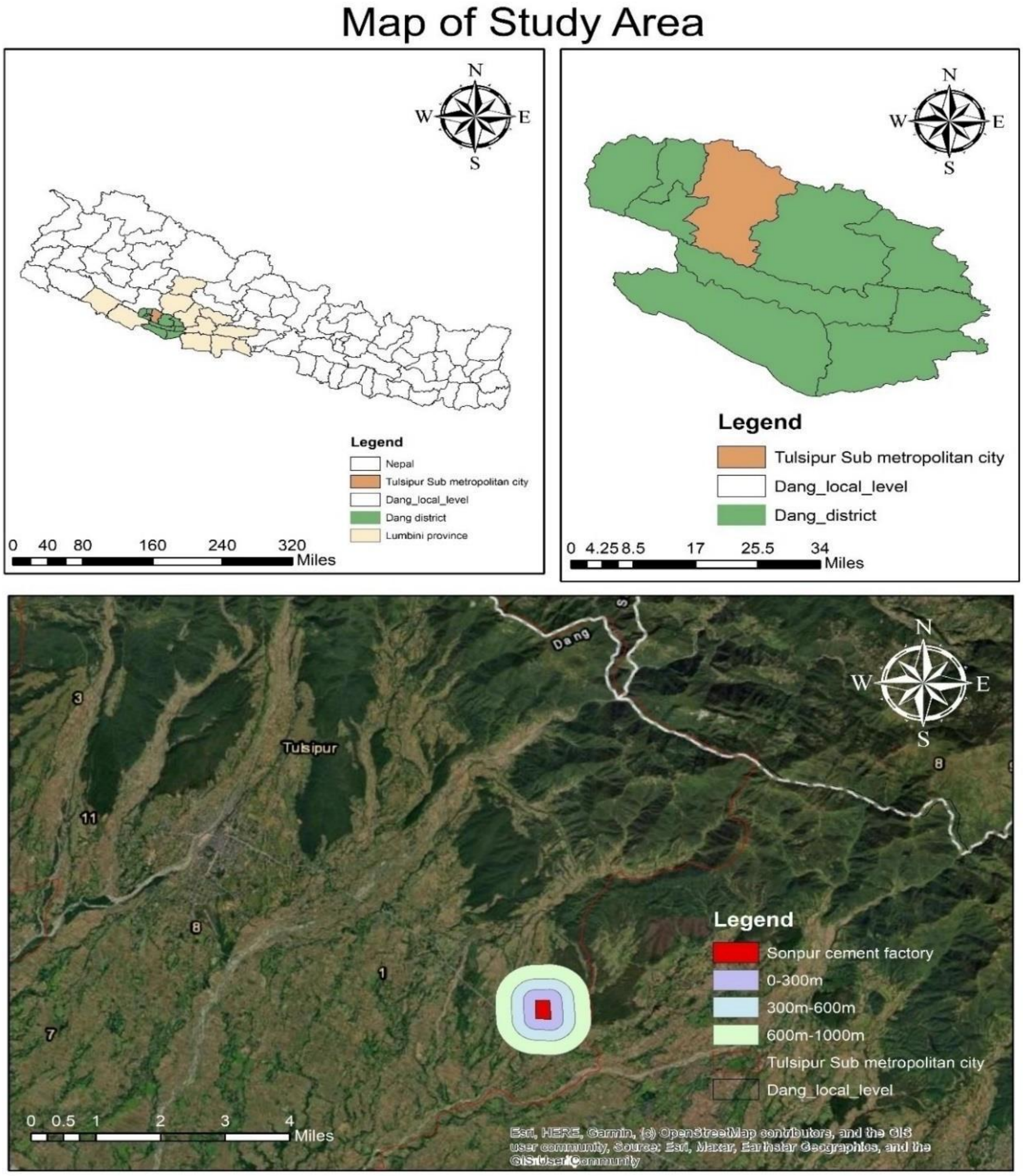
2.6. Research gap

From the literature review, it is evident that APTI related research have been mostly conducted in Kathmandu valley. Very few research on APTI has been conducted around cement factory. The previous works were mostly focused on roadside plants but the work on fodder plants have not been done so far. Therefore, the present study aims to study the air pollution tolerance among the fodder plants around the cement factory.

CHAPTER 3: MATERIALS AND METHODS

3.1. Study area:

The Dang district lies in Lumbini Province, Mid- Western region of Nepal. It is about 450 km from the Kathmandu, the capital city of Nepal. It covers an area of 2,955 square kilometer elevation ranging from 213 to 2,058 meter above sea level. It lies between the Churiya mountain range (in south) and the Mahabharat range (in north). The study area is 636 m above from the sea level with latitude 28˚05’21” N and longitude 82˚22’47” E. Sonapur Cement Industry, located at Tulsipur Sub- Metropolitan city, Dudhras Dang, is the largest cement industry in Western Nepal and occupies nearly 60 hectors of own land. By acquiring Nepal Standard (NS) Certification from the Government of Nepal it was established on 2008, with production capacity of 750 tons per day (TPD). It has started its production of clinker and cement in June 2012 and with the minimum changes in the plant the production has been expanded to 1250 TPD. SPCL `s product range is including Ordinary Portland Cement (OPC) and Pozzolana Portland Cement (PPC) using raw materials reserves of limestone, coal and shale. It is situated on National Highway 13 Km away from Ghorahi City towards Tulsipur city which is just 9 km from the factory site. The land used around the Sonapur cement factory is very different. In the east direction there is a road within 300m which is constructed for the transportation of cement, limestone, clinker and other raw materials for the factory. Onwards to this, there are apartments made for employee of cement factory. Behind the apartment there is a dense community forest which occupy the area about 5000 m^2. There are large number of fodder tress in the forest. In west direction, there are dense residential areas and grazing land for livestock of local people. There is also a gravel road that link to the main highway. In north direction, there is deposition site of raw material need for cement production near to the factory. Behind to this, there is a scattered residential area and water reservoir connected to the community forest. In south direction, within 300 m from the factory there is main highway that connects two sub- metropolitan cities – Ghorahi and Tulsipur. This highway is in re- construction phase for last five years that produces large amount of dust particles by vehicular movement. Behind to this there are also dense residential areas with more number of fodder tress.



Source: Esri, Maxar, Earthstar Geographics and, the GIS user community

Figure 1: Map of study area around the Sonapur cement factory in Dang with boundary and sampling sites.

3.2. Climate and Hydrology

The climate study area is of tropical type. On the basis of data, the average maximum temperature was high during May (34.25°C) and low during January (20.98°C). Similarly average minimum temperature was high during July (23.6°C) and low during January (6.63°C). The average rainfall was maximum during August (99.55 mm) and minimum during November (0. 405mm).

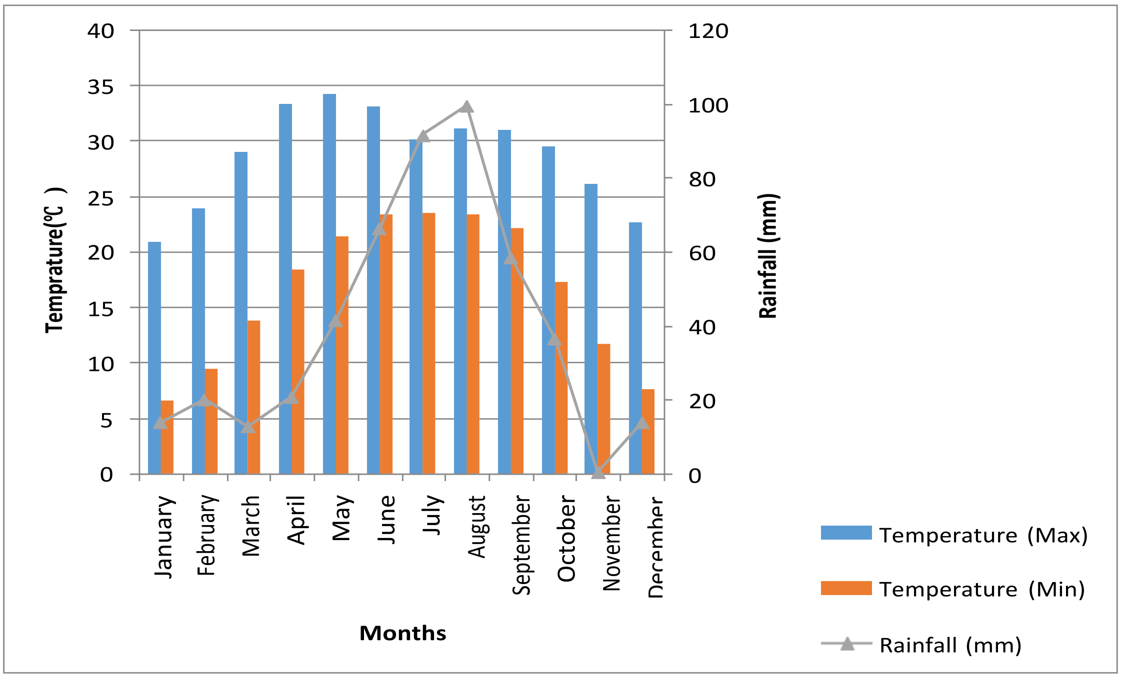


Figure 2: Ten years (2012-2022) climatic graph showing average monthly temperature and precipitation of Dang Nepal. (Source: Department of Hydrology and Meteorology, Babarmahal, Government of Nepal).

3.3. Study species

Five commonly available plants around the Sonapur cement factory were collected. They were selected from three different distances (0-300) m, (300-600) m and (600-1000) m and four directions (north, south, east and west). Plant species were selected on the basis of availability at all the sites. They were identified by the help of literatures and experts. The name of the plant species with their scientific and local name is listed in the table 1.

Table 1: List of plant species selected for the study

S.N.	Scientific name	Family	Local name
1.	*Melia azedarach* L.	Meliaceae	Bakaino
2.	*Leucaena leucocephala* (Lam.) de Wit	Fabaceae	Ipil- Ipil
3.	*Garuga pinnata* Roxb.	Burseraceae	Dabdabe
4.	*Dalbergia sissoo* Roxb. ex. DC	Fabaceae	Sisau
5.	*Bambusa nutans* Wall. ex. Munro	Poaceae	Mai bong

3.4. Methods

3.4.1. Sample collections and designs

The study was conducted from November, 2021 to February, 2022 in winter months. At first, the study area was divided into three different distances ranging from (0-300) m, (300-600) m and (600-1000) m in four directions (east, west, north and south) of Sonapur cement factory. Fully matured leaf samples of fodder plants species above five feet were collected from each distance and directions in the morning time and then they were brought to the laboratory. Three replicates of each sample were taken to get mean value. The laboratory of Mahendra Multiple Campus, Dang was used for measuring air pollution tolerance index and its different parameters like relative water content, leaf extract pH, ascorbic acid, total chlorophyll content and SLA. The dust particles collected on the leaf surface were cleaned in the laboratory using tiny brushes and tissue papers. Then weight of leaf samples were measured with the help of three digital scale balance of 500gram capacity. Photographs of the fresh leaf samples were captured by digital camera.

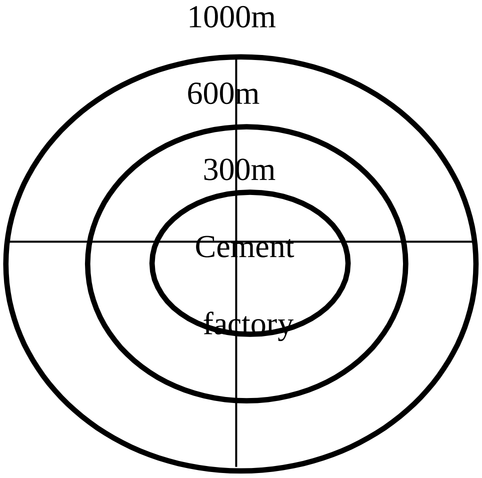


Figure 3: Diagrammatic representation of study area showing different distance

3.4.2. Biochemical analysis (APTI)

The APTI value of all the collected plant species was obtained by analyzing the biochemical parameters for each plant samples, namely RWC, TChl, pH and AA.

3.4.2.1. Relative leaf water content

Weighing the fresh leaves revealed the fresh weight. The leaves were soaked in water overnight before being weighed to determine their turgid weight. The leaves were then dried in a 70°C oven for 24 hours before being reweighed to achieve the dry weight (Turner, 1981). Leaf relative water content was determined using the following method applying fresh weight, dry weight, and turgid weight of leaf samples:

$$\mathrm{RWC}(\%) = \left(\frac{\mathrm{F}-\mathrm{D}}{\mathrm{T}-\mathrm{D}}\right) \times 100$$

Where, F is the fresh weight of the leaves (g), D is the dry weight of the leaves (g), and T is the turgid weight of the leaves (g).

3.4.2.2. Chlorophyll estimation

Chlorophyll extraction was carried out with Dimethyl sulfoxide solvent which has amphiphilic properties (Barnes *et al.*, 1992). 0.5 gm of leaves was weighted and placed in test tubes containing 5 ml of DMSO solvent. Test tubes were incubated in a water bath at 60-65°C for an hour. After water bath there was full decolourisation of leaves. Then, cooled at room temperature for 30 min. The supernatant was collected after filtration. Its absorbance at 665 nm and 648 nm were measured. Blank determination was carried out with DMSO. Absorption measurement was carried out with a Spectrophotometer.

Chlorophyll a (mg/g F.W) = $(14.85\times A_{665} - 5.14\times A_{648})$ ....(1)

Chlorophyll b (mg/g F.W) = $(25.48\times A_{665} - 7.36\times A_{648})$ ....(2)

Total chlorophyll (mg/g F.W) = $(7.49\times A_{665} + 20.34\times A_{648})$......................(3)

3.4.2.3. Leaf extract pH

According to Datta and Sinha – Ray, (1995) pH of leaf was determined. 5 g of fresh leaves were washed and homogenized with 25 ml of distilled water. pH of the leaf extract was filtered then measured with the help of pH meter.

3.4.2.4. Ascorbic acid (AA)

The ascorbic acid level was determined using the spectrophotometric method developed by Bajaj and Kaur., (1981). In a test tube, 1 g of fresh leaf samples were placed, followed by 4 ml of oxalic acid-EDTA, 1 ml of orthophosphoric acid, 1 ml of sulfuric acid, 2 ml of ammonium molybdate solution, and 3 ml of distilled water. The solution was allowed to rest at room temperature for about 15 minutes. After the incubation period, absorbance was measured at 760 nm. Blank determination was carried out with ascorbic acid. Absorption measurement was carried out with a Spectrophotometer. The concentrations of ascorbic acid in the sample was then extrapolated from a standard ascorbic acid curve.

3.4.2.5. Air pollution tolerance index (APTI)

APTI is calculated by using this formula

$$\mathrm{APTI} = \frac{\mathrm{A(T+P)+R}}{10}$$ (Singh and Rao, 1983),

Where A = Ascorbic acid content (mg/g), T = total chlorophyll (mg/g), P = pH of leaf extract and R = relative water content of leaf.

3.4.3. Categorization of plants

According to Padmavathi *et al.*, 2013, studied fodder plant species were grouped in different category (Table 2).

Table 2: Categorization of plant species on the basis of APTI score (Padmavathi et al., 2013).

Category of plant species	APTI score
Sensitive	Less than 11
Intermediate	Between 12 and 16
Tolerant	Above 17

3.4.5. Specific leaf area (SLA)

For calculation of SLA, photographs of healthy mature leaves were taken along with a scale and area was calculated with the help of image- J software (Kovic and Nicolic, 2005). Then leaf samples were dried in hot air oven at 70°C-75°C until to get constant weight. Then dry mass of the leaves was weighed. Following formula given by Zobel *et al.*, (1978) was used for SLA

$$\mathrm{SLA} = \frac{\text{Leaf area (cm2)}}{\text{Leaf dry mass (g)}}$$

3.4.6. Data analysis

The mean value of data was taken by using Microsoft excel 2016. Then the data were entered in SPSS for normality test. The normality test was done using box plot obtained from the data explore in SPSS. The normal distribution of the data was ascertained based on Skewness and Kurtosis (ranging from -2 to +2) (George and Mallery, 2010). As the data of biochemical parameters were normally distributed in all the cases, the further statistical analysis i.e. one-way ANOVA followed by Ducan's Multiple range test was conducted using SPSS version 27 to understand significant differences at ($p= 0.05$) among different distances from the factory. Correlation coefficient analysis between the biochemical parameters (RWC, Tchl, pH, AA and APTI) and SLA was conducted using SPSS version 27.

CHAPTER 4: RESULTS

4.1. Air pollution tolerance index (APTI)

4.1.1. Relative water content (RWC)

The mean value of RWC was high in most of fodder plant species near the factory. The value of RWC ranged from 58.81±0.72 to .95.15±1.87%. The highest RWC was found in *Leucaena leucocephala* (95.15±1.87%) which was followed by *Melia azedarach* (94.08%) and *Garuga pinnata* (93.16%) and lowest RWC was found in *Bambusa nutans* (58.81±0.72%) (Table 3).

Table 3: Relative water content (%) in leaves of different plant species at different directions and distance from the Sonapur cement factory.

Plant species	**Distance**	**East**	**West**	**North**	**South**
Melia azedarach	(0-300) m	76.77±2.75A	94.08±14.83 A	85.91±5.71 A	70.33±4.54 A
	(300-600) m	71.06±9.34A	75.29±16.62 A	81.17±8.72 A	68.31±1.25 A
	(600-1000) m	73.36±1.57A	65.71±9.37 A	72.21±10.56 A	75.16±8.86 A
Leucaena leucocephala	(0-300) m	87.47±5.80 C	95.15±1.87 B	79.56±1.54 A	77.09±3.13 A
	(300-600) m	80.21±1.28 B	86.54±2.95 B	69.18±20.53 A	84.59±11.26 A
	(600-1000) m	60.69±0.69 A	63.79±6.98 A	64.04±25.17 A	77.67±3.49 A
Garuga pinnata	(0-300) m	91.18±2.42 B	93.16±1.46 B	83.20±0.68 A	86.18±1.01 A
	(300-600) m	75.72±10.98 A	88.48±1.55 AB	65.36±21.19 A	83.99±3.32 A
	(600-1000) m	83.48±3.46 AB	81.26±9.56 A	78.62±10.32 A	77.42±11.33 A
Dalbergia sissoo	(0-300) m	72.68±1.54 A	83.84±5.59 B	72.69±6.13 A	78.75±10.08 A
	(300-600) m	65.07±10.31 A	79.85±3.17 B	70.60±5.52 A	75.67±2.74 A
	(600-1000) m	63.17±4.38 A	66.09±4.31 A	73.35±5.61 A	65.07±9.52 A
Bambusa nutans	(0-300) m	78.57±345 B	84.89±3.09 A	78.43±12.45 A	58.81±0.72 A
	(300-600) m	75.74±3.24 B	80.20±2.63 A	70.28±8.04 A	75.18±3.08 B
	(600-1000) m	66.73±3.32 A	77.60±7.67 A	80.45±3.90 A	80.88±5.45 B

Same capital letter after mean ± standard deviation for a particular species in a column does not differ significantly at *p=0.05* according to Ducan's multiple range test followed after one-way ANOVA (n=9).

Mostly the RWC was high in the plants collected from west direction (0-300) m. In remaining three direction of same range, fodder trees like *M. azedarach* showed significant decrease in RWC towards north direction but was insignificant in east and south direction. *L. leucocephala* showed significant decrease in RWC towards east and north direction but was insignificant only in south direction. *G. pinnata* showed significant decrease in RWC at south direction but was insignificant at east and north direction. *Dalbergia sissoo* showed significant decrease in RWC at east and south direction but was insignificant only in north direction. *B. nutans* showed significant decrease in RWC at east direction, but was insignificant at north and south direction.

4.1.2. Total chlorophyll content

The mean value of total chlorophyll content was low near the factory at (0-300) m distance in all fodder plant species. The value of total chlorophyll content ranged from 0.84±0.24 to 5.04±0.45(mg/g) (Table 4). The value of total chlorophyll content was highest in *G. pinnata* (5.04±0.45 mg/g) and lowest in *M. azedarach* (0.84±0.24 mg/g). While moving from (0-300) m to (600-1000) m range away from factory, fodder tree like *G. pinnata* showed significantly higher value of total chlorophyll content in the all directions (east, west, north and south). Only in west direction, all fodder and other plant species studied showed significantly higher value of total chlorophyll content moving away from the factory in same range. In south direction, all fodder and other plant species studied, except *D. sissoo*, showed significantly high value of total chlorophyll. The value of total chlorophyll content of *M. azedarach* and *B. nutans* is insignificantly high at east and north direction but *L. leucocephala* at north direction only.

Table 4: Total chlorophyll content (mg/g) in leaves of different plant species at different directions and distance from the Sonapur cement factory.

Plant species	**Distance**	**East**	**West**	**North**	**South**
Melia azedarach	(0-300)m	1.47±0.09 A	1.10±0.20 A	2.64±0.21 B	0.84±0.24 A
	(300-600)m	3.45±0.18 C	2.42±0.05 B	2.27±0.13 A	1.68±0.37 B
	(600-1000)m	2.34±0.14 B	2.94±0.56 B	2.20±0.01 A	2.06±0.26 B
Leucaena leucocephala	(0-300)m	1.43±1.09 A	1.52±0.59 A	2.19±0.04 A	1.84±0.47 A
	(300-600)m	1.56±0.10 A	2.48±0.55 B	2.08±0.06 A	2.54±0.31 AB
	(600-1000)m	3.89±0.02 B	2.99±0.07 B	3.68±0.51 B	2.65±0.27 B
Garuga pinnata	(0-300)m	1.66±0.13 A	2.94±0.08 A	1.85±0.02 A	3.03±0.18 A
	(300-600)m	3.29±0.29 B	4.72±0.08 B	3.50±0.23 B	3.16±0.33 A
	(600-1000)m	5.04±0.45 C	5.02±0.26 B	4.40±0.71 C	3.65±1.04 A
Dalbergia sissoo	(0-300)m	1.77±0.22 A	1.29±0.01 A	1.89±0.18 A	3.94±0.50 B
	(300-600)m	3.08±1.35 A	2.26±0.48 A	3.53±0.25 B	2.46±0.09 A
	(600-1000)m	3.25±0.07 A	3.87±1.27 B	3.54±0.12 B	2.82±0.27 A
Bambusa nutans	(0-300)m	2.9±0.34 B	2.12±0.49 A	3.74±0.07 A	2.38±0.48 A
	(300-600)m	2.25±0.13 A	2.79±0.28 AB	3.42±0.34 A	3.66±0.31 B
	(600-1000)m	3.85±0.12 C	3.42±0.34 B	4.52±0.54 B	5.16±0.48 C

Same capital letter after mean ± standard deviation for a particular species in a column does not differ significantly at $p=0.05$ according to Ducan's multiple range test followed after one-way ANOVA (N=9).

4.1.3. Leaf extract pH

The result obtained from the analysis of leaf pH mean value showed increasing trend while moving away from the factory in most of the fodder plant species. The pH of leaf extract ranged from 4.13±0.15 to 8.47±0.21. The value of pH was highest in *B. nutans* (8.47±0.21) and lowest in *G. pinnata* (4.13±0.15) (Table 5). All the studied plants showed low pH value in south direction at the range of (0-300) m distance. Here, while moving away from the factory i.e. (0-300) m to (600-1000) m, *L. leucocephala* and *G. pinnata* showed significant increase in pH value at west, north and south direction and insignificant in east direction. *D. sissoo* showed significant decrease of pH value at east and west direction. *B. nutans* showed significant decrease in pH value at east and south direction. *M. azedarach* showed significant decrease in pH value only at south direction.

Table 5: Leaf extract pH in leaves of different plant species at different directions and distance from the Sonapur cement factory.

Plant species	**Distance**	**East**	**West**	**North**	**South**
Melia azedarach	(0-300)m	7±0.1 A	7.07±0.15 B	6.17±0.15 A	5.63±0.15 A
	(300-600)m	7.47±0.35 B	7.2±0.1 B	7.2±0.1 C	5.9±0.1 A
	(600-1000)m	6.8±0.06 A	6.63±0.15 A	6.77±0.05 B	7.03±0.21 B
Leucaena leucocephala	(0-300)m	6.2±0.26 A	6.16±0.05 A	6.17±0.12 A	5.43±0.15 A
	(300-600)m	6.5±0.2 A	6.7±0.1 B	6.63±0.15 B	5.53±0.15 A
	(600-1000)m	6.47±0.05 A	7.27±0.15 C	6.73±0.21 B	6.03±0.57 A
Garuga pinnata	(0-300)m	5.63±0.25 A	5.43±0.15 A	5.9±0.26 A	4.13±0.15 A
	(300-600)m	6.33±0.15 B	6.2±0.1 B	6±0.26 A	5.33±0.31 B
	(600-1000)m	6.1±0.1 B	6.47±0.21 B	6.2±0.1 A	6.83±0.31 C
Dalbergia sissoo	(0-300)m	6.3±0.1 A	6±0.1 A	6.7±0.21B	7.63±0.15 B
	(300-600)m	6.47±0.15 A	6.47±0.05 B	6.77±0.06 B	5.73±0.15 A
	(600-1000)m	7.3±0.1 B	6.8±0.15 C	6.2±0.1 A	5.47±0.21 A
Bambusa nutans	(0-300)m	7.1±0.1 A	7.17±0.25 B	7.57±0.25 B	5.53±0.15 A
	(300-600)m	7.27±0.20 A	7.73±0.05 C	7.67±0.15 B	6.77±0.11 B
	(600-1000)m	7.3±0.36 A	6.83±0.05 A	6.73±0.06 A	8.47±0.21 C

Same capital letter after mean ± standard deviation for a particular species in a column does not differ significantly at $p=0.05$ according to Ducan's multiple range test followed after one-way ANOVA (n=9).

4.1.4 Ascorbic acid

The mean value of ascorbic acid in the leaves ranged from 0.23±0.18 to 8.95±1.17mg/g (Table 6). The value of ascorbic acid was highest in *L. leucocephala* (8.95±1.17mg/g) and lowest in *B. nutans* (0.23±0.18mg/g). Plants species like *L. leucocephala, G. pinnata* and *D. sissoo* showed high ascorbic acid mean value in eastern direction at the distance of (0-300) m. At the same distance (0-300) m in south direction ascorbic acid of *M. azedarach* was high, and at west direction it was high in *B. nutans*. While moving away (0-300) m to (600-1000) m from the factory *G. pinnata* and *M. azedarach* showed significant (*p=0.05*) decrease in ascorbic acid at all directions. *B. nutans* showed significant (*p=0.05*) decrease in ascorbic acid at north and south direction. *L. leucocephala* showed significant (*p=0.05*) decrease in ascorbic acid at west direction. But in case of *D. sissoo* ascorbic acid was found to be statistically insignificant only in south direction.

Table 6: Ascorbic acid content (mg/g) in leaves of different plant species at different directions and distance from the Sonapur cement factory.

Plant species	**Distance**	**East**	**West**	**North**	**South**
Melia azedarach	(0-300)m	2.97±0.04 B	2.85±1.49 A	4.28±0.48 C	5.29±2.24 B
	(300-600)m	1.09±0.09 A	1.87±0.43 A	2.81±0.24 B	2.91±0.98 A
	(600-1000)m	1.22±0.37 A	0.97±0.70 A	0.41±0.56 A	1.69±0.83 A
Leucaena leucocephala	(0-300)m	8.95±1.17 B	6.90±0.07 B	6.66±2.04 B	5.3±1.40 A
	(300-600)m	2.64±0.27 A	3.48±2.15 A	2.29±0.26 A	3.51±1.21 A
	(600-1000)m	3.87±0.26 A	2.67±0.10 A	2.90±0.04 A	3.52±1.17 A
Garuga pinnata	(0-300)m	7.63±1.04 B	5.14±0.12 B	4.96±0.42 C	6.34±2.27 B
	(300-600)m	2.73±0.55 A	2.34±1.11 A	2.08±0.70 B	2.92±0.30 A
	(600-1000)m	1.75±0.06 A	2.05±0.26 A	0.89±0.34 A	2.10±0.48 A
Dalbergia sissoo	(0-300)m	6.85±1.16 B	3.74±0.74 A	5.01±0.19 B	5.76±1.82 B
	(300-600)m	3.40±0.25 A	2.81±1.67 A	3.62±0.30 B	2.70±0.22 A
	(600-1000)m	2.90±0.21 A	1.93±0.14 A	1.74±1.18 A	3.89±1.10 AB
Bambusa nutans	(0-300)m	5.55±0.58 C	5.87±0.44 B	4.83±0.61 C	4.74±0.74 B
	(300-600)m	1.82±0.10 B	2.66±0.11 A	2.91±0.05 B	4.44±0.98 B
	(600-1000)m	3.83±0.05 A	2.93±1.41 A	0.23±0.18 A	1.88±0.74 A

Same capital letter after mean ± standard deviation for a particular species in a column does not differ significantly at *p=0.05* according to Ducan’s multiple range test followed after one-way ANOVA (n=9).

4.1.5. Air pollution tolerance index (APTI)

The mean value of APTI of fodder plant species were increased near the factory. The value of APTI ranged from 7.49±1.04 to 15.63±2.13 (Table 7). Highest APTI was found in *L. leucocephala* (15.63±2.13) and lowest in *M. azedarach* (7.49±1.04). Among the studied plants, *L. leucocephala* showed highest APTI value at east direction at nearest distance from the factory (0-300m). *G. pinnata* showed highest APTI value at west direction at the same distance (0-300) m. Remaining studied plants like *M. azedarach*, *D. sisso* and *B. nutans* showed high APTI value at north, south and west direction, respectively, at the same distance (0-300) m near the factory. Here, while moving from (0-300) m to (600-1000) m away from the factory the APTI value of all studied plants decreased significantly in west and north directions but the APTI value of *D. sissoo* significantly ($p=0.05$) decreased in all direction. Other plant species like *M. azedarach* and *B. nutans* showed significantly ($p=0.05$) decreased value of APTI at north direction. The value of APTI of *L. leucocephala* decreased significantly ($p= 0.05$) at east and south but insignificant only at north direction. *G. pinnata* showed significantly decreased value of APTI at south direction but insignificantly decreased at north and east direction.

Table 7: APTI of different plant species at different directions and distance from the Sonapur cement factory.

Plant species	**Distance**	**East**	**West**	**North**	**South**
Melia azedarach	(0-300) m	10.19±0.21 B	11.71±2.42 B	12.36±0.55 B	10.44±1.62 A
	(300-600) m	8.30±0.85 A	9.33±1.26 AB	10.78±1.06 B	9.030±2.60 A
	(600-1000) m	8.46±0.34 A	7.49±1.04 A	7.58±1.48 A	9.043±3.67 A
Leucaena leucocephala	(0-300) m	15.63±2.13 B	14.82±0.35 B	13.50±1.70 B	11.59±1.24 A
	(300-600) m	10.15±0.18 A	11.89±2.38 A	8.92±1.80 A	11.29±2.03 A
	(600-1000)m	10.08±0.18 A	9.12±0.63 A	9.42±2.43 A	10.80±0.61 A
Garuga pinnata	(0-300) m	14.69±0.61 B	13.62±0.19B	12.16±0.28 B	13.18±1.82 C
	(300-600) m	10.18±1.49 A	11.40±1.16 A	8.49±2.15 A	10.88±0.25 A
	(600-1000) m	10.29±0.34 A	10.48±0.96 A	8.82±1.07 A	9.96±0.63 A
Dalbergia sissoo	(0-300) m	12.80±1.14 B	11.11±1.01 B	11.59±0.73 B	14.57±1.52 B
	(300-600) m	9.76±1.58 A	10.50±1.47 AB	10.79±0.61 B	9.78±0.39 A
	(600-1000) m	9.38±0.46 A	8.67±0.47 A	9.03±0.80 A	9.75±0.22 A
Bambusa nutans	(0-300) m	13.39±0.44 C	13.94±0.59 B	13.30±1.66 B	9.64±0.64 A
	(300-600) m	9.31±0.35 A	10.82±0.38 A	10.26±0.93 A	12.17±1.03 B
	(600-1000) m	10.95±0.45 B	10.77±2.21 A	8.32±0.43 A	10.68±1.48 AB

Same capital letter after mean ± standard deviation for a particular species in a column does not differ significantly at *p=0.05* according to Ducan's multiple range test followed after one-way ANOVA (n=9).

4.2. Specific leaf area (SLA)

The mean value of SLA of all studied species was low near the factory (0-300m) at all four directions. SLA value ranged from 50.31±0.80 to 346.75±52.56 cm²/g. The value of SLA was lowest in *B. nutans* (50.31±0.80cm²/g) and highest in *D. sissoo* (346.75±52.56cm²/g) (Table 8). The value of SLA at 0-300m distance in *M. azedarach* and *B. nutans* was low at north direction, but in case of *G. pinnata* and *D. sissoo*, it was low at south direction and in *L.*

leucocephala it was low at east direction. While moving away from the factory i.e. (0-300) m to (600-1000) m, the value of SLA get significantly increased at all directions in almost all studied plant species.

Table 8: Specific leaf area (cm^{2}/g) of different plant species at different directions and distance from the Sonapur cement factory.

Plant species	**Distance**	**East**	**West**	**North**	**South**
Melia azedarach	(0-300) m	107.13±16.67 A	130.59±7.47 A	82.20±12.66 A	146.97±13.93 A
	(300-600) m	124.42±15.13 A	143.84±9.57 A	116.38±69.06 A	163.68±13.84 AB
	(600-1000) m	259.87±11.45 B	177.65±14.14 B	234.13±22.80 B	187.38±9.04 B
Leucaena leucocephala	(0-300) m	76.55±17.43 A	107.17±2.84 A	91.47±16.01 A	141.98±4.81 A
	(300-600) m	101.82±27.38 A	128.68±16.89 B	145.78±30.74 A	182.82±10.43 B
	(600-1000) m	145.20±9.67 B	141.12±3.04 B	147.57±43.34 A	224.71±32.51 C
Garuga pinnata	(0-300) m	97.83±14.82 A	90.93±9.34 A	87.18±12.94 A	83.90±3.39 A
	(300-600) m	100.00±17.96 A	103.35±3.17 A	92.49±7.91 A	92.14±3.88 A
	(600-1000) m	118.34±13.65 A	138.17±10.16 B	131.82±8.48 B	171.52±8.46 B
Dalbergia sissoo	(0-300) m	68.44±7.10 A	73.39±20.62 A	70.46±10.45 A	61.60±2.78 A
	(300-600) m	110.34±16.01 B	101.45±13.81 AB	132.35±42.95 A	117.90±1.44 B
	(600-1000) m	111.86±13.86 B	147.95±49.81 B	346.75±52.56 B	118.12±8.03 B
Bambusa nutans	(0-300) m	98.28±25.41 A	113.80±2.97 A	50.31±0.80 A	136.31±6.02 A
	(300-600) m	101.67±16.42 A	129.07±8.67 AB	116.50±8.29 B	188.8±±4.49 B
	(600-1000) m	108.92±12.55 A	133.02±10.84 B	122.61±15.09 B	223±22.17 C

Same capital letter after mean ± standard deviation for a particular species in a column does not differ significantly at *p=0.05* according to Ducan's multiple range test followed after one-way ANOVA (n=9).

4.3. Leaf area

The mean value of leaf area was found greatly different in all direction and ranges. The fluctuating value of leaf area around the cement factory does not show significant relation with pollution. It ranged from 5.21±0.39 cm² to 84.41±0.82 cm² (Table 9). At east direction *M. azedarach, L. leucocephala* and *B. nutans* showed significant increase in leaf area while moving away from the factory. But in other plant species like *G. pinnata* and *D. sissoo* at east direction it was insignificantly different.

Table 9: Leaf area (cm²) of different plant species at different directions and distance from the Sonapur cement factory.

Plant species	**Distance**	**East**	**West**	**North**	**South**
Melia azedarach	(0-300)m	37.22±4.32A	97.44±5.00 C	93.07±2.69C	35.96±1.92A
	(300-600)m	43.72±6.02A	78.95±7.51B	27.75±1.02A	31.23±0.49A
	(600-1000)m	84.41±0.82B	51.65±1.40 A	41.49±2.47B	64.68±5.26 B
Leucaena leucocephala	(0-300)m	7.7±1.20A	10.31±1.36A	14.77±0.88A	24.09±4.93B
	(300-600)m	7.58±1.14 A	12.00±0.72A	21.99±0.57A	12.08±1.15A
	(600-1000)m	14.78±1.20 B	16.59±0.31B	49.79±11.92B	14.63±1.00A
Garuga pinnata	(0-300)m	38.38±4.72A	35.55±3.01 C	31.39±1.98A	21.03±0.65A
	(300-600)m	35.85±2.25A	19.38±3.17 B	48.43±2.64B	61.07±4.13C
	(600-1000)m	40.94±2.68A	9.07±0.26 A	49.79±11.92 B	42.02±2.25B
Dalbergia sissoo	(0-300)m	10.73±2.32 A	19.38±3.17 B	5.21±0.39A	29.12±0.71B
	(300-600)m	11.44±0.72 A	9.075±0.26A	11.64±2.25A	9.73±0.83A
	(600-1000)m	11.21±0.55 A	12.80±1.16A	35.18±7.97B	8.39±0.75 A
Bambusa nutans	(0-300)m	18.77±1.70 A	51.52±4.28B	21.46±2.87AB	32.55±2.10A
	(300-600)m	15.26±1.41 AB	26.02±0.61A	25.18±1.48B	33.50±2.64A
	(600-1000)m	21.91±2.19 B	22.72±0.75A	20.12±1.83A	31.49±5.20A

Same capital letter after mean ± standard deviation for a particular species in a column does not differ significantly at *p=0.05* according to Ducan’s multiple range test followed after one-way ANOVA (n=9).

At west direction *L. leucocephala* showed significant increase in leaf area while moving away from the factory. But in other plant species like *M. azedarach, G. pinnata, D. sissoo* and *B. nutans* at west direction it was insignificant. At north direction *G. pinnata, L. leucocephala* and *D. sissoo* showed significant ($p=0.05$) increase in leaf area while moving away from the factory but other plant species like *M. azedarach* and *B. nutans* it was insignificantly different. At south direction *M. azedarach* only showed significant increase in leaf area while moving away from the factory but remaining plant species showed insignificantly different.

4.4. Correlation of SLA with APTI and biochemical parameters

In the east direction, specific leaf area of *L. leucocephala* showed significantly (p<0.05) negative correlation with relative water content, ascorbic acid, air pollution tolerance index and was positively significant (p<0.05) with total chlorophyll content. Specific leaf area of *D. sissoo* showed significant (p<0.05) negative correlation with relative water content, ascorbic acid and air pollution tolerance index and positively significant (p<0.05) with total chlorophyll content and leaf extract pH. All the measured parameters of *M. azedarach*, *G. pinnata* and *B. nutans* were insignificantly correlated with SLA (Table 10).

Table 10: Correlation of SLA with APTI and its parameters in east direction (n=9).

S.N.	**Plant species**	**SLA-RWC**	**SLA-TChl**	**SLA-pH**	**SLA-AA**	**SLA-APTI**
1.	*Melia azedarach*	-0.019	0.016	-0.457	-0.529	-0.427
2.	*Leucaena leucocephala*	-0.851**	0.674*	0.482	-0.559*	-0.697*
3.	*Garuga pinnata*	0.277	0.424	0.163	-0.417	-0.195
4.	*Dalbergia sissoo*	-0.292	0.825**	0.596*	-0.903***	-0.681*
5	*Bambusa nutans*	-0.189	0.397	0.077	-0.186	-0.149

Note: *p<0.05, **p<0.01, ***p<0.001.

In the west direction, specific leaf area of all studied fodder plants showed positively significant (p<0.05) correlation with total chlorophyll content, however, negatively significant (p<0.05) correlation was observed with relative water content, except in *B. nutans*. The studied plants *L. leucocephala, G. pinnata* and *D. sissoo* showed positive significant correlation with leaf extract pH but *M. azedarch* showed significant negative correlation. All the plants showed negative correlation between SLA with ascorbic acid and was significant in *G. pinnata* and *D. sissoo*. The correlation of SLA with APTI were negative in all species and was significant in *M. azedarch*, *G. pinnata* and *D. sissoo* (Table 11).

Table 11: Correlation of SLA with APTI and its parameters in west direction (n=9)

S.N.	Plant species	SLA-RWC	SLA-TChl	SLA-pH	SLA-AA	SLA-APTI
1.	*Melia azedarach*	-0.666*	0.692*	-0.695*	-0.387	-0.633*
2.	*Leucaena leucocephala*	-0.694*	0.733*	0.876**	-0.551	-0.576
3.	*Garuga pinnata*	-0.628*	0.748*	0.771**	-0.675*	-0.708*
4.	*Dalbergia sissoo*	-0.591*	0.867**	0.619*	-0.705*	-0.648*
5	*Bambusa nutans*	-0.066	0.750*	-0.018	-0.469	-0.316

Note: *p<0.05, **p<0.01, ***p<0.001.

In north direction, specific leaf area of all studied fodder plants was insignificant with RWC. Specific leaf area of *G. pinnata* and *D. sissoo* showed positively significant (*p<0.05*) correlation with total chlorophyll content showed negatively significant *(p<0.05)* with ascorbic acid except *L. leucocephala*. SLA of *M. azedarch* showed negatively significant (*p<0.05*) correlation with total chlorophyll content and ascorbic acid. SLA of *L. leucocephala* showed positively significant (*p<0.05*) correlation with pH but it was negatively significant in *D. sissoo*. Except *G. pinnata* and *L. leucocephala* SLA of studied plants showed negatively significant (*p<0.05*) correlation with APTI (Table 12).

Table 12: Correlation of SLA with APTI and its parameters in north direction (n=9).

S.N.	Plant species	SLA-RWC	SLA-TChl	SLA-pH	SLA-AA	SLA-APTI
1.	*Melia azedarach*	-0.408	-0.598*	0.213	-0.827**	-0.727*
2.	*Leucaena leucocephala*	-0.013	0.333	0.629*	-0.577	-0.357
3.	*Garuga pinnata*	-0.072	0.801**	0.315	-0.711*	-0.501
4.	*Dalbergia sissoo*	-0.024	0.850**	-0.667*	-0.882**	-0.846**
5	*Bambusa nutans*	-0.170	0.165	-0.451	-0.831**	-0.866**

Note: *p<0.05, **p<0.01, ***p<0.001.

In south direction, SLA of *B. nutans* only showed positively significant (*p<0.05*) correlation with RWC. SLA of *M. azedarach,* and *B. nutans* showed positively significant correlation (p<0.05) with total chlorophyll content and pH. *D. sissoo* showed negatively significant (p<0.05) correlation with APTI and its parameters except relative water content. SLA of all studied plants except *L. leucocephala* showed negatively significant (p<0.05) correlation with ascorbic acid. SLA of *G. pinnata* and *D. sissoo* showed positively significant correlation with APTI (Table 13).

Table 13: Correlation of SLA with APTI and its parameters in south direction (n=9)

S.N.	**Plant species**	**SLA-RWC**	**SLA-TChl**	**SLA-pH**	**SLA-AA**	**SLA-APTI**
1.	*Melia azedarach*	0.114	0.686*	0.820**	-0.679*	-0.541
2.	*Leucaena leucocephala*	-0.137	0.553	0.556	-0.521	-0.366
3.	*Garuga pinnata*	-0.568	0.399	0.899***	-0.608*	-0.656*
4.	*Dalbergia sissoo*	-0.408	-0.855**	-0.982***	-0.742*	-0.944***
5	*Bambusa nutans*	0.907***	0.867**	0.915***	-0.806**	0.249

Note: $*p<0.05$, $**p<0.01$, $***p<0.001$.

CHAPTER 5. DISCUSSION

5.1. Air pollution tolerance index

APTI helps in the screening of plants for their tolerance level to air pollutants, which is essential since sensitive plants can serve as bio indicators and tolerant plants can serve as sinks for air pollution mitigation (Manjunath and Reddy, 2017). Because trees are always exposed to the environment and are strongly influenced by pollution concentrations in the air as a result of their perennial habit, they absorb, deposit, and integrate contaminants on their foliar surface. Their sensitivity level causes visible changes (Trivedi and Raman, 2001). The results of APTI and four parameters (relative water content, total chlorophyll concentration, leaf extract pH, and ascorbic acid) are discussed below:

5. 1.1. Relative water content

The relative water content (RWC) of a particular leaf is its overall water content relative to its entirely turgid or hydrated state (Bora and Joshi, 2014). As a result, RWC is a measure of hydration status in plant species. It is related to cell protoplasmic permeability, and its loss results in early leaf senescence (Tsega and Devi Prasad, 2014; Ogunkunle *et al*., 2015; Mulay, 2020). Since transpiration rates are usually high in polluted environments, the plant's ability to maintain relative water content may determine its tolerance to pollution (Verma 2003; Gholami *et al.,* 2016). In the present study, RWC of most of the fodder plant species were high and increased significantly nearer to the factory i.e. 0-300 m distance. The greater RWC nearer to industry might be responsible for the normal functioning of biological processes in plants (Meerabai *et al.,* 2012). Plants with higher RWC have stronger drought tolerance and assist in the regulation of physiological balance under stress produced by air pollution (Dedio, 1975). *L. leucocephala* showed highest RWC of 95.15% at 0-300meters distances in western direction which was followed by *M. azedarach* 94.08% and *G. pinnata* 93.16% in same direction. The lowest RWC was found in *B. nutans* at south direction 58.81%. Plants with a high relative water content are more likely to resist negative effects and maintain ecological balance (Kuddus *et al*., 2011), whereas plants with a low RWC may experience a decrease in transpiration, resulting in damage to the leaf engine, which pushes water up from the roots (Chouhan *et al*., 2012). *B. nutans* showed lower RWC near the factory i.e. 0-300 m. RWC indicates changes in the leaf matrix hydration condition and creates more acidic condition when RWC is low (Akpoghelie *et al*., 2017). While moving away from the factory i.e. 0-300 m to 600-1000 m the RWC value of most of studied plants goes on decreasing. This means the value of RWC is low in less polluted or controlled sites (Amulya *et al*., 2015; Sharma, 2019; Yadhav and Pandey, 2020). In such a plant reduction in relative water content is due to the impact of pollutants on transpiration rate in leaves (Swami *et al*., 2004).

5.1.2. Total chlorophyll content

Chlorophyll measurement is an important method for assessing the effects of air pollution on plants since it plays an important role in plant metabolism and any loss in chlorophyll content corresponds directly to plant development (Wagh *et al*., 2006). Plant chlorophyll content indicates photosynthetic activity as well as biomass growth and development (Achakzai *et al*., 2017). From the result analysis the value of total chlorophyll content ranged from 0.84±0.24 to 5.04±0.45(mg/g). The value of total chlorophyll content was highest in *G. pinnata* (5.04±0.45 mg/g) and lowest in *M. azedarach* (0.84±0.24 mg/g). The content of chlorophyll varies according to the sensitivity and tolerance level of plants. This variation is also based upon the leaf age, plant species and atmospheric condition of the particular area such as temperature and light intensity (Hibda and Harikrishna, 2010; Achakzai *et al*., 2017). The plant growing in polluted site have higher sensitive level and contains lower chlorophyll (Rai and Panda, 2014). In the present study, the value of total chlorophyll content was low near the factory and increased significantly while moving away from factory. The loss in chlorophyll content in plant species' leaves could be because of a significant load of dust in polluted areas, and plants that are regularly exposed to pollution absorb, accumulate, and integrate pollutants into their system (Mir *et al*., 2008; Achakzai *et al*., 2017). In west direction, all the studied plants showed low value of TChl near the factory and significantly increased while moving away from the factory. Maximum chlorophyll was recorded near factory or polluted sites in *D. sissoo* in south direction which contrast with the study of several researchers who reported a reduction in chlorophyll under pollution. However, Ogunkunle *et al*., (2015); Nwadinigwe, (2013) recorded an increase in chlorophyll with the rise in pollution. This could be due to increased level of carbon dioxide and high temperatures in urban and industrial areas which favored plant growth as demonstrated by Poorter, (1993); Allen *et al*., (1987). From this study, the value of total chlorophyll of *M. azedarach*, *B. nutans* and *L. leucocephala* in east and north direction varied and was insignificant. Chlorophyll content in the plant varies with the pollution status that also varies with the tolerance as well as sensitivity of the plants i.e. higher the sensitive nature of the plant species lowers the chlorophyll content (Hamal and Chettri, 2017). Among all studied plants, the degradation of chlorophyll content in *M. azedarach* was lower near the factory. Hence *M. azedarach* can be considered as tolerant plant species due to its nature of maintaining chlorophyll content even under the stress condition. Chlorophyll content are essential for the photosynthetic activity and decrease in the level of chlorophyll content has been used as an indicator of air pollution (Pawer and Dubey, 1985).

5.1.3. Leaf extract pH

The pH of plants served as a sensitive indicator of air pollution. Plant species with lower pH are more sensitive, whereas plant species with neutral and higher pH are more tolerant. (Singh and Verma, 2007). The pH of leaf extract ranged from 4.13±0.15 to 8.47±0.21. *B. nutans* showed highest pH (8.47) and *G. pinnata* showed lowest pH (4.13). A high pH can improve the tolerance of plants to air pollution in areas with high pollution (Chen *et al.*, 1990) whereas lower pH shows good correlation with sensitivity to air pollution (Liu and Ding, 2008; Kuddus *et al.*,2011). A high pH can lead to the increased conversion of hexose sugar to ascorbic acid (Liu and Ding 2008; Bui *et al.*, 2022). All the studied fodder plant species showed low pH value in south direction at the range of 0-300 m. Plant species collected from the industrial site have more acidic pollutants such as SO_2 and NO_2 or in responses to different metabolic changes due to the presence of specific pollutants (Ahmad, 2019). Under SO_2 from the environment, the H+ can react with SO_2 through the stomata of the plant, resulting in H_2SO_4 and a decreased pH (Ahmad, 2019). Most of studied plant species showed low pH value and significantly increasing while moving away from the factory. Photosynthesis is strongly related to leaf pH, and low leaf pH lowers photosynthesis in plants (Liu and Ding, 2008; Thaker and Mishra, 2010; Rai, 2019). Studied plants showed changing leaf extract pH at different directions. Pollution-induced changes in leaf extract pH can affect stomatal sensitivity (Chouhan *et al.*, 2012).

5.1.4. Ascorbic acid

Ascorbic acid is a powerful antioxidant that is found in all plant parts (Singh *et al.*, 1991) that acts as reducing agent and influence resistance to harsh environmental stress including atmospheric pollution (Lima *et al.*, 2000; Rai *et al.*, 2013). It is essential for cell wall formation, defense, and cell division (Seyyednjad *et al.*, 2011). The value of ascorbic acid was highest in *L. leucocephala* which is followed by *G. pinnata* near the factory (0-300) m. Plants species like *L. leucocephala, G. pinnata* and *D. sissoo* showed high ascorbic acid mean value in eastern direction at the distance of (0-300) m. At the same distance (0-300) m in south direction ascorbic acid of *M. azedarach* was high, and at west direction it was high in *B. nutans.* Because of the higher rate of formation of reactive oxygen species (ROS) and high pollution, caused an increase in ascorbic acid concentration in plants (Tripathi and Gautam, 2007). Ascorbic acid induces tolerance to air pollution in plants (Lima *et al*., 2000; Zhang *et al*., 2016) and may protect plant tissue from damage (Singh *et al*., 1991; Kapoor and Bansal, 2013). Ascorbic acid also protects chloroplasts against SO_2-induced H_2O_2, O_2 and OH deposits, hence preventing the inactivation of CO_2 fixation cycle enzymes and chlorophyll (Tiwari *et al*., 2006). While moving away from the factory the value of ascorbic acid was significantly decreasing. *G. pinnata* and *M. azedarach* showed significant ($p=0.05$) decrease in ascorbic acid at all directions. Ascorbic acid is higher in polluted site than those of control site which is a strong reductant that activates many physiological mechanism (Agbarie and Esiefarienrhe, 2009). The lowest value of ascorbic acid was found in plants like *B. nutans* and *M. azedarach* i.e. 0.23 and 0.41 respectively. The reducing power of ascorbic acid is directly proportional to its concentration (Lewin, 1976). Plants with high ascorbic acid are resistant plants where as sensitive plants have low level of ascorbic acid.

5.1.5. Air pollution tolerance index (APTI)

Air pollution tolerance index (APTI) plays an important role to determine sensitivity as well as tolerance of plant species to pollution level. Plants growing in various locations of industrial area is significant because of the increased and severe threat on environment due to air pollution. They have the possibility to utilize as an important qualitative biological indicator of air pollution (Mohamed *et al.,* 2017). Screening of plants on the basis of their susceptibility level is very important. APTI gives a more reliable result than its parameters as they are linked to each other (Liu and Ding, 2008; Agbaire and Esiefarienrhe, 2009). The mean value of APTI of studied plants have increased near the factory. Such result was also found by Rai *et al.,* (2013) in industrial site and are the indicative of high pollution. Babu *et al.,* (2013) also observed that all the plant species showed higher value of APTI in polluted sites as compared to control sites. The highest APTI value was found in *L. leucocephala* (15.63±2.13) and lowest APTI was found in *M. azedarach* (7.49±1.04.) Higher APTI value in polluted site will help the plant to maintain its physiological balance than those with the lower APTI value (Agbaire and Esiefarienrhe, 2009). Among the studied plants, *L. leucocephala* showed highest APTI value in east direction at nearest distance from the factory (0-300) m. Highest APTI in east direction may be due to the heavy dust produced by the vehicular movement in the road that lies in between the factory to carry cement and cement clinkers (Radhapriya *et al.*, 2012) and these dust are blown to east direction due to westerly wind in winter (Nayava, 1980) which flow from west to east. *G. pinnata* and *B. nutans* showed highest APTI in west direction at nearest distance from the factory. *D. sissoo* showed highest APTI in south direction at nearest distance from the factory. This may be due to the immense dust that arise from highway construction that lies within 300 m distance at south direction from the factory. *M. azedarach* showed high APTI value at north direction at the same distance (0-300) m near the factory. Plant species respond differently to air pollution (Rai *et al.*, 2013). The responses of plants to air pollution differs significantly because of different factors like physiological activity, concentration of air pollutants, nutritional status of plants and other environmental factors (Assadi *et al.*, 2011). Cement factory is one of the highly polluting industries that have direct effect on the environment (Kumar *et al.*, 2008). Plant species may behave differently from one geographical area to another geographical area as sensitive and tolerant (Karmark and Padhay, 2019). On the basis of APTI value plant species were grouped into three categories (Padmavathi *et al*., 2013). Out of five plant species studied, all the plants were considered as intermediate species with APTI value ranging between twelve to sixteen.

5.2. Specific leaf area

SLA is the ratio of leaf area to leaf dry weight. According to Barden *et al.*, (1997), SLA has been related to leaf structure, growth and net photosynthesis. Leaf area and specific leaf area are important parameters in agronomic and ecological processes, including photosynthesis, transpiration and field energy balance can be difficult and expensive to measure (Payhe *et al.*, 1991). The mean value of SLA was decreased near the factory at all four directions. Kayode and Otoide (2007); Seyyednejad *et al.*, (2009) made similar observations at industrial site. SLA value ranged from 50.31±0.80 to 346.75±52.56 cm^2/g. The value of SLA was lowest in *B. nutans* (50.31±0.80 cm^2/g) and highest in *D. sissoo* (346.75±52.56 cm^2/g). Plant species inhibiting the environment with low nutrient content, lack of water and light have low SLA values (Cornelissen *et al*., 2003). However higher water content in the leaves and a narrow leaf blade helps higher SLA (Witkowski and Lamont, 1991; Cunningham *et al.*,1999). SLA is also affected with particulate matter concentration but few difference of SLA at exposure sites and control sites as particulate matter was connected with plant age (Borowia and Filder, 2014). The value of SLA at 0-300m distance in *M. azedarach* and *B. nutans* was low at north direction, but in case of *G. pinnata* and *D. sissoo*, it was low at south direction and in *L. leucocephala* it was low at east direction. If leaf is thicker, the value of SLA is lower

(Borowiak and Filder, 2014) and they found lowest level of SLA at urban site than control site. Continuous dust exposure causes the production of a dense dust layer on the leaf surface, which lowers plant light collecting capability and restricts plant photosynthetic activities (Pourkhabbaz *et al.,* 2010). Leaf size reduction is an adaptational feature of plant species to reduce the entry of toxic chemicals into the leaves when exposed to pollution (Zarinkamar *et al.*, 2013).

5.3. Leaf area

The leaf is the plant's most essential photosynthetic organ, and it influences crop development and bio-productivity (Zhichen *et al.,* 2008). Leaf area is a useful statistic in research on plant nutrition, plant protection, plant soil-water connections, crop ecosystems, and so on (Mohsenin, 1986). Accurate and quick non-destructive leaf area measurement is critical in plant studies to better understand and model ecosystem function **(**Zhichen *et al.,* 2008). From this study the mean value of leaf area was found greatly different in all direction and ranges. The fluctuating value of leaf area only around the cement factory does not show significant relation with pollution. As leaf thickness also has been widely used for screening purposes in crop science and community ecology (Vile *et al.,* 2005).

5.4. Correlation of SLA with APTI and biochemical parameters

Specific leaf area (SLA) of most studied fodder plants in all directions showed negative correlation with APTI. The SLA showed mostly negative correlation with RWC and ascorbic acid but showed mostly positive correlation with leaf extract pH and total chlorophyll content. Similar correlations between SLA with bio-chemical parameters of road side plants was also recorded by Hamal and Chettri, (2022) in road side plants at Kathmandu valley. Pollutants such as particulate matter had negative correlation with SLA (Bui *et al.,* 2022). The differences in correlation between SLA and biochemical parameters among the studied plants differed, which could be due to various strategies and physiological adjustments in plants to survive in adverse conditions (Hamal and Chettri, 2022).

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1. Conclusion

From this study, it is evident that the biochemical parameters relative water content and ascorbic acid increased in all the plants near the cement factory. But the leaf extract pH and total chlorophyll content decreased near the factory in studied plants. The APTI value of all plants increased near the cement factory. The RWC and AA increased with distance from the factory whereas the leaf extract pH and total chlorophyll content mostly increased with distance from the factory. The SLA of all the studied plants decreased near the factory but were found to be increased with distance from the factory. Among the five studied fodder plant species, all studied fodder species showed high APTI ranging between twelve to sixteen indicating as intermediate species. These plant species can act as sink to absorb air pollutants. The highest APTI was found in *Leucaena leucocephala* and *Garuga pinnata* in east direction at 0-300 m from the factory. Similarly, *Melia azedarach* showed highest APTI in north direction, *Dalbergia sissoo* in south direction and *Bambusa nutans* in west directions in same distances which revealed that there is air pollution in all four directions in near distance around the cement factory. Specific leaf area of studied plants showed negative correlation with APTI.

6. 2. Recommendations

i. All the studied plants could score APTI value of intermediate range (between twelve and sixteen) and were moderately tolerant, hence these species can be recommended for plantation around the cement factory.
ii. Among five fodder plant species *Leucaena leucocephala* has highest APTI value, so it is recommended to plant near and marginal land extensively.
iii. Though these fodder plants have high APTI value and can be recommended for plantation but further research is important to evaluate the impact of air pollution on their nutrient status.

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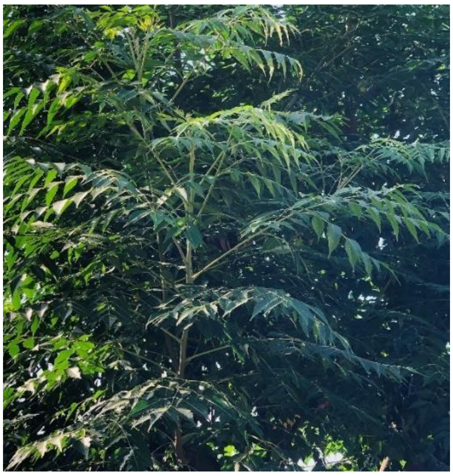
APPENDICES

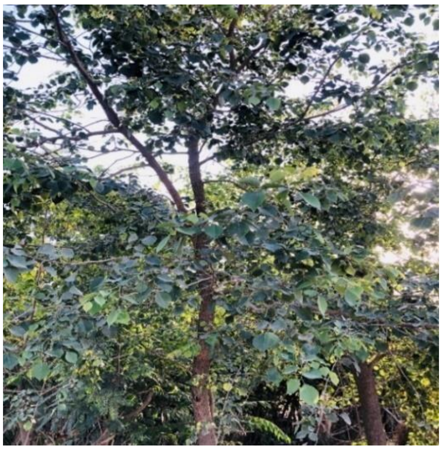
Appendix I. Plant species used for analysis



Melia azedarach

Leucaena leucocephala

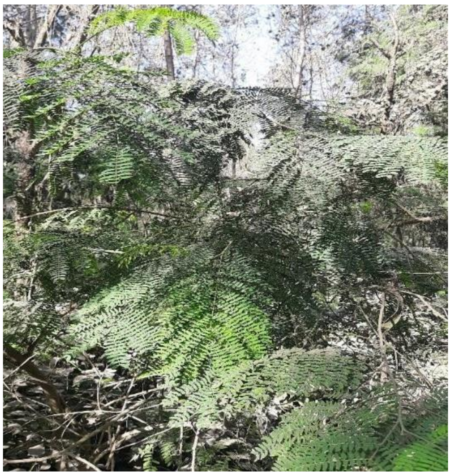
Garuga pinnata



Dalbergia sisoo

Bambusa nutans

Appendix II: Dust deposition



Dust deposition on *L. Leucocephala*

Surrounding vegetation and smoke of cement factory

Appendix III: Photos of SLA and Lab Work

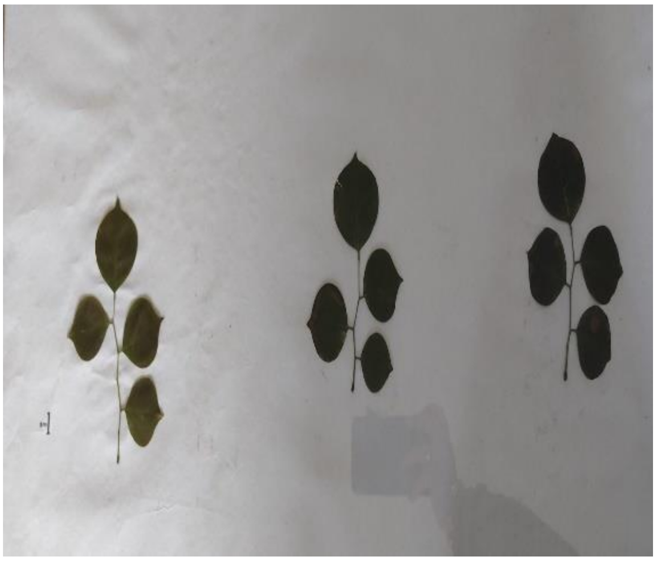


Photo of *Dalbergia sissoo* for SLA

Lab Work