RESPONSES OF SOME CROPS TO AIR POLLUTION BY USING AIR POLLUTION TOLERANCE INDEX

A Dissertation Submitted for the Partial Fulfillment of the Requirements for the Master's Degree in Botany (Ecology)

To

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March, 2020

DECLARATION

I hereby declare that the project work entitled **“RESPONSES OF SOME CROPS TO AIR POLLUTION BY USING AIR POLLUTION TOLERANCE INDEX”** is a genuine work done by me and has not been published elsewhere for the award of any degree. All sources of information have been specifically acknowledged by reference to the author(s) or institution(s). All the information in the project work is copyright to me and could be used for educational purpose by taking my permission.

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RECOMMENDATION LETTER

This is to certify that **Ms. Sajana Shrestha** has completed this dissertation work entitled **“RESPONSES OF SOME CROPS TO AIR POLLUTION BY USING AIR POLLUTION TOLERANCE INDEX”** as a partial fulfillment of the requirements for Masters Degree in Botany under my supervision. To the best of my knowledge, this research has not been submitted for any other degree, anywhere else.

I therefore, recommend the dissertation for acceptance and approval.

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LETTER OF APPROVAL

On the recommendation of supervisor **“Prof. Dr. Kumudini Shakya”**, this dissertation submitted by **“Ms. Sajana Shrestha”** entitled **“RESPONSES OF SOME CROPS TO AIR POLLUTION BY USING AIR POLLUTION TOLERANCE INDEX”** has been accepted for the examination and submitted to the Amrit Campus, Tribhuvan University for partial fulfillment of the requirements for Masters degree in Botany.

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CERTIFICATE OF ACCEPTANCE

This dissertation entitled **"RESPONSES OF SOME CROPS TO AIR POLLUTION BY USING AIR POLLUTION TOLERANCE INDEX"** submitted by **"Ms. Sajana Shrestha"** has been examined and accepted for partial fulfillment of the requirements of Master's Degree in Botany.

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ABSTRACT

Responses of plants toward the air pollution were assessed by air pollution tolerance index (APTI). APTI is calculated from the values of different biochemical parameters of plant leaves such as relative water content, total chlorophyll content, ascorbic acid content, and leaf extract pH by using standard methods. Plants with a high index value were tolerant of air pollutants and vice-versa. Based on their indices, different plant groups were categorized into sensitive, intermediate, and tolerant. This study was aimed to identify the most tolerant and sensitive crop plants. The present study was carried out to evaluate the air pollution tolerance index (APTI) of eight economically important winter crop plants. Plants were cultivated in polluted site 1 (Thamel), polluted site 2 (Banasthali), and less-polluted site (Phutung) in Kathmandu based on vehicular movement. The result of the study showed higher APTI values in polluted site 1 than in less-polluted sites and polluted site 2. Among the studied species, *Brassica juncea* (10.69±1.07), *Brassica campestris* (10.45±0.88), *Triticum aestivum* (9.74±0.77) and *Hordeum vulgare* (9.64±1.00) respectively were recorded high APTI values indicating resistance to pollution and *Trigonella foenum-graecum* (7.52±2.08) with the lowest APTI value indicating sensitive to pollution. The impact of the air pollutants on crop productivity was also measured from the selected crop plants. The result revealed that plant growth was found to be reduced in polluted sites. And *Triticum aestivum* (64.48±31.53 kg ha^{-1}) was a high productivity crop plant while low was *Trigonella foenum-graecum* (2.09±0.68 kg ha^{-1}). The response of crop plants was varied in species, studied sites, and level of pollution. Hence, this study helps to identify the tolerant crop plant which can act as a good absorbent of air pollutants.

***Keywords*:** Relative water content, Total chlorophyll content, Ascorbic acid content, Leaf extract pH, Productivity

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ABBREVIATIONS

%	:	Percent
°C	:	Degree Celsius
AA	:	Ascorbic acid content
ANOVA	:	Analysis of Variance
APTI	:	Air Pollution Tolerance Index
CANN	:	Clean Air Network Nepal
CEN/ENPHO	:	Clean energy Nepal/Environment &Public Health Organization
cm	:	Centimeter
DMSO	:	Dimethyl sulfoxide
EDTA	:	Ethylene diamine tetra acetic acid
et. al.	:	And others
F.W.	:	Fresh weight
Fig.	:	Figure
g	:	Gram
ha	:	Hector
Kg	:	Kilogram
Mg	:	Milligram
ml	:	Milliliters
PAG	:	Above ground productivity
PBG	:	Below ground productivity

pH : Leaf extract pH

PT : Total productivity

ROS : Reactive oxygen species

RSPM : Respirable Suspended Particulate Matter

RWC : Relative water content

SD : Standard Deviation

SE : Standard Error

SPM : Suspended Particulate Matter

Tchl : Total chlorophyll content

1. Introduction

1.1 Background

Air is the vital resource of this planet for the sustenance of life. In the biosphere, all organisms need clean air for their healthy growth, development, and survival. A slight change in its composition may have a significant impact on the biotic components of the environment. The air becomes polluted due to the addition of different pollutants like sulfur dioxide, nitrogen oxides, carbon monoxide, soot particles as well as heavy metals, organic molecules, radioactive isotopes, etc. (Odilora 2006). The consistent increment in population growth, industries and automobile vehicles are responsible for the addition of toxic gases and other substances in the environment (Jehan and Iqbal 1992; Joshi *et al.* 2009; Bhattacharya *et al.* 2013). It has pronounced consequences on human health ranging from eye irritation, skin disease, cardiovascular diseases, asthma, respiratory diseases, infections and risk factors for cancer, and death depending on the dosage of exposure and accumulation of these pollutants in the body over time (Wong 2014). Thus, air pollution has become a major environmental problem facing the world today causing a hazardous effect on all organisms including humans, animals, and plants.

Plants serve as an integral basis for our ecosystems and provide some ecosystem functions like temperature improvement, drainage, and water storage, filtration, air filtering, etc. (Bolundand and Hunhammers 1999). The whole ecosystem could be affected by air pollution depending upon its intensity. Being the plants are stationary, they are constantly exposed to environmental pollutants hence they become the primary receptor of pollutants (Joshi and Swami 2009; Randhi and Reddy 2012). They can absorb, accumulate and integrate these pollutants into their systems. In a polluted environment, plants often respond and show significant changes in their morphology, physiology, and biochemistry. Air pollution can affect plants directly through the leaves as well as indirectly by the acidification of the soil (Steubing *et. al.* 1989; Kumar and Nandini 2013). Of all the plant parts, leaves are the most sensitive part than other parts to the air pollutants (Lal and Singh 1990) so, the effects of pollutants are most apparent on leaves showing a direct harmful impact on them (Randhi and Reddy 2012; Lohe *et al.* 2015). At first some physiological changes before exhibiting visible damage to leaves (Dohmen *et al.* 1990; Liu and Ding 2008;

Abida and Harikrishna 2010). A significant reduction in stem perimeter, dry weight, chlorophyll content and also in flowering and fruiting will be seen gradually. In sensitive plant species, pollutants can cause leaf injury, stomatal damage, premature senescence, decrease photosynthetic rate, disturb membrane permeability and reduce growth and yield (Tiwari *et al.* 2006; Tiwari 2013; Subramani and Devaanandan 2015).

Leaves have a very large surface area and they are in direct contact with pollutants, they can function as an efficient pollutant- trapping device. They can detoxify, metabolize and accumulate the polluting compounds and also act as a living filter for air pollutants. But, their response to air pollutants varies from species to species, the concentration of pollutants and the length of exposure to the pollutant. As different plant species show a striking variation in their sensitivity to air pollution, so plants are different in their ability to remove and tolerate pollutants (Treshow 1984). According to the response of plants towards particular as well as gaseous stress, they can be categorized into “sensitive” and “tolerant” species. Sensitive species are early indicators of pollution which signify the level of pollution, and the tolerant species help in reducing the overall pollution load and act as a sink (Singh and Rao 1983; Prajapati and Tripathi 2008).

The ability of each plant species to absorb pollutants can be known by examining the biochemical parameters of leaves (Varshney 1985; Shannigrahi *et al.* 2004; Sharma *et al.* 2007). Biochemical parameters that act as a key indicator in the plants are used to evaluate the changes in the tolerance level of plants to air pollution. To assess the tolerance of plants against air pollution, Singh and Rao (1983) developed the air pollution tolerance index (APTI). Hence, it is an empirical relation that estimates the tolerance level of the plant species to air pollution from leaf biochemical parameters such as relative water content of the leaf (RWC), total chlorophyll content (Tchl), ascorbic acid content (AA) and leaf extract pH. Plant sensitivity and tolerance toward air pollutants differ with these above parameters. The relative water content is a useful indicator of the state of the plant’s water balance. Dedio (1975) reported that high relative water content helps plants to maintain their physiological balance under stress conditions and also favors the drought resistance in plants. The plants with high relative water content under polluted conditions were found to be more tolerant of pollution (Chandawat *et al.* 2011). Chlorophyll is the most important photoreceptor in photosynthesis and is significant to growth and development of plant biomass, thereby playing a crucial role in plant metabolism. The measurement of chlorophyll is a significant tool to evaluate the effects of air pollutants on plants. The pollutants, when absorbed by the leaves, may cause a reduction in the concentration of photosynthetic pigments. Changes in Chlorophyll content cause a change in the rate of photosynthesis and reduction in chlorophyll content directly affects the plant growth, which in turn directly affects the plant productivity (Joshi and Swami 2009). So, chlorophyll is an index of productivity of the plant. Ascorbic acid is a natural antioxidant in plants. It activates many physiological and defense mechanisms. In plants, the higher ascorbic acid concentration of leaves might be an effective strategy to protect thylakoid membranes from oxidative damage (Tambussi *et al.* 2000). Hence, plants having high ascorbic acid content were found to be more tolerant of air pollution. Among all the four parameters, ascorbic acid acts as the first line of defense against the oxidative stress of pollutants (Sharma *et al.* 2016). pH is a biochemical parameter that serves as a sensitive indicator of air pollution. Plants with a pH of around 7 are more pollution-tolerant and plants with lower pH are more susceptible (Singh and Verma 2007). By measuring these parameters, the effectiveness of plants as possibly being suitable in terms of pollution reduction can be predicted.

Air pollution has become serious environmental stress to crop plants also (Rajput and Agrawal 2004). Hence, the air pollutants have been found responsible not only for vegetation injury but also for crop yield losses worldwide (Joshi and Swami 2007). Crops can be injured when exposed to high concentrations of various air pollutants. Injury ranges from visible markings on crop leaves, reduced growth and yield, premature death and in turn to the economy of the crop (Meera bai *et al.* 2012). The present study aimed to know the comparative analysis of the biochemical parameters and the evaluation of the air pollution tolerance index in eight economically important winter crop plants from polluted and less-polluted sites.

1.2 Justification of the Study

The air quality of Kathmandu is in deteriorating condition and the problem is growing year by year. The major factors which make them vulnerable to air pollution are high population growth with unplanned and unmanaged urbanization, a rapid increase in vehicles and industries. A poor road network and a largely unmanaged transportation system add a large number of pollutants to the environment. Overall, the bowl-shaped topography of the valley restricts the air movement thereby retaining the pollutants in the air (Parajuly 2016; CANN 2014; Regmi *et al.* 2003). Similarly, the climate of the valley with the temperature inversion further intensifies this problem.

The crop plants are being exposed to the high air pollutant concentrations which can cause damage to many of them. The effect of air pollution on plants can be quantified using the air pollution tolerance index. But, the evaluation of the crop plants in the Kathmandu by using air pollution tolerance index has not been undertaken till now. Similarly, the effect of air pollution on productivity is also not understood until now. The appraisal of crop plants by using the air pollution tolerance index may be of great importance. Hence, the present study will help to identify the tolerant and sensitive crop plants in different areas of Kathmandu and will guide to know the impact of index values on productivity.

1.3 Research question

Is there any significant relation of air pollution tolerance index with species, experimental sites, and productivity?

1.4 Objectives

To assess air pollution tolerance index of economically important winter crop plants in different studied sites.

1. To identify the most pollution tolerant crop plants.
2. To measure the productivity of crop plants.

2. Literature review

In recent past the effect of pollution due to industries, vehicles, expansion and maintenance of the high ways on the plants have been studied world over. As the relationship between pollution and plant health is complex, the literature has been scanned to gather information about the various effect of vehicular pollution and road dust on the APTI based biochemical and physiological parameters on the plant species. The literature has been cited under the following headings:

2.1 Relative water content

The Relative water content is a useful indicator of the state of the water balance of the plant. Dedio, (1975) reported that high relative water content helps plants to maintain its physiological balance under stress condition and it favors the drought resistance in plants. The plants with high relative water content under polluted condition were more tolerant to pollution (Chandawat *et al.* 2011). Plants with high amount of water content is favorable to combat the adverse effects of air pollutants (Kuddus *et al.* 2011) and maintain the ecological balance, whereas plants with lower tolerance may lead to reduction in the transpiration rate resulting in damage to the leaf engine that pulls water up from the roots (Chouhan *et al.* 2012; Seyyednejad *et al.* 2011). The Relative water content was high in plant species growing at polluted sites and it further increased the drought and stress tolerance in plants (Mohamad *et al.* 2015).

2.2 Total Chlorophyll content

The continuous accumulation of dust closes the stomata, interfere with gaseous exchange and reduces chlorophyll content. Hence any in chlorophyll concentration may change the morphology, physiology and biochemistry of plants (Lerman 1972). The chlorophyll level in plants decreases under pollution stress (Speeding and Thomas 1973). Leaf chlorophyll being an index of plant productivity has been reported to be influenced adversely by certain pollutants in the atmosphere (Allen *et al.* 1987; Raza and Murthy 1988). The industrial pollution has been reported to fluence the photosynthetic pigment of plants and consequently their productivity. The position of leaves with respect to sun has been noticed to exhibit different responses. Durrani and Baloch (2003), while studying the influence of industrial pollution sunny, semi-shady and shady leaves observed that the total leaf chlorophyll content was found to decline drastically in shady and semi-shady leaves. The most common impacts of air pollution are the gradual disappearance of chlorophyll and concomitant yellowing of leaves, which may be associated with a consequent decrease in the capacity for photosynthesis (Joshi and Swami 2007). Air pollutants make their entrance into the tissues through the stomata and cause partial denaturation of the chloroplast and decreases pigment contents in the cells of polluted leaves (Tripathi and Gautam 2007). The pollutants like $SO_{2,}$ NO_2 and CO as suspended particulate matter when absorbed by leaves of the plants cause reduction in the concentration of photosynthetic pigment and ultimately influence the plant productivity (Joshi and Swami 2009). Iqbal *et al.* (2015) reported that the higher traffic exposures decreased the chlorophyll content in leaves due to automobile stress.

2.3 Ascorbic Acid content

Ascorbic acid, a natural antioxidant in plants plays an important role in pollution tolerance. Foliar ascorbic acid is generally accepted as a good biomonitoring system. It activates many physiological and defense mechanism and its reducing power has been known to be directly proportional to its concentration (Lewin 1976). Agarwal (1988) related pollution tolerance of plants by ascorbic acid and concluded that resistant plants contain higher ascorbic acid whereas sensitive one possesses lower amount of it. It being a strong reductant protects chloroplast against SO_2 induced H_2O_2, O_2 and OH accumulation and thus protects the enzyme of the CO_2 fixation cycle and chlorophyll from inactivation (Tanaka *et al.* 1982) The higher ascorbic acid of plant has been reported as a sign of their tolerance against SO_2 pollution (Varshney 1985). The defense mechanism of plants to the stress conditions has been reported to trigger the level of ascorbic acid content (Cheng *et al.* 2007). The tolerance of plant species growing alongside the highway has also been reported to be influenced by their higher ascorbic acid content (Jyothi and Jaya 2010). Rai *et al.* (2013) ascorbic acid is a stress reducing factor and the plant species maintaining high ascorbic acid content under polluted conditions are considered to be tolerant to air pollution stress. The highest amount of ascorbic acid was recorded at the polluted sites and lowest at control sites (Anju and Jaya 2014). Ascorbic acid is an important metabolite which activates the resistance mechanism under pollution stress in plants

(Gupta and Purohit 2015). The ascorbic acid increased with an increase in dust accumulation (Younis *et al.* 2015). The higher level of ascorbic acid content may be due to the resistance mechanism of plant to cope with stress condition (Joshi *et al.* 2016).

2.4 Leaf extract pH

Leaf pH was reduced by acidic pollutants and decline in pH was more pronounced in sensitive species. Leaf pH was always found in the acidic range in the plants growing at sites where gaseous pollutants were more pronounced (Joshi and Chauhan 2008). Escobedo *et. al.* (2008) reported that the photosynthetic efficiency is strongly dependent on the pH of leaf and at low pH the photosynthesis in plant species was reduced. The leaf extract pH plays a crucial role in regulating the pollution sensitivity in plants (Das and Prasad 2010). Kumar and Nandini (2013) reported that plants with lower pH are more susceptible while those with pH around 7 are tolerant. Mohamad *et. al.* (2015) reported that plant with acidic pH were more susceptible than plants with alkaline pH content. Kaur and Nagpal (2017) analyzed that the leaf pH is reduced in the presence of an acidic pollutant (SO_2 and NO_2), and the reducing rate is more in sensitive plants compared to that in tolerant plant species.

2.5 Air pollution tolerance index (APTI) works from Nepal

In Nepal, the work on APTI has don by many researchers. Rawal *et. al.* (2001) studied air pollution tolerance index of some tree species of Kathmandu Valley. From the investigation the APTI value of *Cinnamomum camphora* was highest while *Grevellia robusta* has the lowest value. APTI value helps in the selection of the plant species for plantation at the polluted areas, whereas plants with lower level of APTI value can be used in biomonitoring works. Similar work was done by Kanwar *et. al*. (2016) and Rajbanshi and Pradhananga (2017). Hamal and Chettri (2017) worked on Air pollution tolerance index of some selected gymnosperm species along the road side of Kathmandu valley. They found that *Pinus roxburghii, Thuja orientiales, Cedrus deodara* and *Araucaria bidwillii* have high APTI value among four gymnosperms.

2.6 Air pollution tolerance index (APTI) works from outside Nepal

Singh (1991) studied the susceptibility level of plants to air pollutants, four parameters, namely ascorbic acid, chlorophyll, relative water content, and leaf-extract pH were determined and computed together in a formulation signifying the air pollution tolerance index (APTI) of plants. He worked on 69 plant species, growing in the urban-industrial Lahartara region of Varanasi and categorized into sensitive, intermediate, moderately tolerant plant. The susceptibility level of plants to air pollution, indicated through their index values that observed under laboratory and field experiments. The APTI provides a reliable method for screening sensitive/tolerant plants. Joshi and Swami (2007) analyzed to determine the physiological response of few economically important trees species Mango (*Mangifera indica), Eucalyptus citriodora*, Sagon (*Tectonagrandis*) and Sal (*Shorea robusta*) to roadside automobile pollution. A higher value of air pollution tolerance index (APTI) was recorded for *S. robusta* (9.02) while the minimum value of APTI was recorded for *M. indica* (6.76). Rathore *et. al.* (2018) found the similar result on his work on air pollution tolerance of selected plants. Sulistijorini *et. al.* (2008) analyzed tolerance levels of roadside trees to air pollutants. The combination of the relative growth rate (RGR) and physiological responses in determining tolerance levels of plant species to air pollutants. The combination of RGR and APTI value was better to the determinate tolerance level of a plant to air pollutant than merely APTI method. Agbaire and Esiefarienrhe (2009) worked on air Pollution tolerance indices (APTI) of some plants around Otorogun Gas Plant in Delta State, Nigeria. They examined the air pollution tolerance indices (APTI) of six plant species around Otorogun gas plant in Local Government Area of Delta State. Joshi *et. al* (2009) studied on impact of industrial air pollutants on some biochemical parameters and yield in wheat and mustard plants. The wheat and mustard plants grown at polluted sites showed significant reduction in chlorophyll ‘a’, chlorophyll ‘b’, total chlorophyll, carotenoid, pH, and yield. The ambient air pollutants have a potential adverse impact on reduction in the yield of wheat and mustard crops. Jyothi and Jaya (2010) worked on evaluation of air pollution tolerance index of selected plant species along roadsides in Thiruvananthapuram, Kerala. They studied on three species each of evergreen dicotyledonous trees and dicotyledonous shrubs, which are common in all the ten stations in the study area were selected for the purpose. Among the trees in the roadside areas *Polyalthia longifolia*, (Sonner) Thw. and in shrubs, *Clerodendron infortunatum,* L., in expressed highest APTI values. Joshi and Bora (2011) studied the impact of air quality on physiological attributes of certain plants. This study also examined the dust interception efficiency and air pollution tolerance index (APTI) of 8 plant species. This study also showed ambient air pollution had a negative impact on physiological characteristics of plants. Enete *et. al*. (2013) compared the air pollution tolerance indices (APTI) of five plant species and five ornamental shrubs in Enugu Urban. The APTI of all the plants examined were higher than those of ornamental shrubs. Bakiyaraj and Ayyappan (2014) studied air pollution tolerance index of some terrestrial plants around an industrial area. This study examined the air pollution tolerance index (APTI) of 11 plant species. The *Eucalyptus* sp. (6. 52%) have higher APTI value reflects the higher tolerance level in air pollution. Similarly, *Murrya koenigii* (0.81) showed lower APTI value reflects sensitive nature against air pollution. Ogunkunle *et.al.* (2015) studied the air pollution tolerance index and anticipated performance index of some tree species. The API indicated that *Vitellaria paradoxa* (API =4) is a good performer while *Terminalia catappa, Acacianilotic a*and *Prosopisafricana* (API =3) are moderate performers, in green belt development. Ogunrotimi *et. al.* (2017) worked on urban air pollution control. The air pollution tolerance index (APTI) ranged from 8.5 to 13.9 for the entire tree species. According to the API grading, species having 62.5% grading classified as ‘good’ greenbelt performers, 56.25% grading as ‘moderate’ performers and less than 50% as ‘poor’ performers for bio-indicators of air pollution. This study concluded that *Gmelina arborea, Tectonagrandis* and, *Mangifera indica* were good bio-monitors for greenbelt development.

2.7 Productivity

It has been reported that air pollutants effect plant growth adversely (Rao 2006; Horsefall 1998). Air pollution has the potential to reduce both yield and the nutritional quality of crop plants (Ashmore and Marshall 1999). The pollutants like SO_2, NO_2, SPM, and RSPM, are responsible for reduction of biological and physiological response of various plants and crops grown in polluted areas. Pollutants can cause leaf injury, stomatal damage, premature senescence, decrease in photosynthetic activity, disturb membrane permeability and reduce growth and yield in sensitive plant species (Tiwari *et al.* 2006).

Sulphur dioxide, nitrogen oxides and CO_2 along with suspended particulate matter, when absorbed by the leaves may cause a reduction in the concentration of photosynthetic pigments like chlorophyll and carotenoids. This may directly affect the plant productivity (Joshi and Swami 2009). The wheat and mustard grew at polluted sited which led to lower yield due to experiencing higher levels of pollutants (Joshi and Chauhan 2010).

3. Materials and Methods

3.1 Study area

The present study was conducted in Kathmandu. It lies between the latitudes 27°42'6.08" N and 85°19'14.16" E longitudes at a mean elevation of about 1,300 meters above sea level. The climate of Kathmandu is sub-tropical. The temperature ranges from a minimum of 3°C to a maximum of 23°C. The average rainfall is 400 to 450 mm, from June to August (DoHM, 2019).

3.1.1 Study sites

Three different sites were selected (Fig 1). These sites were categorized into polluted and less-polluted sites based on the frequency of vehicular movement. There are approximately 1.19 million vehicles registered in the Bagmati zone out of 3.5 million vehicles registered in Nepal (DOTM 2018). On the road of polluted site 1, polluted site 2 and less-polluted site nearly 2000, 1800 and 500 vehicles were plied per day, respectively (Metropolitan traffic Police Division, 2019). Besides vehicular movement, the immigrant population is a source of air pollution. It was estimated that about 20% of the additional population (i.e. tourists and floating population) has settled in Kathmandu (Shrestha, 1999) with frequent cycles.

Polluted site 1: Polluted site 1 (Amrit Campus), located inside ring road and is a commercial area with high population density and vehicular movement. The roads of this area bear a very heavy traffic load, including public buses, private buses, a very high number of cars, scooters, bikes, etc. Hence, the air quality was reported to be poor in polluted site 1 (Chettri *et al.* 2001; CEN/ENPHO 2003; Shakya *et al.* 2012).

Polluted site 2: Polluted site 2 (Banasthali), lies along the ring road (approximately 25 m away from the road). It is a residential area, with high population density and moderate vehicular movement. It is relatively less vehicular pollution than polluted site 1 (Shakya *et al.* 2012).

Less-polluted site: Phutung (Nagpokhari), lies at the outskirt of the ring road (nearly 5 km away). It is a rural area with low population density and low vehicular movement.

Source: Google Earth

Fig 1: Map of Nepal along with Kathmandu valley showing different experimental sites; Polluted site 1 (A), Polluted site 2 (B) and Less-polluted site (C).

3.2 Preparation for the preliminary study

Some economically important winter crop plants were cultivated in November for the present study (Table 1). The healthy seeds were grown in pot. The pot used were of 10 cm diameter and 25 cm height. A total of forty pots were prepared. Each crop in all different sites was planted in five replicates. The soil was prepared by mixing soil, sand and, cow dung in the ratio of 2:1:1. The crops were planted on the open terrace just adjacent to the road in polluted site 1. Similarly, the crops were also planted in polluted site 2, semi-shaded terrace, which was located about 25m away from the ring road. To compare the results, the crops were also planted near the roadside in the comparatively less polluted site. The soil and water from less-polluted site were used in the pots of site 1. However, the polluted site 2 were different in term of edaphic and water condition. 300 ml of the groundwater was poured on the soil per day in all sites. Then cultivated crop plants were harvested after 6 months and then measured their biomass.

Table -1: Economically important winter crop plants considered for study APTI in Polluted site 1, Polluted site 2, and Less-polluted site.

S.N.	Botanical name	Family	Common name	Local name
1	*Brassica campestris* L.	Brassicaceae	Mustard	Tori
2	*Brassica juncea* (L)Czern	Brassicaceae	Broadleaf mustard	Rayo
3	*Brassica oleracea var. botrytis* L.	Brassicaceae	Cauliflower	Cauli
4	*Brassica oleracea var. capitata* L.	Brassicaceae	Cabbage	Banda gobi
5	*Hordeum vulgare* L.	Poaceae	Barley	Jau
6	*Raphanus sativus* L.	Brassicaceae	Radish	Mula
7	*Trigonella foenum-graecum* L.	Leguminaceae	Fenugreek	Methi
8	*Triticum aestivum* L.	Poaceae	Wheat	Gau

3.3 Plant sampling and analysis

Five leaves samples of each plant species were collected from all selected sites in the morning around 9 to 10 am. Fully mature leaves from each replicate were collected and brought to the laboratory of Department of Botany, Amrit campus for physiological analysis. From each site, fresh weight of sample leaves was taken immediately to minimize the loss of water from the plant bodies. First of all, the dust particles accumulated on the leaf surface were cleaned by removing it with tissue paper. After taking the leaf fresh weight of all samples, the leaf samples were then examined for relative water content (RWC), total chlorophyll content (Tchl), ascorbic acid (AA), and leaf extract pH.

3.4 Relative leaf water content (RWC)

The relative water content technique, was originally described by Weatherly and has been widely accepted as a reproducible and meaningful index of plant water status. Fresh weight was obtained by weighing the fresh leaves. The leaves were dipped in water over night and weighed to get the turgid weight. The turgid weight was recorded. Then the leaves were subsequently oven-dried to a constant weight at about 70°C for 24 h. RWC was calculated by the method as described by Turner (1981).

$$\text{RWC (\%)} = \frac{(\text{Fresh weight - Dry weight})}{(\text{Turgid weight - Dry weight})} \times 100$$

3.5 Total chlorophyll content (Tchl)

Chlorophyll extraction has been carried out with DMSO solvent which has amphiphilic properties Barnes *et. al*. (1992). 1 gm of leaves was weighted and placed in test tubes containing 10 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 decolorization of tissues. Cooling at room temperature was followed for 30 min. After filtration the supernatant was later collected and absorbance was measured at 665 nm and 648 nm. Blank determination was carried out with DMSO. Absorption measurement was carried out with a Spectrophotometer (Model no. 31).

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

A_{665}= Absorbance of the extract at the wavelength 665

A_{648} = Absorbance of the extract at the wavelength 648

3.6 Ascorbic Acid content (AA)

Ascorbic acid content was measured by the spectrophotometric method of Bajaj and Kaur (1981). 1 g of fresh leaf samples was taken in a test tube after that 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 were added to it. The solution was allowed to rest for about 15 minutes at room temperature condition. 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 (Model no. 31). The concentrations of ascorbic acid in the sample then extrapolated from a standard ascorbic acid curve.

3.7 Leaf extract pH

pH of leaf was determined according to method described by Datta and Sinha – Ray (1995). 5 g of fresh leaves were washed and homogenized with 10 ml of distilled water. pH of the leaf extract filtrate was measured with the help of pH meter (Model no. 10).

3.8 Air pollution tolerance index (APTI) determination

APTI was calculated according to Singh and Rao (1983) and the formula of APTI was given below

$$\text{APTI} = \frac{[\,A\,(T + P) + R]}{10}$$

Where, R = Relative water content of leaf (%),

T = Total chlorophyll (mg/g),
A = Ascorbic acid content (mg/g),
P = pH of leaf extract

3.9 Productivity

The harvested biomass was brought to the laboratory and determined the fresh weight separately for aboveground and belowground parts. The biomass was placed in an oven at 70°C for 24 hours and dry weight was measured. The primary productivity was calculated by the method as described by Zobel *et. al*. (1987).

$$\text{Primary productivity} = \frac{\text{Biomass}}{\text{Time (since the site was barren)}}$$

3.10 Soil Properties under Study and Methods of Measurement

3.10.1 Soil pH

Soil pH was determined electronically a direct-reading pH meter (Model no. 10), using a glass electrode, with a saturated potassium chloride-calomel reference electrode. 1:2 soil water ratio was used to prepare soil solution (Gupta 2000).

3.11 Statistical Analysis

Data were checked for normality. Normally distributed variables or those that could be transformed to normal. The data obtained from the above experiments were statistically analyzed by using R version 3. 5. 1. One-way ANOVA was followed by Tukey’s HSD (honestly significant difference). Pearson correlation (r) analysis and linear regression analysis were used to express the relationship between all variables.

4. Result

To understand responses of some economically important winter crops to air pollution, different parameters like relative water content, total chlorophyll content, ascorbic acid content and leaf extract pH were measured in plants growing in different experimental sites. Result of each parameter are given below in detail.

4.1 Relative water content (RWC)

The relative water content of the selected crop plants had been found to vary in different experimental sites with varying air pollution level (Table 2). Among the species, the highest mean relative water content of 87.96±4.86 % was noticed in *Triticum aestivum* in polluted site 2 whereas the lowest mean relative water content of 69.33±9.64 % was obtained in *Trigonella foenum-graecum* in less-polluted site. In polluted site 1 and less-polluted site the highest mean relative water content was recorded in *Brassica oleracea var. capitata* of 87.15±6.07 % and 86.76±5.88 % respectively. In polluted site 2 the highest mean relative water content was recorded in *Triticum*

Table 2: Relative water content (Mean ± SD) in the economically important winter crop leaves grown in Polluted site 1, Polluted site 2, and Less-polluted site. Subscript (capital alphabets) in a row indicates significant difference ($p<0.05$) in relative water content among the experimental sites where (n=40).

S.N.	**Name of species**	**Relative water content (%)**		
		Polluted site 1	**Polluted site 2**	**Less-polluted site**
1	*Brassica campestris* L.	$76.62\pm6.62_{A}$	$74.89\pm9.13_{A}$	$79.53\pm5.20_{A}$
2	*Brassica juncea* (L)Czern	$85.10\pm4.04_{A}$	$84.81\pm4.13_{A}$	$83.04\pm10.40_{A}$
3	*Brassica oleracea var. botrytis* L.	$81.97\pm4.57_{A}$	$86.84\pm1.98_{A}$	$80.55\pm9.14_{A}$
4	*Brassica oleracea var. capitata* L.	$87.15\pm6.07_{A}$	$87.08\pm2.27_{A}$	$86.76\pm5.88_{A}$
5	*Hordeum vulgare* L.	$84.45\pm7.12_{A}$	$75.42\pm3.32_{A}$	$82.81\pm7.09_{A}$
6	*Raphanus sativus* L.	$85.69\pm4.21_{A}$	$77.70\pm7.94_{A}$	$80.77\pm12.33_{A}$
7	*Trigonella foenum-graecum* L.	$70.17\pm19.71_{A}$	$73.79\pm7.93_{A}$	$69.33\pm9.64_{A}$
8	*Triticum aestivum* L.	$81.91\pm7.89_{A}$	$87.96\pm4.86_{A}$	$82.90\pm3.79_{A}$

aestivum of 87.96±4.86 % and was chased by *Brassica oleracea var. capitata* of 87.08±2.27 %. The lowest mean relative water content was recorded by *Trigonella foenum-graecum* of 70.17±19.71%, 73.79±7.93 %, and 69.33±9.64% respectively in all experimental sites.

Relative water content of all plants except *Brassica campestris* and *Triticum aestivum* was found to be higher at polluted site 1 as compared to the less-polluted site. The relative water content of all plant species showed statistically insignificant in all crop plants.

4.2 Total chlorophyll content (Tchl)

The total chlorophyll content in all plants showed variation among the experimental sites (Table 3). The total chlorophyll content ranged from 1.96±0.37 mg g^{-1} to 5.47±0.73 mg g^{-1}. In polluted site 1 and polluted site 2 the highest mean value of chlorophyll content was showed in *Raphanus sativus* of 3.72±0.34 mg g^{-1} and 5.47±0.73 mg g^{-1} respectively. In less-polluted site the highest mean value of chlorophyll content of 4.46±0.63 mg g^{-1} was noticed in *Brassica campestris* and was followed by *Raphanus sativus* of 4.29±0.43 mg g^{-1}. The lowest

Table 3: Total chlorophyll content (Mean ± SD) in the economically important winter crop leaves grown in Polluted site 1, Polluted site 2, and Less-polluted site. Different letters in subscript (capital alphabets) in a row indicates significant difference ($p<0.05$) in total chlorophyll content among the experimental sites where ($n=40$).

S.N.	**Name of species**	**Total chlorophyll content (mg g^{-1} F.W.)**		
		Polluted site 1	**Polluted site 2**	**Less-polluted site**
1	*Brassica campestris L.*	$3.22\pm0.83_{B}$	$3.99\pm0.49_{AB}$	$4.46\pm0.63_{A}$
2	*Brassica juncea* (L)Czem	$3.40\pm0.74_{A}$	$3.63\pm0.87_{A}$	$3.75\pm0.72_{A}$
3	*Brassica oleracea var. botrytis* L.	$3.47\pm0.32_{A}$	$3.86\pm0.44_{A}$	$3.73\pm0.45_{A}$
4	*Brassica oleracea var. capitata* L.	$3.54\pm0.31_{A}$	$3.48\pm1.11_{A}$	$3.54\pm0.32_{A}$
5	*Hordeum vulgare* L.	$1.96\pm0.3_{B}$	$2.08\pm0.48_{AB}$	$2.74\pm0.46_{A}$
6	*Raphanus sativus* L.	$3.72\pm0.34_{A}$	$5.47\pm0.73_{B}$	$4.29\pm0.43_{A}$
7	*Trigonella foenum-graecum* L.	$2.85\pm0.41_{A}$	$5.20\pm0.88_{B}$	$3.48\pm0.71_{A}$
8	*Triticum aestivum* L.	$2.79\pm0.31_{A}$	$2.58\pm1.24_{A}$	$2.74\pm1.08_{A}$

mean value of chlorophyll content was revealed in *Hordeum vulgare* of 1.96±0.37 mg g^{-1}, 2.08±0.48 mg g^{-1}, and, 2.74±0.46 mg g^{-1} respectively in all experimental sites.

A significant reduction in chlorophyll content was revealed in the plant samples grown in polluted site 1 in comparison to polluted site 2 and less-polluted site. In *Brassica campestris*, *Hordeum vulgare*, *Trigonella foenum-graecum* and *Raphanus sativus* chlorophyll reduced significant ($p<0.05$) in polluted site 1. Insignificant difference in total chlorophyll in *Brassica juncea, Brassica oleracea var. botrytis, Brassica oleracea var. capitata,* and *Triticum aestivum* were recorded among the site. Mean chlorophyll content of *Raphanus sativus* and *Trigonella foenum-graecum* of polluted site 2 were statistically higher than less-polluted site and polluted site 1.

4.3 Ascorbic acid content (AA)

Ascorbic acid content in different experimental sites ranged from 0.54±0.27 mg g^{-1} to 3.10±0.34 mg g^{-1} (Table 4). When ascorbic acid content of the leaf samples from polluted site 1, polluted site 2 and less-polluted site were compared, significant increase in ascorbic acid was recorded in most of the sample of site 1, except in *Brassica oleracea var. capitata*, *Hordeum vulgare* and *Raphanus sativus*. In polluted site 1 the highest mean ascorbic acid was recorded in *Brassica campestris* of 3.10±0.34 mg g^{-1} while it was lowest in *Raphanus sativus* of 0.57±0.38 mg g^{-1}. In polluted site 2, the highest mean ascorbic acid was showed in *Brassica campestris* of 1.86±0.23 mg g^{-1} whereas, the lowest mean value in *Brassica oleracea var. capitata* of 0.54±0.27 mg g^{-1} and followed by *Trigonella foenum-graecum* of 0.58±0.11 mg g^{-1}. In less-polluted site *Brassica campestris* and *Brassica juncea* observed the highest mean ascorbic acid content of 2.4±0.62 mg g^{-1} and 2.49±1.06 mg g^{-1} respectively whereas, *Trigonella foenum-graecum* showed the lowest mean ascorbic acid content of 0.59±0.17 mg g^{-1}.

Brassica campestris, Hordeum vulgare, Raphanus sativus and *Triticum aestivum* showed statistically significant ($p<0.05$) variation in ascorbic acid content among sites. Insignificant variation in ascorbic acid content was recorded in *Brassica juncea, Brassica oleracea var. botrytis, Brassica oleracea var. capitata,* and *Trigonella foenum-graecum.*

Table 4: Ascorbic acid content (Mean ± SD) in the economically important winter crop leaves grown in Polluted site 1, Polluted site 2, and Less-polluted site. Different letters in subscript (capital alphabets) in a row indicates significant difference ($p<0.05$) in ascorbic acid content among the experimental sites where (n=40).

S.N.	**Name of species**	**Ascorbic acid content (mg g^{-1} F. W.)**		
		Polluted site 1	**Polluted site 2**	**Less-polluted site**
1	*Brassica campestris L.*	$3.10\pm0.34_{A}$	$1.86\pm0.23_{B}$	$2.41\pm0.62_{AB}$
2	*Brassica juncea* (L)Czem	$2.64\pm1.23_{A}$	$1.36\pm0.32_{A}$	$2.49\pm1.06_{A}$
3	*Brassica oleracea var. botrytis* L.	$1.36\pm0.56_{A}$	$0.87\pm0.28_{A}$	$1.08\pm0.37_{A}$
4	*Brassica oleracea var. capitata* L.	$0.77\pm0.31_{A}$	$0.54\pm0.27_{A}$	$1.11\pm0.45_{A}$
5	*Hordeum vulgare* L.	$1.65\pm0.87_{AB}$	$0.80\pm0.12_{B}$	$1.90\pm0.79_{A}$
6	*Raphanus sativus* L.	$0.57\pm0.38_{B}$	$1.55\pm0.50_{A}$	$0.64\pm0.16_{B}$
7	*Trigonella foenum-graecum* L.	$0.66\pm0.20_{A}$	$0.58\pm0.11_{A}$	$0.59\pm0.17_{A}$
8	*Triticum aestivum* L.	$1.89\pm0.06_{A}$	$0.84\pm0.10_{B}$	$1.38\pm0.82_{AB}$

4.4 Leaf extract pH

The selected plant species of different experimental sites was noticed a significant variation in leaf extract pH (Table 5). The mean value of leaf extract pH of plant species was found to be decreased in polluted site 1 than less-polluted site and polluted site 2. The lowest pH value of 4.71±0.40 was recorded in *Trigonella foenum-graecum* whereas the highest mean value of 6.18±0.03 was recorded in *Triticum aestivum*. In polluted site 1 maximum value of pH, 5.92±0.05 was noticed in *Brassica oleracea var. capitata* whereas the minimum value of pH, 4.71±0.40 was observed on *Trigonella foenum-graecum*. In polluted site 2 maximum value of pH, 6.18±0.03 was obtained by *Triticum aestivum* and the minimum value of pH, 5.84±0.12 by *Brassica oleracea var. capitata*. In less-polluted site maximum value of pH, 6.04±0.05 was observed on *Brassica oleracea var. capitata* whereas the minimum value of pH 5.39±0.04 was observed on *Trigonella foenum-graecum*.

Mostly the pH reduced in polluted site 1 than less-polluted site. But in polluted site 2, significant ($p<0.05$) increase in pH was recorded in *Brassica campestris*, *Brassica* *juncea, Raphanus sativus, Trigonella foenum-graecum,* and *Triticum aestivum* than less-polluted site.

Table 5: Leaf extract pH (Mean ± SD) in the economically important winter crop leaves grown in Polluted site 1, Polluted site 2, and Less-polluted site. Different letters in subscript (capital alphabets) in a row indicates significant difference ($p<0.05$) in leaf extract pH among the experimental sites where ($n=40$).

S.N.	**Name of species**	**Leaf extract pH**		
		Polluted site 1	**Polluted site 2**	**Less-polluted site**
1	*Brassica campestris L.*	$5.74\pm0.24_{A}$	$6.01\pm0.08_{A}$	$5.72\pm0.35_{A}$
2	*Brassica juncea* (L)Czem	$4.94\pm0.06_{A}$	$6.03\pm0.19_{C}$	$5.54\pm0.04_{B}$
3	*Brassica oleracea var. botrytis* L.	$5.78\pm0.18_{A}$	$5.89\pm0.09_{AB}$	$6.00\pm0.13_{B}$
4	*Brassica oleracea var. capitata* L.	$5.92\pm0.05_{AB}$	$5.84\pm0.12_{B}$	$6.04\pm0.05_{A}$
5	*Hordeum vulgare* L.	$5.25\pm0.37_{B}$	$5.98\pm0.21_{A}$	$5.98\pm0.20_{A}$
6	*Raphanus sativus* L.	$5.05\pm0.22_{A}$	$6.15\pm0.07_{C}$	$5.83\pm0.11_{B}$
7	*Trigonella foenum-graecum* L.	$4.71\pm0.40_{A}$	$5.90\pm0.07_{C}$	$5.39\pm0.04_{B}$
8	*Triticum aestivum* L.	$5.41\pm0.34_{A}$	$6.18\pm0.03_{B}$	$5.85\pm0.23_{B}$

4.5 Air Pollution Tolerance Index (APTI)

The selected plant species growing in different experimental sites revealed variation.in APTI value (Table 6) and were significant ($p<0.05$) different in *Hordeum vulgare*. The mean APTI values among the selected species ranged from 7.46±0.90 to 10.69±1.07. The highest mean APTI value of 10.69±1.07, 9.79±0.63, and 10.66±1.92 was recorded by *Brassica juncea* in polluted site 1, polluted site 2, and less-polluted site respectively. The lowest mean values of APTI was presented by *Trigonella foenum-graecum* with respective value of 7.52±2.08 and 7.46±0.90 in polluted site 1 and less-polluted site. But in polluted site 2 the lowest mean values of APTI was presented by *Hordeum vulgare* of 8.19±0.71 and was followed by *Trigonella foenum-graecum* of 8.41±0.85.

The highest APTI was observed in *Brassica juncea* 10.69 in polluted site and 10.66 in less-polluted site, indicating the ability of this species to grow well even in polluted environment. *Trigonella foenum-graecum was obtained* the lowest APTI *in polluted* and less-polluted site with the respective value of 7.52 and 7.46.

Table 6: Air pollution tolerance index (Mean ± SD) of economically important winter crop plants grown in Polluted site 1, Polluted site 2, and Less-polluted site. Different letters in subscript (capital alphabets) in a row indicates significant difference ($p<0.05$) in APTI among the experimental sites where ($n=40$).

S.N.	**Name of species**	**Air Pollution Tolerance Index (APTI)**		
		Polluted site 1	**Polluted site 2**	**Less-polluted site**
1	*Brassica campestris L.*	10.45±0.88$_{A}$	9.36±1.03$_{A}$	10.42±0.90$_{A}$
2	*Brassica juncea* (L)Czem	10.69±1.07$_{A}$	9.79±0.63$_{A}$	10.66±1.92$_{A}$
3	*Brassica oleracea var. botrytis* L.	9.45±0.84$_{A}$	9.52±0.25$_{A}$	9.1±0.97$_{A}$
4	*Brassica oleracea var. capitata* L.	9.45±0.51$_{A}$	9.21±0.32$_{A}$	9.74±0.18$_{A}$
5	*Hordeum vulgare* L.	9.64±1.00$_{A}$	8.19±0.71$_{B}$	9.96±0.33$_{A}$
6	*Raphanus sativus* L.	9.07±0.67$_{A}$	9.19±0.82$_{A}$	8.73±1.26$_{A}$
7	*Trigonella foenum-graecum* L.	7.52±2.08$_{A}$	8.41±0.85$_{A}$	7.46±0.90$_{A}$
8	*Triticum aestivum* L.	9.74±0.77$_{A}$	9.53±0.45$_{A}$	9.50±1.04$_{A}$

4.6 Above ground Productivity

The mean above ground productivity of the selected crop plants ranged from 1.60±0.4 9 to 47.77±16.79 kg/ha (Table 7). The highest mean above ground productivity of 47.77±16.79 kg/ha and 38.47±9.04 was recorded by *Brassica oleracea var. botrytis* in less-polluted site and polluted site 1 respectively. In polluted site 2 the highest mean above ground productivity was recorded in *Brassica oleracea var. capitata* (26.52±10.42 kg/ha) and was competed by *Brassica oleracea var. botrytis* (23.26±7.44 kg/ha). The lowest mean above ground productivity of 1.60±0.4 9 kg/ha was recorded in *Trigonella foenum-graecum.*

Above ground productivity of *Brassica campestris, Brassica oleracea var. botrytis, Hordeum vulgare, Trigonella foenum-graecum,* and *Triticum aestivum* recorded significant($p<0.05$). variation. In *Brassica juncea, Brassica oleracea var. capitata,* and *Raphanus sativus* showed insignificant differences in above ground productivity among the study sites.

Table 7: Above ground productivity (Mean ± SD) of economically important winter crop plants grown in Polluted site 1, Polluted site 2, and Less-polluted site. Different letters in subscript (capital alphabets) in a row indicates significant difference ($p<0.05$) in above ground productivity among the experimental sites where ($n=40$).

S.N.	**Name of species**	**Above ground Productivity (kg/ha)**		
		Polluted site 1	**Polluted site 2**	**Less-polluted site**
1	*Brassica campestris L.*	16.84±9.14$_{AB}$	5.58±3.14$_{A}$	27.08±10.35$_{B}$
2	*Brassica juncea* (L)Czem	12.76±5.39$_{A}$	11.08±2.3$_{A}$	18.6±11.51$_{A}$
3	*Brassica oleracea var. botrytis* L.	38.47±9.04$_{AB}$	23.26±7.44$_{B}$	47.77±16.79$_{A}$
4	*Brassica oleracea var. capitata* L.	25.07±4.83$_{A}$	26.52±10.42$_{A}$	34.75±0.48$_{A}$
5	*Hordeum vulgare* L.	23.72±10.22$_{AB}$	13.58±3.6$_{B}$	27.53±8.80$_{A}$
6	*Raphanus sativus* L.	17.12±9.39$_{A}$	18.06±3.01$_{A}$	24.38±9.00$_{A}$
7	*Trigonella foenum-graecum* L.	3.16±1.69$_{B}$	1.60±0.49$_{B}$	10.37±5.48$_{A}$
8	*Triticum aestivum* L.	16.76±5.03$_{B}$	7.00±0.61$_{B}$	40.91±13.91$_{A}$

4.7 Below ground Productivity

The mean below ground productivity of plant species ranged from 0.43±0.21 kg/ha to 23.56±18.44 kg/ha. In polluted site 1 and polluted site 2 the highest mean below ground productivity of 15.52±1.38 kg/ha and 7.77±2.30 kg/ha was respectively presented by *Brassica oleracea var. botrytis*. In less-polluted site the highest mean below ground productivity was noticed by *Triticum aestivum* of 23.56±18.44 kg/ha and was followed by *Brassica oleracea var. botrytis* of 13.3±7.83kg/ha. The lowest mean below ground productivity of was recorded in *Trigonella foenum-graecum* of 0.43±0.21 kg/ha, 0.48±0.17 kg/ha, and 1.35±0.57 kg/ha respectively in all experimental sites.

There was statistically significant ($p<0.05$) reduction in below ground productivity of *Brassica campestris, Raphanus sativus, Trigonella foenum-graecum,* and *Triticum* *aestivum* in the study sites. Insignificant variation in below ground productivity of *Brassica juncea*, *Brassica oleracea var. botrytis, Brassica oleracea var. capitata,* and *Hordeum vulgare* was observed among sites.

Table 8: Below ground productivity (Mean ± SD) of economically important winter crop plants grown in Polluted site 1, Polluted site 2, and Less-polluted site. Different letters in subscript (capital alphabets) in a row indicates significant difference ($p<0.05$) in below ground productivity among the experimental sites where ($n=40$).

S.N.	**Name of species**	**Below ground Productivity (kg/ha)**		
		Polluted site 1	**Polluted site 2**	**Less-polluted site**
1	*Brassica campestris L.*	$1.15±0.75_B$	$0.91±0.44_B$	$4.26±2.94_A$
2	*Brassica juncea* (L)Czem	$1.96±1.74_A$	$3.33±2.66_A$	$2.57±0.73_A$
3	*Brassica oleracea var. botrytis* L.	$15.52±1.38_A$	$7.77±2.30_A$	$13.3±7.83_A$
4	*Brassica oleracea var. capitata* L.	$6.95±0.82_A$	$5.53±3.49_A$	$5.3±1.08_A$
5	*Hordeum vulgare* L.	$3.72±2.21_A$	$6.37±4.41_A$	$7.26±7.21_A$
6	*Raphanus sativus* L.	$2.01±1.17_B$	$1.45±0.57_B$	$4.59±2.04_A$
7	*Trigonella foenum-graecum* L.	$0.43±0.21_B$	$0.48±0.17_B$	$1.35±0.57_A$
8	*Triticum aestivum* L.	$2.68±1.10_B$	$3.52±0.88_B$	$23.56±18.44_A$

4.8 Productivity

The productivity was found to be increased in less-polluted site than other experimental sites. The mean productivity ranged from 2.09±0.68 kg/ha to 64.48±31.53 kg/ha (Table 9). In polluted site 1 the highest mean total productivity of 53.99±8.88 kg/ha was noticed by *Brassica oleracea var. botrytis*. In polluted site 2 the highest mean total productivity was noticed in *Brassica oleracea var. capitata* of 32.05±12.97kg/ha and was followed by *Brassica oleracea var. botrytis* of 31.03±11.90 kg/ha. In less-polluted site the highest mean total productivity of 64.48±31.53 kg/ha was noticed in *Triticum aestivum.* The lowest mean productivity of 2.09±0.68 kg/ha, 3.59±5.88 kg/ha, and 11.71±4.36 kg/ha were noticed in *Trigonella foenum-graecum* respectively in all experimental sites.

Statistically significant ($p<0.05$) reduction in productivity in polluted sites was observed in *Brassica campestris*, *Trigonella foenum-graecum* and *Triticum aestivum*. But, insignificant variation in productivity among study sites was observed in *Brassica juncea, Brassica oleracea var. capitata, Hordeum vulgare,* and *Raphanus sativus*.

Table 9: Productivity (Mean ± SD) of economically important winter crop plants grown in Polluted site 1, Polluted site 2, and Less-polluted site. Different letters in subscript (capital alphabets) in a row indicates significant difference ($p<0.05$) in total productivity among the experimental sites where ($n=40$).

S.N.	**Name of species**	**Total Productivity (kg/ha)**		
		Polluted site 1	**Polluted site 2**	**Less-polluted site**
1	*Brassica campestris L.*	$17.99 \pm 9.88_{AB}$	$6.49 \pm 3.38_{B}$	$31.34 \pm 13.15_{A}$
2	*Brassica juncea* (L)Czem	$14.73 \pm 5.87_{A}$	$14.42 \pm 3.00_{A}$	$21.17 \pm 10.96_{A}$
3	*Brassica oleracea var. botrytis* L.	$53.99 \pm 8.88_{A}$	$31.03 \pm 11.90_{B}$	$61.07 \pm 20.68_{A}$
4	*Brassica oleracea var. capitata* L.	$32.03 \pm 5.41_{A}$	$32.05 \pm 12.97_{A}$	$40.05 \pm 9.49_{A}$
5	*Hordeum vulgare* L.	$27.44 \pm 11.53_{A}$	$19.85 \pm 7.10_{A}$	$34.80 \pm 14.28_{A}$
6	*Raphanus sativus* L.	$19.13 \pm 10.00_{A}$	$19.51 \pm 2.45_{A}$	$28.97 \pm 9.64_{A}$
7	*Trigonella foenum-graecum* L.	$3.59 \pm 5.88_{A}$	$2.09 \pm 0.68_{A}$	$11.71 \pm 4.36_{B}$
8	*Triticum aestivum* L.	$19.44 \pm 4.36_{A}$	$10.52 \pm 1.21_{A}$	$64.48 \pm 31.53_{B}$

4.9 Correlation

The relative water content ($r=0.74$) and ascorbic acid ($r=0.68$) obtained significant ($p<0.05$) and strong positive correlation with APTI (Table 10). Total chlorophyll content ($r=0.19$) observed significant ($p<0.05$) and positive correlation to pH. Among the parameters, RWC presented positive correlation with AA and pH while negative correlation to Tchl, AA obtained positive correlation to Tchl and negative correlation to pH.

Besides these parameters, APTI presented a positive correlation with total productivity together with above ground productivity and below ground productivity. APTI showed statistically significant ($p<0.05$) to above ground productivity ($r=0.21$) and total productivity ($r=0.20$). Above ground productivity and below ground productivity showed significant ($p<0.05$) and a strong correlation to total productivity as well as with each other. RWC and pH showed significant correlation with above ground productivity and total productivity.

4.10 Linear Regression

RWC and AA showed significant ($p<0.05$) linear relation relationship with APTI value (Figures 2-3). Tchl and pH exhibited insignificant positive relation with APTI (Figures 4-5). Above ground productivity and total productivity (Figure 6) noticed significant positive relation with APTI. The coefficient of determination (R^2) in between APTI and biochemical parameters RWC, Tchl, AA and pH were found to be 0.55, 0.004, 0.46, 0.01 respectively. RWC accounted for more than 50 % variability.

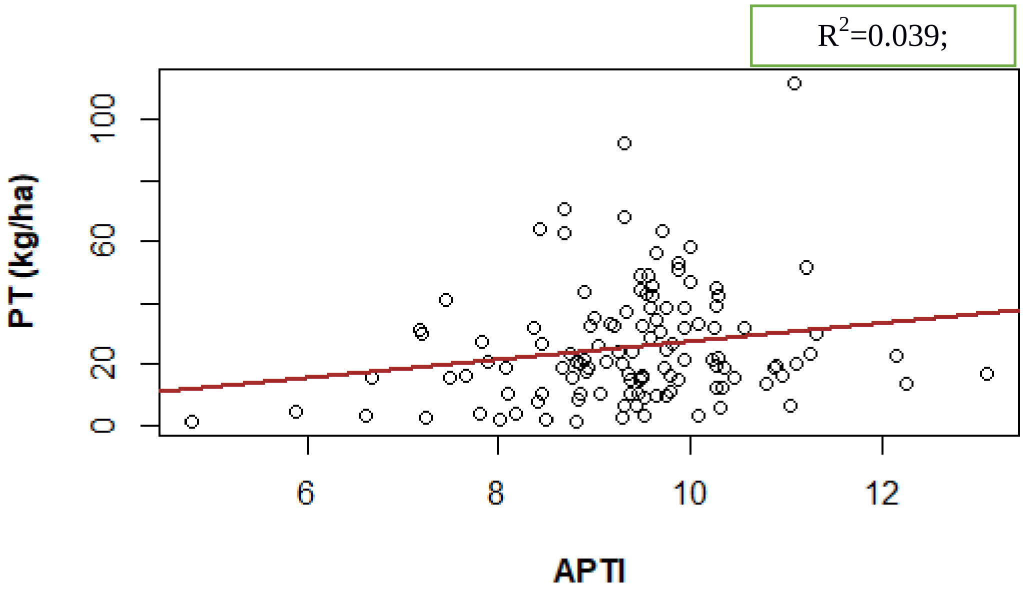

Fig 2: Relationship between total productivity (kg/ha) and APTI.

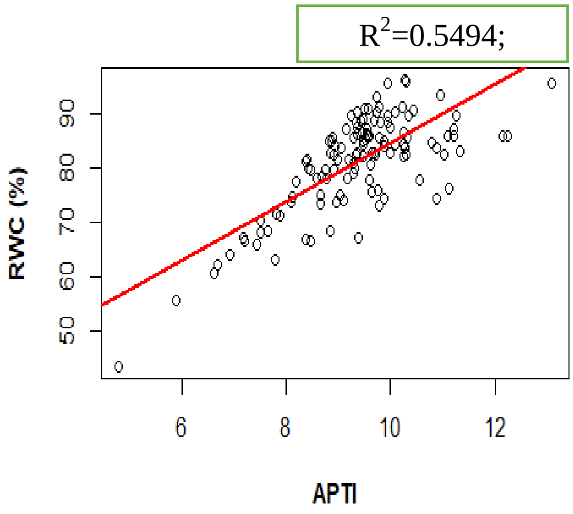

Fig 3: Relationship between relative water content (%) and APTI.

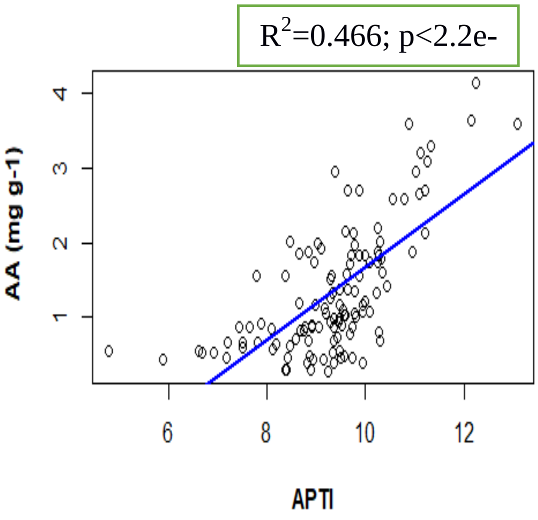

Fig 4: Relationship between ascorbic acid content (mg g^{-1}) and APTI.

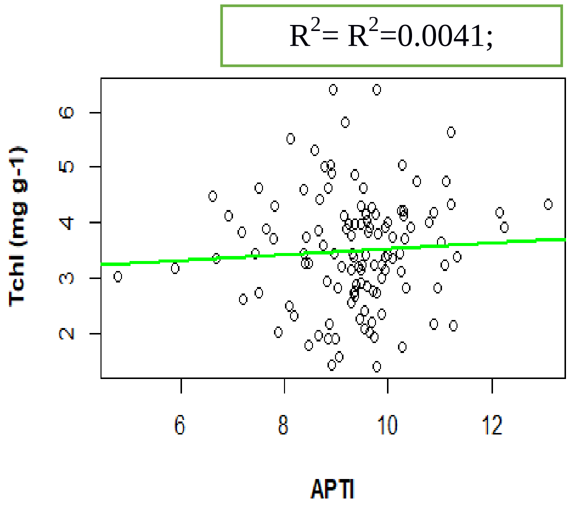

Fig 5: Relationship between total chlorophyll content (mg g^{-1}) and APTI.

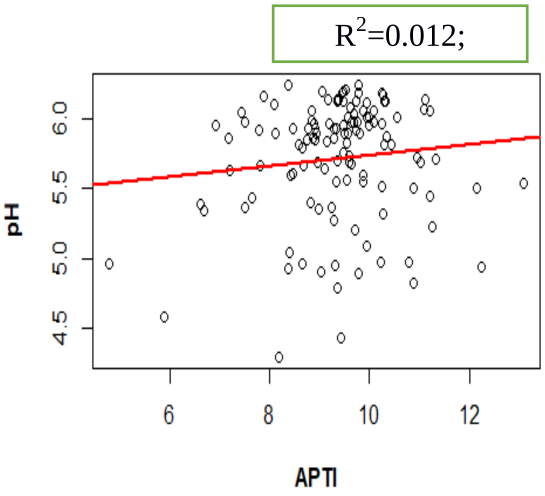

Fig 6: Relationship between pH and APTI.

Table 10: Pearson Correlation Coefficient values among APTI parameters and productivity.

	Air Pollution Tolerance Index	Relative water content	Total chlorophyll content	Ascorbic acid content	Leaf extract pH	Above ground productivity	Below ground productivity	Total productivity
Air Pollution Tolerance Index	1	0.74***	0.06	0.68***	0.11	0.21*	0.12	0.20*
Relative water content		1	-.0.11	0.04	0.11	0.20**	0.14	0.20*
Total chlorophyll content			1	0.03	0.19*	-0.03	-0.09	-0.06
Ascorbic acid content				1	-0.06	0.07	0.04	0.06
Leaf extract pH					1	0.20*	0.22*	0.22*
Above ground productivity						1	0.67***	0.96***
Below ground productivity							1	0.84***
Total productivity							.	1

(*) p<0.05, (**) p<0.01, (***) p<0.001

5. Discussion

Current study revealed that air pollution tolerance index in all the crop plants varied with the pollution status of the study sites. The variation in the values of APTI of all the crop plants in different sites can be attributed to the variation in any of the four biochemical parameters which governs the computation of the index.

5.1 Relative water content (RWC)

The relative water content of a leaf is the water present in it relative to its full turgidity. Hence, RWC is an index of hydration conditions in plant species. It is a direct measure of deficit in leaves. It also serves as an indicator of drought resistance in plants (Dedio 1975). As transpiration rates are frequently high under polluted conditions, maintenance of relative water content by the plant may determine its relative tolerance to pollution (Verma 2003; Gholami *et al.* 2016). From the result, *Triticum aestivum* recorded the highest RWC and was followed by *Brassica oleracea var. capitata.* Under stress condition plants have to improve drought tolerant ability by maintaining water balance as a result of increasing relative water content (Jyothi and Jaya 2010; Ogunkunle *et al*. 2015).

Brassica oleracea var. capitata observed comparatively high mean relative water content in polluted site 1 which was followed by polluted site 2 and less-polluted site with respective values of 87.15±6.07 %, 87.08±2.27 %, and 86.76±5.88 %. It showed that the relative water content in *Brassica oleracea var. capitata* in polluted site 1 increased by 0.36 % while in polluted site 2 increased by 0.44%. High water content inside of a plant body will keep up its physiological equalization under stress conditions when the transpiration rates are usually high (Chouhan *et al*. 2012; Seyyednjad *et al*. 2011). RWC is usually associated with the protoplasmic permeability of cells which is involved in the loss of water and dissolved nutrients in plants (Tsega and Devi prasad 2014; Ogunkunle *et al.* 2015). *Trigonella foenum-graecum* showed low relative water content in all experimental sites. There is an increment in relative water content by 1.20% in polluted site 1 and 6.03 % in polluted site 2. Therefore, water in plants plays an important role to maintain the temperature, nutrient conduction and help in metabolic processes. The decrease in value of relative water content was observed in *Brassica campestris* and *Triticum aestivum* in polluted site 1 and in *Brassica campestris, Hordeum vulgare* and *Raphanus sativus* in polluted site 2 than in less-polluted site. Sensitive plants may have relatively low relative water content when they were grown in polluted conditions. In such aa plant reduction in relative water content, is due to the impact of pollutants on transpiration rate in leaves (Swami *et al.* 2004). Increasing and decreasing levels of various plant parameters at selected sites can be considered as an adaptation of the plant to the environmental condition to protect plants against air pollution stress (Karmakar *et al.* 2016).

The relative water content of all plant species showed insignificant variation because of there was regular watering in the experimental plants in all sites.

5.2 Total chlorophyll content (Tchl)

Chlorophyll measurement is an important tool to evaluate the effects of air pollutants on plants as it plays an important role in plant metabolism and any reduction in chlorophyll content corresponds directly to plant growth (Wagh *et al.* 2006). Chlorophyll can provide valuable information about the physiological status of plants. Chlorophyll content in all the plants varies with the pollution status of the area Chandawat *et. al*. 2011). The leaf chlorophyll content of plant species ranged from 1.96±0.37 mg g^{-1} to 5.47±0.73 mg g^{-1} in the present study. It was well evident that chlorophyll content of plants varies from species to species; age of leaf, genetic variation, and also with the pollution level as well as with other biotic and abiotic conditions (Katiyar and Dubey 2001; Kumar and Nandini 2013).

The plants exposed to automobile pollution to know the changes in the concentration of chlorophyll in the leaf samples. Chlorophyll content in plants decreases near the roadside, because of high levels of automobile pollution. (Tripathi and Gautam 2007; Mir *et al.* 2008; Jyothi and Jaya 2010 and Kapoor 2014). Shakya *et al.* (2008) also found the decreasing amount of chlorophyll in polluted sites than in less-polluted of Kathmandu. *Brassica oleracea var. botrytis* showed low degradation (6.97 %) in chlorophyll content while in *Hordeum vulgare* showed high degradation (28.99 %) in polluted site 1.

The total concentration of chlorophyll content was significantly ($p<0.05$) increased in polluted site 2 in *Brassica oleracea var. botrytis*, *Trigonella foenum-graecum* and *Raphanus sativus*. Heavy metals Pb, Cr, Zn in mosses were found to be higher in polluted site 2 (Shakya *et al.* 2012) so, the accumulation of these metals by plants was enhanced. An increase in chlorophyll content in polluted site 2 may be due to the presence of a higher amount of Zn and Zn uptake was strongly correlated with the synthesis of chlorophyll (Barcelo *et al.* 1985). Several researches have exhibited an increase in chlorophyll content under air pollution. As reported by Tripathi and Gautam (2007), in *Magnifera indica* leaves subjected to air pollution to showed an increase (12.8%) in chlorophyll. Agbaire and Esiefarienrhe (2009), also reported similar result in study plants from experimental site to contain more chlorophyll compared with those from the control.

Brassica campestris and *Hordeum vulgare* also showed significant ($p<0.05$) degradation of chlorophyll content. The degradation of chlorophyll in polluted site 1 may be due to exposure of plants to the air pollutants emitted by heavy traffic in the roadside. Nearly 2000 vehicles, including heavy and light, per day, were reported to be plying in the road of polluted site 1 (Metropolitan traffic Police Division, 2019). The number of vehicles plied in polluted site 1 was higher than polluted site 2 and least in less-polluted (Metropolitan traffic Police Division, 2019). Hence, the higher traffic exposures decreased the chlorophyll content in leaves due to automobile stress (Honour *et al.* 2009; Iqbal *et al.* (2015).

5.3 Ascorbic acid content (AA)

Ascorbic acid is vital in cell wall synthesis, defense, and cell division. It is a stress reducing factor and is present in tolerant plant species generally in higher levels (Rai *et al.* 2013). It plays an important role in photosynthetic carbon fixation (Thakar and Mishra 2010; Nwadinigwe 2014). Among the studied species maximum ascorbic acid content was recorded in *Brassica campestris* and minimum in *Brassica oleracea var. capitata*. Both *Brassica campestris* and *Brassica juncea* showed a high in ascorbic acid content in polluted site 1 than less-polluted and was increased by 22.58 % and 5.68 % respectively. Rise in ascorbic acid may be due to the increased rate of production of reactive oxygen species during the photo oxidation process of SO_2 to SO_3 or other pollutants (Chaudhary and Rao 1977). SO_2 exposure would increase the free radical scavenger such as ascorbic acid to protect plants from damage by oxidative stress (Chandawat *et al*. 2011). Furthermore, the higher ascorbic acid content of the plant was a sign of its tolerance against sulphur dioxide pollution

(Agarwal 1988; Chaudhary and Rao 1977 and Varshney and Varshney 1984). Thus, the increase in the ascorbic acid content enhanced the tolerance against the pollutants indicates the defense mechanism of plants (Swami and Chauhan 2015; Subramani and Devanandan 2015 and Bhattacharya *et al.* 2013). *Brassica oleracea var. capitata, Raphanus sativus* and *Trigonella foenum-graecum* observed low ascorbic acid indicated sensitivity to pollution. Randhi and Reddy (2012), reported that lower ascorbic acid contents support the sensitive nature of the pollutants.

Brassica campestris, Hordeum vulgare, Raphanus sativus and *Triticum aestivum* were significantly ($p<0.05$) different may be due to the capability of plant species to synthesize ascorbic acid and other molecules to overcome stress. These results were in line with findings of Subramani and Devaanandan (2015) who have pointed out that ascorbic acid influences the resistance of plants to adverse environmental conditions. In polluted site 2, ascorbic acid was found to be low may be due to light regime. Bukatsch (1943) and Mozafar (1993) reported that reducing the concentration of ascorbic acid in shaded plants than well-lighted plants. Falusi *et al.* (2016) and Tanee and Albert (2013) also found the reduction in ascorbic acid content in polluted site in comparison to the control site.

Brassica oleracea var. capitata, Hordeum vulgare, and *Raphanus sativus* showed an increase in ascorbic acid by 30.63 %, 13.16 %, and 10.94 % respectively in less-polluted site than in both polluted sites. It is because the boost in the level of ascorbic acid content may be due to the resistance mechanism of a plant to cope with stress conditions since it slows down the leaf senescence (Garg and Kapoor 1972; Joshi *et al.* 2016). The results were in line with the findings of Prajapati and Tripathi (2007) and Joshi *et. al*. (2016) who reported that plants under stress improve in their ascorbic acid content to fight adverse conditions.

5.4 Leaf extract pH

The plant species growing in all study sites exhibited significant ($p<0.05$) variation in leaf extract pH. The maximum pH was obtained by *Triticum aestivum* whereas the minimum was recorded by *Trigonella foenum-graecum*. The leaf pH is a biochemical parameter that serves as a sensitive indicator of air pollution. The change in leaf extract pH might influence stomatal sensitivity due to air pollution (Chouhan *et al.*

2012). pH plays an important role in signifying the condition of plants with respect to the study area (Subramani and Devaanandan 2015). Leaf extract pH of polluted site 1 was low. In polluted sites presence of acidic pollutants, leaf pH is brought down and decrease extraordinarily in sensitive species (Paulsamy *et al.* 2000). Maximum decreased in pH value in polluted site 1 was found to be *Raphanus sativus* (13.37%), *Trigonella foenum-graecum* (12.62 %) and in *Hordeum vulgare* (12.21%) from the less-polluted site. In less-polluted site and polluted site 2, the leaf extract pH was relatively high. High pH level will increase the efficiency of the conversion of hexose sugar into ascorbic acid (Liu and Ding 2008) and upgrade the reducing power of ascorbic acid (Pravin and Madhumita 2013) thus providing a better resistance in plants against pollutants. According to their resistance and susceptibility, *Triticum aestivum* was tolerant and *Trigonella foenum-graecum* was sensitive species.

Except for *Brassica campestris,* all plant species showed significant ($p<0.05$) variation in pH. Increasing and decreasing pH is tolerance or sensitive nature towards air pollution. High pH improves tolerance against air pollution (Agarwal 1986; Shannigrahi *et al.* 2004). The decline in pH was greater in sensitive plants than tolerant plants (Singh and Verma 2007; Kumar and Nandini 2013). Similar result was also obtained by Tiwari and Tiwari (2006) and Gholami *et al*. (2016).

5.5 Air Pollution Tolerance index (APTI)

The selected plant species growing at different experimental sites were found significant variations in the air pollution tolerance index. The plant species vary considerably with their susceptibility to air pollutants (Tiwari and Tiwari 2006). Among all the plant species the maximum air pollution tolerance index was recorded in *Brassica juncea* (10.69). It was significantly different from all other values. The minimum air pollution tolerance index was recorded in *Trigonella foenum-graecum* (7.46). The higher mean APTI of *Brassica juncea* may be attributed to its higher tendency to synthesize ascorbic acid during pollution stress (Kuddus *et al.* 2011). Gholami *et al.* (2016) and Lohe *et al.* (2015), have pointed that APTI value varies from species to species depending on the plant's capacity to endure the effect of pollutants. The APTI values were higher in polluted site 1 than in polluted site 2 and less-polluted site. The highest APTI values may occur associated with the capacity of plants to adapt to stress conditions and the lower values maybe to its less pollution level. High APTI values are associated with tolerance of plant species to air pollutants (Jyothi and Jaya 2010) and tolerant of the plant towards air pollutants was specific to a site and depends on the type and level of pollution (Noor *et al.* 2015). *Trigonella foenum-graecum* had minimum APTI values. Plants having low index value show less tolerance and can be used to indicate the level of air pollution (Singh and Rao 1983).

The *Hordeum vulgare* was statistically significant ($p<0.05$) in APTI values. It can be said that *Hordeum vulgare* has the adaptive capacity to combat stress in diverse environmental conditions. The APTI value of *Brassica juncea* and *Brassica campestris* was increased in less-polluted site than polluted site 2 because of enhancing in ascorbic acid content. APTI value was decreased in *Brassica oleracea var. capitata* and *Hordeum vulgare* both in Polluted site 1 and Polluted site 2. Decreasing percent were 3.06 % and 5.75 % in *Brassica oleracea var. capitata* and 5.75 % and 21.6 % in *Hordeum vulgare* respectively in polluted site 1 and polluted site 2. Plants under stress brought by air pollutants act defensively by either increasing or decreasing its relative water content, total chlorophyll content, ascorbic acid content, and leaf extract pH thereby showing variation in APTI value.

5.6 Variation in order of tolerance of economically important winter crop plants under this study

5.6.1 Order of tolerance of selected plants on Polluted site 1.

Brassica juncea > Brassica campestris > Triticum aestivum > Hordeum vulgare > Brassica oleracea var. botrytis = Brassica oleracea var. capitata > Raphanus sativus > Trigonella foenum-graecum

5.6.2 Order of tolerance of selected plants on Polluted site 2.

Brassica juncea > Triticum aestivum > Brassica oleracea var. botrytis > Brassica campestris > Brassica oleracea var. capitata > Raphanus sativus > Trigonella foenum-graecum > Hordeum vulgare

5.6.3 Order of tolerance of selected plants on Less-polluted site.

Brassica juncea > *Brassica campestris* > *Hordeum vulgare* > *Brassica oleracea var. capitata* > *Triticum aestivum* > *Brassica oleracea var. botrytis* > *Raphanus sativus* > *Trigonella foenum-graecum*

5.7 Relationship of four parameters with APTI

Statistically significant ($p<0.05$) and strong positive correlation was found in between RWC and APTI ($r = 0.74$, $p<0.05$) and AA and APTI ($r = 0.68$, $p<0.05$). Total chlorophyll content and leaf extract pH presented positive correlation with APTI. The ascorbic acid is statistically increased with increasing APTI was also found by Garg and Kapoor (1972), Kuddus *et al.* (2011); Joshi *et al.* (2016) and Sharma *et al.* (2018). The RWC also statistically increased with increasing APTI. These results are in line with findings of (Ogunkunle 2015) who reported that higher relative water content might favor tolerance to pollutants.

5.8 Productivity

Productivity is the organic matter or energy stored by plants at any given time. The reduction of plant growth in polluted sites than the control site may be the extent of growth reduction depends on the plant species, concentration and distribution of pollutants and several environmental factors (Mann *et al.* 1980; Mansfield *et al.* 1981). Plants of polluted site 1 and less-polluted site were maintained at similar edaphic and water conditions, so the observed variation in plant growth may be attributed to an atmospheric pollutant which is emitted by automobiles. Automobiles are responsible for the maximum amount of air pollutants and the crop plants are very sensitive to gaseous and particulate pollution (Joshi and Swami 2009). These air pollutants can cause leaf injury, stomatal damage, premature senescence, decrease photosynthetic rate, disturb membrane permeability and reduce growth and yield in sensitive plant species. Studies conducted in North America and Europe have clearly shown significant yield losses in a range of major crop species due to ambient air pollutant levels (Heck *et al.* 1988).

Plant height is an important component that also helps to determine plant growth. The height of all plant species was reduced in both polluted sites where plants received the greatest pollution load as compared to the control site. Agrawal *et al.* (2003) who have reported reductions in height of wheat and mustard under varying levels of air pollution stress. Similar study was undertaken by Ashmore *et al.* (1988) who concluded that the air pollutants were a major factor influencing plant growth in and around London.

The total productivity of *Triticum aestivum* was maximum in the less-polluted site. According to Saeed *et al.* (2001) optimum plant height is claimed to be positively correlated with the productivity of plants, which may be the reason for the high productivity of *Triticum aestivum (Annex 3).* The total productivity of *Brassica oleracea var. botrytis* was maximum in polluted site 1. However, in the polluted site 2 total productivity of *Brassica oleracea var. capitata* was maximum. Leaf extract pH of *Brassica oleracea var. botrytis* and *Brassica oleracea var. capitata* were 5.78 and 5.83 respectively in polluted site 1 and polluted site 2. As we know, photosynthetic efficiency is strongly dependent on the pH of leaf and at low pH, photosynthesis in plant species was reduced in plants (Escobedo *et al.* 2008). Photosynthesis decreased in plants when the leaf pH was low and vice-versa. Both *Brassica oleracea var. botrytis* and *Brassica oleracea var. capitata* have relatively high leaf pH that may be the possible reason for the increase in productivity. It has been determined that most plant nutrients are optimally available to plants within this 6 to 7.5 pH range of soil (Annex 4, Jensen and Thomas 2010) and are suitable for leafy vegetables (Boeckmann 2019). This may be the reason for the high productivity of those plants. The possible reason for the minimum total productivity in *Trigonella foenum-graecum* may be due to the low APTI value than in other crop plants. The APTI value of *Trigonella foenum-graecum* was 7.52±2.08, 8.41±0.85 and 7.46±0.90 respectively in polluted site 1, polluted site 2, and less-polluted site. Here, low APTI indicates its sensitivity toward air pollution. The sensitive plants were hard to grow in stress conditions and ultimately reduces their productivity. According to Sharma (2013), *Trigonella foenum-graecum* species was hard to grow in Pb and Zn contaminated soil, which may also be one of the reasons for low productivity. In polluted site 2, the reduce in productivity was recorded than polluted site 1 that may be due to the low production of ascorbic acid and sufficient production of ascorbic acid helps in growth and development (El Hariri *et al.* 2010; Gallie 2013).

6. Conclusion and Recommendation

6.1 Conclusion

The response of crop plants to air pollution varies with species to species and also with the intensity of pollutants.

Based on the evaluation of APTI of eight crop plants *Brassica juncea, Brassica campestris, Triticum aestivum* and *Hordeum vulgare* were the more tolerant species that have the potential to combat the air pollution. *Trigonella foenum-graecum* and *Raphanus sativus* were sensitive to air pollution and demonstrate the level of pollution.

The pollutants emitted from vehicles adversely affecting agriculture production by changing its physiological characters, photosynthetic pigment, and productivity of crop plants.

6. 2 Recommendation

1. Tolerant crop plants *Brassica juncea, Brassica campestris, Triticum aestivum* and *Hordeum vulgare* can be planted in polluted sites also.
2. *Triticum aestivum* can be recommended to the farmers for their economic growth because of their high productivity.
3. More works on APTI determination of many other crop plants should be carried out in future.

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PHOTO PLATES

Brassica campestris L.

Brassica juncea (L)Czern

Brassica oleracea var. botrytis L

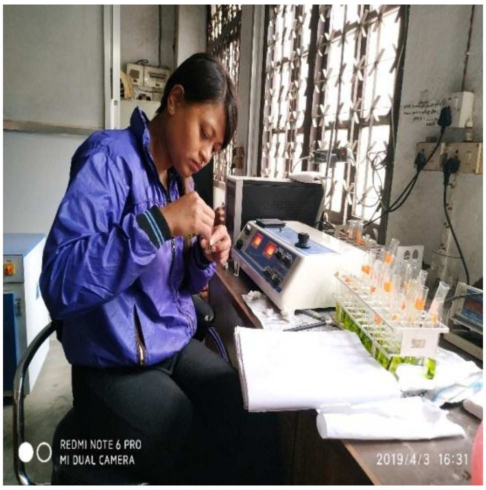
Brassica oleracea var. capitata L.

Hordeum vulgare L.

Raphanus sativus L.

Trigonella foenum-graecum L.

Triticum aestivum L.



Some photographs

Appendices

APPENDIX I: Range (in parentheses) and standard error (S.E) values of biochemical parameters and APTI values of economically important winter crop plants grown in Polluted site 1, Polluted site 2, and Less-polluted site.

Name of species	**Site**	**RWC (%)**	**Tchl (mgg^{-1})**	**AA (mgg^{-1})**	**pH**	**APTI**
Brassica campestris L.	Polluted site 1	67.21 - 83.30 SE. 2.96	2.01 - 4.18 SE. 0.37	2.69 - 3.58 SE. 0.15	5.50 - 6.14 SE. 0.11	9.39 - 11.32 SE. 0.39
Brassica juncea (L)Czem		80.03 - 91.19 SE. 1.80	2.16 - 4.02 SE. 0.33	1.32 - 4.14 SE. 0.55	4.83 - 4.98 SE. 0.03	9.31 - 12.24 SE. 0.48
Brassica oleracea var. botrytis L.		75.14 - 86.67 SE. 2.04	3.13 - 3.86 SE. 0.14	0.45 - 1.83 SE. 0.25	5.60 - 5.96 SE. 0.08	8.42 - 10.26 SE. 0.37
Brassica oleracea var. capitata L.		79.65 - 93.24 SE. 2.71	3.22 - 3.90 SE. 0.14	0.45 - 1.08 SE. 0.14	5.85 - 5.97 SE. 0.02	8.75 - 10.08 SE. 0.23
Hordeum vulgare L.		73.57 - 91.13 SE. 3.18	1.4 - 2.4 SE. 0.17	1.06 - 3.09 SE. 0.39	4.89 - 5.83 SE. 0.17	8.65 - 11.25 SE. 0.45
Raphanus sativus L.		81.18 - 89.86 SE. 1.88	3.26 - 3.99 SE. 0.15	0.28 - 1.08 SE. 0.17	4.79 - 5.37 SE. 0.1	8.37 - 9.94 SE. 0.3
Trigonella foenum-graecum L.		43.55 - 88.64 SE. 8.81	2.3 - 3.2 SE. 0.18	0.43 - 0.95 SE. 0.09	4.30 - 5.27 SE. 0.18	4.80 - 9.43 SE. 0.93
Triticum aestivum L.		74.13 - 93.57 SE. 3.53	2.33 - 3.20 SE. 0.14	1.84 - 1.98 SE. 0.03	4.91 - 5.72 SE. 0.15	9.04 - 10.96 SE. 0.35
Brassica campestris L.	Polluted site 2	63.05 - 84.51 c4.08	3.34 - 4.62 SE. 0.22	1.55 - 2.12 SE. 0.1	5.92 - 6.12 SE. 0.03	9.39 - 11.32 SE. 0.39
Brassica juncea (L)Czem		79.74 - 90.63 SE. 1.84	2.72 - 4.89 SE.0.39	0.88 - 1.79 SE. 0.15	5.81 - 6.24 SE. 0.08	9.31 - 12.24 SE. 0.48
Brassica oleracea var. botrytis L.		84.47 - 88.90 SE. 0.88	3.14 - 4.26 SE. 0.2	0.43 - 1.16 SE. 0.13	5.76 - 5.98 SE. 0.04	8.42 - 10.26 SE. 0.37
Brassica oleracea var. capitata L.		84.92 - 90.36	2.18 - 5.03	0.29 - 1.03	5.70 - 5.96	8.75 - 10.08

		SE.1.01	SE. 0.5	SE. 0.13	SE. 0.05	SE. 0.23
Hordeum vulgare L.		66.59 - 82.95	1.42 - 2.60	0.66 - 0.91	5.63 - 6.16	8.65 - 11.25
		SE. 3.19	SE. 0.21	SE. 0.05	SE. 0.09	SE. 0.45
Raphanus sativus L.		67.03 - 87.34	4.60 - 6.41	0.99 - 2.12	6.06 - 6.24	8.37 - 9.94
		SE. 3.55	SE. 0.33	SE. 0.22	SE. 0.03	SE. 0.3
Trigonella foenum-graecum L.		64.03 - 84.07	4.11 - 6.41	0.43 - 0.70	5.81 - 5.98	4.80 - 9.43
		SE. 3.55	SE. 0.39	SE. 0.04	SE. 0.03	SE. 0.93
Triticum aestivum L.		83.84 - 96.28	1.56 - 4.64	0.68 - 0.94	6.14 - 6.21	9.04 - 10.96
		SE. 2.17	SE. 0.55	SE. 0.05	SE. 0.01	SE. 0.35
Brassica campestris L.	Less-polluted site	73.85 - 86.07	3.43 - 5.04	1.73 - 3.21	5.32 - 6.14	7.80 - 10.31
		SE. 2.32	SE. 0.28	SE. 0.28	SE. 0.16	SE. 0.46
Brassica juncea (L)Czem		66.76 -95.56	2.72 - 4.34	1.32 - 3.64	5.50 - 5.61	8.92 - 10.45
		SE. 4.65	SE. 0.32	SE. 0.47	SE. 0.02	SE. 0.28
Brassica oleracea var. botrytis L.		66.01 - 88.95	3.15 - 4.29	0.55 - 1.51	5.86 - 6.19	9.16 - 9.81
		SE. 4.09	SE. 0.2	SE. 0.17	SE. 0.06	SE. 0.11
Brassica oleracea var. capitata L.		80.70 - 95.79	3.16 - 3.91	0.38 - 1.57	5.98 - 6.11	8.88 - 9.60
		SE. 2.63	SE. 0.14	SE. 0.2	SE. 0.02	SE. 0.14
Hordeum vulgare L.		74.29 - 90.33	1.94 - 3.11	0.87 - 2.69	5.69 - 6.18	7.20 - 8.91
		SE. 3.17	SE. 0.21	SE. 0.31	SE. 0.09	SE. 0.32
Raphanus sativus L.		67.21 - 96.03	3.82 - 5.00	0.47 - 0.87	5.66 - 5.93	8.38 - 11.22
		SE. 5.51	SE. 0.19	SE. 0.07	SE. 0.05	SE. 0.47
Trigonella foenum-graecum L.		60.70 - 85.01	2.74 - 4.47	0.40 - 0.87	5.34 - 5.44	6.93 - 8.94
		SE. 4.31	SE. 0.31	SE. 0.08	SE. 0.02	SE. 0.36
Triticum aestivum L.		78.60 - 87.22	1.78 - 4.41	0.63 - 2.66	5.56 - 6.07	9.06 - 10.27
		SE .1.69	SE. 0.48	SE. 0.37	SE. 0.1	SE. 0.2

APPENDIX II: Range (in parentheses) and standard error (S.E) values of above ground productivity, below ground productivity and total productivity of economically important winter crop plants grown in Polluted site 1, Polluted site 2, and Less-polluted site.

Names of Species	Site	PAG (kg/ha)	PBG (kg/ha)	PT (kg/ha)
Brassica campestris L.	Polluted site 1	6.11 – 28.03 SE. 4.09	0.25 - 2.17 SE. 0.33	6.37 -30.19 SE. 4.42
Brassica juncea (L)Czem		5.73 - 20.64 SE. 2.41	0.51 – 4.71 SE. 0.78	6.24 - 21.66 SE. 2.62
Brassica oleracea var. botrytis L.		27.52 – 47.3 SE. 4.04	13.76 - 17.45 SE. 0.62	44.97 – 63.95 SE. 3.97
Brassica oleracea var. capitata L.		17.32 – 30.7 SE. 2.16	6.11 – 7.9 SE. 0.37	23.47 – 38.47 SE. 2.42
Hordeum vulgare L.		14.78 – 38.47 SE. 4.57	1.27 – 5.99 SE. 0.99	16.18- 43.44 SE. 5.16
Raphanus sativus L.		6.75 – 30.32 SE.4.20	1.02 – 3.95 SE. 0.52	7.77 – 32.23 SE. 4.47
Trigonella foenum-graecum L.		1.15 - 5.48 SE. 0.76	0.13 - 0.64 SE. 0.10	1.27 – 6.11 SE. 2.63
Triticum aestivum L.		10.57 – 24.2 SE. 2.24	1.91 – 4.46 SE. 0.50	15.03 – 26.11 SE. 1.95
Brassica campestris L.	Polluted site 2	2.29 – 9.68 SE. 1.40	0.51 – 1.66 SE. 0.20	3.18 - 10.57 SE. 1.51
Brassica juncea (L)Czem		7.77 – 13.63 SE. 1.03	1.27 – 7.9 SE. 1.19	11.08 – 18.73 SE. 1.34
Brassica oleracea var. botrytis L.		12.74- 32.36 SE. 1.03	3.31 – 16.56 SE. 2.30	16.05 – 48.92 SE. 5.32
Brassica oleracea var. capitata L.		12.99 – 38.85 SE. 4.66	2.04 - 10.32 SE. 1.56	15.03 – 43.69 SE. 5.80
Hordeum vulgare L.		7.52 – 16.31 SE. 1.61	2.93 – 13.89 SE. 1.97	10.45 – 30.19 SE. 3.18
Raphanus sativus L.		13.25 -21.02 SE. 1.35	1.02 – 2.42 SE. 0.26	15.67 – 22.04 SE. 1.10

Trigonella foenum-graecum L.		1.02 – 1.29 SE. 0.22	0.25 - 0.64 SE. 0.08	1.27 – 2.80 SE. 0.27
Triticum aestivum L.		6.24 - 7.64 SE. 0.28	2.68 – 4.84 SE. 0.39	9.17 – 12.48 SE. 0.54
Brassica campestris L.	Less-polluted site	17.45 - 43.06 SE. 4.63	1.91 – 8.92 SE. 1.33	19.49 – 51.97 SE. 5.88
Brassica juncea (L)Czem		7.52 – 37.58 SE. 5.14	1.53 – 3.57 SE. 0.32	10.06 - 39.11 SE. 4.90
Brassica oleracea var. botrytis L.		35.16 – 70.45 SE. 7.51	6.24 – 22.17 SE. 3.50	41.4 – 92.61 SE. 9.25
Brassica oleracea var. capitata L.		26.11 – 52.74 SE. 4.69	3.57 – 6.24 SE. 0.49	32.23 – 56.31 SE. 4.24
Hordeum vulgare L.		17.32 – 37.96 SE. 3.93	1.27 – 19.49 SE. 3.22	18.6 – 52.99 SE. 6.38
Raphanus sativus L.		9.94 – 34.65 SE. 4.03	2.93 – 7.77 SE. 0.91	15.41 – 42.42 SE. 4.31
Trigonella foenum-graecum L.		2.17 – 14.78 SE. 2.45	0.64 – 2.04 SE. 0.25	2.80 – 16.05 SE. 1.95
Triticum aestivum L.		22.17 – 61.4 SE. 6.22	4.46 – 50.7 SE. 8.25	26.62 – 31.53 SE. 14.10

APPENDIX III: Height of crop plants in Polluted site 1, Polluted site 2 and Less-polluted site.

S.N.	Name of species	Height (cm)		
		Polluted site 1	**Polluted site 2**	**Less-polluted site**
1	*Brassica campestris L.*	35.2	42.32	43.22
2	*Brassica juncea* (L)Czem	23.9	25.04	29.32
3	*Brassica oleracea var. botrytis* L.	25.4	20.4	29.12
4	*Brassica oleracea var. capitata* L.	20.28	22.46	26.98
5	*Hordeum vulgare* L.	30.76	32.76	41.06
6	*Raphanus sativus* L.	27	37.2	41.24
7	*Trigonella foenum-graecum* L.	22.06	23.66	26.54
8	*Triticum aestivum* L.	44.3	64.46	74.2

APPENDIX IV: Soil pH of Polluted site 1, Polluted site 2 and Less-polluted site.

	Polluted site 1	**Polluted site 2**	**Less-polluted site**
Soil pH	6.48	8.26	6.48