Assessment of Crop Damage from Ground Level Ozone and Evaluation of Ethylene Diurea (EDU) Treatment on the Performance of Plants Exposed to Ozone

Thesis Submitted to the Jawaharlal Nehru University for the Award of Degree of

DOCTOR OF PHILOSOPHY

CHITRASEN ROUT

SCHOOL OF ENVIRONMENTAL SCIENCES
JAWAHARLAL NEHRU UNIVERSITY
NEW DELHI-110 067
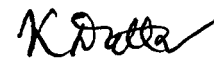## INDIA
2003

....Dedicated to

my Family

जवाहरलाल नेहरू विश्वविद्यालय
Jawaharlal Nehru University
SCHOOL OF ENVIRONMENTAL SCIENCES
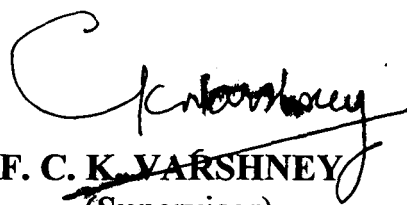### New Delhi - 110 067

25th September, 2003

CERTIFICATE

The research work embodied in this thesis entitled **"Assessment of Crop Damage from Ground Level Ozone and Evaluation of Ethylene Diurea (EDU) Treatment on the Performance of Plants Exposed to Ozone"**, has been carried out at School of Environmental Sciences, Jawaharlal Nehru University, New Delhi. This work is original and has not been submitted in part or full, for any degree or diploma of the University.

CHITRASEN ROUT
(Candidate)

PROF. K. DATTA
(Dean)

PROF. C. K. VARSHNEY
(Supervisor)

ACKNOWLEDGEMENTS

(Chitrasen Rout)

Preface....

Agriculture, the lifeblood of Indian economy is not only suffering from problems of land degradation, salinity, pest out break but it is also seriously threatened by environmental pollution particularly, from air pollution. The problem of air pollution in relation to agricultural production is a cause of serious concern requiring immediate attention to ensure the food security. The present work "Assessment of Crop Damage from Ground Level Ozone and Evaluation of Ethylene Diurea (EDU) Treatment on the Performance of Plants Exposed to Ozone" is an outcome of my research work, solely devoted to determine the impact of phytotoxic ground level ozone on agricultural crops. In India, some short-term preliminary studies have shown that build up of ground level ozone is widespread in different parts of the country. The study deals with the effect of ozone on the growth and yield of wheat (*Triticum aestivum*), moong (*Phaseolus aureus*), mustard (*Brassica campestris*) and paalak (*Spinacia oleracea*). It also evaluates the efficacy of ethylene diurea (EDU) in preventing ozone damage. The results of the study may be of help in developing strategies for preventing crop loss from ground level ozone.

The thesis is divided into seven chapters. Chapter-I provides a brief introduction and the objectives of the present investigation. Chapter-II provides a critical review of literature on three aspects: a) tropospheric ozone, b) effect of ozone on plants and c) effect of protectant chemicals including ethylene diurea (EDU) in preventing ozone damage in plants. A description of the study area is given in Chapter-III. The results of the study are presented in Chapter-IV. Chapter-V is devoted to discussion, and chapter-VI to assess the crop loss from ground level ozone and its economic implications. Chapter –VII includes a summary and conclusions. A list of cited references is provided at the end. Paper published by the candidate is given in annexure- I.

(Chitrasen Rout)

CONTENTS

List of Figures

List of Tables

List of Plates

Chapter-I

Introduction

INTRODUCTION

Rapid industrialisation, urbanisation and economic development have created serious problems of air pollution in many countries including India. Air pollution kills more than 2.7 million people annually, of which over 90 per cent of such deaths occur in developing countries and two-third of these in Asia (UNDP, 1998). Air pollutants not only affect human health adversely but also have serious consequences for agricultural and horticultural crops. Agriculture - the main driver of economic growth in developing countries including India, apart from being critically important for food security - is threatened by growing air pollution (Marshall, 2002). Ground level ozone is one of the most damaging phytotoxic gaseous air pollutants known to cause serious damage to agricultural crops, trees and natural ecosystems (Emberson *et al.*, 2001; Mauzerall and Wang, 2001; Oksanen and Holopainen, 2001; Prather *et al.*, 2003).

In the stratosphere, 15-45 km above the ground, ozone is an omnipresent trace gas; it absorbs the incoming UV radiation and protects the living organisms from their harmful effects. As a result of growing anthropogenic activities, stratospheric ozone is getting eroded. On the contrary, ozone build-up in the lower troposphere, i.e., at ground level is increasing. During the last two decades, ambient ozone levels have increased between ~1 to 2 % per year (Hough and Derwent, 1990). Ground level ozone is a secondary gaseous pollutant, readily formed in the lower troposphere from photochemical reactions involving hydrocarbons (including CH_4), CO and NO_X, largely emitted from automobiles and from the combustion of fossil fuels (Krupa and Manning, 1988; Crutzen and Zimmermann, 1991). Feister and Warmbt (1990) have reported that ozone concentration has increased by 0.5-3.0% in the Northern Hemisphere as a whole. Analysis of the historical data on ozone suggests that ground level ozone concentration at mid to high latitudes have more than doubled during the last century (Volz and Kley, 1988). Higher levels of ozone in the extra tropical Northern Hemisphere are not surprising, given the growing number of sources of ozone precursors. In the extra tropical Northern Hemisphere tropospheric O_3 is strongly related to emissions from combustion of fossil fuels, whereas in the tropics and in the Southern Hemisphere, natural sources of ozone precursors (natural sources include NO_X formed during lightning and non-agricultural soil exhalation) play a major role.

1

Presently, in the tropics of Northern Hemisphere industrial sources contribute 20-30% to the tropospheric column O_3; in the tropical and extra-tropical Southern Hemispheric such contribution is about 10-20% (Lelieveld and Dentener, 2000).

Reliable historical or time series data on ground level ozone are scanty, and for India they are practically non-existent. Even where information on ozone levels is available, it is difficult to compare because of the variation in measurement techniques used by different workers (Volz and Kley, 1988; Hough and Derwent, 1990). Notwithstanding the data limitation there is a growing evidence to suggest that since World War II, ground level ozone in the troposphere has been steadily increasing (Low et al., 1990). There has been a concurrent increase in the frequency of photochemical episodes (Hough and Derwent, 1990). Unlike other criteria pollutants, problem of ground level ozone pollution is not restricted to any particular air shed but it is invariably regional character. High ozone levels have been reported from many remote rural areas far away from urban and industrial areas (Coffey and Stasiuk, 1975; Rubino et al., 1976; White et al., 1976; Rodes and Holland, 1981; Gusten et al., 1988; Derwent and Jenkin, 1991; Hakola et al., 1991; Colbeck and Mackenze, 1994; Wild and Akimoto, 2001; Prather et al., 2003).

The effects of ozone pollution on plants were mainly based on field studies restricted to identification and description of injury symptoms (Middleton et al., 1950). During the late 1960s and early 1970s, estimates of yield loss caused by ozone were based on field surveys of foliar injury (Benedict et al., 1973; Pell, 1973; Heagle, 1989). This was the best available technique even though there was no proven cause-effect relationship between observed foliar injury and yield. During the last 30 years, several attempts have been made to quantify air pollution-induced economic losses to important agricultural and horticultural crops (Millecan, 1971; Heck et al., 1982, 1986; Heagle, 1989). The first systematic attempt to estimate economic loss from oxidant-induced stress to crops was made in USA. It has been estimated that economic loss due to air pollution in the Los Angeles basin was in the range of U.S. $ 448000 (Middleton et al., 1950). Later Millecan (1971) estimated that in the United States crop loss was to the tune of 62 million U.S. dollars; ozone and PAN were responsible for approximately 50% and 20% of the loss respectively. Heck et al. (1982) have reported that an annual crop loss in U.S. was between 1 to 2 billion dollars, and 90% of this loss, works out to

2

about 2-4% of total crop production was attributed to ozone pollution either alone or in combination with SO_2 or NO_2 or both. It has been suggested that ozone substantially reduces yield of several crops with serious economic consequences (Tonneijck, 1989; Heck et al., 1982). A number of studies have been attempted to assess economic loss to agricultural crops from air pollution stress (Shriner et al., 1982; Wilson et al., 1984; Adams et al., 1989; Tonneijck, 1989). In US nearly 3 billion dollar i.e., about 5-6 % of the gross value of farm commodities were lost due to ozone pollution in 1980 (Shriner et al., 1982; Wilson et al., 1984; Adams et al., 1989). It has been estimated that in United Sates, a 25% reduction of ambient ozone level would result in an annual saving of approximately 1.9 billion dollars (Adams et al., 1989). In the Netherlands, ground level ozone pollution was found to cause considerable loss to legumes, potatoes, cut flowers and fodder crops (Tonnejik, 1989). It has been shown that sulphur dioxide, hydrogen fluoride and ozone reduce the crop yield by 5%, and 70% of such reduction was attributed to ground level ozone pollution (Tonnejik, 1989). The crop loss assessment on account of ozone stress is yet to be attempted in India.

In India, some *ad hoc* short-term studies have shown that the ground level ozone build up in urban, peri-urban as well as rural areas is quite high (Pandey et al., 1992; Varshney and Aggarwal, 1992; Singh et al., 1997; Varshney and Rout 1998). In Delhi, ambient ground level ozone was found to vary between 20 to 273 $\mu g/m^3$, and WHO one-hour ozone standard of 110.74 $\mu g/m^3$ was violated on many occasions (Varshney and Aggarwal, 1992). In a subsequent study, Varshney and Rout (1998) have reported that in some urban and peri-urban locations of Delhi during March-June, 1997, average hourly ground level ozone concentration varied between 88-90 $\mu g/m^3$ and the average hourly peak concentration varied between 113-125 $\mu g/m^3$.

The leaf spot disease of potato reported from Punjab in 1978 was shown to be primarily due to ozone pollution and foliar spray of EDU was found to reduce about 25-30% of leaf spots in potato plants (Bambawale, 1986). The performance of EDU-treated plants was better as compared to plants grown without EDU and this was attributed to the protective role of EDU against ozone damage (Clarke et al., 1990; Smith et al., 1987).

3

Prevention of crop loss from air pollution is an important aspect of crop protection. A diverse group of chemical compounds such as: antioxidants, anti-senescence compounds, anti-transpirants, growth regulators, growth retardants, pesticides and even dust have been tried for protecting plants from ozone damage (Manning, 1999). Chemical plant protectants can serve as an effective measure if their production and application becomes safe, easy and cost effective. Exploratory studies have shown that ethylene diurea (EDU), an antioxidant, protects cereals, legumes and vegetables plants from ozone damage (Hofstra *et al.*, 1978; Brennan *et al.*, 1990; Heggestad, 1988; Clarke *et al.*, 1990; Kostaka-Rick and Manning, 1992, 1993; Miller *et al.*, 1994; Astorino *et al.*, 1995; Brunschon-Harti, 1995a, 1995b; Hassan *et al.*, 1995; Tonneijck and Vandijk, 1997a, 1997b, 2002a, 2002b; Wahid *et al.*, 2001). Ethylene diurea (EDU) has been used as a tool for determining crop losses from ozone pollution (Carnahan *et al.*, 1978).

Varshney and Rout (1998) have shown that the yield loss in field-exposed plants of soybean and tomato on account of ambient ozone level was quite significant. In case of soybean, yield loss from ambient ozone was about 16-31% in untreated plants as compared EDU treated soybean plants exposed to ambient ozone. The biomass of tomato reduced by 24% as compared to EDU treated plants. Most of the EDU related studies have been carried out with plants artificially exposed in fumigation chambers to ozone concentrations which were much higher as compared to the values of ozone reported in the ambient environment. Moreover, ozone fumigation schedules were restricted only to few hours per day. Results from such fumigation experiments are difficult to extrapolate for assessing the effect of ground level ozone pollution on field grown crops. Systematic studies on the effect of ground level ozone covering the entire crop cycle are lacking in spite of increasing build up of ground level ozone in India and other part of the world (Varshney and Rout 1998; Krupa *et al.*, 1995, 1998, 2000).

The present study was undertaken to determine the effectiveness of ethylene diurea (EDU) in preventing ozone damage in wheat (*Triticum aestivum*), moong (*Phaseolus aureus*), mustard (*Brassica campestris*) and paalak (*Spinacia oleracea*) exposed to ambient ground level ozone at Delhi and Faridabad. Experiments with plants exposed to ozone in fumigation chambers were also carried out to corroborate field observations.

The specific objectives of the study were as follows:

1. To measure ground level ozone, at different sites in urban and peri-urban environments, in Delhi and Faridabad.

2. To assess crop damage from ground level ozone in case of four field-grown crop plants namely, wheat (*Triticum aestivum*), moong (*Phaseolus aureus*), mustard (*Brassica campestris*) and paalak (*Spinacia oleracea*) using transplant experiments.

3. To carry out controlled fumigation experiments for validating field observations.

Chapter-II

Review of Literature

"To the philosopher, the physician, the meteorologist, and the chemist, there is perhaps no subject more than that of ozone" (Fox, 1873).

Ozone is an important component of the stratosphere i.e., between 15 and 50 km above the surface, where it is formed naturally, when molecular oxygen (O_2) absorbs ultraviolet radiations. In the atmosphere about 90% of ozone is present in the stratosphere and only 10% is present in the troposphere (Lelieveld and Dentener, 2000). Stratospheric ozone layer protects life on earth from harmful ultraviolet radiations (about 210 to 290 nm: radiation < 280 nm is UV-C and 280 to 315 nm is UV-B). Unlike stratospheric ozone layer, the tropospheric ground level ozone is formed through a series of complex photochemical reactions; it is extremely harmful to plants and animals. Globally tropospheric ozone is expected to increase by 0.3 to 1.0% per year over the next 50 years (Chamedies *et al.*, 1994).

Ozone in the Troposphere

The source of O_3 in the troposphere is both natural and anthropogenic. Earlier, it was assumed that ozone in troposphere comes from stratosphere-troposphere exchange (STE) across the extra-tropical tropopause. (Regener, 1957; Junge, 1962; Danielsen, 1968; Dutch, 1971). This was supported by the observed gradient of ozone with altitude, suggesting a source at the tropopause and a sink towards the surface. In the 1960s, *in situ* photochemical ozone formation in the troposphere drew attention as it was shown that the breakdown of hydrocarbons could cause ozone episodes in urban environment during the summer season (Haagen-Smit and Fox, 1956; Leighton, 1961). In subsequent years, two different schools of thoughts evolved about the origin of tropospheric ozone: one emphasized the role of *in situ* photochemical formation of ozone (Crutzen, 1974; Chamedies and Walker, 1976; Fishman *et al.*, 1979; Bielke, 1987; Crutzen *et al.*, 1985; Logan, 1985), and the other emphasized the ozone transport from the stratosphere i.e., intrusion of stratospheric ozone (Chatfield and Harrison, 1976; Fabian and Pruchniewicz, 1977; Singh *et al.*, 1978, 1980; Johnson and Viezee, 1981; Levy *et al.*, 1985). Recently, three-dimensional global chemistry transport (3-D) models have shown that tropospheric ozone formation is dependent on photochemical and meteorological processes (Crutzen and Zimmerman, 1991; Levy *et al.*, 1997; Wang *et al.*, 1998; Crutzen *et al.*, 1999). Results of this model indicate that the mean global tropospheric O_3 column is 350 ± 80 Tg, the transport from the stratosphere accounts for 550 ± 300 Tg yr^{-1}, the net contribution by *in situ* photochemistry is 150 ± 300 Tg yr^{-1},

and the dry deposition completes the budget through the removal of 700 ± 300 Tg yr^{-1} (Lelieveld and Dentener, 2000). These source and sink terms are suggestive of an important role of Stratosphere and Troposphere Exchange (STE). However, net *in situ* photochemistry is the residual of much larger O_3 formation and loss terms, being in the order of 3000-3500 Tg yr^{-1}. Globally, these terms are in approximate balance. Locally, however, this may be very different, which determines the highly variable distribution of ozone. During the past decades, ozone in the troposphere has been steadily increasing mainly on account of growing emission of ozone forming substances from fossil fuel consumption (Finlayson-Pitts and Pitts, 1999). Ozone in the troposphere contributes about 7% to the global warming (Krupa, 1997).

In situ Ozone Formation

Ozone is a secondary pollutant and formed readily in the troposphere through a complex series of photochemical reactions involving ozone precursors namely hydrocarbons (including CH_4), CO and NO_X largely emanating from vehicles (Krupa and Manning, 1988; Crutzen and Zimmermann, 1991). White *et al.,* (1976) estimated that one to two parts of O_3 were produced for each part (as carbon) of non-methane hydrocarbons emitted by the source. The chemistry of the tropospheric ozone formation is given below in the reaction pathways in Table-2.1and Figure-2.1.

Table 2.1: Reactions leading to ozone synthesis.

$O_3 + h\nu = O\,(^1D) + O_2\ (\lambda \leq 310\ nm)$
$O\,(^1D) + H_2O = 2\ OH^-$

$O_3 + H_2O = 2OH^- + O_2$
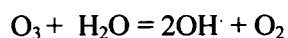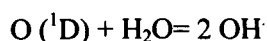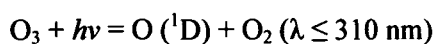
a) Formation of ozone by carbon monoxide and nitric oxide in the atmosphere is given below (Crutzen and Zimmermann, 1991) and the reaction sequences are as follows:

$CO + OH^- = H^- + CO_2$
$H + O_2 + M = HO_2^- + M$
$HO_2^- + NO = OH^- + NO_2$
$NO_2 + h\nu = NO + O\ (\lambda \leq 400\ nm)$
$O + O_2 + M = O_3 + M$

$CO + 2O_2 = CO_2 + O$

7
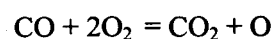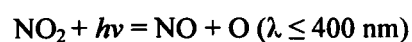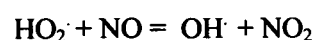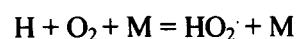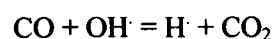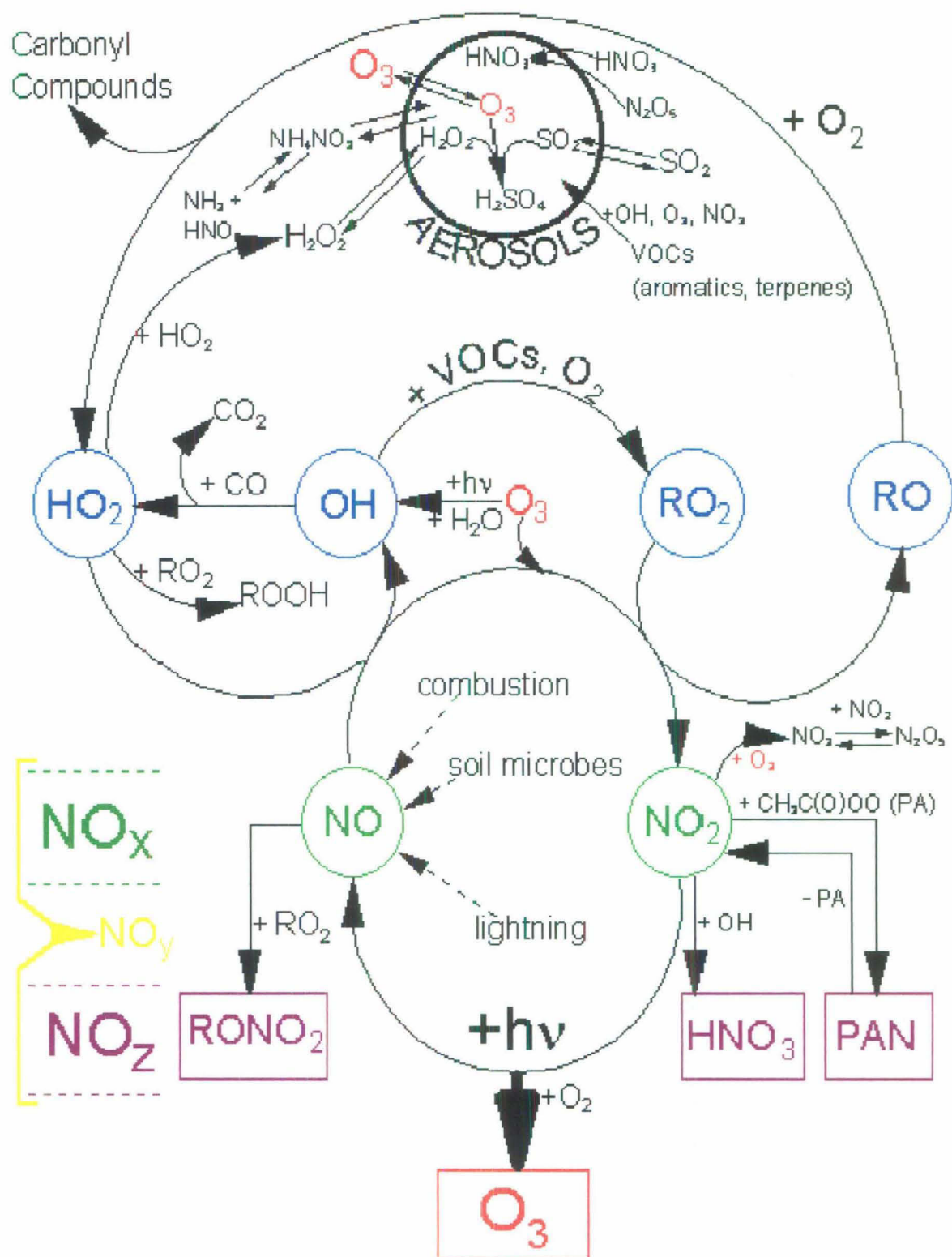
Figure 2.1: Chemistry of tropospheric ozone formation (after USEPA, 1996).

b) The only feasible route for the production of ozone in the polluted troposphere is the photolysis of NO_2 :

$$NO_2 + hv = NO + O$$
$$O + O_2 + M = O_3 + M$$
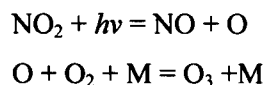
However rapid formation of NO by O_3 maintains an overall balance between oxidizing and reducing agents:

$$NO + O_3 = NO_2 + O_2$$
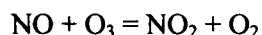
The presence of peroxy radicals (RO_2) produced by the degradation of hydrocarbons leads to new ozone formation as follows:

$$RO_2 + NO = RO + NO_2$$
$$NO_2 + hv = NO + O$$
$$O + O_2 + M = O_3 + M$$

$$\overline{RO_2 + O_2 = RO + O_3}$$
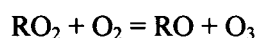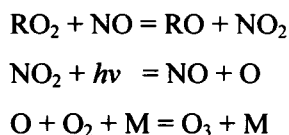
c) Formation of ozone by methane in the atmosphere is given below (Crutzen and Zimmermann, 1991) and the reaction sequences are as follows:

$$CH_4 + OH^. = CH_3^. + H_2O$$
$$CH_3^. + O_2 + M = CH_3O_2^. + M$$
$$CH_3O_2^. + NO = CH_3O^. + NO_2^.$$
$$CH_3O^. + O_2 = HCHO + HO_2^.$$
$$HO_2^. + NO = OH^. + NO_2^.$$
$$2[NO_2^. + hv = NO + O]$$
$$2[O + O_2 + M = O_3 + M]$$

$$\overline{CH_4 + 4O_2 + hv = H_2O + HCHO + 2O_3}$$
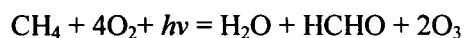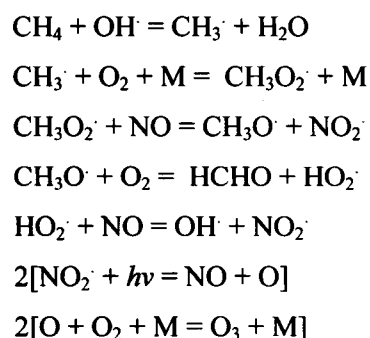
The reactions, which are involved in O_3 formation, were worked out by Haagan-Smit and Fox (1956). The oxidation of HCs and VOCs in the presence of NO_x and sunlight; represent the basic mechanism of photochemical smog formation (Haagan-Smit and Fox, 1956, Seinfeld, 1988; 1989).

$$RH + OH \rightarrow R + H_2O \text{------------------------------------(R1)}$$

$$R + O_2 + M \rightarrow RO_2 + M \text{-----------------------------------(R2)}$$

$$RO_2 + NO \rightarrow RO + NO_2 \text{----------------------------------(R3)}$$

$$RO + O_2 \rightarrow HO_2 + RHO \text{----------------------------------(R4)}$$

$$HO_2 + NO \rightarrow OH + NO_2 \text{----------------------------------(R5)}$$

$$2NO_2 + h\nu \rightarrow NO + O \text{------------------------------------(R6)}$$

$$2O + O_2 + M \rightarrow O_3 + M \text{------------------------------------(R7)}$$

Net: $RH + 4O_2 + h\nu \rightarrow RCHO + 2H_2O + 2O_3$
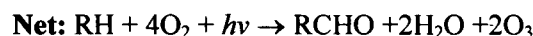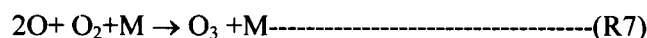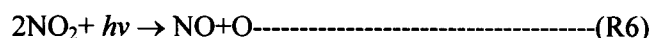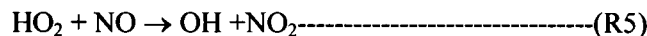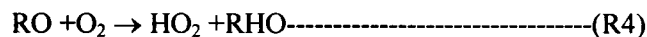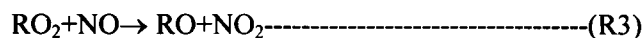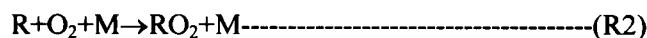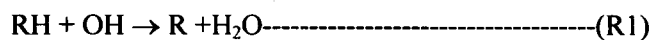
Minor pathways of ozone formation in many urban, sub-urban and rural regions are (Seinfeld, 1989):

$$CO + OH \rightarrow CO_2 + H$$

$$H + O_2 + M \rightarrow HO_2 + M$$
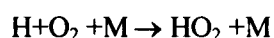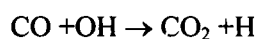
Followed by R5, R6 and R7.

Solar UV radiations dissociate a range of stable molecule to form hydrogen containing free radicals (HO_X). In the atmosphere with sufficient NO_X, free radicals catalyse oxidation of VOCs leading to the formation of O_3 as a by-product. Ozone formation and its destruction are dependent upon oxides of nitrogen. It is for this reason ambient ozone levels may vary widely in time and space. If NO_X concentration is less than 20 parts per trillion (ppt), the photochemical process leads to net O_3 destruction and if NO_X concentration is high in the atmosphere i.e., > 20 ppt, then it leads to ozone formation (Flower *et al.,* 1999). However, it is important to note that there are substantial areas of the troposphere in which O_3 is consumed. In clean air with ambient NO_2 concentration smaller than that about 20ppt, the oxidation of HCs forms RO_2 (peroxy radicals), which react with HO_2 (hydroxy radicals) forming peroxides and thus terminating the reaction sequence (Figure-2.2). When NO_X levels are greater than odd-hydrogen ($OH + HO_2$), the primary free radical loss pathway reaction with NO_2 is given below:

$$OH + NO_2 + M \rightarrow HNO_3 + M$$

The production of O_3 becomes limited by the supply of VOCs and NO_X, whose oxidation leads to secondary production of odd-hydrogen and there is an excess of free

radicals (Luo *et al.*, 2000). Under these conditions the primary free radicals loss pathway occurs via;

$$HO_2 + HO_2 + M \rightarrow H_2O_2 + M$$

(a) POLLUTED ATMOSPHERE
NO$_2$ > 20 ppt

(b) CLEAN ATMOSPHERE
NO$_2$ < 20 ppt
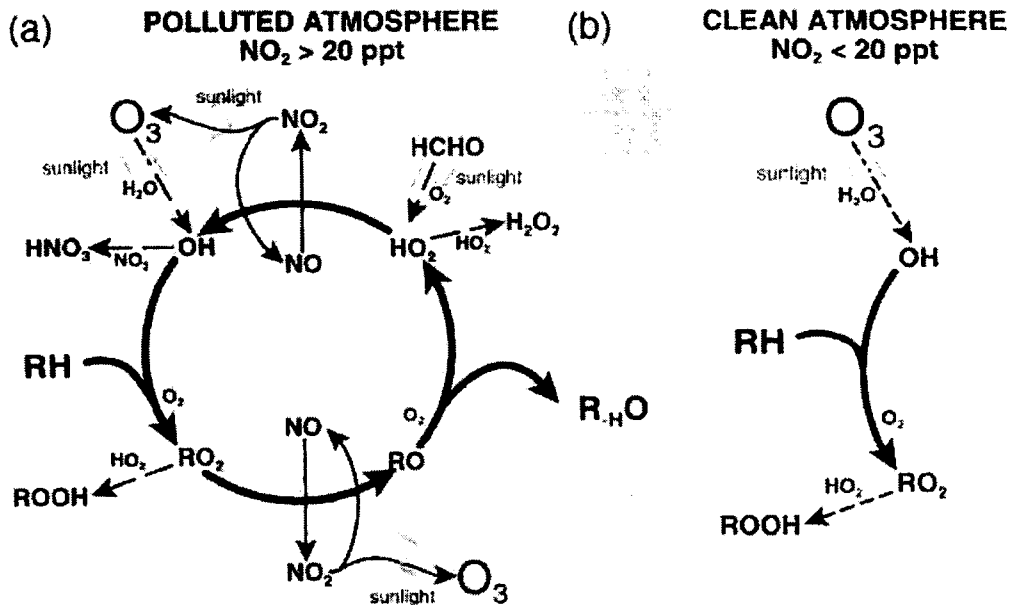
Figure-2.2: Photochemical production of ozone (a) a polluted atmosphere (b) a clean atmosphere (after Flower *et al.*, 1999).

The photochemical mechanism responsible for ozone production in lower atmosphere becomes nonlinear, and the peak ozone concentration depends on the availability of its precursors: VOCs and NO$_X$ and their ratio, which varies from one locale to another (Lou *et al.*, 2000). The factors, which determine the direction of the reaction include:

1. Ratio between VOC and NO$_X$ in the ambient environment at a given time and space.

2. Relative reactivity of the VOC species.

3. Meteorological conditions which control the rate of transport of ozone precursors from source region to rural sites.

4. The emission of NO/NO$_2$ depends on the action soil bacteria.

5. The quantum of biogenic VOCs emission.

Long Range Transport of Ozone and its Precursors

Presence of ozone in rural areas which are relatively free from pollution is due to the long range transport of ozone and ozone forming precursors (Coffey and Stasiuk, 1975; Rubino *et al.*, 1976; White *et al.*, 1976; Rodes and Holland, 1981; Westberg *et al.*, 1981; Gusten *et al.*, 1988; Hov, 1990; Derwent and Jenkin, 1991; Hakola *et al.*, 1991; Wild and Akimoto, 2001; Prather *et al.*, 2003). Volatile organic carbon compounds and oxides of nitrogen, which are the key ozone precursors can be transported to hundred of kilometres from emission sources across air shed. In most of the agricultural areas in the United States and Europe, ozone concentrations were reported two to three times over its levels in urban and industrial areas, which in fact, were the prime foci-emitting ozone precursors. The relatively elevated ozone levels at rural sites can be attributed to favourable photochemical conditions during downwind transport of ozone precursors. White *et al.* (1976) have successfully tracked out the St. Louis urban plume in the down wind direction up to 240 km, and mapped the details of the plume up to 160 km. Over these distances the plume was well defined and 50km wide. Ozone concentration within the plume was higher than either side of the plume, which was ≤ 0.08 ppm and a peak of 0.17 ppm was found at a distance of 66 km from the origin point within the plume (White *et al.*, 1976).

Intrusion of Stratospheric Ozone

Deep and rapid intrusions of the lower stratospheric ozone into troposphere by jet streams (low-pressure trough system) through tropopause folding (TF) (Singh *et al.*, 1978, 1980; Johnson and Viezee, 1981) or mean meridional circulation (MMC) (Singh *et al.*, 1978, 1980) are the most likely natural mechanisms ozone intrusion in the lower troposphere. Singh *et al.* (1980) have estimated that a small amount of stratospheric ozone can trigger chemical reactions resulting in dis-proportionate increase in ozone production in the polluted atmosphere. In this regard, two mechanisms have gained theoretical and experimental support: (i) coupling of free troposphere to a frontal zone associated with a cold front and transport to the surface by frontal down drafts, or (ii) entertainment of frontal or pre-frontal convection with transport to the surface through down drafts with associated rain showers or thunder storms. Generally, the episodic injections from the stratosphere occur five-six times a year, accompanied by frontal

transit from the north to north-west layers in the troposphere and a parallel current in the upper layer (Singh *et al.*, 1978, 1980).

Tropospheric Ozone Trend

Most of the ground level ozone measurements have been largely confined to 35-60^{0}N latitudes particularly from USA, Canada and Europe, in addition to some information from Australia and Japan. Ozone values reported in literature show a steady increase in tropospheric ozone over the last 20 years in Europe, N. America, Australia and Japan (Feister and Warmbt, 1987; Fishman *et al.*, 1979; Stevens, 1987; Ogawa and Miyata, 1985). In Europe, ozone concentration had increased by 1-2% per year over the last three to four decades (Hartmannsgruber and Claude, 1985). Ground level ozone build up is not only restricted to industrialised countries but high ozone levels have been also reported from increasing number of stations from developing countries including India (Kanbour *et al.*, 1987; Varshney and Aggarwal, 1992; Wahid *et al.*, 1995; Zhang *et al.*, 1998; Ganor *et al.*, 1978; Logan, 1985; Stevens, 1987). Ozone concentration at Delhi varied between 20 to 273µg/m^3, and one-hour WHO ozone standard 110µg/m^3 was violated on many occasions (Varshney and Aggarwal, 1992). At Ahmedabad the average ozone concentration increased from 14.7 ppbv during 1954-55 to 25.3 ppbv during 1991-93 representing a linear increase of 1.45% per year (Naja and Lal, 1996). Measurement values at Varanasi (Pandey *et al.*, 1992) and Ahmedabad suggest that ground level ozone build up in India is not an isolated instance but it is increasing both in intensity and geographical spread. Global and Indian scenarios are discussed below to provide an overview of the recent trends of tropospheric ozone.

Tropospheic Ozone: Global Overview

The presence of photochemical oxidants in tropospheric air were recognized since 1940s in Southern California, where steps were taken for the first time for controlling emission of O$_3$ precursors as early as 1960s. In 1988, Crutzen estimated that the maximum tropospheric ozone column produced per year is of the order of 6.5 x 10^{11} molecules cm^2/s. The concentration of tropospheric surface ozone at different regions is mainly controlled by *in-situ* photochemistry, which depends on its precursors, their emission pattern, rate of transformation and deposition. Increasing emission of ozone precursors has led to a marked increase in the background ozone concentration since

the industrial revolution (Ashmore and Bell, 1991). Monitoring of surface ozone has been carried out at many places in developed countries (Karenlampi and Skarby, 1996; USEPA, 1996). The O_3 monitoring data show that over past 50 years there has been an appreciable build up of ground level ozone over its background levels of 10-20 ppb (Singh *et al.*, 1978).

High ozone levels have been also reported from some developing countries namely Baghdad (Kanbour *et al.*, 1987), India (Varshney and Aggarwal, 1992), Pakistan (Wahid *et al.*, 1995) and China (Zhang *et al.*, 1998). Information from Asia-Pacific region (Ganor *et al.*, 1978), South America (Logan, 1985) and Africa (Stevens, 1987) is rather scanty, the available data show significant build up of ozone in the region.

Except for few stray observations, information on ozone levels over the oceanic regime, which covers almost 3/4th of the globe, is extremely limited. Suhre *et al.* (1997) reported up to 500 ppbv ozone over Tropical Atlantic between 10 -12 km and very low levels (<10 ppbv) from equatorial Pacific Ocean (Kley *et al.*, 1994).

High ozone levels in the extra tropical Northern Hemisphere are not surprising, given the growing sources of ozone precursors. Reliable historical or time series data on surface ozone are rare. Even where such information on ozone level is available, it is difficult to compare them due to the variation in measurement techniques used by different workers. Estimates of production and loss of total tropospheric ozone in the two hemispheres are given in the Table 2.2.

Table 2.2: Estimate of production and loss of total tropospheric O_3 (cm^2 s^{-1}) in the two Hemispheres (after Liu *et al.*, 1988).

Region	N. Hemisphere	S. Hemisphere
Free troposphere above 2 km	5×10^{10}	2.5×10^{10}
Ocean boundary layer	-4.5×10^{10}	-4.5×10^{10}
Clean continental boundary layer	-5.5×10^{10}	-1.0×10^{10}
Biomass burning area	0.2×10^{10}	0.2×10^{10}
Industrial area	~ 1 to 3×10^{10}	~ 0.5 to 1.5×10^9
Stratospheric flux	7×10^{10}	4×10^{10}

- indicate loss

In the South East Asian countries biomass burning includes clearing of forest and bush land, fire wood burning, pest, insects and weeds control, nutrient mobilization and removal of bush and litter contributes to ozone formation (Crutzen and Andreae, 1990; Levine, 1991). It has been estimated that approximately 85% of biomass burning takes place in tropical countries (Andreae, 1991). Global annual biomass burning represent about 1.8 to 4.7 GT of carbon burned (Crutzen and Carmichel, 1993). Burning of biomass emits NO_X (NO_2 + NO), CO and VOC. The oxidation of methane, CO and other hydrocarbons in NO_X enriched environment leads to ozone formation. According to Galanter et al. (2000) biomass burning indirectly contributes to more than 15% of the total tropospheric ozone in tropics and 10 to 20% in the Southern Hemisphere from September to November. An estimate of ozone emission precursors from different sources category for the year 1860, 1993 and 2025 is given in Table 2.3.

Table 2.3: Estimated annual global emission of O_3 precursors for the years 1860, 1993 and 2025 (after Lelieveld and Dentener, 2000).

Sources Category	CO Tg C yr^{-1}			NMHC Tg yr^{-1}			NO_X TgN yr^{-1}		
	1860	1993	2025	1860	1993	2025	1860	1993	2025
Energy use									
Fossil fuel consumption	2	112	142	1	37	67	0.3	24.4	41.1
Fossil fuel production	-	-	-	0	26	65	0.4	1.3	1.3
Bio-fuel combustion	22	83	83	8	32	32	-	-	-
Air-craft	-	-	-	-	-	-	0	0.5	1.6
Industrial process	6	15	18	0	56	102	0	1.5	2.8
Biomass burning									
Savannah burning	24	77	95	5	15	17	0.9	3.1	3.6
Tropical deforestation	8	48	71	1	8	12	0.2	1.1	1.6
Temperate wildfires	90	46	50	7	4	4	1.6	0.8	0.9
Agriculture waste burning	36	89	156	5	16	19	0.9	2.2	3.9
Agriculture soils							0	2.2	4.5
Natural vegetation soils	115	115	115	403	403	403	3	3	3
Lightning	-	-	-	-	-	-	5	5	5
NOx from stratosphere	-	-	-	-	-	-	0.6	0.6	0.6
Natural	205	161	165	410	407	407	10.2	9.4	9.5
Anthropogenic	98	424	565	20	190	314	2.7	36.3	60.4
Total	303	585	730	430	597	721	12.9	45.7	69.9

Here NMHC is non-methane hydrocarbons; Tg $=10^{12}$g

15

Tropospheric Ozone: Indian Scenario

India is one of the rapidly growing economies in the Asian region. Large emission of anthropogenic and biogenic trace gases and relatively high solar intensity provide most favourable conditions for the formation of photochemical oxidants. Ground level ozone measurements in India are available for the following locations namely, Delhi, Varanasi, Chandigarh, Ahmedabad, Pune, Agra, Bhubaneswar, Berhampur and Cochin (Table 2.4). Surface ozone at Varanasi varied between 20 -152 $\mu g/m^3$ (10-76ppb, 2 hr average) (Pandey et al., 1992). At Pune tropospheric ozone concentration ranged between 2-68 $\mu g/m^3$ (1-34 ppb, 1 hr mean) (Khemani et al., 1992). Tewari and Peshin (1995) reported that surface O_3 concentration at Pune during 1988-91 had increased at a rate of 0.03% per year (Table 2.5). The concentration of ground level ozone at Chandigarh was monitored by CSIO (Central Scientific Instruments Organization) from April 1984 to December1984 and November 1990 to March 1992. Average values of these two periods were 88.2 and 84.28 $\mu g/m^3$ (0.045 and 0.043 ppm) and the maximum values were 115.64 and 101.92 $\mu g/m^3$ (0.059 and 0.052 ppm) respectively. Ozone concentration at Ahmedabad during 1993-94 was 50.6 ± 31.4 $\mu g/m^3$ (25.3 ± 15.7 ppbv) (Naja and Lal, 1996). Lal et al. (2000) have reported that ozone concentration at Ahemedabad increased by 0.49% from 1993 to 1996 (Table 2.5). The ground level ozone concentration measured by Carmichael et al. (2003) by using passive samplers at Agra, Bhubaneswar, Berhampur (Orissa) and Cochin between September, 1999 to June, 2001 showed that the average ozone concentration during this period was 60.37$\mu g/m^3$ (30.8 ppb), 61.54$\mu g/m^3$ (31.4 ppb), 46.45$\mu g/m^3$ (23.7 ppb) and 23.13$\mu g/m^3$ (11.8 ppb) respectively. The Central Pollution Control Board, made a small beginning of ozone monitoring at few locations after 1997. Monitoring sites were only confined to traffic cross sections in the urban environment, where emission of ozone forming and destroying substances were relatively high and have low ozone levels. Ozone status in rural and remote areas is not known, where potential damage to agriculture from ozone is very high (Table 2.4). A summary of Indian data on ozone is given in Table 2.4.

Ground Level Ozone Scenario in Delhi

Studies on ground level ozone at Delhi were initiated in 1989. Average monthly values were reported in the range of 54.88-58.8 $\mu g/m^3$ (September 1989-January 1990) and 76.44-81.33 $\mu g/m^3$ (March-June, 1990) (Varshney and Aggarwal, 1992). The

subsequent ozone measurements were carried in urban and peri-urban locations (Singh *et al.*, 1997; Varshney and Rout, 1998; NAAQMS, 1999; 2001). Singh *et al.* (1997) have reported that the daytime ozone concentration was 100 ppb during the winter months in 1993. According to Srinivasan *et al.* (1997) ground level ozone concentration during 1992-1996 has increased at a rate of 0.74% per year (Table 2.5). During 1996-97 ambient ozone levels varied between 46-65 $\mu g/m^3$ (Aug-Oct, 1996) and 88-90 $\mu g/m^3$ (Mar-Jun, 1997) (Varshney and Rout, 1998).

Table 2.4: Concentrations of ground level ozone reported from different stations in India.

Station	Year	Surface O_3 level ($\mu g/m^3$)	Reference
Delhi	1989-91 1993 1996-97 1998 1999	55 - 82 21-333 46 - 90 26 to 82 19.6-104	Varshney and Aggarwal, 1992 Singh *et al.*, 1997 Varshney and Rout, 1998 NAAQMS, 2001 NAAQMS, 2001
Ahemdabad	1994	18 – 110	Naja and Lal, 1996
Varanasi	1990-92	20 – 152	Pandey *et al.*, 1992
Pune	1992	2 – 68	Khemani *et al.*, 1992
Chandigarh	1984 –92	58 –114	CSIO, 1992
Agra	September, 1999-June, 2001	60.37	Carmichael *et al.*, 2003
Bhubaneswar	September1999-June, 2001	61.54	Carmichael *et al.*, 2003
Berhampur	September, 1999-June, 2001	46.45	Carmichael *et al.*, 2003
Cochin	September, 1999-June, 2001	23.13	Carmichael *et al.*, 2003

Table 2.5: A comparison of ground level ozone build-up rate at few locations in India.

Site	Rate of O_3 build up	Reference
Ahemdabad	0.49% (Jan1993-Mar 1996)	Lal *et al.*, 2000
Pune	0.03% (Jan 1988-July 1995)	Tiwari and Peshin, 1995
New Delhi	0.74% (Mar 1989-Sep 1997)	Srinivasan *et al.*, 1997

Till date ozone monitoring has been carried out only at 17 locations in Delhi. A summary of ground level ozone concentrations at different sites in Delhi during 1989-2000 is given in Table 2.6. The ozone monitoring by the Central Pollution Control Board (CPCB) started only after 1997 and its stations are located at traffic intersections in the city and there are no data measurements in peri-urban and rural areas where lies

the major threat of ozone pollution to agricultural crops. The ground level ozone concentration is going to increase in Delhi as the growth of transport sector has experienced many fold increase as the total number of motor vehicles have increased from 0.2 in 1971 to 3.55 million in 2000 (APR, 2002). In Delhi, transport sector is found to be the biggest emission source of ozone precursors (NO_X 49%; HCs 97%) followed by power sector (NO_X 44%; HCs 0.5%), industrial (NO_X 6%; HCs 2%), and domestic (NO_X 1%; HCs 0.5%) (CPCB, 1995) (Table 2.7). An estimate by TERI (1993), shows that by the year 2009-2010 emission of ozone precursors in Delhi will increase by 112.9% from the base year 1990-1991, which will translate into many fold increase in the concentration of ground level ozone (Table 2.7).

Table 2.6: Ground level ozone at different sites in Delhi 1989-2000.

Different sites	O_3 concentration range ($\mu g/m^3$)	Year	Reference
JNU	20-273 (1989-90)		
Mehrauli	33-243 (1990-91)	August, 1989-August, 1991	Varshney and Aggarwal, 1992
Vikas Minar	(average of all the		
Pitampura	4 sites)		
Parliament Street	110-333		
Darya Ganj	66-333		
Pahar Ganj	55-266	January-February, 1993	Singh *et al.*, 1997
Karol Bagh	21-333		
Ashram	55-222		
Vasant Kunj	110-233		
Tilak Bridge	57-71		
Ashram	41-75	August- October 1996	Rout, 1997
Maidangarhi	19-81		
JNU	32-80		
Tilak Bridge	62-114	March- June 1997	Varshney and
Jonapur	36-119		Rout, 1998
JNU	61-125		
B. Z. Marg	19.6-104	Januray -December, 1998	NAAQMS, 2001
B. Z. Marg	19.6-82.0	Januray -December, 1999	NAAQMS, 2001
B. Z. Marg	19.6-82.0	Januray-December, 2000	NAAQMS, 2001

Table 2.7: Emission of O_3 precursors from transport sector 1990-91 to 2009-10 (after TERI, 1993).

Year	NO_X ('000 tonne)	HCs ('000 tonne)
1990-91	16.12	73.0
1994-95	19.95	90.35
2000-01	25.70	116.39
2000-05	29.53	133.75
2009-10	34.32	155.44

Effect of ozone on plants

The adverse effects of ozone on plants were recognized way back in 1905, when vegetable crops in Los Angeles suffered adversely from air pollutants and led to a series of investigations to identify the cause of crop damage. The smog chemistry studies by Haagen-Smit and Fox (1956) and Darley et al. (1959), promoted air pollution research on crop plants. Middleton et al. (1950) and Haagen-Smit and Fox (1956) reported that a mixture of the NO_2 and olefins induced injury to plants was similar to the vegetable damage observed in Los Angeles. Ozone, a major oxidant in smog, formed from photochemical reaction between hydrocarbons and NO_X was identified as the main cause of crop damage (Darley et al., 1959). Extensive damage to crops and forests from air pollution has been attributed to ozone (Ashmore et al., 1985; deBauer et al., 1985; Krause et al., 1983). Ozone is highly toxic to living beings. It cannot be used anywhere in the normal metabolism; in contrast to other air pollutants such as nitrogen oxides, ammonia, or sulphur dioxide that might serve as plant nutrient, when present in low concentrations (Prince and Ross, 1972; Cowling and Lockyer, 1978).

To begin with studies on plant damage from ozone pollution were mainly based on field studies restricted to the identification and description of injury symptoms (Middleton et al., 1950). Although field studies provided valuable information but it was difficult to attribute the observed injury to ozone with certainty because plants in the field were generally exposed to a mixture of air pollutants. Subsequently, dose response studies were undertaken to evaluate ozone injury in plants at morphological, physiological and biochemical levels.

Morphological Ozone Injury Symptoms

Ozone injury appears as small flecks (white, red, black or bronze) or stipples on the interveinal areas of the upper surface of leaves. Foliar injury is inter-veinal, along the main vein and generally limited to the upper leaf surface in older and middle-aged leaves, but may also involve both leaf surfaces (bifacial) in some species. Inter-veinal leaf tissue collapses but the main vein remains green. In case of severe injury, leaf veins may be also affected. Several other symptoms also commonly associated with O_3

exposure; include flecks (tiny light-tan irregular spots less than 1mm diameter), stipples (small darkly pigmented areas approximately 2-4 mm diameter), bronzing, and reddening. These flecks may coalesce to form areas of chlorosis with aging of leaf (PROG, 1987; Prinz, 1988; Colbeck and Mackenzie, 1994; Mills *et al*, 2001). Some times no visible injury symptoms were found in plants but a marked difference were observed in different yield parameters such as: shoot length, shoot biomass, leaf size, number of flowers per plant, pod size, pods per plant, seeds per pod and seed yield are found to be reduced due to ozone stress (Ashmore and Marshall, 1998). For example, in winter wheat and oilseed rape no visible injury was observed, although a loss in grain and straw yield of winter wheat dropped by 13% and 8% respectively and oilseed rape there was a drop of 14% seed yield and 38% drop in yield of flowering branches. (Ollerenshaw *et al.*, 1999a, 1999b). Seed quality of oilseed rape deteriorated due to exposure to elevated O_3 concentrations. The type and severity of injury depends on several factors including concentration of O_3, duration of exposure, weather conditions, and plant genetics. Classical symptoms (stippling, flecking, bronzing, and reddening) are gradually obscured by chlorosis and necrosis, when plants were exposed to ozone continuously for many days (Table 2.8).

Depending upon concentration and duration of exposure plants may suffer from acute or chronic damage.

1. Plants may suffer from acute damage from relatively high dose of pollutant experienced on a given day or on recurring basis. Injury symptoms manifest within a few to several days after the acute exposure. Acute response involves rapid and drastic changes in physiological and bio-chemical plant processes (Schulte-Hostede *et al.,* 1988).

2. Chronic response arises from prolonged exposure to low concentration of gaseous pollutants for weeks, months or over the entire crop season. Chronic response manifests as foliar chlorosis, retarded growth, premature foliar abscission, retarded flowering, flower abscission, reduced biomass, economic yield and poor nutritional quality of consumable plant product (Kickert and Krupa, 1990). The chronic effects are of major concern in the context of agricultural plants, particularly because growth and yield may suffer adversely without showing any visible foliar injury symptoms.

The acute and chronic ozone injury symptoms and foliar injury symptoms in crop plants are given in Tables 2.8 and 2.9.

Table 2.8: Acute and chronic injury symptoms of ozone.

Acute Injury	Chronic Injury
Flecking: small necrotic area due to death of palisade cells, metallic or brown, failing to tan, grey or white Strippling: tiny punctuate spots where a few palisade cells dead or injured, may be white, black, red or red purple	Pigmentation (bronzing): leaves turn red brown as phenolic pigments accumulates Chlorosis: may result from pigmentation or may occur alone as chlorophyll breaks down. Premature senescence: early loss of leaves or fruits

Table 2.9: Illustrative examples of foliar ozone injury in crop plants.

Crop		Injury Symptoms
Bean	(*Phaseolus*)	Bronzing and chlorosis
Cucumber	(*Cucumis*)	White stipple
Grape	(*Vitis*)	Red to black stipple
Morning Glory	(*Ipomoea*)	Chlorosis
Onion	(*Allium*)	White flecks and tip dieback
Potato	(*Solanum*)	Grey fleck and chlorosis
Soybean	(*Glycine*)	Red-bronzing and chlorosis
Tobacco	(*Nicotiana*)	Metallic to white fleck
Watermelon	(*Citrullus*)	Grey fleck

Ozone Uptake by Plants

Ozone enters leaves through stomata during normal gas exchange. As a strong oxidant O_3 (or free radicals formed from the oxidation by O_3) causes several types of symptoms including chlorosis and necrosis. Morphological change, due to ozone includes

21   TH-11156

corrosive effect of ozone on the cuticle (a waxy layer that covers the surfaces of plant leaves). Uptake of ozone at a given atmospheric concentration is largely but not solely determined by the size of the stomatal pore. Environmental conditions favouring stomatal opening occurs at low concentrations, below the threshold for effect and closure occurs at injurious concentration (Darrall, 1989).

Once ozone molecules enter through stomatal pore into the leaf, and react with compounds in the cell wall and the cells surrounding the stomatal cavity. Most of the ozone is destroyed here, forming free radicals, which have detrimental effect on plasmalemma (the outer bio-membrane of a cell). Only a minor part of the ozone entering the leaf will pass through the plasmalemma. Thus, the ability of a cell to defend its outer membrane against attack by free radicals is the most important feature determining the ozone sensitivity. Ascorbic acid and some other antioxidants have been found to act as free radical scavengers in apoplast, thus preventing injury to plasma-lemma.

However, plants may suffer from other stresses, such as attack by phytopathogenic fungi, chilling and drought from the formation free radicals. Resistance mechanisms in plants have evolved the damage from free radical attack. Thus, plants respond to free radicals generated from ozone similar to the formation of free radicals from any other stress factors (e.g. phytopathogenic fungi).

Physiological Changes due to Ozone

Ozone reduces important physiological processes such as: photosynthesis, respiration, carbon allocation and stomatal function in plants (Darrall, 1989). Photosynthesis is highly sensitive to ozone and its suppression occurs well before the appearance of visible injury (Furukawa *et al.,* 1984). Ozone inhibits photosynthesis by influencing the chlorophyll content and electron transport system in photosystems PS-I and PS-II (Heath, 1994). Prolonged exposure of ozone results in the inhibition of electron transport chain between PS-II and PS-I (Schreiber *et al.,* 1978, Heath, 1994). It has been reported that 0.02 ppm to 1.0 ppm of ozone can reduce photosynthesis 5 to 80% under short and long term ozone fumigation (Heath, 1994).

Ozone stress enhances plant respiration possibly to meet the excessive energy demand for repair of the damaged cells (MacDowall, 1965a, 1965b; Heath, 1994). Ozone stress also affects the carbohydrate and lipid metabolism as well as amino acid and protein content in plants (Heath, 1994).

Inhibition of RuBP carboxylase by ozone: The inhibition of RuBP carboxylase by ozone (Farage et al., 1991; Pell et al., 1992; Mudd, 1996) is responsible for reducing carbon dioxide fixation, and consequently removes a sink for the assimilatory capacity (ATP and NADPH) produced by light reactions in photosynthesis. The elevation of carbon dioxide concentration in the internal gas spaces of the leaf is proposed to be the reason for the closure of stomata (Farage et al., 1991). A lack of pathway from the light reaction to the fixation of the carbon dioxide may also lead to photo inhibition of the photosystems and hence to the premature leaf senescence (Reich, 1983; Heath, 1994; Mudd, 1996).

Biochemical Changes due to Ozone

Biochemical changes due to ozone may trigger the following three types of reactions:

i.   Reaction in the solid phase
ii. Reaction in the gas phase
iii. Reaction in the liquid phase

(i) Reaction in the solid phase: Solid phase reaction takes place at cuticular surface of the leaf. The cuticle is composed of two components. Cutin overlies the membrane of the cells mainly composed of polymers of hydroxy-fatty acids with easter linkages. The second component is lipid of the cuticle, which both impregnates the cutin and is overlaid as epi-cuticular lipids. These lipids contain a number of different structures: alkanes, branched alkanes, alkenes, esters of long chain alcohols and fatty acids, in some cases glycolipids, and some terpenoid compounds. The synthesis of these compounds is presumably a property of epithelial cells (Mudd, 1996). Kerstein and Lendzian (1989) have reported that the ozone deposition varies from species to species. It is calculated that ozone flux through the cuticle is less than 1/10,000 of the amount that diffuses through the stomata. Although such rate of flux appears to be negligible, there are effects of ozone on the appearance of epicuticular lipids on leaf surfaces after

exposure to ozone. Barnes *et al.* (1988) have reported the effects of ozone on the epicuticular lipids Norway spruce (*Picea abeis*). In the unexposed plants the epicuticula array of fine tubules, but the epicuticular lipid in the exposed plants has a melted amorphous structure, which blocks stomata, hence photosynthesis. Miller *et al.* (1969) have reported that photosynthesis in Penderosa pine (*Pinus ponderosa*) is inhibited with a concomitant decrease in carbohydrate content.

(ii) **Reactions in the gas phase:** The generation of hydrogen peroxide and aldehydes in spruce leaves (Elstner and Osswald, 1984) is a result of reaction between ozone and ethylene. Gab *et al.* (1985) discovered the formation of hydroxy-methyl hydroperoxide and bis- (hydroxy-methyl)-peroxide, formed in the process of ozonolysis of alkenes emitted from plants. It should be noted that these reactions take place in the gas phase in the humid atmosphere. Ozonolysis gives rise to an aldehyde fragment and a biradical which react with water to form hydroxy-methyl hydroperoxide and its further break down gives aldehyde and hydrogen peroxide; however, there is sufficient evidence to sow that under certain conditions the hydroxy hydroperoxide is quite stable (Hellpointner and Gab, 1989). Mehlhorn and Wellburn (1987) reported that the synthesis of ethylene was intimately related to injury caused by ozone. Some researchers also believe that ribulose-1, 5-bis-phosphate carboxylase is sensitive to ozone, there appears to be an aggregate of the enzyme in presence of ozone (Mudd, 1996).

It is believed that the reactions of ozone with alkenes in the gas phase may be an important factor for the ozone toxicity in plants, and the product of these ozonolyses may eventually disrupt metabolism. This mechanism of toxicity should be focussed not only on the gases escaping from plants but also the interstitial wall fluid in plant cell. This liquid contains both proteins and compounds of low molecular weight that are susceptible to oxidation by ozone, and the oxidation products may be responsible for intercellular responses.

(iii) **Reaction in the liquid phase:** Reactions of ozone in aqueous media immediately raise the question of active species of oxidation. Is it ozone itself, or is it oxidants derived from ozone? But it is generally assumed that radicals generated from ozone are the active agents. These assumptions need careful evaluation (Weiss, 1935). The

decomposition rate of ozone in aqueous solution was a function of hydroxyl ion concentration.

$$O_3 + OH^- \rightarrow O_2^- + HOO \text{---(1)}$$

The above reaction was postulated on the basis of spectroscopic evidence: "absorption in the blue region of the visible, due presumably to KOO and O_2^- ion. This reaction was verified by Gorbenkov-Germanov and Kozalov (1973, 1974) after 37 years, using modern spectroscopic instrumentation. Ozone was added to 8M solutions of KOH at -50^0C. The first product were OH radical and O_3^-. At -50^0C there was degradation to O_2^-.

$$O_3 + OH^- \rightarrow O_3^- + OH^- \text{---(2)}$$
$$3O_3^{\cdot} + H_2O \rightarrow O_2^- + 3O_2 + OH^- \text{--(3)}$$
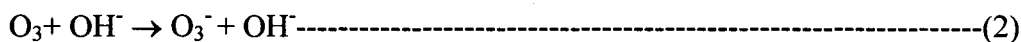
The reaction of ozone with water is much more rapid at alkaline pH than at acid pH. The half-life at pH 4 is 30 minutes, where as at pH 10 are 0.33 minutes (Hoigne and Badar, 1976). The capability of ozone to oxidize various substrates also varies with pH. At high pH the oxidation is non-selective, very complete and independent of temperature, typical of radical induced oxidations. At pH $\leq$ 7.0, the oxidation is selective and dependent on temperature, indicating a reaction mechanism not involving radicals (Gorbenkov-Germanov *et al.*, 1973).

There has been a great deal of research on the use of ozone, much of being relevant to biological effects of air pollutants. Hoigne and Badar (1975) came to a similar conclusion to that of Gorbenkov-Germanov *et al.* (1973), suggested two reaction pathway for ozone:

$$O_3 + S \rightarrow \text{direct oxidation of S, highly selective-------------------------------(4)}$$
$$O_3^{\cdot} + OH^- \rightarrow O_3^{\cdot} + OH^- \text{---(5a)}$$
$$OH^- + S \rightarrow \text{fast oxidation of S, low selectivity--------------------------------(5b)}$$

$$O_2 + S \overset{H+}{\rightleftarrows} HOO^- \text{--(5c)}$$

$$HOO^- + S \rightarrow \text{oxidation/reduction of S, high selectivity-----------------------(5d)}$$
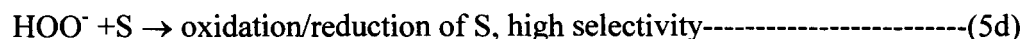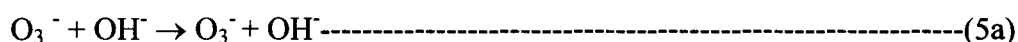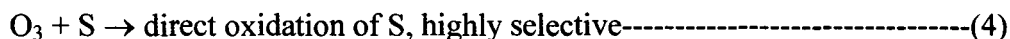
Reaction (4) is typical of ozone oxidation at neutral pH, whereas the radical reactions of (5) are typical of those at high pH.

Reactions of ozone in the liquid phase require initial dissolution of ozone in aqueous medium; however, the action of ozone may be attributed to diffusion of ozone into lipid, e.g., the lipid bi-layer of plasma membrane. The amount of gaseous pollutant uptake is clearly related to the water solubility of the gas. The ozone uptake to the plant system is predicted from its water solubility. In normal case, the gas in the gaseous phase is equilibrium with the gas in the liquid phase. The later phase can be depleted due to its reaction with the liquid phase.

Sensitivity of Plant to Ozone

Plant response or sensitivity to ozone is determined by many factors such as: leaf conductance, leaf morphology, efficiency of biochemical detoxification mechanism and plant genetics. Leaf conductance has been suggested to be the most important factor in determining the differential level of tolerance to ozone as conductance regulate ozone uptake in plants (Postiglione *et al.*, 2000). For example, Tobacco Bel-B and Tobacco Bel W-3 are good examples to explain the sensitivity to ozone. Tobacco Bel W-3 is very sensitive cultivar, where as tobacco Bel-B is a resistant cultivar to ozone. Sensitive varieties can be used as good biomonitors of ozone pollution as they develop characteristic leaf stipples even when exposed to low ozone concentration (PROG, 1987; Prinz, 1988; Colbeck and Mackenzie, 1994). A list of different crop plants according to their ozone sensitivity (sensitive, moderately sensitive, moderately tolerant and tolerant) is given in Table 2.10.

Table 2.10: Sensitivity of crop plants to ozone (after ICP-2002).

Sensitive	Moderately sensitive	Moderately tolerant	Tolerant
Wheat	Potato	Rice	Oat
Soybean	Tobacco	Maize	Barley
Bean	Sugar beet	Grape	
Cotton	Oilseed rape		

Genetic basis of plant response to ozone: Different crop cultivars vary greatly in their susceptibility to ozone (Lee *et al.*, 1984). The genetic basis enables the plant to grow, survive and reproduce in polluted environments either through avoidance or tolerance

mechanism. Avoidance is suggested to be an effective process of adaptation to acute pollution, whereas tolerance is the mechanism of resistance to chronic pollution (Pitelka, 1988). Wolfenden *et al.* (1992) have suggested that enzyme induction or the regulation of alternative biochemical pathways are under genetic control and some of these characters can be used to induce tolerance in plants. Plants develop a range of mechanisms to repair the disorders by detoxifying the toxic molecules (Foyer *et al.*, 1994) by activating its enzymatic systems (catalase, peroxidase, super oxide dismutase), ascorbic acid, vitamin E (α-tocopherol), peptides (glutationes), carotenoids (β-carotene), polyamines and organic buffering systems for tolerance. Since there have been suggestions that superoxide, hydrogen peroxide and hydroxyl radicals are involved in ozone toxicity, and the enzymes which detoxify superoxide or hydrogen peroxide may be responsible for ozone resistance (Lee and Bennet, 1982).

Resistant plants have to pay a metabolic cost for their pollution tolerance because energy is used for neutralizing the damaging effect of pollutants, which ultimately reduces the available energy for plant growth and development (Pitelka, 1988).

The variable responses of different species and cultivars to pollutants suggest phenotypic expressions of genotypes that may evolve naturally or may be introduced by selective breeding (Roose *et al.*, 1982: Pitelka, 1988). To avoid the crop yield loss due to ozone, there is every possibility that ozone-resistant varieties of agricultural crops may be developed in future by the help of genetic engineering.

Effects of Ozone on Crop Yield

Loss of crop yield refers to the loss of economic part of a crop plant. The concept includes any impairment of the intended use of plant; loss in weight, number or size of the plant parts that might be harvested; changes in quality or loss in aesthetic value. Studies on the effect of ozone on crop yield reduction have been conducted since last 40 years mainly in developed countries. The relationship between O_3 dosage and crop yield is complex and depends on several factors namely species and developmental stage of the crop, environmental conditions and the pattern and duration of ozone exposure (Pleijel *et al.*, 1991, 1998, 2000; Tingey *et al.*, 1991).

In Europe, studies initiated by the Commission of European Communities (CEC) on the effect of O_3 on crop yield were carried out at 18 sites from Central London to Ascot (a rural location 37.5 km away) on 3 crops namely, barley, peas and red clover. Crop yields were found to decrease from Ascot towards Central London due to variation in pollution load (Ashmore *et al.*, 1988).

Fumigation of tomato (*L. esculentum*) with 1000-ppm h and 2000-ppm h resulted in yield reduction of 23% and 50% respectively (Heggestad and Bennett, 1984). To gain an understanding of the impact of O_3 on crop yield an extensive study was undertaken during 1980 to 1987 under the National Crop Loss Assessment Network (NCLAN) of USA. The plant species selected for this study included soybean, corn, potato, tomato, kidney bean, alfalfa, wheat, cotton, peanuts, tobacco and the forage crops clover and fescue. The results of this study show that ozone concentration ranging from 0.04, 0.05 and 0.06ppm reduce crop yield exponentially with the increasing ozone concentration (Table 2.11). The yield loss includes visible injury, reduced plant growth and crop quality. It is interesting to note that approximately 57% of the 37 cultivars were found to suffer 10% yield of loss at 50 ppb of O_3. Almost 35% cultivars suffered 10% loss at 40-45 ppb ozone. Ozone in excess of 80 ppb reduced 10% yield in 19% of the cultivars. The threshold concentration for sensitive crops to reduce 10% yield was 40 to 75 ppbv and for resistant crop it was above 75 ppbv. NCLAN studies also revealed that dicot species (soybean, cotton and peanut) were more sensitive to ozone as compared to monocot species (sorghum, field corn and winter wheat) (USEPA, 1996) (Table 2.12).

Table 2.11: Yield loss suffered by different crops from 8 h ozone exposure for 90days (after NCLAN studies).

Crop	Yield loss (%) on O_3 concentration (ppm)		
	0.04	0.05	0.06
Glycine max	5	10	16
Zea mays	1	3	5
Gossypium hirsutum	6	12	21
Triticum aestivum	8	13	17
Arachis hypogea	8	13	20
Solanum tuberosum	9	14	19
Phaseolus vulgaris	4	9	15
Medicago sativa	5	8	12
Nicotiana tabaccum	3	6	9
Sorghum bicolor	1	2	3
Lycopersicon esculentum	5	10	18

Table 2.12: Ozone concentrations (averaged over 7 hour a day through out the growing season) required to reduce 10% of the crop yield.

Crop	Ozone Concentration (ppbv)
Corn	75-132
Wheat	69-93
Soybean	38-43
Peanut	43-49
Kidney bean	72-86
Cotton	41
Turnip	40-60
Lettuce	53-57
Spinach	41-60

It is important to ascertain the threshold concentration of air pollutants above which plants suffer adversely. This threshold concentration of pollutants is called critical level, which is defined as "the mean concentrations of pollutants in the atmosphere above which adverse effects on receptors such as plants, ecosystems or materials, may occur according to present knowledge" (Ashmore and Wilson, 1993). The critical level varies with species and cultivars.

In Europe, critical level for agricultural crops are based on AOT40 index (accumulated exposure over a threshold of 40 ppb) and corresponding to a 10% change in yield loss. The threshold ozone concentration required for 10 % reduction in yield in a crop varies from region to region. For example, for reduction of 10% in wheat yield in USA, the required threshold concentration is 120 $\mu g/m^3$ and it is 90 $\mu g/m^3$ for Europe. For rice it is 160 $\mu g/m^3$ in USA and 120 $\mu g/m^3$ in Japan. In case of soybean and field bean it is 90 $\mu g/m^3$ in USA and for field bean in Europe it is 80 $\mu g/m^3$ (Ashmore and Marshall, 1998).

An Overview of Indian studies

The ozone concentrations reported from Delhi, Varanasi, Chandigarh and Ahemedabad indicate that the threshold level of ozone for crop plants appears to have exceeded on many occasions at these locations (see Table 2.4). The ozone values reported from these locations far exceed critical levels reported for wheat and field bean for Europe.

The potential impacts of ground level ozone have largely remained unrecognized in India. Except for some preliminary studies carried out at Delhi and Varanasi no serious attempt has been made to determine the effect of ground level ozone on Indian crop plants. Fumigation of *S. oleracea, S. melongena* and *A. cepa* with O_3 at 0.05 and 0.1 ppm reduced plant biomass by 7.72-36.16%, 3.94-24.25% and 16.71-29.08% respectively (Aggarwal, 1993). The plant biomass of the above crops was reduced by 6 to 93%, when exposed to 98 to 196 $\mu g/m^3$ of ozone. The yield losses in cereals varied between 8-60% at 78 to 156 $\mu g/m^3$ of ozone and in pulses yield loss varied between 55-80% at 78 to 156 $\mu g/m^3$ of ozone. A summary of the effect of ozone on Indian crop plants includes five cereals, eight pulses, three oil seeds, six vegetables and one fibre crop is given in Table 2.13.

Table 2.13: A list of ozone fumigation studies carried out in India.

Crop	Method	Pollutant (No.of study)	O_3 concentration / dose ($\mu g/m^3$/ μg m^{-3} h)	Yield loss (%) due to O_3	Reference
Triticum aestivum	OTC	O_3 (1)	156	8.68	Cited in Varshney *et al.,* 1997
Oryza sativa	CTC, OTC	O_3 (2) O_3 + SO_2 (3)	156	55.20	Cited in Varshney *et al.* 1997
Pannicum milaceaum	CTC	O_3 (1), O_3 + SO_2 (1)	156	28	Cited in Varshney *et al.* 1997
Cicer arinetum	CTC, OTC	O_3 (2), O_3 + SO_2 (1)	6272	80.64	Cited in Varshney *et al.* 1997
Viginia sps	CTC	O_3 (1), O_3 + SO_2 (1)	6272	52.89	Cited in Varshney *et al.*
Phaseolous vulgaris	CTC	O_3 + SO_2 (4)	-	-	Cited in Varshney *et al.* 1997
Vicia faba	CTC	O_3 (3)	78	48.69	Cited in Varshney *et al.*1997
Solanum melangeona	CTC	O_3 (1)	6272	21.60	Cited in Varshney *et al.* 1997
Spinach	CC	O_3 (1)	98-196	6.78- 25.02	Aggarwal, 1993
Brinjal	CC	O_3 (1)	98-196	87.33- 93.80	Aggarwal, 1993
Onion	CC	O_3 (1)	98-196	27.80- 37.50	Aggarwal, 1993
Barley	CC	O_3 (1)	110	60.00	Mina, 2000
Gram (Pusa-256)	CC	O_3 (1)	110	57.14	Mina, 2000
Gram (Pusa-391)	CC	O_3 (1)	110	66.9	Mina, 2000
Mustards	CC	O_3 (1)	110	66.07	Mina, 2000
Onion	CC	O_3 (1)	110	72.67	Mina, 2000
Potato	CC	O_3 (1)	110	53.73	Mina, 2000
Radish	CC	O_3 (1)	110	46.02	Mina, 2000
Tomato	CC	O_3 (1)	110	70.00	Mina, 2000
Wheat	CC	O_3 (1)	110	47.14	Mina, 2000
Spinach	CC	O_3 (1)	110	59.62	Mina, 2000

CC and CTC = Close top chamber; OTC = Open top chamber

Effect of protectant chemicals including Ethylene diurea (EDU) in preventing ozone damage in plants

Air pollutants get dispersed and transported through the airshed to long distances with the moving air masses. Pollution from ground level ozone particularly has regional character, as often high concentration of ozone have been observed in remote agricultural area (Coffey and Stasiuk, 1975; Rubino *et al.*, 1976; White *et al.*, 1976; Rodes and Holland, 1981; Gusten *et al.*, 1988; Derwent and Jenkin, 1991; Hakola *et al.*, 1991).

A number of chemicals have been tried to protect crop from injury by air pollutants. A chemical plant protectant is a chemical applied to crop plants in the form of foliar spray, soil drench (simplest application - adding a solution of protectant to soil), by directly injecting into stem or by any other means for protecting plants from the damaging effect of air pollutants (Heagle, 1989). Chemical plant protectants can be broadly classified into two groups, namely *in situ* biochemical protectants and chemical protectants.

In situ Biochemical Protectants

The biochemical protectant includes a wide variety of antioxidants, growth regulators and retardants. Antioxidants (Ascorbic Acid) plant growth regulators (Gibberellic Acid and Indole Acetic Acid) and retardants (Abscisic Acid, Cytokinin and Kinetin) have been tested against different air pollutants (Freebairn and Taylor, 1960; Seigel, 1962; Ormrod and Adedipe, 1974; Agrawal *et al., 1982;* Lee *et al.,* 1984; Rao *et al.,* 1985; Hausloden and Kunert, 1990; Lee *et al.,* 1987, 1990; Pandey and Agrawal, 1993). Ascorbic Acid was shown to be ineffective in reducing ozone injury in cucumber but was effective in bean and *Petunia* (Freebairn and Taylor, 1960; Siegel, 1962). Adedipe and Ormrod (1972) have observed that Gibberellic Acid (GA) or Indole Acetic Acid (IAA) protects radish plants against O_3-exposure. Abscisic Acid was known to protect bean leaves from ozone injury (Fletcher *et al.,* 1972) and shows antagonistic effect against SO_2 in *Vicia faba* but protect poinsettia (Taylor *et al.,* 1981). Kinetin was known to protect bean plants from visible ozone injury (Pellissier *et al.,* 1972). *In situ* occurrence of biochemical protectant have genetic basis, and may not be present in

sufficient quantities in agricultural crops. To prevent crop damage from air pollution, various chemicals have been examined for crop protection.

Chemical protectants

A wide range of inorganic and organic chemicals has been screened for their protective role against air pollution damage in plants. These include antioxidants, antisenescence compounds, antitranspirants, growth regulators, growth retardants, fertlizers, mineral nutrients and pesticides. Information on various chemicals examined for preventing air pollution damage to plants has been summarized in Table 2.14.

The early studies on testing of chemicals involved mineral nutrients particularly, calcium (Allmendinger *et al.*, 1954) against SO_2 and HF and commonly used fungicides against smog injury (Kendrick *et al.*, 1954). Bisessar (1982) showed that various insecticides, fungicides and anti-oxidants confer protection to plants from O_3 damage to varying degree. The total of 168 studies have been reported in literature on different chemicals examined for preventing air pollutants damage in plants. Around 38 chemicals have been studied to prevent injury from O_3, PAN, SO_2, NO_2, Smog and Oxidant, HF and Auto-exhaust in 23 species of plants. The number of studies on chemical protectants in relation to O_3 is 20; with SO_2 13; with PAN, Smog and Oxidants 9; with HF 2; and with Auto-exhaust 1. Out of these 168 studies, more than 50% of the studies have been carried out on the ozone phytotoxicity i.e., on 13 different crops and their cultivars as compared to other air pollutants. Until recently fungicides namely benomyl and carboxin were considered most effective in reducing both injury and yield loss from air pollution stress (Manning *et al.*, 1974; Papple and Ormrod, 1977). Subsequent studies have shown that ethylene diurea (EDU) significantly more effective as compared to benomyl and carboxin (Carnahan *et al.*, 1978; Hofstra *et al.*, 1978) against ozone injury. A discussion on different classes of chemical protectants against ozone injury is given below:

Chemical Plant Protectants Against Ozone Damage

For many years a large number of chemicals have been tried against preventing ozone damage in crop plants such as: antioxidants, anti-senescence compounds, anti-transpirants, growth regulators, growth retardants, pesticides and dust to provide short term protection. Most of these studies were short-term single applications aimed at

identifying effectiveness in preventing acute ozone injury (Manning, 1999). Some chemical protectants that were effective also had other effects on plants made them unsuitable for research on the long-term effects of chronic exposure to ozone in the ambient conditions (Bialobok, 1984; Guderian *et al.*, 1985; Kender and Forsline, 1983; Ormrod and Beckerson, 1986). The use of protective chemical becomes successful, when their repeated use does not affect plants as well as the soil. Dose-response studies on number of applications, time interval, concentration and the application route must be determined to eliminate any side effect. A list chemicals tested against ozone injury to protect plants are given in Table 2.14.

Table 2.14: A list of chemicals tested against ozone injury to protect plants (after Manning, 1999).

Antioxidants	
Ascorbic Acid	K-, N-ascorbate
Butox	Piperonyl butoxide
DPA	Diphenylamine
EDU	N-(2-(2-oxy-1-imidazolidinyl)-ethyl)-N'-phenyl urea
NBC	Nickel-N-dibutyledithiocarbamate
Anti-senescence Agents	
Polyamines	Putrescine, spermidine, spermine
Anti-transpirants	
Folicote	Parafinic hydrocarbon waxes
Wilt-Pruf	
Dusts	Charcoal, diatomaceous earth, ferric oxide, kaoline
Growth Regulators	
Cytokinins	6-Benzyleamine purine
BA	N-6-Benzyladinine
Kinetin	
Growth Retardants	
CBCP	2,4-Dichloro-benzyle tributyle phosphomium chloride
SADH	Succinic Acid. 2,2-dimethyle hydrazide
Pesticides	
Fungicides	
Benomyl	Methyl-1-butyl-carbamyl-2-benzimidazole
Carboxin	5,6-dihydro-2-methyl-1,4-oxathin-3-carboxanilide
Dithiocarbamates	Ethylene bis dithiocarbamates
Maneb (Manganese)	
Zineb (Zinc)	
Herbicides	
Diphenamid	N,N-Dimethyl-2,2-diphenylacetamide
Isopropalin	2,6-Dinitro-N,N-dipropyl cumidine
Insecticides	
Spectracide 25	Diazinon

Among the wide variety of protective chemicals, EDU has been used extensively to protect crop plants against ozone injury for its non-toxic, simple application method and provides higher protection as compared to other chemical protectants (Carnahan *et al.* 1978; Rubin *et al.*, 1980; Heagle, 1989). Carnahan *et al.* 1978 have determined in the dose response study that one application of 500µg ml^{-1} (500 ppm) dose of EDU before 24 hours of ozone exposure can prevent acute ozone injury in pinto beans. Other investigators have also reported that repeated application of EDU as a foliar spray or soil drench can suppress ambient ozone injury. It has been observed that the application of EDU in higher doses is not toxic to plants (Rubin *et al.*, 1980).

Chemical Nature of Ethylene diurea (EDU)

Ethylene diurea is chemically N-(2-(2-oxy-1-imidazolidinyl)- ethyl)-N'-phenyl urea and abbreviated as EDU having this following structural formula.
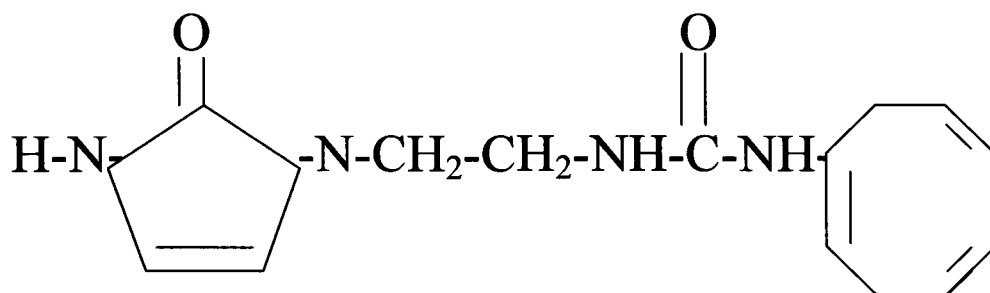
EDU is a white crystalline chemical was prepared by E. L. Jenner, E. I. duPont de Numours Co. ltd. The duPont chemists have predicted that the antioxidant- EDU can be used " a useful tool to determine the magnitude crop losses due to ozone". EDU can be applied by foliar spray, soil drench and by directly injecting into stem at at 10-14 day intervals, depending on plant species and air quality.

Ethylene diurea (EDU) Protection to Plants Against Ozone damage: Mechanism of Action.

Ethylene diurea (EDU) has been effectively used as a specific antioxidant to protect plants from ozone damage, but the mechanism of EDU induced resistance to air pollution is still unclear (Manning, 1988; Heagle, 1989). Regner-Joosten *et al.* (1994) and Gatta *et al.* (1997) have reported that EDU concentrates in plant leaves and persists for 10days or more in the apoplast, suggesting a direct role of EDU itself in ozone protection. McLeod and Baker (1988) suggested EDU-induced protection against O_3 damage is due to either breakdown of O_3 on the leaf surface, induction of stomatal

closure or modification plant metabolism. However, in a recent study, Lee *et al.* (1990) did not find any significant difference in stomatal resistance in EDU-treated and non-treated plants of snap bean and soybean. Regarding the mechanism of the antioxidant action, there are three different hypotheses.

1. According to Rubin *et al.,* (1980) the mechanism of antioxidant action involves the inhibition of microsomal-mixed function oxidase activity. The microsomal-mixed function oxidase system requires molecular oxygen for activity. Ozone is a superactive form of oxygen, and in plants exposed to ozone; the microsomal-mixed function oxidase system becomes "superactive", abnormally oxygenating different cellular constituents. Inhibition of microsomal-mixed function oxidase system by an anti-oxidant may prevent this "superactivation" and there by prevent ozone damage to plants.

2. Lee and Bennett (1982) have shown that EDU enhances the basic aerobic nature of the cell by inducing and regulating the oxidant scavenging enzymes and protects the cells from oxy-radicals formed under stress conditions. EDU induced enhancement in the activity of free radical scavenging enzymes, such as superoxide dismutase (SOD), and catalase in plants leaves have been reported. Lee and Chen (1982) suggested that EDU not only induces the formation of free radical scavenging enzymes, but also acts as cytokinin in retarding chlorophyll degradation, protein and RNA syntheses, and in stimulating cell proliferation.

   It has been established that EDU does not close stomata (Bennett *et al.,* 1979), thus ruling out the simplest explanation for its protective action. In cell-free systems EDU does not appear to scavenge O_3 or O_3 induced free radicals such as superoxide radicals (Amuruso *et al.,* 1986) or hydroxyl radicals (Grimes *et al.,* 1983) but EDU stimulates SOD that in turn scavenges free oxygen radicals.

3. Mehlhorn and Wellburn (1987) advanced the hypothesis that ozone phytotoxicity manifested as visible foliar lesions, is the result of a chemical reaction between ozone and stress ethylene, which generates toxic free radicals. In the absence of ethylene, a plant becomes tolerant to air pollutants. Zilinskas *et al.* (1990) verified that EDU prevents ethylene emission and thereby protect plants from ozone damage.

Ethylene diurea (EDU): A Tool for Assessing Crop Damage

The difference in the growth and performance between EDU treated and non-treated plants subjected to ozone stress reveals the yield loss from ozone exposure. This clearly demonatrates the importance of EDU as a potential tool for assessing yield loss from ozone.

The EDU studies for preventing O_3 injury and loss of yield have been carried out on 9 crop species and 31 cultivars. The maximum number of studies are on soybean involving 10 cultivars followed by Potato (8) and on Beans (5), Tomato (2), and one each on Ground nut, Onion, Cotton, Sweet corn and Tobacco. The studies using EDU were carried out to ascertain the quantum of protection against ozone damage revealed that EDU application prevented yield loss by 37% in onion (Wukasch and Hofstra, 1977), 24-36% in beans (Hofstra *et al.*, 1978; Temple and Bisessar, 1979), 30% in tomato (Legassike and Ormrod, 1981), 35% in potato (Bisessar, 1982) and 20% in tobacco (Bisessar and Palmer, 1984). It has been shown that EDU treatment does not increase the yield of ozone sensitive cultivars grown deliberately in ozone free environment (Foster *et al.*, 1983) or in ozone free air (Clarke *et al.*, 1983). The summary of the studies reported in literature is given in Table 2.15.

Bambawale (1986) have shown that the leaf spot disease of potato that appeared in Punjab since 1978 is primarily due to ambient ozone and foliar application of EDU controls about 25-30% leaf spot disease (i.e., leaf injury caused by ozone) in the treated plants. Studies were carried out to estimate crop loss under various ozone concentrations and crops have shown marked yield reduction. Response of soybean and tomato were also studied with EDU under field conditions and the yield of the treated plants was 7.38-24.94 % more in tomato and 29.73-46.98 % in soybean (Varshney and Rout, 1998, 2003).

Studies carried out under tropical and sub-tropical conditions are difficult to compare with studies from temperate regions on account of variation in methodology, ozone dosimetry, crop cultivars, environmental conditions and exposure duration. In absence of sufficient number of field level studies, it may not be possible to recommend any chemical for preventing ozone damage in field crops. Hence, experimental studies on field exposed plants are critical to ascertain the potential of EDU as a plant protectant against damage from ground level ozone in crop plants.

Table 2.15: A comprehensive list of studies on ethylene diurea (EDU) against ozone injury in crop plants.

Crop	Cultivar	Application method	Application rate	Number of application (s) (interval)	Ambient ozone concentration (ppm h)	Percentage yield improvement due to application of EDU	Reference
Vegetables							
Solanum tuberosum	Norchip	Soil Drench	6.7 kg/ha	5 (21-day)	50-110	20	Clarke *et al.*, 1978; 1983
	Norchip	Foliar Spray	1.1 kg/ha	5 (10-day)	0.037 (14h/d mean)	36	Bisessar, 1982
	Norchip	Foliar Spray	1.68 kg/ha (1500 ppm)	6 (10-day)	67 (July- August)	7	Hofstra *et al.*, 1983
	Norchip	Foliar Spray	1.68 kg/ha (1500 ppm)	6 (10-day)	59 (July- August)	N	Hofstra *et al.*, 1983
	Norland	Soil Drench	6.7 kg/ha	5 (21-day)	50-110	20	Clarke *et al.*, 1983
	Green mountain	Soil Drench	6.7 kg/ha	5 (21-day)	50-110	N	Clarke *et al.*, 1983
	-	Soil Drench	6.7 kg/ha	5 (21-day)	-	Upto 35	Clarke *et al.*, 1983
	Centennial Russet, White Rose	Soil drench (D) and Foliar Spray (S)	3.4 and 1.1 kg/ha	1D, 5S (14-day)	NR NR	45 N	Foster *et al.*, 1983

	Norland Norchip Green Mountain Irish Cobbler Belrus Superior	Soil drench	1.5 kg/ha	2 weeks	0.08ppm	24-25 31 5 11 9 -2	Clarke et al., 1983
L. esculentum	Tiny TimNew Yorker	Foliar Spray	1000, 2500 ppm	8 (7-days)	NR	31, 22 16, 1	Legassicke and Ormrod, 1981
	Pusa Ruby	Soil drench	400 ppm[f]	5 (14-day)	0.04 - 0.048	27	Varshney and Rout, 1998
Radish (*Raphanus sativus* L.)	-	Soil drench	500 mg litre^{-1}	10-day interval	80nl l^{-1}, 54.8 nl l^{-1} and 66.9 nl l^{-1}	32, 17, 16	Hassan et al., 1995
Turnip (*Brassica rapa* L.)	-	Soil drench	500 mg litre^{-1}	10-day	80nl l^{-1}, 54.8 nl l^{-1} and 66.9 nl l^{-1}	60, ns , 11	Hassan et al., 1995
Allium cepa	Autumn Spice, Rocket	Foliar Spray	500 ppm (2374 l / ha)	4 ((10 or 11-day)	NR	39 N	Wukasch and Hofstra, 1977
Legumes							
Phaseolus vulgaris	White bean	Foliar Spray	-	-	-	24	Temple and Bisessar, 1979
	White bean Seafarer, Sanilac, Kentwood	Foliar Spray	2000 ppm[ef]	3 or 4 (10-day)	NR	18 18 13	Toivonen et al., 1982
	Seafarer	Furrow	5.6 and 3.4 kg/ha	2 (28-day)	NR	4	Saettler, 1981
	Seafarer	Furrow	5.6 and 3.4 kg/ha	2 (34-day)	NR	34	Saettler, 1981

	Seafarer, Spurt	Foliar Spray	1750^f, 3500^f ppm	6 (7-day)	NR	10 , 1 12 , 10	Saettler, 1981
	L. cv. Lit	Soil drench	100, 150, 200, 250 mg /L	2 weeks	49-55 nl l^{-1}	20	Tonneijck and Vandijk, 1997a, 1997b
Navy bean	L. cv. Lit	Soil drench	100, 150, 200, 250 mg/L	2 weeks	40ppb	35	Tonneijck and Vandijk, 2002a, 2002b
	-	Foliar spray	-	-	-	36	Hofstra et al., 1978
Glycine max	0686, 0670	Soil drench and foliar spray	2.24 kg/ ha (2000 ppm)		18-37.5		Rubin et al., 1980
	Williams, Cutler,71	Soil drench	500 ppm^e	6 to 8 (14-days)	0.059-0.062 (7 h / d mean)	1 N	Smith et al., 1987
	Willium-82	Soil drench	500 ppm^e	5 (14-days)	0.058 (7 h / d mean)	N	Brennan et al., 1990
	NARC-1	Soil drench	400 ppm^f	5 (14-day)	0.04-0.048	32-63	Shamsi, 1996
	Pusa −16	Soil drench	400 ppm^f	5 (14-day)	0.04-0.048	27	Rout, 1997
	NARC-1 and 2	Soil drench	100, 200 and 400 ppm^f	5 (14-day)	0.04-0.048	27	Wahid et al., 2001
Oil seeds							
A. hypogea	NcRan, USDA, PI-268661	Foliar Spray	1000 ppm^f	6 to 8 (7 or 14days)	NR	N 23	Ensing et al., 1985
Fibre crop							
Gossypium hirsutum (Cotton)	-	Foliar Spray	-	-	-	10	Heagle et al., 1972

Cereal							
Sweet Corn	-	Foliar Spray	-	-	-	19	Heagle *et al.*, 1986
Cash crops							
Trifolium subterraneum(L).	Geraldton	Soil drench	100, 150, 200, 250 mg/L	2 weeks	80 nl l[-1]	31	Tonneijck and Vandijk, 2002b
Tobacco	-	Foliar spray	-	-	-	20	Bisessar and Palmer, 1984
Watermelon (*Citrus vulgaris*)	-	Soil drench	-	-	-	upto 30	Fieldhouse, 1978

N- not significant; NR- not reported; [e]- EDU formulation not specified; [f]- total amount applied not specified; - not available

Information Gaps

The use of chemical protectants against phytotoxicity of air pollutants can be very useful to reduce the severity of air pollution damage in plants. The below mentioned gap areas need to be taken care to properly evaluate the role of chemical plant protectants against air pollution damage to plants.

1. Extensive studies are required on different crop cultivars, medicinal plants, fruit bearing plants, herbs, shrubs, woody plants and lower plants against single or combination of pollutants and the usefulness of different chemical protectants.

2. The application methodology of chemical protectants needs to be properly studied in terms of imparting maximum protection to the plants against air pollution damage.

3. The economics involved in using chemical protectants in different environmental conditions needs to be properly assessed. As these chemicals not only have a high cost but also they have limited effective period and need repeated application for their efficacy.

4. There is an urgent need to develop low cost, non-toxic, non-persistent and eco-friendly chemical protectant that can protect plants against more number of pollutants in different environmental conditions. Although certain pesticides and fertilizes bear more relevance to the protection aspect, as they confer multiple benefits and are routinely used in agriculture. But they may pose serious secondary problems.

5. It is very important to develop simple application method for chemical protectants.

6. Further elaborative studies are required on plant breeding for developing air pollution resistant variety of plants with maximum productivity.

Chapter-III

Study Area, Materials and Methods

I. A General Description of the Study Area

The study was carried out at Delhi and the adjoining city of Faridabad, Haryana, located at the south-eastern end of Delhi. These two cities are almost completely integrated due to the rapid expansion of Delhi and appear as twin cities (see Figure 3.1). A brief description of the study area, Delhi and Faridabad is given below.

1. Delhi: Delhi, the capital city of India is located between $76^0 50'E$ - $77^0 23'E$ longitude and $28^0 12'N$ - $28^0 53'N$ latitude, on the banks of River Yamuna and in the lap of the Himalayas and Aravali ranges. Delhi, the third populous city of India, is spread over an area of 1483 sq km, and has a population of more than 1.28 crore (ES, 2002). It is surrounded by Uttar Pradesh in the east and by Haryana from the other three sides. It lies in the subtropical belt, has continental monsoon climate exhibiting a masked seasonal rhythm, hot summer, cool winter, un-reliable rainfall and great variation in temperature. In summer, the maximum temperature may reach up to 46^0C and in winter, the temperature may be as low as 1^0C. It has a monsoon climate and receives an annual average rainfall of 75 cm, out of which about 91 % occurs during June-August (July-60.8%). Wind is mild for most of the year except for the month of May and June, when on few occasions the city is lashed by severe dust storms. For the most part of the year wind direction is from W to NW; however, during monsoon it is from S to SE.

Over the years, Delhi has experienced a rapid growth in small, medium and large-scale industries and now it is a major industrial and commercial centre. The total numbers of motor vehicles have increased from 0.2 in 1971 to 3.55 million in 2000 (APR, 2002), and industries have grown from 0.26 to 1.26 millon in the year 1996 (ESD, 2002). A rapid increase in point and non-point sources of pollution has adversely affected air quality as SPM, NO_2 and SO_2 levels have increased over the years (NAAQMS, 2001). In Delhi, the levels of suspended particular matter (SPM) are above the National Ambient Air Quality Standard almost on every day of the year. The annual average level of SPM ranged between 255 to $443\mu g/m^3$ and 282 to $510\mu g/m^3$ in residential and industrial areas for the year 2000, and the concentration of SPM remained consistently high and much above the national standards of $360\mu g/m^3$ for most of the days of the year (NAAQMS, 2001). The maximum suspended particulate matter varied from $1360\mu g/m^3$ in 1987 to $1448\mu g/m^3$ in 2000, and peak value of $2340 \ \mu g/m^3$ was recorded in the year 1992 (NAAQMS, 1996; 2001).

The annual mean NO_2 concentration in residential areas ranged between 15 and 38 $\mu g/m^3$ and between 16 to 45$\mu g/m^3$ in industrial areas for the year 2000 (NAAQMS, 2001) and the annual mean concentration has increased from 20.4$\mu g/m^3$ in 1987 to 41.5$\mu g/m^3$ in 2000 (NAAQMS, 1996; 2001).

Sulphur dioxide, in Delhi had generally remained below the prescribed air quality standard of 60$\mu g/m^3$. The annual mean SO_2 concentration in residential areas ranged between 4.8 and 21$\mu g/m^3$ and between 6.6 to 30$\mu g/m^3$ in industrial areas and the year 2000 (NAAQMS, 2001), and the annual mean concentration of SO_2 has increased from 16.5$\mu g/m^3$ in 1987 to 21$\mu g/m^3$ in 2000, the (NAAQMS, 1996; 2001).

The ambient ozone concentration during 1989 to 1991 varied between 20 to 273$\mu g/m^3$ (Varshney and Aggarwal, 1992). A study by JNU-CRRI also reported high levels of ozone even during winter month (Singh *et al.*, 1997). A more recent report by Varshney and Rout (1998) shows that during August-October, 1996 the hourly peak ground level ozone concentration ranged from 72.15-80.84$\mu g/m^3$, and hourly average ozone concentration varied between 46.8-64.89$\mu g/m^3$. But the hourly peak ozone concentration varied between 113-125$\mu g/m^3$ and the hourly average concentration varied between 88-90 $\mu g/m^3$ in March-June, 1997. The ozone monitoring by Central Pollution Control Board (CPCB) started only after 1997. The CPCB monitoring stations are located at traffic intersections in the city and there are no data measurements in peri-urban and rural areas, where lies the major threat of ozone pollution to agricultural crops. The average ozone concentration varies between 26 to 82$\mu g/m^3$ in 1998 and between 20 to 104$\mu g/m^3$ in 1999 and between 29 to 77$\mu g/m^3$ in 2000 (NAAQMS, 2001).

2. Faridabad: Faridabad spreads over approximately 69.48 sq km, located at 77° 18' 28" East Longitude and 28° 25' 16" North Latitude at a distance of 30 kilometres in the S-E direction of Delhi. It is bounded by the National Capital Territory of Delhi on its north, Gurgaon District on the west and State of Uttar Pradesh on its east and south. Delhi-Mathura National Highway No.2 (NH-2) passes through the centre of Faridabad town, and incoming and outgoing traffic from Delhi passes through the city. Faridabad is completely integrated with Delhi and appears like a twin city having a population more than 10.54 lakh (ES, 2002). Faridabad has experienced a rapid growth of small,

medium and large-scale industries and now it is a major industrial centre on the Industrial Map of India and ranks 9th amongst the large industrial estates in Asia. There are about 15,000 small, medium and large industries providing direct and indirect employment to nearly half a million people (SAH, 2001). The total number of motor vehicles over the years in the city has increased from 0.02 in 1971 to 0.2 million by 2000 (APR, 2002). A rapid increase in point and non-point sources of pollution has adversely affected air quality (APR, 2002).

II. Description of Field Sites

The eleven field sites were spread over Delhi and Faridabad covering a distance of 90 km (both the ends). Out of these eleven sites, seven sites were located in Delhi and four were in Faridabad representing different levels of anthropogenic activity and traffic density (see Figure 3.1 and Table 3.1). Out of the seven sites in Delhi, four were located at the outskirts of the city in N-W direction viz; Bakoli (S1), S. College (S2), J.Temple (S3) and Libaspur (S4) and fifth was within the city at Tilak Bridge (S5) and the remaining two sites were also at the outskirts of the city in the S-E direction viz; JNU (S6) and Badarpur (S7). The JNU site located within the university campus, which has least anthropogenic activity and pollution and was chosen as reference site for comparison. The four Faridabad sites viz: DPS-Faridabad (S8), IOC (S9), CRI (S10) and AIIMS (S11) were located in the S-E direction. A detailed description of each field site is given below (Figure 3.1 and Table 3.1).

DELHI

A. North-West

1. Site-I (S1): *Bakoli*: Located inside an academic complex of Mahatma Gandhi Institute of Integrated Planning and Development (MGIIPD), Delhi, in a rural area, at a distance of approximately 2 km from the G. T. Karnal Road (National Highway, NH-1). It is least polluted and taken as reference site.

2. Site-II (S2): *S. College (Swami Shradhananda College, Alipur, Delhi):* An academic institution having an experimental botanical garden approximately 250m away from the National Highway, NH-1; relatively less polluted.

3. Site-III (S3): *J. Temple (Shree Atma Vallabh Jain Smarak Sikshan Nidhi, Bodhpur, Delhi):* A large temple complex, besides NH-1. Surrounded by Private farmhouses and relatively less polluted.

4. Site IV (S4): *Libaspur:* It is located at the campus of Delhi Energy Development Agency, Delhi, which is an old research centre. It is approximately 200m away from the National Highway, NH-1 and about 1km away from Azadpur vegetable market (Sabzi Mandi) traffic crossing and close to Badli solid waste dumping site; moderately polluted.

B. Within the city

5. Site-V (S5): *Tilak Bridge (ITO), (Delhi):* This site is on the busiest road connecting New Delhi with Old Delhi. The traffic at this site is very heavy and there is a coal fired thermal power plant of 250 MW in the vicinity, which make it one of the most polluted sites among the sites.

C. South-East

6. Site-VI (S6): *Jawaharlal Nehru University (JNU) (Delhi):* A university campus in the southern part of Delhi, having a vast tract of natural vegetation. Traffic is low, and the campus is relatively free from pollution.

7. Site-VII (S7): *Badarpur (Delhi-Faridabad Border):* It is located within the premises of a coal powered thermal power plant of 720 MW and is about 500 m away from the National Highway-2 (NH-2 connecting Delhi to Faridabad, Mathura and Agra. Traffic density is high with predominance of diesel trucks and inter-state buses. This is one of the highly polluted localities of Delhi.

FARIDABAD

8. Site-VIII (S8): *Delhi Public School (DPS), Sector-19, Faridabad:* Located in a school complex besides Delhi-Agra-Mathura National Highway (NH-2) and relatively less polluted area.

9. Site-VIII (S9): *Indian Oil Corporation Ltd (IOC), Sector-13,Faridabad:* It is located inside a large research and development complex of IOC, near to the Escort's Tractor Factory and at a distance of 2 km east of the NH-2.

10. Site-VIII (S10): *Cement Research Institute (CRI), Faridabad:* This is an academic-cum-research institution devoted to cement research and development. The experimental pots were kept in the plant nursery of the institute, which was about 300 m east of the NH-2.

11. Site-IX (S11): *All India Institute of Medical Sciences, Ballabhgarh (AIIMS), Faridabad:* A branch of AIIMS, New Delhi, devoted to rural projects. The experimental pots were kept in the plant nursery of the hospital which was about 200 m southeast of the NH-2.
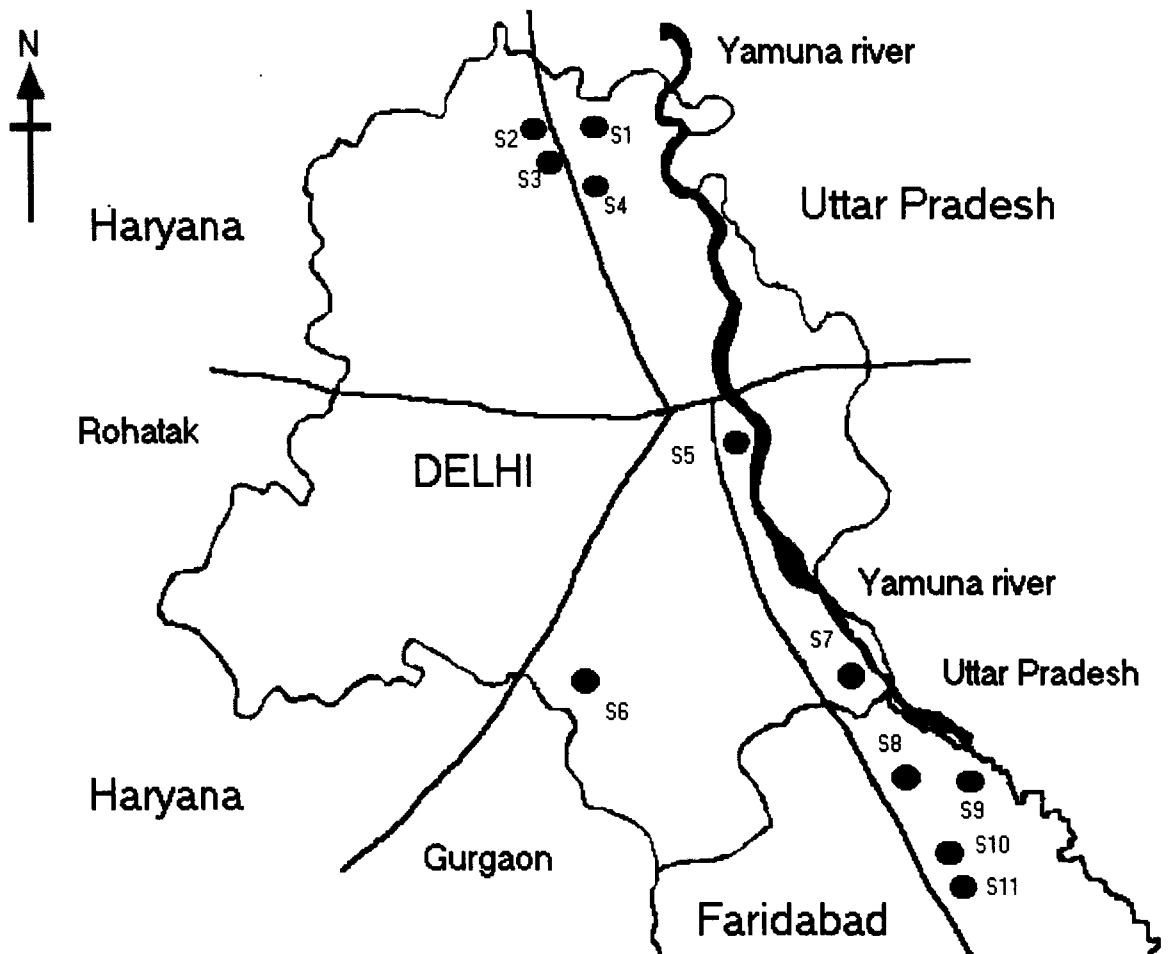
Figure 3.1: Map of Delhi and Faridabad showing eleven field sites.

Table 3.1: A comparative description of eleven field sites (S1-S11).

Site		Location	Land use / Activity	Relative traffic density	Air pollution in the area
S1	Bakoli	North- West / Rural	Academic Complex	+	Low
S2	S. College	North- West / Semi-Urban	Academic Complex	++++	Moderate
S3	J.Temple	North- West / Semi-Urban	Temple Complex	++++	Moderate
S4	Libaspur	North- West / Semi-Urban	Garden Complex	++++++	Moderate to High
S5	Tilak Bridge (ITO)	Central- East / Urban	Academic Complex	+++++++	High
S6	JNU	South	University Campus	++	Low
S7	Badarpur	South-East / Semi-Urban	Thermal Power Station Complex	+++++++	High
S8	DPS-Faridabad	South-East / Semi-Urban	School Complex	+++++	Moderate
S9	IOC-Faridabad	South-East / Semi-Urban	Research Institute	+++	Moderate
S10	CRI-Faridabad	South-East / Semi-Urban	Research Institute	++++	Moderate
S11	AIIMS-Faridabad	South-East / Semi-Urban	Hospital campus	+++	Moderate

Materials and Methods

III. Plant Materials

Four crops, two summer crops and two winter crops commonly cultivated in rural and peri-urban areas of Delhi and in adjoining states were selected for study.

(i) Summer (Rabi) crops:

    1) *Phaseolus aureus* var. PS-16

    2) *Spinacea oleracea* var. all green

(ii) Winter (Rabi) crops:

    3) *Triticum aestivum* var. HD-2329

    4) *Brassica campestris* var. Pusa Jai Kisan

Certified seeds of the crop species were obtained from the Indian Agriculture Research Institute (IARI), New Delhi.

Experimental Design

A. Ambient Ozone Estimation

The ambient ozone monitoring was carried out at one metre height from the ground level, at 30-day interval, during May to July-1998, January to April-1999 and February-2003. Air samples were drawn at hourly interval at a rate of 2 litres per min. using KIMOTO Handy Sampler model HS-7 (see Plate 2.1) for 5 h (from 11.00-16.00 hr) and analyses were done using Byers and Saltzman (1959) method with modification suggested by Boyd *et al.* (1970).

The amount of iodine liberated was determined by measuring OD at 352nm using JASCO Spectrophotometer Model 7800 UV/ VIS and UV-Visible Spectrophotometer Model-EL-010-34627, with the help of a calibration curve prepared according to the standard procedure. Continuous Ozone Monitor Model ML-9810B (Monitor Labs, USA) (see Plate 2.2) was used to measure the ambient ozone concentration at JNU during the fumigation studies in February- 2003.

B. Ethylene Diurea (EDU) Treatment: Ethylene diurea (EDU) solution of a concentration of 400 ppmv was prepared (i.e., 0.4 g EDU dissolved in 1 litre of tap water with continuous stirring for 4 h) and kept for two days at room temperature prior to its application. EDU treatment was given by drenching the pots with 600 ml of 400 ppm aqueous solution of EDU as per the treatment schedule (at 10 days interval).

C. Preparation of Plant Materials

Seeds were raised in the earthen pots (size: diameter - 23 cm and depth - 23 cm) filled with garden soil and vermiform compost at 3:1 ratio in the Ecological Garden, JNU as per their growing season. Both field and experimental fumigation studies were carried out in two phases between April 1998 to April 1999 in the field and experimental fumigation in between October 2002 to May 2003.

I. Field Study

Twelve pots of each species (three plants in each pot) were transferred to each field site (see Plate 2.4 to 2.7) as per their growing season and one set consisting of twelve pots in respect of each crop was maintained in the ecological garden of SES, JNU, to serve as control for comparison. The plants of four pots out of twelve were given EDU treatments (600 ml) and the other eight pots were irrigated with equal volume of water equally spaced at 10 day intervals. Observations on the growth and performance of plants were recorded on maturity.

a) *Phaseolus aureus* var. PS-16 and *Spinacea oleracea* var. all green plants after 75 days of field exposure (90 days old) were harvested for measurement of different parameters in the second week of July 1998, after bringing back the plants to the laboratory from field sites.

b) *Triticum aestivum* var. HD-2329 and *Brassica campestris* var. Pusa Jai Kisan, plants after 120 days of field exposure (135 days old) were harvested for measurement of different parameters in the second week of April, 1999, after bringing back the plants to the laboratory from field sites.

II. Experimental Fumigation

a) Fumigation Chamber

To validate the field observations controlled fumigation studies were carried out using the dynamic chamber made of glass of size 1 m^3 (1m × 1m × 1m) capacity in the ecological garden of SES, JNU. The chambers were made airtight after placing the pots of experimental plants inside it. Each chamber had an inlet at the base connected to an ozone generator and an outlet at the top on the opposite end of the chamber to serve as an exit port. The gas flow in the chamber was maintained at 1.51 litre per min. with the help of a rotameter. A small electric fan of 25 × 22 cm size was fixed inside the chamber to ensure uniform mixing.

b) Ozone Generation and Monitoring

An ozone generator BARC Model was used for ozone generation (Plate 2.3). For measuring ozone concentration, gas samples from the exit port of the chamber were analysed with the help of Continuous Ozone Monitor Model-ML9810B (Monitor Labs, USA).

c) Standardization of Fumigation Chamber

The fumigation chamber was standardised for 150μg/m^3 of ozone concentration. The desired concentration 150μg/m^3 of ozone was obtained by regulating the flow rate of ozone generator. During fumigation gas samples were drawn from the fumigation chamber to determine ozone concentration; moreover, ozone concentration chosen for fumigation of plants was at 150μg/m^3 because it was found that the average hourly ozone concentration at one site was about 150μg/m^3.

d) Treatment Schedule

The 30day old plants (E1 set- eight pots each with three plants) and 50day old plants (E2 set- eight pots each with three plants) were chosen to validate field observations. The E2 set was meant to determine the effect of prophylactic treatments of EDU on crop plants against ozone damage. Plants of four pots out of eight in E1 set were given EDU treatment (600 ml) while the remaining four pots were irrigated with equal

Plate 2.1: KIMOTO Handy Sampler Model HS-7.

Plate 2.2: Continuous Ozone Monitor Model ML-9810B (Monitor Labs, USA).

Plate 2.3: BARC Model Ozone Generator with Rotameter.

Plate 2.4: Experimental Plants Exposed at S-1 (Bakoli) Site.

Plate 2.5: Experimental Plants Exposed at S-3 (J.Temple) Site.

Plate 2.6: Experimental Plants Exposed at S-4 (Libaspur) Site.

Plate 2.7: Experimental Plants Exposed at S-9 (IOC-Faridabad) Site.

volume of water followed by 150μg/m^3 of ozone for 4 h. This treatment was repeated five times at 10day intervals (a total of 20 h of ozone exposure). The plants of four pots out of eight in E2 set were given three EDU treatments (600 ml) and the other four pots were irrigated with equal volume of water equally spaced at 10 day intervals followed by five cycles of exposure to 150μg/m^3 of ozone daily for 4 h over five successive days. Plants of E2 set, also received a total of 20 h of ozone exposure, and followed by two more EDU treatments at 10 days interval. Plants subjected to experimental ozone fumigation were also given EDU and water treatment in a similar manner described above. Observations on the growth and performance of plants were recorded on maturity.

a) *Phaseolus aureus* var. PS-16 and *Spinacea oleracea* var. all green, plants after five cycles of ozone exposure, i.e., 90 days old plants were harvested for measurement of different parameters in the second week of May, 2003.

b) *Triticum aestivum* var. HD-2329 and *Brassica campestris* var. Pusa Jai Kisan, plants after five cycles of ozone exposure, i.e., 135 days old plants were harvested for measurement of different parameters in the second week of April, 2003.

D. Measurement of Plant Growth and Performance

Measurement of biochemical parameter-total chlorophyll and ascorbic acid content were made in 55days old plant in case of *Phaseolus* and *Spinacia* and in 60days old plant in case of *Triticum* and *Brassica*. Morphological parameters were measured in 90 days old plant in case of *Phaseolus* and *Spinacia* and in 135days old plant in case of *Triticum* and *Brassica*.

Morphological Parameters

The following morphological parameters were observed for each crop except for paalak, which unlike other plants has rosette habit and lacks a distinct stem.

1) Shoot length /Culm length
1) Shoot biomass
2) Root length

51

3) Leaf number*

4) Leaf area*

5) Leaf fresh weight*

6) Leaf dry weight*

7) Root biomass*

8) Plant biomass*

9) Pod number /Spike number

10) Pod size /Spike size

11) Seed per pod /Grains per spike

12) Total seed weight per plant/ Total grain weight per plant

* Parameters measured in respect of paalak, i.e., *Spinacea oleracea* var. all green

Biochemical Parameters

Chlorophyll estimation: Fresh leaves weighing 0.5 gm were homogenised in 20 ml of 80% acetone (acetone: water v/v) in a pre-chilled mortar and pestle. The homogenate was filtered through two layers of cheesecloth. The filtrate was centrifuged at 3000g for 15 min. in Janetzki refrigerated centrifuge model K-24 at 4°C. The supernatant was decanted and the volume was made up to 25 ml with 80% acetone. Care was taken to shield the chlorophyll extract from bright light. The optical density was measured at 450, 645, 663 nm wavelength using (JASCO spectrophotometer model) 7800UV/VIS and UV-Visible Spectrophotometer Model-EL-010-34627. The amount of total chlorophyll was determined by using the formulae described by Maclachlan and Zalik, (1963).

Total Chlorophyll = $\dfrac{[20.2 \times D645 + 8.02 \times D663] \times V}{d \times 1000 \times w}$
(mg/g fresh wt)

where

D = Optical density at 645, 663 nm

V = volume of chlorophyll extract in acetone

d = length of light path (cm)

w = fresh weight of leaves

Ascorbic acid: The ascorbic acid content of leaf tissue was estimated by the method given by Roe (1954). Ascorbic acid standard solution was prepared by dissolving 100 mg of ascorbic acid solution in 500 ml of 0.5 % oxalic acid solution. The solution is unstable, therefore the dye was standardised immediately. DCPIP dye, i.e., 2, 6–dichloro-phenol indophenol) dye was prepared by dissolving 50mg sodium salt of DCPIP in 150 ml of double distilled water and then placed in an oven at 80°C for 5 min. 42 gm of $NaHCO_3$ was added to this solution and decanted into a 200 ml volumetric flask. After cooling and filtering, the volume was made up to 200 ml with double distilled water. The dye was stored in a dark bottle in a refrigerator where it remains stable for one week. For standardisation, DCPIP dye was titrated against 5 ml of ascorbic acid solution until a peak end point, lasting for 15 seconds, was reached. As 5 ml of the standard ascorbic acid solution contains 1 mg of vitamin-C, the burette reading represents the amount of the dye required to oxidise 1 mg of ascorbic acid. The amount of ascorbic acid oxidised by 1 ml of the dye was calculated.

Fresh leave tissue of 0.5g was homogenised in a pre-chilled mortar and pestle with 20 ml of 0.5% oxalic acid solution. The homogenate was centrifuged at 1800 g in Janetezki refrigerated centrifuge model K-24 at 4 °C for 25 min. 10 ml of supernatent was titrated with DCPIP dye till the pink colour persists for at least 15 seconds. The amount of ascorbic acid in the sample was calculated using the following formula:

mg AA in gm sample = (V x T)/W

Where V = volume of dye in ml used for titration of extract

T = AA equivalent of dye solution expressed as per ml of dye

W = Weight of leaf material

Statistical application

The data generated during the study were subjected to the following statistical analyses such as: standard deviation, co-rrelation, t-test (comparison between groups), regression and regression equations were worked out to develop the relationship between the ozone concentration and yield parameters.

(i) Standard deviation: The standard deviation was calculated according to the below given formula;

$$s = [\Sigma fx^2 / N-1]^{1/2}$$

$$x = x-x_i$$

N= population size

(ii) Co-rrelation: Co-rrelation (which measures the closeness of the relationship between the two variables) was determined by positive/negative in the linear relation.

Linear co-rrelation coefficient

If relationship between two variables

$$r = (\Sigma xy) / \sqrt{(\Sigma x)^2 (\Sigma y)^2}$$

$$x = x-xi$$

$$y = y-yi$$

The coefficient of determination is explained, as R^2 is the ratio of explained variation to the total variation.

(iii) Regression Equation $Y= a_1 X + a_0$, the regression line Y on X is obtained on the basis of sample data, which also determines the relationship between two variable.

a_1 = regression co-efficient

a_0 = intercept of the regression line

Chapter-IV
Results

Measurement of Ground Level Ozone at Delhi and Faridabad

Measurement of ground level ozone in the ambient environment was carried at eight field sites (Bakoli, S.College, J. Temple, Tilak Bridge, JNU, Badarpur, DPS-Faridabad and IOC) between May to July, 1998. The average hourly ozone concentration was $38.46\mu g/m^3$ at Bakoli (S1), $37.77\mu g/m^3$ at S.College (S2), $35.72\mu g/m^3$ at J.Temple (S3), $44.15\mu g/m^3$ at Tilak Bridge (S5), $38.21\mu g/m^3$ at JNU (S6), $50.20\mu g/m^3$ at Badarpur (S7), $41.67\mu g/m^3$ at DPS-Faridabad (S8) and $38.75\mu g/m^3$ at IOC (S9) (Table 4.1 and Figure 4.1). The maximum hourly ozone concentration was $41.13\mu g/m^3$ at Bakoli (S1), $41.13\mu g/m^3$ at S.College (S2), $40.05\mu g/m^3$ at J.Temple (S3), $48.7\mu g/m^3$ at Tilak Bridge (S5), $47.62\mu g/m^3$ at JNU (S6), $56.28 \mu g/m^3$ at Badarpur (S7), $44.37\mu g/m^3$ at DPS-Faridabad (S8) and $42.21\mu g/m^3$ at IOC (S9) and minimum was $29.22\mu g/m^3$ at Bakoli (S1), $31.31\mu g/m^3$ at S.College (S2), $33.55\mu g/m^3$ at J.Temple (S3), $20.56\mu g/m^3$ at Tilak Bridge (S5), $29.22\mu g/m^3$ JNU (S6), $29.22\mu g/m^3$ at Badarpur (S7), $22.73\mu g/m^3$ at DPS-Faridabad (S8) and $20.56\mu g/m^3$ at IOC (S9) (Table 4.1). According to the average hourly ozone concentrations monitored during May to July, 1998 the eight field sites fall in the following order: S7 > S5 > S8 > S9 > S1 > S6 > S2 > S3 (see Table 4.1 and Figure 4.1).

Ozone measurements during January to April-1999 were carried out at nine field sites (Bakoli, S.College, J. Temple, Libaspur, JNU, Badarpur, IOC, CRI and AIIMS). The average hourly ozone concentration was $87.57\mu g/m^3$ at Bakoli (S1), $83.01\mu g/m^3$ at S.College (S2), $69.07\mu g/m^3$ at J.Temple (S3), $91.70\mu g/m^3$ at Libaspur (S4), $104.74\mu g/m^3$ at JNU (S6), $158.33\mu g/m^3$ at Badarpur (S7), $70.05\mu g/m^3$ at IOC (S9), $89.41\mu g/m^3$ at CRI (S10) and $85.38\mu g/m^3$ at AIIMS (S11) (Table 4.2 and Figure 4.2). The maximum hourly ozone concentration was $112.56\mu g/m^3$ at Bakoli (S1), $109.86\mu g/m^3$ at S.College (S2), $110.4\mu g/m^3$ at J.Temple (S3), $126.27\mu g/m^3$ at Libaspur (S4), $110.4\mu g/m^3$ at JNU (S6), $167.22 \mu g/m^3$ at Badarpur (S7), $96.33\mu g/m^3$ at IOC (S9), $123.93\mu g/m^3$ at CRI (S10) and $106.61\mu g/m^3$ at AIIMS (S11) and minimum was $20.56\mu g/m^3$ at Bakoli (S1), $18.4\mu g/m^3$ at S.College (S2), $14.61\mu g/m^3$ at J.Temple (S3), $20.56\mu g/m^3$ at Libaspur (S4), $22.73\mu g/m^3$at JNU (S6), $26.52\mu g/m^3$ at Badarpur (S7), $23.27\mu g/m^3$ at IOC (S9), $16.23\mu g/m^3$ at CRI (S10), $16.23\mu g/m^3$ at AIIMS (S11) (Table 4.2). The average hourly ozone concentrations at all the nine sites during January to

April, 1999 were in the following order: S7 >S6 > S4 > S10> S1> S11 > S2> S9 >S3 (see Table 4.2 and Figure 4.2).

Figure 4.1: Average hourly ground level ozone concentration at Delhi - Faridabad sites during May to July, 1998.

Figure 4.2: Average hourly ground level ozone concentration at Delhi - Faridabad sites during January to April, 1999.
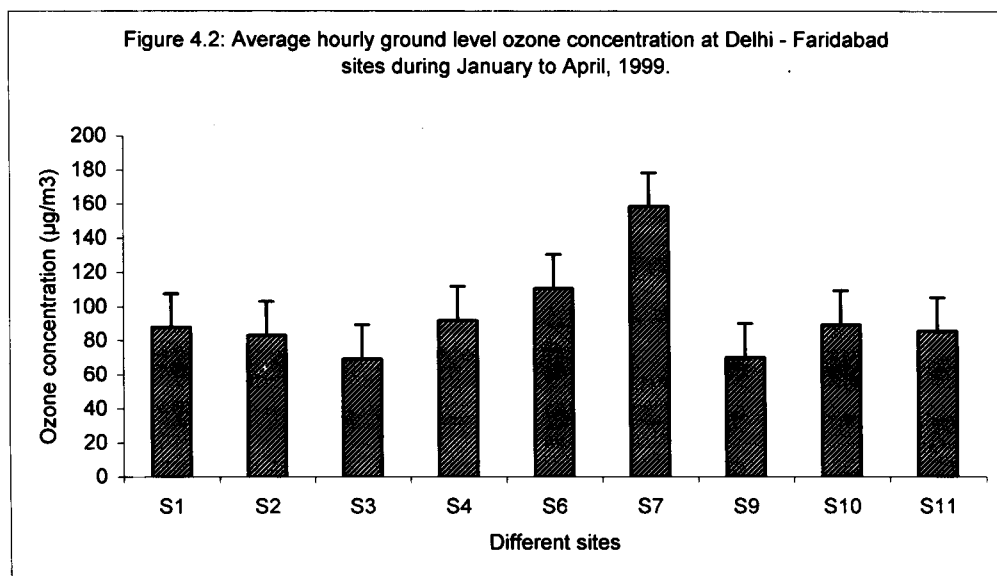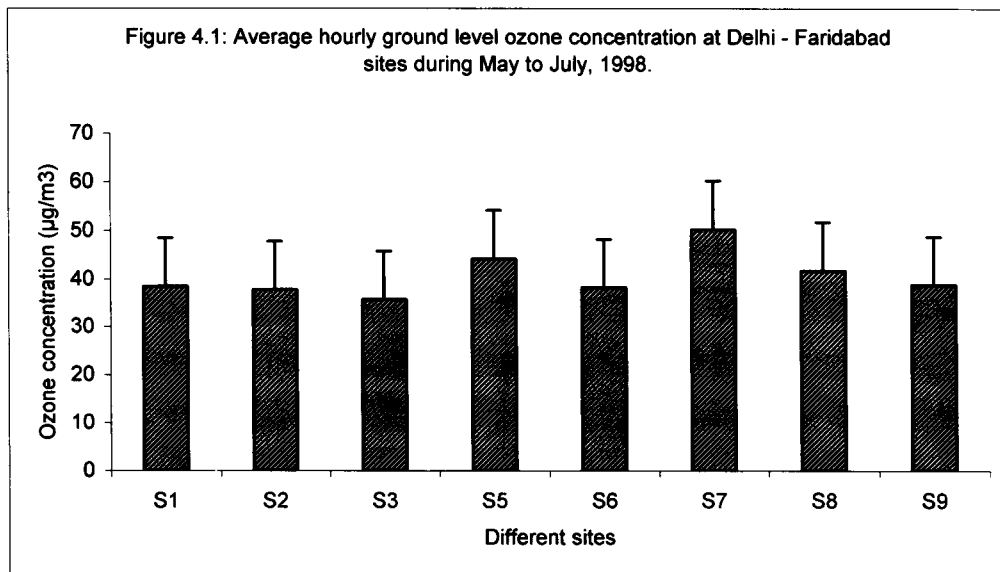
Table 4.1: Ground level ozone concentration ($\mu g/m^3$) at Delhi-Faridabad sites during May-July, 1998.

Field sites	May		June		July		Average
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	
S1	38.96	41.13	36.80	41.13	29.22	40.05	38.46 ± 5.42
S2	40.05	41.13	34.63	36.80	31.31	41.13	37.77 ± 3.99
S3	34.63	36.80	33.55	36.80	33.55	40.05	35.72 ± 2.51
S5	47.62	48.70	44.37	46.53	20.56	46.53	44.15 ± 10.76
S6	38.96	47.62	33.55	40.05	29.22	33.55	38.21 ± 6.48
S7	55.20	56.28	49.79	50.87	29.22	48.70	50.20 ± 9.84
S8	42.21	44.37	43.83	44.37	22.73	44.37	41.67 ± 8.65
S9	40.05	41.13	41.13	42.21	20.56	37.88	38.75 ± 8.26

S1: Bakoli, S2: S. Collge, S3: J. Temple, S5: Tilak bridge, S6: JNU, S7: Badarpur, S8: DPS-Faridabad, S9: IOC

Table 4.2: Ground level ozone concentration ($\mu g/m^3$) at different Delhi-Faridabad sites during January- April, 1999.

Field sites	January		February		March		April		Average
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	
S1	20.56	58.45	80.09	86.59	67.13	112.56	94.162	107.15	87.57 ± 18.29
S2	18.40	55.20	60.07	99.57	61.69	107.15	92.54	109.86	83.01 ± 28.72
S3	14.61	32.47	54.66	93.08	60.61	104.44	99.57	110.40	69.07 ± 36.63
S4	20.56	60.61	51.95	80.10	58.44	102.28	103.36	126.27	91.70 ± 28.81
S6	22.73	54.66	41.13	80.63	77.38	84.42	87.67	110.40	104.74 ± 31.09
S7	26.52	50.87	49.46	140.16	88.75	149.36	117.43	167.22	158.33 ± 47.41
S9	23.27	47.62	51.95	74.68	66.56	90.92	88.75	96.33	70.05 ± 22.59
S10	16.23	49.79	49.24	86.04	61.15	88.21	95.24	123.93	89.41 ± 30.76
S11	16.23	49.24	33.35	90.915	76.845	88.21	83.34	106.61	85.38 ± 28.84

S1: Bakoli, S2: S. Collge, S3: J. Temple, S4: Libaspur, S6: JNU, S7: Badarpur, S9: IOC, S10: CRI, S11: AIIMS

Wheat (*Triticum aestivum* var. HD-2329)

Field Study:

Effect of ambient ozone on growth and yield parameters of wheat (*Triticum aestivum* var. HD-2329) was evaluated among ethylene diurea (EDU) treated plants and untreated EDU plants under field condition at Delhi-Faridabad. Nine different sites (S1, S2, S3, S4, S6, S7, S9, S10 and S11) were chosen in Delhi and Faridabad representing different levels of anthropogenic activity and traffic density. The ground level ozone concentrations varied between 69.07-158.33μg/m^3 at these nine sites. Observations of growth performances of *Triticum aestivum* plants were made in respect of following morphological and biochemical parameters.

Culm Length

Initially, growth of culm was slow up to 37th day. Subsequently, there was a rapid increase till 52nd day except at site S7, where growth was relatively slow. Between 52-75th days, growth of culm length was gradual and beyond 75th day there was no further increase in culm length.

The average culm length in 135days old mature plants grown without EDU at different sites was 55.6 ± 7.27, 54.1 ± 4.45, 53.82 ± 8.03, 51.51 ± 4.65, 55.91 ± 6.09, 49.61 ± 5.8, 53.55 ± 6.39, 52.15 ± 6.58 and 51.47 ± 8.84 cm respectively (Plate 4.1-4.2). The maximum culm length was 55.6 ± 7.27 cm at site S1 and minimum was 49.61 ± 5.8 cm at site S7 (Table 4.3).

In EDU-treated plants the average culm length at different sites was 60.5 ± 7.85, 58.2 ± 3.74, 58.00 ± 8.21, 55.8 ± 5.2, 59.7 ± 7.83, 54.1 ± 1.74, 57.8 ± 7.45, 56.3 ± 7.86 and 55.9 ± 4.69 cm respectively (Plate 4.1-4.2). The maximum culm length was 60.5 ± 7.85 cm at site S1 and minimum was 54.1 ± 1.74 cm at site S7 (Table 4.3).

A comparison of plants with and without EDU treatments shows that the culm length in EDU treated plants was 6.45%, 7.01%, 7.20%, 7.89%, 6.35%, 8.89%, 7.27%, 7.37% and 7.96% more in EDU treatment plants (Table 4.3 and Figure 4.3).

The difference in culm length between plants with and without EDU was statistically significant (P ≤0.01 level) (Table 4.3).

Culm Number

The average number of culms at maturity in plants with EDU at different sites was 5.65 ± 1.66, 4.75 ± 2.15, 4.75 ± 1.71, 3.75 ± 1.25, 5.5 ± 1.43, 3.75 ± 1.11, 5.00 ± 0.85, 4.75 ± 0.64 and 4.75 ± 0.64 respectively. The maximum number of culm per plant was 5.65 ± 1.66 at site S1 and minimum was 3.75 ± 1.11 at site S7 (Table 4.3).

In EDU-treated plants the average number of culms per plant at different nine sites was 6.75 ± 1.75, 5.75 ± 0.7, 5.75 ± 1.16, 4.88 ± 1.12, 6.5 ± 1.06, 4.88 ± 0.64, 6.00 ± 1.59, 5.75 ± 1.98 and 5.75 ± 1.16 respectively. The maximum number of culms per plant was 6.75 ± 1.75 at site S1 and minimum was 4.88 ± 1.12 at site S7 (Table 4.3).

A comparison of culm number in plants treated with and without EDU shows that number of culms was more by 16.29%, 17.39%, 17.39%, 23.08%, 15.38%, 23.08%, 16.67%, 17.39% and 17.39% over plants grown without EDU treatment (Table 4.3 and Figure 4.4).

The difference in culm number between plants grown with and without EDU was statistically significant ($P \leq 0.01$ level) (Table 4.3).

Shoot Biomass

At maturity the average shoot biomass in plants grown without EDU at different sites was 3.47 ± 0.61, 2.85 ± 1.19, 2.83 ± 1.05, 2.43 ± 0.52, 3.44 ± 0.77, 2.39 ± 0.35, 2.89 ± 0.49, 2.87 ± 0.67 and 2.87 ± 0.67 g respectively. The maximum shoot biomass was 3.47 ± 0.61g at site S1 and minimum was 2.39 ± 0.35, 2.8 g at site S7 (Table 4.3).

In EDU-treated plants, the average shoot biomass at different sites was 4.01 ± 1.36, 3.58 ± 0.71, 3.55 ± 0.52, 3.33 ± 0.63, 3.97 ± 0.95, 3.3 ± 0.65, 3.68 ± 0.48, 3.68 ± 0.68 and 3.66 ± 0.74 g respectively. The maximum shoot biomass was 4.01 ± 1.36 g at site S1 and minimum was 3.3 ± 0.65 g at site S7 (Table 4.3).

A comparison of EDU treated and non-treated plants show that the shoot biomass of EDU treated plants was 13.45%, 20.25%, 20.28%, 26.92%, 13.35%, 27.78%, 21.53%, 21.86% and 21.75% more as compared to the plants grown without EDU treatment (Table 4.3 and Figure 4.5).

59

The difference in shoot biomass between plants grown with and without EDU was statistically significant (P ≤0.01 level) (Table 4.3).

Root Length

The average root length in matured plants without EDU at different sites was 9.87 ± 0.96, 8.37 ± 3.06, 8.38 ± 2.42, 7.71 ± 1.79, 9.12 ± 1.73, 7.61 ± 2.03, 8.46 ± 1.5, 7.92 ± 1.5 and 7.81 ± 1.34 cm respectively. The maximum root length was 9.87 ± 0.96 cm at site S1 and minimum was 7.61 ± 2.03 cm at site S7 (Table 4.3).

The average root length in EDU-treated plants at different sites was 10.6 ± 1.61, 9.1 ± 0.84, 9.1 ± 2.92, 8.63 ± 2.06, 9.8 ± 1.32, 8.61 ± 1.67, 9.25 ± 1.39, 9.2 ± 1.48 and 9.13 ± 0.99 cm respectively. The maximum root length was 10.6 ± 1.61 cm at site S1 and minimum was 8.61 ± 1.67 cm at site S7 (Table 4.3).

A comparison between root length EDU treated and non-treated plants shows that the root length in EDU treated plants was more by 6.84%, 8.02%, 7.91%, 10.56%, 6.94%, 11.65%, 8.46%, 8.52% and 8.82% over plants grown without EDU treatment (Table 4.3 and Figure 4.6).

The difference in root length between plants grown with and without EDU was statistically significant (P ≤0.01 level) (Table 4.3).

Root Biomass

The average root biomass at maturity in plants grown without EDU at different sites was 0.47 ± 0.17, 0.42 ± 0.15, 0.42 ± 0.2, 0.38 ± 0.18, 0.42 ± 0.2, 0.35 ± 0.17, 0.42 ± 0.12, 0.42 ± 0.25 and 0.4 ± 0.23 g respectively. The maximum root biomass was 0.47 ± 0.17 g at site S1 and minimum 0.35 ± 0.17 g at site S7 (Table 4.3).

In EDU-treated plants, the average dry root biomass at different sites was 0.7 ± 0.09, 0.66 ± 0.11, 0.68 ± 0.17, 0.64 ± 0.09, 0.67 ± 0.23, 0.63 ± 0.14, 0.66 ± 0.1, 0.65 ± 0.13 and 0.64 ± 0.17 g respectively. The maximum root biomass was 0.7 ± 0.09 g at site S1 and minimum 0.63 ± 0.14 g at site S7 (Table 4.3).

The root biomass of EDU treated plants at different sites was more by 31.43%, 36.36%, 38.23%, 40.95%, 35.92%, 43.36%, 34.95%, 34.00% and 35.77% over the non-treated plants (Table 4.3 and Figure 4.7).

The difference in root biomass between plants with and without EDU was statistically significant (P ≤0.01 level) (Table 4.3).

Spikes per Plant

The average number of spikes at maturity in plants without EDU at different sites was 4.6 ± 0.82, 4.05 ± 1.14, 4.2 ± 0.77, 3.75 ± 0.78, 4.4 ± 0.82, 3.55 ± 0.6, 4.5 ± 1.43, 4.4 ± 1.14 and 4.3 ± 1.08 respectively. The maximum number of spikes per plant was 4.6 ± 0.82 at site S1 and minimum was 3.55 ± 0.6 at site S7 (Table 4.3).

In EDU-treated plants, the number of spikes per plant at different sites was 4.88 ± 1.46, 4.63 ± 0.91, 4.63 ± 1.06, 4.25 ± 0.7, 4.75 ± 1.03, 4 ± 0.75, 4.75 ± 0.88, 4.63 ± 0.52 and 4.63 ± 1.06 respectively. The maximum number of spike per plant was 4.88 ± 1.46 at site S1 and minimum was 4 ± 0.75 at site S7 (Table 4.3).

A comparison of number of spikes in plants with and without EDU shows that in treated plants was 4.17%, 9.09%, 8.70%, 10.71%, 6.38%, 12.50%, 5.26%, 5.48% and 6.52% more as compared to plants grown without EDU treatment (Table 4.3 and Figure 4.8).

The difference in number of spikes between plants with and without EDU was statistically significant (P ≤0.05 level) (Table 4.3).

Spike Length

The average length of spike at maturity in plants grown without EDU at different sites was 9.25 ± 1.12, 8.81 ± 0.825, 8.76 ± 2.1, 7.92 ± 1.61, 9.18 ± 1.46, 7.7 ± 1.09, 9.01 ± 1.61, 8.76 ± 1.16 and 8.71 ± 1.13 cm respectively. The maximum length of spike was 9.25 ± 1.12 cm at site S1 and minimum was 7.7 ± 1.09 cm at site S7 (Table 4.3).

In EDU-treated plants, the average length of spike at different sites was 9.89 ± 1.8, 9.45 ± 0.64, 9.38 ± 0.694, 8.88 ± 0.835, 9.83 ± 2.44, 8.86 ± 1.33, 9.63 ± 1.06, 9.38 ± 0.74

and 9.38 ± 1.18 cm respectively. The maximum average length of spike was 9.89 ± 1.8 cm at site S1 and minimum was 8.86 ± 1.33 cm at site S7 (Table 4.3).

A comparison of plants grown with and without EDU shows that the length of spike in EDU treated plants was 6.70%, 6.77%, 6.61%, 10.76%, 6.51%, 13.09%, 6.34%, 6.51% and 7.04% more over plants without EDU treatment (Table 4.3 and Figure 4.9).

The difference in spike length in plants with and without EDU was statistically significant ($P \leq 0.05$ level) (Table 4.3).

Grains per Spike

The average of number of grains per spike at maturity in plants grown without EDU at different sites was 32.5 ± 6.07, 29.5 ± 8.21, 29.5 ± 8.03, 28.25 ± 5.85, 32 ± 3.57, 27.00 ± 6.35, 31.5 ± 6.57, 29.7 ± 6.73 and 29.5 ± 7.48 respectively. The maximum number of grains per spike was 32.5 ± 6.07 at site S1 and minimum was 27 ± 6.35 at site S7 (Table 4.3).

In EDU-treated plants, the average of number of grains per spike at different sites was 42.00 ± 6.07, 39.5 ± 5.78, 39.00 ± 1.3, 38.5 ± 5.55, 41.8 ± 1.67, 38.00 ± 4.24, 41.00 ± 4.17, 39.5 ± 2.56 and 38.9 ± 5.08 respectively. The maximum number of grains per spike was 42 ± 6.07 at site S1 and minimum was 38 ± 4.24 at site S7 (Table 4.3).

The number of grains per spike in EDU treated plants at different sites was 22.61%, 25.32%, 24.36%, 26.62%, 23.35%, 28.95%, 23.17%, 24.81% and 24.12% more as compared to plants grown without EDU treatment (Table 4.3 and Figure 4.10).

The difference in number of grains per spike between plants grown with and without EDU was statistically significant ($P \leq 0.01$ level) (Table 4.3).

Grain Weight per Plant

The grain weight at maturity in plants grown without EDU at different sites was 3.92 ± 0.99, 3.79 ± 0.9, 3.8 ± 0.48, 3.28 ± 0.48, 3.88 ± 0.48, 3.24 ± 0.65, 3.83 ± 0.71, 3.77 ± 0.74 and 3.75 ± 0.69 g respectively. The maximum grain weight per plant was 3.92 ± 0.99 g at site S1 (Plate 4.3) and minimum was 3.24 ± 0.65 g at site S7 (Table 4.3).

Plate 4.1: EDU-treated (EDU-Tr) and non-treated (N-Tr) Wheat (*Triticum aestivum*) Plants at S-1 (Bakoli) Site.

Plate 4.2: EDU-treated (EDU-Tr) and non-treated (N-Tr) Wheat (*Triticum aestivum*) Plants at S-7 (Badarpur) Site.

Plate 4.3: A Comparison of Wheat (*Triticum aestivum*) Grains of EDU-treated (EDU-TR) and non-treated (N-TR) Plants Grown at S-1 (Bakoli) Site.

In EDU-treated plants, the seed weight per plant at different sites was 4.18 ± 1.31, 4.08 ± 0.77, 4.07 ± 0.59, 3.795 ± 0.59, 4.17 ± 0.5, 3.79 ± 0.16, 4.12 ± 0.77, 4.08 ± 0.55 and 4.08 ± 1.26 g respectively (Plate 4.3). The maximum grain weight per plant was 4.18 ± 1.31 g at site S1 and minimum was 3.79 ± 0.16 g at site S7 (Table 4.3).

A comparison between EDU plants and non-treated shows that grain weight in EDU treated plants was 6.22%, 7.10%, 6.64%, 13.57%, 6.95%, 14.39%, 7.03%, 7.35% and 7.84% more over plants grown without EDU treatment (Table 4.3 and Figure 4.11).

The difference in grain weight between plants with and without EDU treatment was statistically significant (P ≤0.01 level) (Table 4.3).

Total Chlorophyll

The total chlorophyll content in 60 days old plants without EDU at different sites was 1.68 ± 0.11, 1.62 ± 0.24, 1.61 ± 0.14, 1.42 ± 0.11, 1.63 ± 0.17, 1.34 ± 0.12, 1.51 ± 0.16, 1.20 ± 0.05 and 1.30 ± 0.09 mg/g respectively. The maximum total chlorophyll was 1.68 ± 0.11 mg/g at site S1 and minimum was 1.20 ± 0.05 mg/g at site S10 (Table 4.3).

In EDU-treated plants the total chlorophyll content at different sites was 1.84 ± 0.19, 1.79 ± 0.26, 1.80 ± 0.12, 1.73 ± 0.23, 1.80 ± 0.18, 1.62 ± 0.28, 1.77 ± 0.19, 1.42 ± 0.18 and 1.47 ± 0.15 mg/g respectively. The maximum total chlorophyll was 1.84 ± 0.19 mg/g at site S1 and minimum was 1.42 ± 0.18 mg/g at S10 (Table 4.3).

A comparison between chlorophyll content in EDU treated and non-treated plants shows that the total chlorophyll content in EDU treated plants at different sites was more by 8.68%, 9.37%, 10.27%, 17.78%, 9.26%, 16.90%, 14.96%, 17.99% and 11.14% more over plants grown without EDU treatment (Table 4.3 and Figure 4.12).

The difference in total chlorophyll content between plants grown with and without EDU was statistically significant (P ≤0.01 level) (Table 4.3).

Ascorbic Acid

The ascorbic acid content in 60 days old plants without EDU at different sites was 0.85 ± 0.07, 0.75 ± 0.03, 0.75 ± 0.02, 0.71 ± 0.02, 0.85 ± 0.06, 0.67 ± 0.11, 0.75 ± 0.12, 0.74

± 0.11 and 0.73 ± 0.14 mg/g respectively. The maximum ascorbic acid content was 0.85 ± 0.07mg/g at site S1and minimum was 0.67 ± 0.01 mg/g at site S7 (Table 4.3).

In EDU-treated plants, the ascorbic acid at different sites was 0.96 ± 0.19, 0.89 ± 0.05, 0.88 ± 0.16, 0.86 ± 0.08, 0.98 ± 0.18, 0.82 ± 0.06, 0.89 ± 0.18, 0.87 ± 0.08 and 0.84 ± 0.12 mg/g respectively. The maximum ascorbic acid content was 0.96 ± 0.19 mg/g in plants of S1 site and minimum was 0.82 ± 0.18 mg/g in plants at S7 site (Table 4.3).

A comparison of ascorbic acid content in plants with and without EDU shows that ascorbic acid content in EDU treated plants was 11.45%, 15.73%, 14.72%, 17.44%, 13.26%, 18.29%, 15.73%, 14.94% and 13.09% more over plants grown without EDU treatment (Table 4.3 and Figure 4.13).

The difference in ascorbic acid content between EDU treated and non-treated plants was statistically significant (P ≤0.01 level) (Table 4.3).

Fumigation Study

Three sets of plants namely control, E1 and E2 were prepared to carry out the fumigation study. The E1 and E2 sets were fumigated with 150μg/m^3 of ozone and the control plants was maintained in the ambient environment. Ground level ozone monitoring was also carried out during February-2003 to find out the background ozone concentration in the ambient environment at JNU. The average hourly ozone concentration was 73.5μg/m^3 and the maximum and minimum concentration was 174.44μg/m^3 and 5.88μg/m^3 respectively. The growth and performances of plants exposed to 150μg/m^3 and were made in respect of different morphological and biochemical parameters.

Culm Length

The plant growth was slow up to 30th day. Subsequently, there was a rapid growth till 55th day. Between 55-75th days, the growth was relatively slow and beyond there was no further increase 75th day.

The average culm length in plants without EDU was 41.2 ± 8.27, 26.33 ± 8.42 and 32.92 ± 10.15 cm respectively. The maximum culm length was 41.2 ± 8.27 cm in control plants and minimum was 26.33 ± 8.42 in plants of E1 set (Table 4.3).

In EDU-treated plants, the average culm length in plants was 45.8 ± 9.04, 42.5 ± 8.18 and 43.8 ± 8.95 cm respectively. The maximum culm length was 45.8 ± 9.04 in control plants and minimum was 42.5 ± 8.18 in plants of E1 set (Table 4.3).

A comparison of culm length between EDU and without EDU shows that in EDU-treated plants was 10.04%, 38.05% and 24.84% more over plants grown without EDU treatment (Table 4.3 and Figure 4.14).

The difference in culm length between plants grown with and without EDU was statistically significant ($P \leq 0.05$ level) (Table 4.3).

Culm Number

The average culm number in plants without EDU was 4.5 ± 0.57, 3.0 ± 0.25 and 4.0 ± 0.36 respectively. The maximum culm number was 4.5 ± 0.57 per plant in control plants and minimum was 3.0 ± 0.25 in plants of E1 set (Table 4.3).

The average number of culms per plant in EDU-treated plants was 5.5 ± 0.53, 4.0 ± 0.29 and 5.0 ± 0.58. The maximum culm number was 5.5 ± 0.53 per plant in control plants and minimum was 4.0 ± 0.29 in plants of E1 set (Table 4.3)

A comparison of plants treated with EDU and without EDU show that the culm number in EDU treated plants was 18.18%, 25.0% and 20.0% more over plants without EDU treatment (Table 4.3 and Figure 4.15).

The difference between culm number in plants with and without EDU was statistically significant ($P \leq 0.01$ level) (Table 4.3).

Shoot Biomass

The average shoot biomass in plants grown without EDU was 2.84 ± 0.44, 2.24 ± 0.41 and 2.51 ± 0.37 g respectively. The maximum shoot biomass was 2.84 ± 0.44g in control plants and minimum was 2.24 ± 0.41g in plants of E1 set (Table 4.3).

The average shoot biomass in EDU-treated plants, was 3.37 ± 0.73, 3.24 ± 0.82 and 3.30 ± 0.28g. The maximum shoot biomass was 3.37 ± 0.73g in control plants and minimum was 3.24 ± 0.82g in plants of E1 set (Table 4.3).

A comparison of shoot biomass between EDU treated and non-treated plants shows biomass in EDU treated plants was 15.73%, 30.86% and 29.94% more over plants without EDU treatment (Table 4.3 and Figure 4.16).

The difference in shoot biomass between plants with and without EDU was statistically significant (P ≤0.01 level) (Table 4.3).

Root Length

The average root length at maturity in plants without EDU was 8.55 ± 1.86, 7.42 ± 1.05 and 8.02 ± 1.14 cm respectively. The maximum root length was 8.55 ± 1.86 cm in control plants and minimum was 7.42 ± 1.05 cm in plants of E1 set (Table 4.3).

The average root length in EDU-treated plants was 9.24 ± 0.89, 8.84 ± 0.82 and 9.12 ± 0.71cm respectively. The maximum root length was 9.24 ± 0.89 cm in control plants and minimum was 8.84 ± 0.82cm in plants of E1 set (Table 4.3).

A comparison of root length between EDU treated and non-treated plants shows root length in EDU treated plants was 7.47%, 16.06% and 12.06% more over plants without EDU treatment (Table 4.3 and Figure 4.17).

The difference in root length between plants with and without EDU was statistically insignificant (Table 4.3).

Root Biomass

The average root biomass at maturity in plants without EDU was 0.48 ± 0.05, 0.40 ± 0.01 and 0.44 ± 0.03 g respectively. The maximum root biomass was 0.48 ± 0.05 g in control plants and minimum was 0.40 ± 0.01g in plants of E1 set (Table 4.3).

In EDU-treated plants, the average root biomass was 0.60 ± 0.11, 0.54 ± 0.08 and 0.59 ± 0.11g. The maximum root biomass was 0.60 ± 0.11g in control plants and minimum was 0.54 ± 0.08 in plants of E1 set (Table 4.3).

A comparison of root biomass between EDU treated and non-treated plants show that the root biomass in EDU treated plants was 20.0%, 25.93% and 25.42% more over plants grown without EDU treatment (Table 4.3 and Figure 4.18).

The difference in root biomass between plants with and without EDU was statistically insignificant (Table 4.3).

Spikes per Plant

The average number of spikes in plants without EDU was 3.20 ± 0.57, 2.40 ± 0.32 and 2.80 ± 0.39 respectively. The maximum number of spike per plant was 3.20 ± 0.57 in control plants and minimum was 2.40 ± 0.32 in plants of E1 set (Table 4.3).

In EDU-treated plants, the average number of spike per plant varied between 3.80 ± 0.54, 3.24 ± 0.50 and 3.48 ± 0.71. The maximum number of spike per plant was 3.80 ± 0.54 in control plants and minimum was 3.24 ± 0.50 in plants of E1 set (Table 4.3).

A comparison of number of spike per plant between EDU treated and non-treated plants shows spike per plant was 15.79%, 29.41% and 22.22% more over plants grown without EDU treatment (Table 4.3 and Figure 4.19).

The difference in spike number between plants with and without EDU was statistically significant (P ≤0.05 level) (Table 4.3).

Spike length

The average spike length at maturity in plants without EDU was 8.42 ± 0.94, 7.20 ± 0.71 and 7.80 ± 0.72 cm respectively. The maximum spike length was 8.42 ± 0.94 cm in control plants and minimum was 7.8 ± 0.72cm in plants of E1 set (Table 4.3).

The average spike length in EDU treated plants varied between 9.10 ± 1.34, 8.62 ± 1.38 and 8.80 ± 0.71 cm. The maximum spike length was 9.10 ± 1.34 cm in control plants and minimum was 8.62 ± 1.38 cm in plants of E1 set (Table 4.3).

A comparison of spike length between EDU treated and non-treated plants shows spike length in plants treated with EDU was 7.47%, 16.47% and 12.16% more over plants without EDU treatment (Table 4.3 and Figure 4.20).

The difference in spike length between plants with and without EDU was statistically significant (P ≤0.05 level) (Table 4.3).

Grains per Spike

The average number of grains per spike at maturity in plants without EDU was 30.55 ± 2.65, 24.55 ± 2.65 and 27.80 ± 1.41. The maximum number of grains per spike was 30.55 ± 2.65 in control plants and minimum was 24.55 ± 2.65 in plants of E1 set (Table 4.3).

In EDU-treated plants, the average number of grains per spike varied between 38.68 ± 4.94, 34.44 ± 0.96 and 36.42 ± 1.41. The maximum number of grains per spike was 38.68 ± 4.94 in control plants and minimum was 34.44 ± 0.96 in plants of E1 set (Table 4.3).

A comparison of grains per spike between EDU treated and non-treated plants shows grains per spike in plants treated with EDU was 21.02%, 28.72% and 23.67% more over plants without EDU treatment (Table 4.3 and Figure 4.21).

The difference in grains per spike between plants with and without EDU was statistically significant (P ≤0.05 level) (Table 4.3).

Grain Weight per Plant

The average grain weight in plants grown without EDU was 3.40 ± 0.08, 2.20 ± 0.12 and 2.80 ± 0.32 g respectively. The maximum grain weight per plant was 3.40 ± 0.08 g in control plants and minimum was 2.20 ± 0.12 g in plants of E1 set (Table 4.3).

In EDU-treated plants, the grain weight per plant varied between 3.80 ± 0.54, 3.24 ± 0.05 and 3.48 ± 0.71. The maximum grain weight per plant was 3.80 ± 0.54 g in control plants and minimum was 3.24 ± 0.05g in plants of E1 set (Table 4.3).

A comparison of grain weight per plant in EDU treated and non-treated plants shows grain weight per plants treated with EDU was 10.53%, 32.10% and 19.54% more over plants grown without EDU treatment (Table 4.3 and Figure 4.22).

The difference in grain weight per plant between plants with and without EDU was statistically significant (P ≤0.01 level) (Table 4.3).

Total Chlorophyll

The total chlorophyll content of 60 days old plants of without EDU was 1.464 ± 0.03, 1.312 ± 0.01and 1.43 ± 0.04 mg/g . The maximum total chlorophyll content was 1.464 ± 0.03 mg /gm in control plants and minimum was 1.312 ± 0.01 mg/g in plants of E1 set (Table 4.3).

In EDU-treated plants, the total chlorophyll content was 1.84 ± 0.06, 1.68 ± 0.02 and 1.82 ± 0.09 mg/g. The maximum total chlorophyll content was 1.84± 0.06 mg/g in control plants and minimum was 1.68 ± 0.02 mg/g in plants of E1 set (Table 4.3).

A comparison of total chlorophyll content between EDU treated and non-treated plants show total chlorophyll content in plants treated with EDU was 20.43%, 21.91% and 21.42% more over plants grown without EDU treatment (Table 4.3 and Figure 4.23).

The difference in total chlorophyll content between plants with and without EDU was statistically insignificant (Table 4.3).

Ascorbic Acid

The ascorbic acid content of 60 days old plant without EDU was 0.83 ± 0.01, 0.80 ± 0.01 and 0.81 ± 0.02 mg/g. The maximum ascorbic acid content was 0.83 ± 0.01 mg/g in control plants and minimum was 0.80 ± 0.01mg/g in plants of E1 set (Table 4.3).

In EDU-treated plants, the average ascorbic acid content varied between 0.84 ± 0.02, 0.82 ± 0.03 and 0.83 ± 0.02. The maximum ascorbic acid content was 0.84± 0.02 mg/g in control plants and minimum, 0.82 ± 0.03 mg/g in plants of E1 set (Table 4.3).

A comparison of ascorbic acid content between EDU treated and non-treated plants show ascorbic acid content in plants treated with EDU was 1.19%, 2.44% and 2.41% more over plants without EDU treatment (Table 4.3 and Figure 4.24).

The difference in ascorbic acid content between plants with and without EDU was statistically insignificant (Table 4.3).

Table 4.3: Performance of *Triticum aestivum* plants with and without EDU exposed to ozone at field sites and in fumigation chamber.

Parameters	Field study									Fumigation study		
	S1	S2	S3	S4	S6	S7	S9	S10	S11	C	E1	E2
Culm length (cm) EDU	60.50 ± 7.85	58.20 ± 3.74	58.00 ± 8.21	55.80 ± 5.20	59.70 ± 7.83	54.10 ± 1.74	57.80 ± 7.45	56.30 ± 7.86	55.90 ± 4.69	45.80 ± 9.04	42.50 ± 8.18	43.80 ± 8.95
N-TR	55.60[1] ± 7.27	54.10[1] ± 4.45	53.82[1] ± 8.03	51.51[1] ± 4.65	55.91[1] ± 6.09	49.61[1] ± 5.80	53.55[1] ± 6.39	52.15[1] ± 6.58	51.47[1] ± 8.84	41.20[2] ± 8.27	26.33[2] ± 8.42	32.92[2] ± 10.15
Difference (%)	6.45	7.01	7.20	7.89	6.35	8.89	7.27	7.37	7.96	10.04	38.05	24.80
No. of culms EDU	6.75 ± 1.75	5.75 ± 0.70	5.75 ± 1.16	4.88 ± 1.12	6.50 ± 1.06	4.88 ± 0.64	6.00 ± 1.59	5.75 ± 1.98	5.75 ± 1.16	5.50 ± 0.53	4.00 ± 0.29	5.00 ± 0.58
N-TR	5.65[1] ± 1.66	4.75[1] ± 2.15	4.75[1] ± 1.71	3.75[1] ± 1.25	5.50[1] ± 1.43	3.75[1] ± 1.11	5.00[1] ± 0.85	4.75[1] ± 0.64	4.75[1] ± 0.64	4.50[1] ± 0.57	3.00[1] ± 0.25	4.00[1] ± 0.36
Difference (%)	16.29	17.39	17.39	23.08	15.38	23.08	16.67	17.39	17.39	18.18	25.00	20.00
Shoot biomass (gm) EDU	4.01 ± 1.36	3.58 ± 0.71	3.55 ± 0.52	3.33 ± 0.63	3.97 ± 0.95	3.30 ± 0.65	3.68 ± 0.48	3.68 ± 0.68	3.66 ± 0.74	3.37 ± 0.73	3.24 ± 0.82	3.30 ± 0.28
N-TR	3.47[1] ± 0.61	2.85[1] ± 1.19	2.83[1] ± 1.05	2.43[1] ± 0.52	3.44[1] ± 0.77	2.39[1] ± 0.35	2.89[1] ± 0.49	2.87[1] ± 0.67	2.87[1] ± 0.67	2.84[1] ± 0.44	2.24[1] ± 0.41	2.51[1] ± 0.37
Difference (%)	13.45	20.25	20.28	26.92	13.35	27.78	21.53	21.86	21.75	15.73	30.86	29.94

Root length (cm) EDU	10.60 ± 1.61	9.10 ± 0.84	9.10 ± 2.92	8.63 ± 2.06	9.80 ± 1.32	8.61 ± 1.67	9.25 ± 1.39	9.20 ± 1.48	9.13 ± 0.99	9.24 ± 0.89	8.84 ± 0.82	9.12 ± 0.71
N-TR	9.87^{1} ± 0.96	8.37^{1} ± 3.06	8.38^{1} ± 2.42	7.71^{1} ± 1.79	9.12^{1} ± 1.73	7.61^{1} ± 2.03	8.46^{1} ± 1.50	7.92^{1} ± 1.50	7.81^{1} ± 1.34	8.55^{ns} ± 1.86	7.42^{ns} ± 1.05	8.02^{ns} ± 1.14
Difference (%)	6.84	8.02	7.91	10.56	6.94	11.65	8.46	8.52	8.82	7.47	16.06	12.06
Root biomass (gm) EDU	0.70 ± 0.09	0.66 ± 0.11	0.68 ± 0.17	0.64 ± 0.09	0.67 ± 0.23	0.63 ± 0.14	0.66 ± 0.10	0.65 ± 0.13	0.64 ± 0.17	0.60 ± 0.11	0.54 ± 0.08	0.59 ± 0.11
N-TR	0.47^{1} ± 0.17	0.42^{1} ± 0.15	0.42^{1} ± 0.20	0.38^{1} ± 0.18	0.42^{1} ± 0.20	0.35^{1} ± 0.17	0.42^{1} ± 0.12	0.42^{1} ± 0.25	0.40^{1} ± 0.23	0.48^{ns} ± 0.05	0.40^{ns} ± 0.01	0.44^{ns} ± 0.03
Difference (%)	31.43	36.36	38.23	40.95	35.92	43.36	34.95	34.00	35.77	20.00	25.93	25.42
Spikes per plant EDU	4.88 ± 1.46	4.63 ± 0.91	4.63 ± 1.06	4.25 ± 0.70	4.75 ± 1.03	4.00 ± 0.75	4.75 ± 0.88	4.63 ± 0.52	4.63 ± 1.06	3.80 ± 0.54	3.24 ± 0.50	3.48 ± 0.71
N-TR	4.60^{2} ± 0.82	4.05^{2} ± 1.14	4.20^{2} ± 0.77	3.75^{2} ± 0.78	4.40^{2} ± 0.82	3.55^{2} ± 0.60	4.50^{2} ± 1.43	4.40^{2} ± 1.14	4.30^{2} ± 1.08	3.20^{2} ± 0.57	2.40^{2} ± 0.32	2.80^{2} ± 0.39
Difference (%)	4.17	9.09	8.70	10.71	6.38	12.50	5.26	5.48	6.52	15.79	29.41	22.22

Spike length (cm) EDU	9.89 ± 1.80	9.45 ± 0.64	9.38 ± 0.694	8.88 ± 0.835	9.83 ± 2.44	8.86 ± 1.33	9.63 ± 1.06	9.38 ± 0.74	9.38 ± 1.18	9.10 ± 1.34	8.62 ± 1.38	8.80 ± 0.71
N-TR	9.25[2] ± 1.12	8.81[2] ± 0.825	8.76[2] ± 2.10	7.92[2] ± 1.61	9.18[2] ± 1.46	7.70[2] ± 1.09	9.01[2] ± 1.61	8.76[2] ± 1.16	8.71[2] ± 1.13	8.42[2] ± 0.94	7.20[2] ± 0.71	7.80[2] ± 0.72
Difference (%)	6.70	6.77	6.61	10.76	6.51	13.09	6.34	6.51	7.04	7.47	16.47	12.16
Grains per spike EDU	42.00 ± 6.07	39.50 ± 5.78	39.00 ± 1.30	38.50 ± 5.55	41.80 ± 1.67	38.00 ± 4.24	41.00 ± 4.17	39.50 ± 2.56	38.90 ± 5.08	38.68 ± 4.94	34.44 ± 0.96	36.42 ± 1.41
N-TR	32.50[1] ± 6.07	29.50[1] ± 8.21	29.50[1] ± 8.03	28.25[1] ± 5.85	32.00[1] ± 3.57	27.00[1] ± 6.35	31.50[1] ± 6.57	29.70[1] ± 6.73	29.50[1] ± 7.48	30.55[2] ± 2.65	24.55[2] ± 2.65	27.80[2] ± 1.41
Difference (%)	22.61	25.32	24.36	26.62	23.35	28.95	23.17	24.81	24.12	21.02	28.72	23.67
Grain weight per plant (gm) EDU	4.18 ± 1.31	4.08 ± 0.77	4.07 ± 0.59	3.795 ± 0.59	4.17 ± 0.50	3.79 ± 0.16	4.12 ± 0.77	4.08 ± 0.55	4.08 ± 1.26	3.80 ± 0.54	3.24 ± 0.05	3.48 ± 0.71
N-TR	3.92[1] ± 0.99	3.79[1] ± 0.90	3.80[1] ± 0.48	3.28[1] ± 0.48	3.88[1] ± 0.48	3.24[1] ± 0.65	3.83[1] ± 0.71	3.77[1] ± 0.74	3.75[1] ± 0.69	3.40[1] ± 0.08	2.20[1] ± 0.12	2.80[1] ± 0.32
Difference (%)	6.22	7.10	6.64	13.57	6.95	14.39	7.03	7.35	7.84	10.53	32.10	19.54

Totalchlorophyll (mg/g)												
EDU	1.84 ± 0.19	1.79 ± 0.26	1.80 ± 0.12	1.73 ± 0.23	1.80 ± 0.18	1.62 ± 0.28	1.77 ± 0.19	1.42 ± 0.18	1.47 ± 0.15	1.84 ± 0.06	1.68 ± 0.02	1.82 ± 0.09
N-TR	1.68[1] ± 0.11	1.62[1] ± 0.24	1.61[1] ± 0.14	1.42[1] ± 0.11	1.63[1] ± 0.17	1.34[1] ± 0.12	1.51[1] ± 0.16	1.20[1] ± 0.05	1.30[1] ± 0.09	1.464[ns] ± 0.03	1.312[ns] ± 0.01	1.43[ns] ± 0.04
Difference (%)	8.68	9.37	10.27	17.78	9.26	16.90	14.96	17.99	11.14	20.43	21.91	21.42
Ascorbic acid (mg/g)												
EDU	0.96 ± 0.19	0.89 ± 0.05	0.88 ± 0.16	0.86 ± 0.08	0.98 ± 0.18	0.82 ± 0.06	0.89 ± 0.18	0.87 ± 0.08	0.84 ± 0.12	0.84 ± 0.02	0.82 ± 0.03	0.83 ± 0.02
N-TR	0.85[2] ± 0.07	0.75[2] ± 0.03	0.75[2] ± 0.02	0.71[2] ± 0.02	0.85[2] ± 0.06	0.67[2] ± 0.11	0.75[2] ± 0.12	0.74[2] ± 0.11	0.73[2] ± 0.14	0.83[ns] ± 0.01	0.80[ns] ± 0.01	0.81[ns] ± 0.02
Difference (%)	11.45	15.73	14.72	17.44	13.26	18.29	15.73	14.94	13.09	1.19	2.44	2.41

decrease from EDU
- increase over EDU

S1: Bakoli, S2: S. Collge, S3: Jain Temple, S5: Tilak Bridge, S6: JNU, S7: Badarpur, S8: DPS-Faridabad, S9: IOC

C-Control; E1 set - exposed to five cycles of exposure to 150 $\mu g/m^3$ of ozone for four hours (total exposure of 20 hours) at 10-day interval after each EDU treatment; E2 set - five cycles of exposure to 150 $\mu g/m^3$ ozone daily for 4 hours over five successive days (total exposure of 20 hours) after three EDU treatments.

[1] Significant difference between plants grown without EDU (N-TR) and with EDU treatment at $P \leq 0.01$ level
[2] Significant difference between plants grown without EDU (N-TR) and with EDU treatment at $P \leq 0.05$ level
[3] Significant difference between plants grown without EDU (N-TR) and with EDU treatment at $P \leq 0.1$ level
[ns] Non-significant

In both the cases (Field studies and fumigation studies) EDU treated plants were better as compared to plants grown without EDU. A comparison between the performance of plants exposed to ambient ozone at field sites and those subjected to experimental fumigation shows that the different plant parameters in the fumigated plants were relatively more affected (Table 4.4).

Table 4.4: A comparison between the percentage differences in average values of different parameters in *Triticum aestivum* plants grown with and without EDU exposed to 69.07-158.33μg/m^3 of ground level ozone and fumigated with 150μg/m^3 ozone.

Plant parameter	Field study (% difference) between plants with and without EDU)	Fumigation study (% difference) between plants grown with and without EDU)			Control plants during fumigation study (% difference) between plants grown with and without EDU)
		E1	E2	Average	
Culm length	7.38	38.05	24.84	31.45	10.04
No. of culms per plant	18.23	25.00	20.00	22.5	18.18
Shoot biomass	20.78	30.86	29.94	30.40	15.73
Root length	8.64	16.06	12.06	14.06	7.47
Root biomass	37.48	25.93	25.40	25.67	20.00
Spikes per plant	7.68	29.41	22.22	25.82	15.79
Spike length	7.78	16.47	12.16	14.32	7.47
Grains per spike	24.81	28.72	23.67	26.20	21.02
Grain weight per plant	8.58	32.10	19.54	25.82	10.53
Total chlorophyll	12.79	21.91	21.42	21.67	20.43
Ascorbic acid	14.97	2.44	2.41	2.425	1.19

The protection accorded by EDU to *Triticum aestivum* plants was not uniform in respect of different morphological and biochemical parameters were of following order.

Root biomass > Grains per spike > Shoot biomass > No. of culms per plant > Ascorbic acid > Total chlorophyll > Grain weight per plant > Spike length > Spikes per plant > Culm length.

In case of *Triticum aestivum* plants fumigated with 150 µg/m^3 of ozone, the reduction in different morphological and biochemical parameters was of the following order:

Culm length > Shoot biomass > Grains per spike > Spikes per plant > Grain weight per plant > No. of culms per plant > Root biomass >Total chlorophyll > Spike length > Root length > Ascorbic acid

Both in field and fumigation studies, seed weight per plant were moderately affected as compared to other parameters. It seems that EDU nullifies the adverse effect of ozone on *Triticum aestivum* plants.

Figure 4.3: A comparison of culm length between N-Tr and EDU-Tr plants of *Triticum aestivum* grown at field sites.

Figure 4.4: A comparison of culm number between N-Tr and EDU-Tr plants of *Triticum aestivum* grown at field sites.
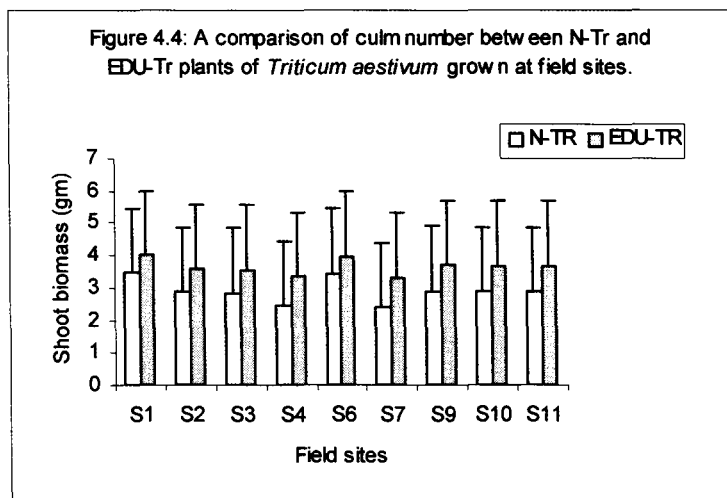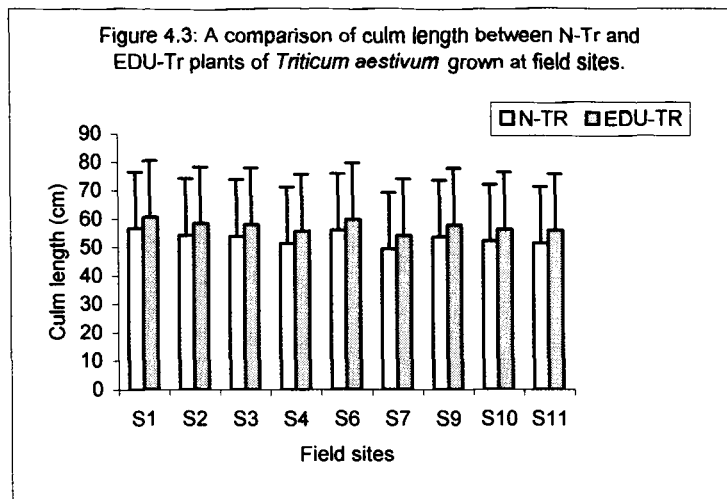
Figure 4.5: A comparison of shoot biomass between N-Tr and EDU-Tr plants of *Triticum aestivum* grown at field sites.
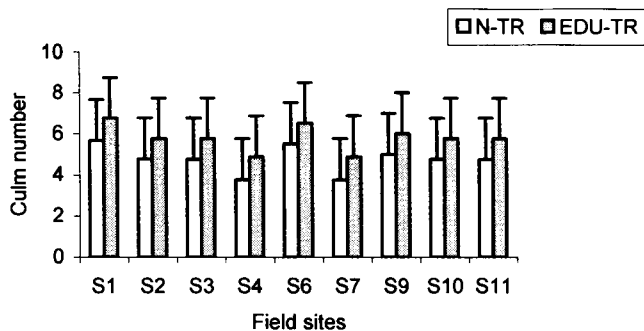
Figure 4.6: A comparison of root length between N-Tr and EDU-Tr plants of *Triticum aestivum* grown at field sites.
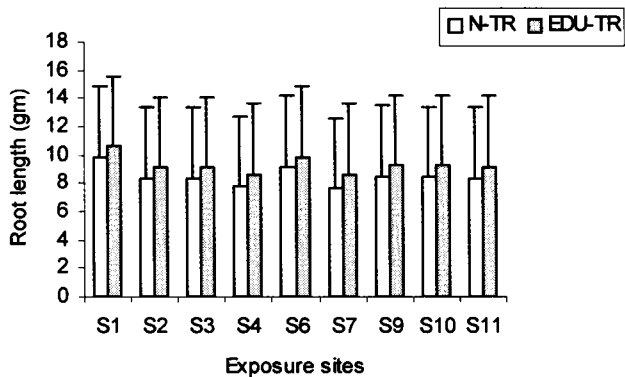
Figure 4.7: A comparison of root biomass between N-Tr and EDU-Tr plants of *Triticum aestivum* grown at field sites.
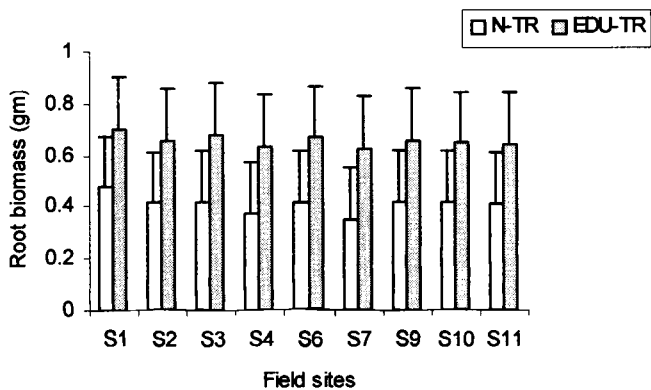
Figure 4.8: A comparison of number of spikes per plant between N-Tr and EDU-Tr plants of *Triticum aestivum* grown at field sites.
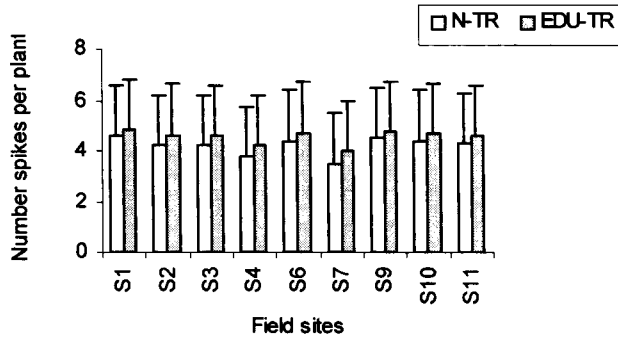
Figure 4.9: A comparison of spike length between N-Tr and EDU-Tr plants of *Triticum aestivum* grown at field sites.
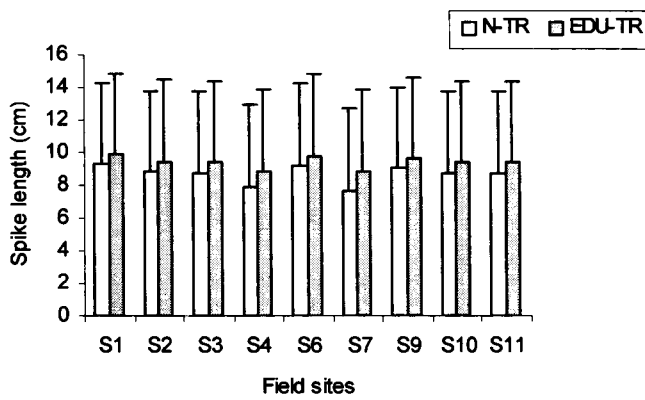
Figure 4.10: A comparison between number of grains per spike between N-Tr and EDU-Tr plants of *Triticum aestivum* grown at field sites.
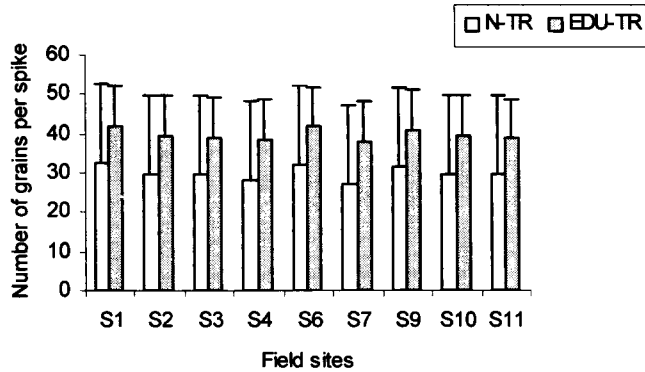
Figure 4.11: A comparison of grain weight per plant between N-Tr and EDU-Tr plants of *Triticum aestivum* grown at field sites.
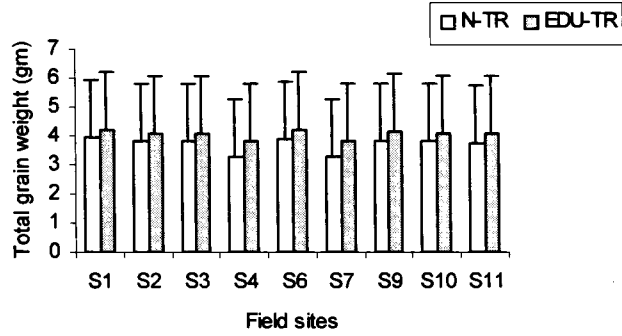
Figure 4.12: A comparison of total chlorophyll contentbetween N-Tr and EDU-Tr plants of *Triticum aestivum* grown at field sites.
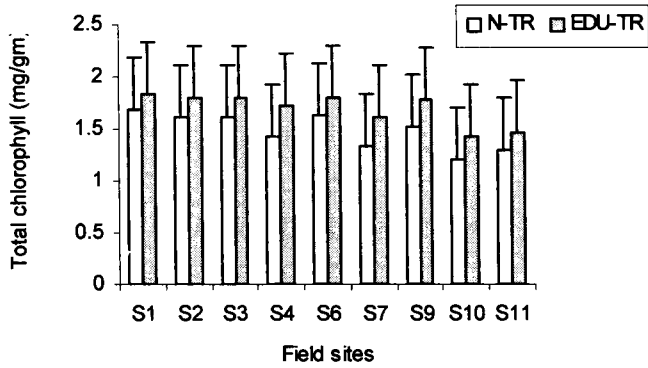
Figure 4.13: A comparison of ascorbic acid content between N-Tr and EDU-Tr plants of *Triticum aestivum* grown at field sites.
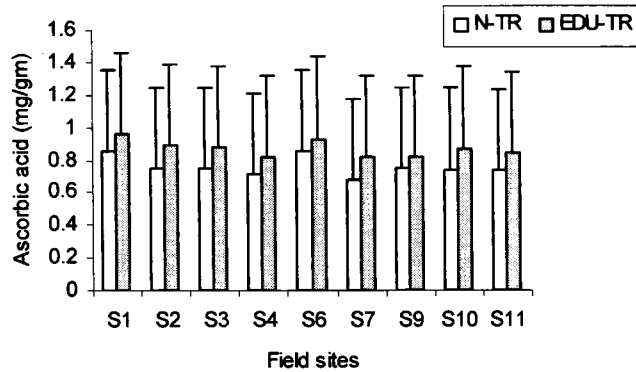
Figure 4.14: A comparison of culm length between ozone fumigated N-Tr and EDU-Tr plants of *Triticum aestivum*.
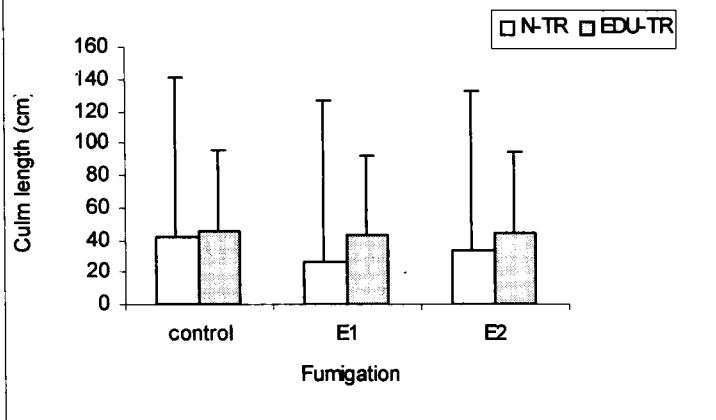
Figure 4.15: A comparison of culm number between ozone fumigated N-Tr and EDU-Tr plants of *Triticum aestivum*.
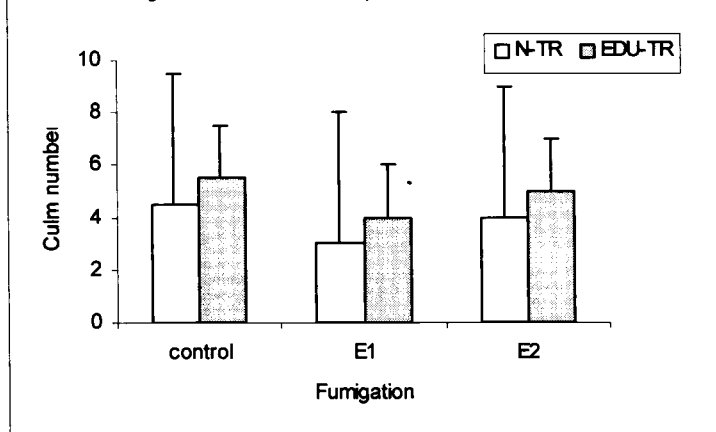
Figure 4.16: A comparison of shoot biomass between ozone fumigated N-Tr and EDU-Tr plants of *Triticum aestivum*.

Figure 4.17: A comparison of root length between ozone fumigated N-Tr and EDU-Tr plants of *Triticum aestivum*.

Figure 4.18: A comparison of root biomass between ozone fumigated N-Tr and EDU-Tr plants of *Triticum aestivum*.

Figure 4.19: A comparison of spikes per plant between ozone fumigated N-Tr and EDU-Tr plants of *Triticum aestivum*.
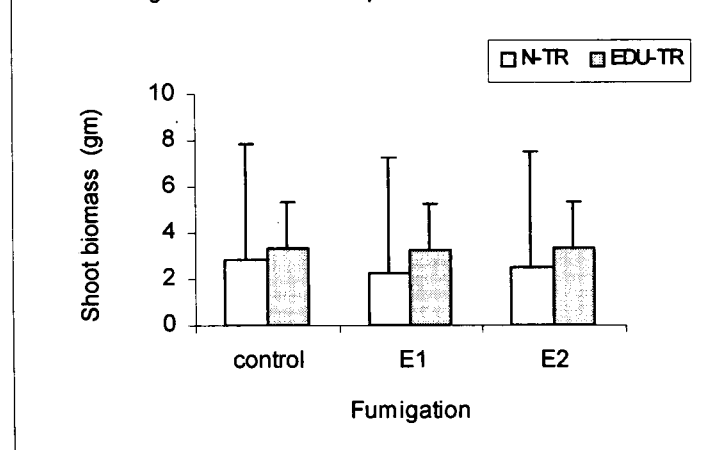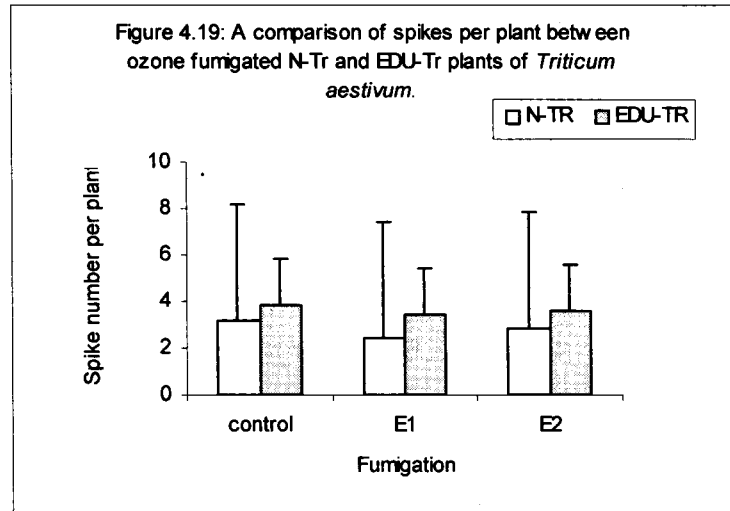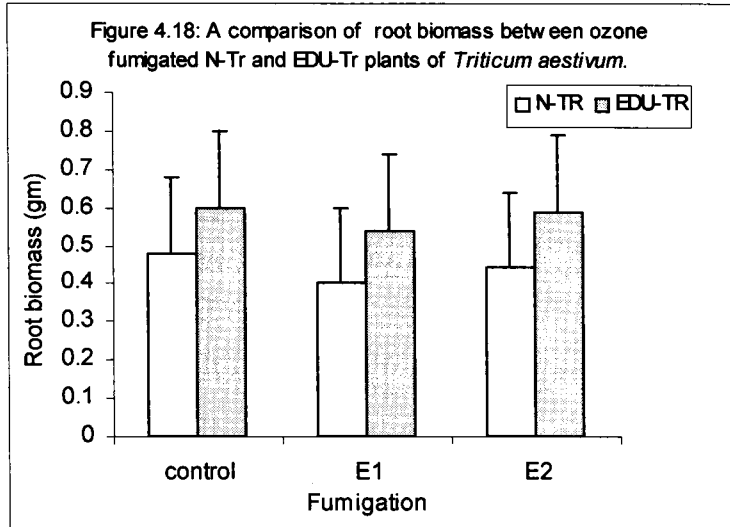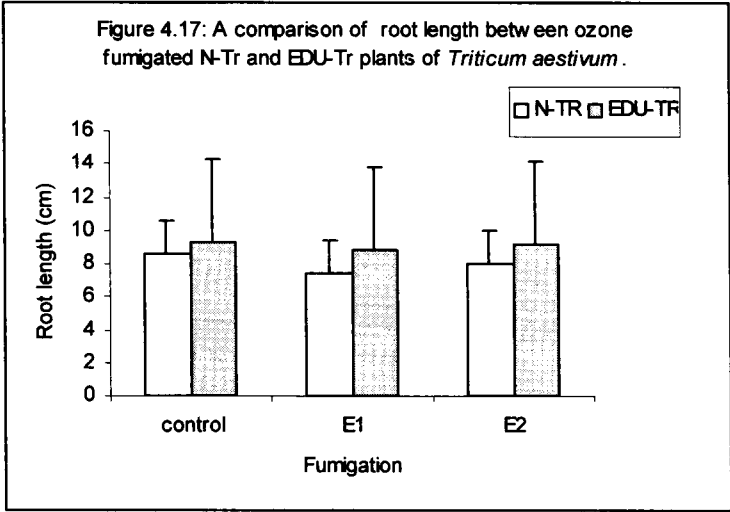
Figure 4.20: A comparison of spike length between ozone fumigated N-Tr and EDU-Tr plants of *Triticum aestivum*.
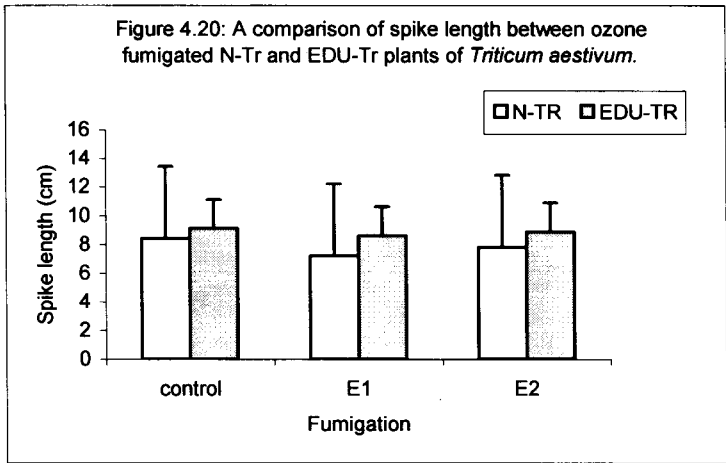
Figure 4.21: A comparison of grains per spike between ozone fumigated N-Tr and EDU-Tr plants of *Triticum aestivum*.
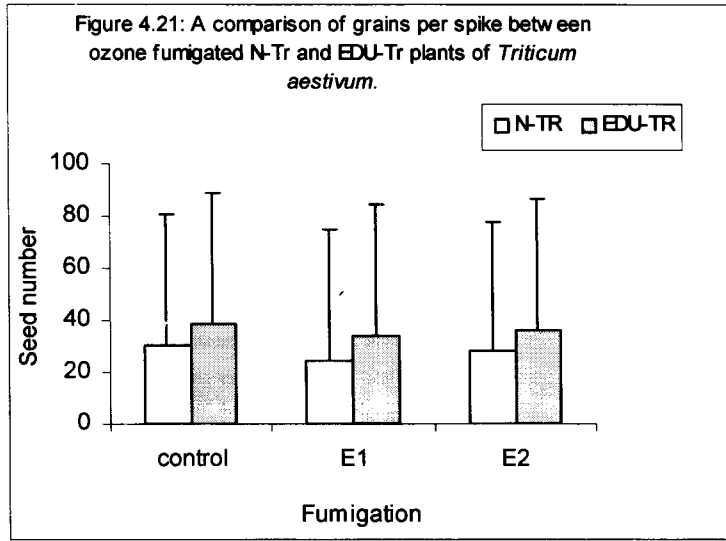
Figure 4.22: A comparison of grain weight per plant between ozone fumigated N-Tr and EDU-Tr plants of *Triticum aestivum*.
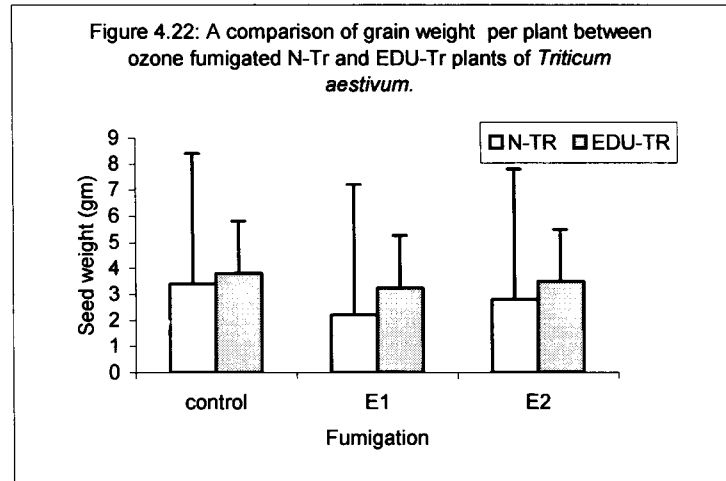
Figure 4.23: A comparison of total chlorophyll content between ozone fumigated N-Tr and EDU-Tr plants of *Triticum aestivum*.
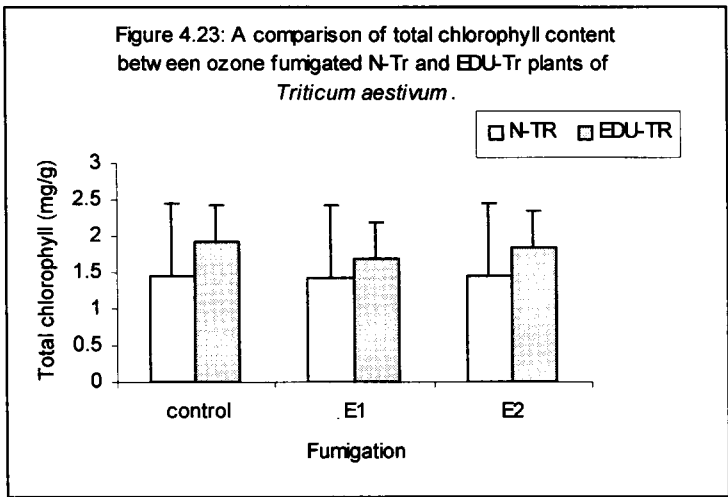
Figure 4.24: A comparison of ascorbic acid content between ozone fumigated N-Tr and EDU-Tr plants of *Triticum aestivum*.
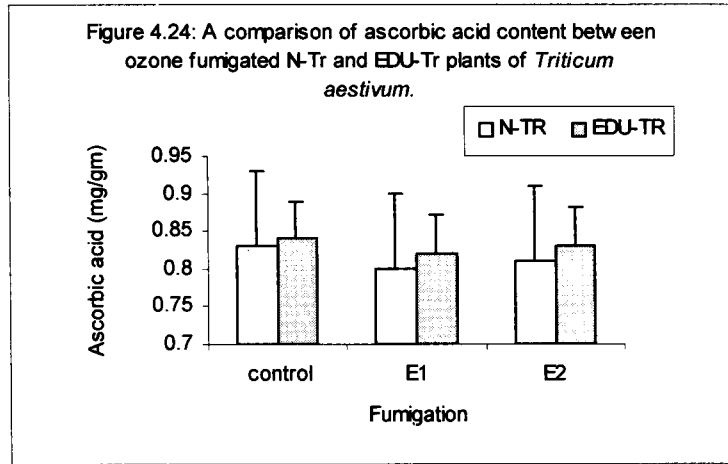
Moong (*Phaseolus aureus* var. PS 16)

Field Studies:

Effect of ambient ozone on growth and yield parameters of Moong (*Phaseolus aureus* var. PS 16) was evaluated among ethylene diurea (EDU) treated plants and untreated EDU plants under field condition at Delhi-Faridabad. Eight different sites (S1, S2, S3, S5, S6, S7, S8 and S9) were chosen in Delhi and Faridabad representing different levels of anthropogenic activity and traffic density. The ground level ozone concentrations varied between 35.72-50.20μg/m^3 at these eight sites. Observations of growth performances of Moong (*Phaseolus aureus* var. PS 16) plants were made in respect of following morphological and biochemical parameters.

Shoot Length

Initially shoot growth was slow up to 25th day of exposure at all sites. Subsequently, there was a rapid increase in shoot length up to 40th days except at site S7. Between 40th -60th day, growth in shoot length was relatively slow and beyond 60th day there was no further growth in shoot length.

The average shoot length in 90days old matured plants without EDU at different sites was 35.93 ± 3.19, 35.44 ± 6.95, 33.08 ± 5.3, 48.00 ± 9.87, 50.88 ± 12.18, 40.06 ± 7.69, 37.5 ± 7.69 and 42.7 ± 9.96 cm respectively. The maximum shoot length was 50.88 ± 12.18 cm at site S6 and minimum was 33.08 ± 5.3 cm at site S3 (Table 4.5).

In EDU-treated plants, the average shoot length at different sites was 37.78 ± 3.49, 36.29 ± 4.89, 36.8 ± 2.51, 41.5 ± 4.26, 39.2 ± 4.15 and 46.44 ± 9.2 cm respectively. The maximum shoot length was at 46.44 ± 9.2 cm at site S9 and minimum was 36.29 ± 4.89 at site S2 (Table 4.5).

A comparison of shoot length between EDU treated and non-treated plants show shoot length in EDU treated plants was 4.89%, 2.32%, 10.11%, 3.46%, 4.34% and 8.07% more over plants without EDU treatment (Table 4.5 and Figure 4.25).

The difference in shoot length between plants with and without EDU was statistically significant ($P \leq 0.01$ level) (Table 4.5).

Shoot Biomass

At maturity the average shoot biomass in plants grown without EDU at different sites was 3.94 ± 0.71, 3.69 ± 0.12, 3.57 ± 0.15, 5.92 ± 1.46, 4.19 ± 0.62, 3.83 ± 0.07, 3.62 ± 0.16 and 3.8 ± 0.38 g respectively. The maximum shoot biomass was 5.92 ± 1.46g at site S5 and minimum was 3.57 ± 0.15 g at site S3 (Table 4.5).

In case of EDU-treated plants, the average shoot biomass at different sites (sites 1-3 and 7-9) was 4.42 ± 0.31, 4.35 ± 0.18, 4.13 ± 0.17, 4.25 ± 0.02, 4.12 ± 0.23 and 4.18 ± 0.26 g respectively. The maximum shoot biomass was at 4.42 ± 0.31g at site S1 and minimum was 4.12 ± 0.23 g at site S7 (Table 4.5).

A comparison of shoot biomass between EDU treated and non-treated plants show shoot biomass in EDU treated plants was 10.85%, 15.17%, 13.56%, 9.88%, 12.13% and 8.61% more over plants without EDU treatment (Table 4.5 and Figure 4.26).

The difference in shoot biomass between plants with and without EDU was statistically insignificant (Table 4.5).

Root Length

The root length in plants without EDU at different sites was 11.68 ± 3.19, 10.96 ± 1.51, 11.28 ± 3.04, 14.75 ± 1.75, 11.58 ± 3.16, 11.38 ± 1.18, 11.42 ± 2.76 and 11.52 ± 0.99 cm respectively. The maximum root length was 14.75 ± 1.75 cm at site S5 and minimum was 10.96 ± 1.51 cm at site S2 (Table 4.5).

In EDU-treated plants, the root length at different sites (sites 1-3 and 7-9) was 12.06 ± 4.19, 11.72 ± 1.25, 12.05 ± 4.45, 12.05 ± 2.74, 12.04 ± 0.39 and 11.91 ± 1.76 cm respectively. The maximum root length was at 12.06 ± 4.19 cm at site S1 and minimum was 11.72 ± 1.25 cm at site S2 (Table 4.5).

A comparison of root length between EDU treated and non-treated plants show root length in EDU treated plants was 3.07%, 6.4%, 6.4%, 5.56%, 5.15% and 3.27% more over plants without EDU treatment (Table 4.5 and Figure 4.27).

The difference in root length between plants with and without EDU was statistically insignificant (Table 4.5).

Root Biomass

The root biomass at maturity in plants without EDU at different sites was 0.26 ± 0.02, 0.22 ± 0.02, 0.21 ± 0.02, 0.65 ± 0.06, 0.34 ± 0.03, 0.24 ± 0.01, 0.22 ± 0.03 and 0.24 ± 0.03 g respectively. The maximum root biomass was 0.65 ± 0.06g at site S5 and minimum was 0.22 ± 0.03 g at site S7 (Table 4.5).

In EDU-treated plants, the average root biomass at different sites was 0.29 ± 0.01, 0.25 ± 0.01, 0.23 ± 0.02, 0.27 ± 0.02, 0.26 ± 0.02 and 0.27 ± 0.01 g respectively. The maximum root biomass was at 0.29 ± 0.01g at site S1 and minimum was 0.23 ± 0.02 g at site S7 (Table 4.5).

A comparison of root biomass between EDU treated and non-treated plants show root biomass in EDU treated plants was 10.34%, 12.00%, 8.69%, 11.11%, 15.38% and 11.11% more over plants without EDU treatment (Table 4.5 and Figure 4.28).

The difference in root biomass between plants with and without EDU was statistically significant ($P \leq 0.05$ level) (Table 4.5).

Pods per Plant

The number of pods in plants without at different sites was 6.86 ± 1.92, 6.39 ± 1.6, 6.21 ± 0.45, 15.42 ± 1.44, 7.75 ± 0.98, 5.92 ± 0.82, 5.75 ± 1.17 and 5.73 ± 1.09 respectively. The maximum number of pods was 15.42 ± 1.44 at site S5 and minimum was 5.73 ± 1.09 at site S9 (Table 4.5).

In EDU-treated plants, the number of pods per plant at different sites was 11.89 ± 1.64, 9.38 ± 0.78, 9.12 ± 0.33, 8.5 ± 0.89, 8.48 ± 1.09 and 8.44 ± 0.54 respectively. The maximum number of pods per plant was at 11.89 ± 1.64 at site S1 and minimum was 8.44 ± 0.54 at site S9 (Table 4.5).

A comparison of number of pods between EDU treated and non-treated plants show number of pods per plant in EDU treated plants was 42.3%, 31.87%, 31.91%, 30.35%, 32.35% and 32.10% more over plants without EDU treatment (Table 4.5 and Figure 4.29).

The difference in number of pods per plant between plants with and without EDU was statistically significant (P ≤0.01 level) (Table 4.5).

Pod Length

The pod length in plants without EDU at different sites was 5.87 ± 0.62, 5.85 ± 0.30, 5.46 ± 0.8, 5.85 ± 0.16, 5.57 ± 0.17, 5.52 ± 0.66, 5.5 ± 0.69 and 5.53 ± 0.11 cm respectively. The maximum pod length was 5.87 ± 0.62 cm at site S1 and minimum was 5.46 ± 0.8 cm at site S9 (Table 4.5).

In EDU-treated plants, pod length at different sites was 6.14 ± 0.21, 6.09 ± 0.36, 6.09 ± 1.17, 6.12 ± 0.54, 6.08 ± 0.47 and 6.04 ± 0.32 cm respectively. The maximum pod length was 6.14 ± 0.21 cm at site S1 and minimum was 6.04 ± 0.32 cm at site S9 (Table 4.5).

A comparison of pod length between EDU treated and non-treated plants show pod length in EDU treated plants was 4.39%, 3.94%, 10.34%, 9.80%, 9.54% and 8.44% more over plants without EDU treatment (Table 4.5 and Figure 4.30).

The difference in pod length between plants with and without EDU was statistically insignificant (Table 4.5).

Seeds per Pod

The number of seeds per pod without EDU at different sites was 8.21 ± 1.26, 7.55 ± 0.79, 7.53 ± 1.51, 7.6 ± 1.54, 7.47 ± 1.21, 7.26 ± 0.75, 7.15 ± 0.75 and 7.03 ± 0.63 respectively. The maximum number of seeds per pod was 8.21 ± 1.26 at site S1 and minimum was 7.03 ± 0.63 at site S9 (Table 4.5).

In EDU-treated plants, the number of seeds per pod at different sites was 8.35 ± 0.53, 8.08 ± 0.81, 8.06 ± 1.14, 8.18 ± 0.55, 8.15 ± 1.03 and 8.08 ± 2.06 respectively. The maximum number of seeds per pod was 8.35 ± 0.53 at site S1 and minimum was 8.06 ± 1.14 at site S3 (Table 4.5).

A comparison of number of seeds per pod between EDU treated and non-treated plants show number of seeds per pod in EDU treated plants was 1.68%, 6.55%, 6.57%,

11.25%, 12.16% and 13.12% more over plants without EDU treatment (Table 4.5 and Figure 4.31).

The difference in number of seeds per pod between plants with and without EDU was statistically insignificant (Table 4.5).

Seed Weight per Plant

The seed weight per plant in plants of without EDU at different sites was 3.05 ± 0.46, 2.67 ± 0.35, 2.57 ± 0.6, 3.82 ± 0.28, 3.39 ± 0.4, 2.51 ± 0.43, 2.61 ± 0.61 and 2.57 ± 0.26 g respectively. The maximum seed weight was 3.82 ± 0.28 g at site S5 and minimum was 2.57 ± 0.26 g at site S9 (Table 4.5).

In EDU-treated plants, the seed weight per plant at different sites was 3.71 ± 0.35, 3.11 ± 0.14, 2.86 ± 0.32, 3.02 ± 0.16, 2.98 ± 0.39 and 3.02 ± 0.26 g respectively. The maximum seed weight was 3.71 ± 0.35 g at site S1 and minimum was 2.86 ± 0.32 g at site S2 (Table 4.5).

A comparison of seed weight per plant between EDU treated and non-treated plants show seed weight per plant in EDU treated plants 17.80%, 14.15%, 10.14%, 16.89%, 12.42 % and 14.90 % was more over plants without EDU treatment (Table 4.5 and Figure 4.32).

The difference in seed weight per plant between plants with and without EDU was statistically insignificant (Table 4.5).

Total Chlorophyll

The total chlorophyll content in 55 days old plants without EDU at all sites was 2.88 ± 0.012, 2.72 ± 0.006, 2.74 ± 0.008, 2.75 ± 0.026, 2.92 ± 0.002, 2.42 ± 0.021, 2.62 ± 0.0031 and 2.83 ± 0.002 mg/g respectively. The maximum total chlorophyll content was 2.92 ± 0.002 mg/g at site S6 and minimum was 2.42 ± 0.021 mg/g at site S7 (Table 4.5).

In EDU-treated plants, the total chlorophyll content at different sites was 3.12 ± 0.016, 3.06 ± 0.018, 3.01 ± 0.008, 2.82 ± 0.031, 2.92 ± 0.015 and 3.07 ± 0.031 mg/g

respectively. The maximum total chlorophyll content was 3.12 ± 0.016 mg/g at site S6 and minimum was 2.82 ± 0.031 mg/g at site S7 (Table 4.5).

A comparison of total chlorophyll content between EDU treated and non-treated plants show total chlorophyll content in EDU treated plants was 7.69%, 11.11%, 8.97%, 14.18%, 10.27% and 8.14% more over plants grown without EDU treatment (Table 4.5 and Figure 4.33).

The difference in total chlorophyll content between plants with and without EDU was statistically significant (P ≤0.01 level) (Table 4.5).

Ascorbic Acid

The average ascorbic acid content in 55 days old plants without EDU at all sites was 0.287 ± 0.001, 0.271 ± 0.001, 0.273 ± 0.002, 0.269 ± 0.003, 0.293 ± 0.001, 0.251 ± 0.003, 0.261 ± 0.003 and 0.281 ± 0.002 mg/g respectively. The maximum ascorbic acid content was 0.293 ± 0.001 mg/g at site S6 and minimum was 0.251 ± 0.003 mg/g at site S7 (Table 4.5).

In EDU-treated plants, the ascorbic acid content at different sites was 0.341 ± 0.001, 0.312 ± 0.001, 0.322 ± 0.002, 0.280 ± 0.031, 0.293 ± 0.015 and 0.317 ± 0.031 mg/g respectively. The maximum ascorbic acid content was 0.341 ± 0.001 mg/g at site S1 and minimum was 0.280 ± 0.031 mg/g at site S7 (Table 4.5).

A comparison of ascorbic acid content between EDU treated and non-treated plants show ascorbic acid content in EDU treated plants was 13.29%, 15.04%, 15.21%, 10.53%, 10.31% and 11.35% more over plants grown without EDU treatment (Table 4.5 and Figure 4.34).

The difference in ascorbic acid content between plants with and without EDU was statistically significant (P ≤0.05 level) (Table 4.5).

Fumigation Study

Three sets of plants namely control, E1 and E2 were prepared to carry out the fumigation study. The E1 and E2 sets were fumigated with 150µg/m^3 of ozone and the control set was maintained in the ambient environment. Ground level ozone monitoring

was also carried out during February-2003 to find out the background ozone concentration in the ambient environment at JNU. The average hourly ozone concentration was $73.5\mu g/m^3$ and the maximum and minimum concentration was $174.44\mu g/m^3$ and $5.88\mu g/m^3$ respectively. The plant growth and performances of plants exposed to $150\mu g/m^3$ and were made in respect of different morphological and biochemical parameters. The ozone injury symptoms on leaves of Moong (*Phaseolus aureus*) plant (without EDU) exposed to $150\mu g/m^3$ of ozone in E1 set (Plate 4.4).

Shoot Length

The shoot length at maturity in plants without EDU was 36.58 ± 4.27, 34.4 ± 2.74 and 33.0 ± 2.31 cm respectively. The maximum shoot length was 36.58 ± 4.27 cm in control plants and minimum was 33.0 ± 2.31cm in plants of E2 set (Table 4.5).

In EDU-treated plants, the average shoot length was 39.78 ± 4.52, 38.78 ± 2.73 and 38.5 ± 3.35 cm respectively. The maximum shoot length was 39.78 ± 4.52 cm in control plants and minimum was 38.5 ± 3.35 cm in plants of E2 set (Table 4.5).

A comparison of shoot length between EDU treated and non-treated plants show the shoot length in EDU treated plants was 8.04%, 11.29% and 14.29% more over plants without EDU treatment (Table 4.5 and Figure 4.35).

The difference in shoot length between plants with and without EDU was statistically significant ($P \leq 0.1$ level) (Table 4.5).

Shoot Biomass

At maturity the average shoot biomass in plants without EDU was 3.77 ± 0.59, 3.58 ± 0.18 and 3.62 ± 0.19g respectively. The maximum shoot biomass was 3.77 ± 0.59g in control plants and minimum was 3.58 ± 0.18g in plants of E1 set (Table 4.5).

In EDU-treated plants, the shoot biomass was 4.58 ± 0.68, 4.42 ± 0.85 and 4.46 ± 0.66 g respectively. The maximum shoot biomass was 4.58 ± 0.68g in control plants and minimum was 4.42 ± 0.85g in plants of E1 set (Table 4.5)

A comparison of shoot biomass between EDU treated and non-treated plants show shoot biomass in EDU treated plants was 17.68%, 19.00% and 18.83% more over plants without EDU treatment (Table 4.5 and Figure 4.36).

The difference in shoot biomass between plants with and without EDU was statistically significant (P ≤0.05 level) (Table 4.5).

Root Length

The average root length in plants without EDU was 9.08 ± 1.36, 7.50 ± 2.07 and 8.50 ± 2.12 cm. The maximum root length was 9.08 ± 1.36 cm in control plants and minimum was 7.50 ± 2.07 cm in plants of E1 set (Table 4.5).

In EDU-treated plants, the average root length was 11.71 ± 1.49, 11.11 ± 1.55 and 11.46 ± 1.15 cm. The maximum average root length was 11.71 ± 1.49 cm in control plants and minimum was 11.46 ± 1.15 cm in plants of E1 set (Table 4.5).

A comparison of root length between EDU treated plants and non-treated plants show root length in EDU treated plants was 22.46%, 32.49% and 25.83% more over plants without EDU treatment (Table 4.5 and Figure 4.37).

The difference in root length between plants with and without EDU was statistically significant (P ≤0.05 level) (Table 4.5).

Root Biomass

At maturity the root biomass in plants without EDU was 0.58 ± 0.08, 0.40 ± 0.13 and 0.44 ± 0.09 g respectively. The maximum root biomass was 0.53 ± 0.08g in control plants and minimum was 0.40 ± 0.13g in plants of E1 set (Table 4.5).

In EDU-treated plants, the average root biomass was 0.67 ± 0.14, 0.58 ± 0.19 and 0.51 ± 0.19 g. The maximum root biomass was 067 ± 0.14g in control plants and minimum was 0.51 ± 0.19 g in plants of E2 set (Table 4.5).

A comparison of root biomass between EDU treated and non-treated plants show root biomass in EDU treated plants was 13.43%, 31.03% and 13.72% more over plants without EDU treatment (Table 4.5 and Figure 4.38).

The difference in root biomass between plants with and without EDU was statistically insignificant (Table 4.5).

Pods per Plant

The average number of pods in plants without EDU was 14.33 ± 1.50, 12.29 ± 1.49 and 13.17 ± 1.17 respectively. The maximum number of pods per plant was 14.33 ± 1.50 in control plants and minimum was 12.29 ± 1.49 in plants of E1 set (Table 4.5).

In EDU-treated plants, the average number of pods per plant was 15.8 ± 2.45, 14.57± 1.13 and 15.33 ± 1.41. The maximum number of pods per plant was 15.8 ± 2.45 in control plants and minimum was14.57± 1.13 in plants of E1 set (Table 4.5).

A comparison of number of pods per plant between EDU treated and non-treated plants show number of pods per plant in EDU treated plants was 9.30%, 15.65% and 14.09% more over plants grown without EDU treatment (Table 4.5 and Figure 4.39).

The difference in number of pods per plant between plants with and without EDU was statistically insignificant (Table 4.5).

Pod Length

The pod length in plants without EDU was 3.90 ± 0.80, 3.16 ± 0.31 and 3.62 ± 0.86 cm. The maximum pod length was 3.90 ± 0.80 cm in control plants and minimum was 3.16 ± 0.31 cm in plants of E1 set (Table 4.5).

In EDU-treated plants, the average pod length was 4.36 ± 0.68, 4.27 ± 0.58 and 4.26 ± 0.67 cm. The maximum pod length was 4.36 ± 0.68 cm in control plants and minimum, 4.26 ± 0.67 cm in plants of E2 set (Table 4.5).

A comparison of pod length between EDU treated and non-treated plants show pod length in EDU treated plants was 10.55%, 25.99% and 15.02% more over plants without EDU treatment (Table 4.5 and Figure 4.40).

The difference in pod length between plants with and without EDU was statistically insignificant (Table 4.5).

Seed per Pod

The number of seeds per pod in plants without EDU was 8.58 ± 1.65, 7.57 ± 1.72 and 8.23 ± 1.802. The maximum number of seeds per pod was 8.0 ± 1.65 in control plants and minimum was 7.57 ± 1.72 in plants of E1 set (Table 4.5).

In EDU-treated plants, the number of seeds per pod was 9.42 ± 1.74, 8.60 ± 1.07 and 9.12 ± 1.45. The maximum number of seeds per pod was 9.5 ± 1.74 in control plants and minimum was 8.60 ± 1.07 in plants of E1 set (Table 4.5).

A comparison of number of seeds per pod between plants with and without EDU show number of seeds per pod in EDU treated plants was 8.92%, 11.98% and 9.75% more over plants without EDU treatment (Table 4.5 and Figure 4.41).

The difference in number of seeds per pod between plants with and without EDU was statistically insignificant (Table 4.5).

Seed Weight per Plant

The average seed weight in plants without EDU was 3.58 ± 0.28, 2.71 ± 0.56 and 3.03 ± 0.12g The maximum seed weight per plant was 3.58 ± 0.28 g in control plants and minimum was 2.71 ± 0.56 in plants of E1 set (Table 4.5).

In EDU-treated plants, the average seed weight per plant varied between 4.64 ± 0.31, 4.15 ± 0.41 and 4.28 ± 0.22 g. The maximum seed weight per plant was 4.64 ± 0.31g in control plants and minimum was 4.15 ± 0.41g in plants of E1 set (Table 4.5).

A comparison of seed weight per plant in EDU treated and non-treated plants and show seed weight in EDU treated plants was 22.84%, 34.70% and 29.20% more over plants without EDU treatment (Table 4.5 and Figure 4.42).

The difference in seed weight between plants with and without EDU was statistically significant (P ≤0.05 level) (Table 4.5).

Total Chlorophyll

The average total chlorophyll content in 55 days old plants grown without EDU was 2.986 ± 0.007, 1.094 ± 0.008 and 1.736 ± 0.002 mg/g. The maximum total chlorophyll

was 2.986 ± 0.007 mg/g in control plants and minimum was 1.094 ± 0.008 mg/g in plants of E1 set (Table 4.5)

In EDU-treated plants, the average total chlorophyll varied between 3.253 ± 0.045, 2.422 ± 0.018 and 2.562 ± 0.006 mg/g. The maximum total chlorophyll was 3.253 ± 0.02 mg/g in control plants and minimum was 2.422 ± 0.018 mg/g in plants of E1 set (Table 4.5).

A comparison of total chlorophyll content between EDU treated and non-treated plants show total chlorophyll content in EDU treated plants was 8.20%, 54.83% and 32.20% more over plants without EDU treatment (Table 4.5 and Figure 4.43).

The difference in total chlorophyll content between plants with and without EDU was statistically significant (P ≤0.05 level) (Table 4.5).

Ascorbic Acid

The average ascorbic acid content in 55 days old plants without EDU was 0.2967 ± 0.0155, 0.2527 ± 0.0155 and 0.2307 ± 0.0155 mg/g. The maximum ascorbic acid content was 0.2967 ± 0.01554 mg/g in control plants and minimum was 0.23077 ± 0.01554 mg/g in plants of E2 set (Table 4.5)

In EDU-treated plants, the average ascorbic acid content of all the three sets remained same 0.34066 ± 0.0155, 0.34066 ± 0.0155, 0.34066 ± 0.0155mg/g (Table 4.5).

A comparison of ascorbic acid content between EDU treated and non-treated plants show ascorbic acid content in EDU treated plants was 12.90%, 25.80% and 32.26% more over plants without EDU treatment (Table 4.5 and Figure 4.44).

The difference in ascorbic acid content between plants with and without EDU was statistically significant (P ≤0.1 level) (Table 4.5).

Table 4.5: Performance of *Phaselous aureus* plants with and without-EDU exposed to ozone at field sites and in fumigation chamber.

Parameters	Field study								Fumigation study		
	S1	S2	S3	S5	S6	S7	S8	S9	C	E1	E2
Shoot length (cm) EDU	37.78 ± 3.49	36.29 ± 4.89	36.80 ± 2.51	-	-	41.50 ± 4.26	39.20 ± 4.15	46.44 ± 9.20	39.78 ± 4.52	38.78 ± 2.73	38.50 ± 3.35
N-TR	35.93^{1} ± 3.19	35.44^{1} ± 6.95	33.08^{1} ± 5.30	48.00 ± 9.87	50.88 ± 12.18	40.06^{1} ± 7.69	37.50^{1} ± 7.69	42.70^{1} ± 9.96	36.58^{3} ± 4.27	34.40^{3} ± 2.74	33.00^{3} ± 2.31
Difference (%)	4.8	2.32	10.11	-	-	3.46	4.34	8.07	8.04	11.29	14.29
Shoot biomass (gm) EDU	4.42 ± 0.31	4.35 ± 0.18	4.13 ± 0.17	-	-	4.25 ± 0.02	4.12 ± 0.23	4.18 ± 0.26	4.58 ± 0.68	4.42 ± 0.85	4.46 ± 0.66
N-TR	3.94^{ns} ± 0.71	3.69^{ns} ± 0.12	3.57^{ns} ± 0.15	5.92 ± 1.46	4.19 ± 0.62	3.83^{ns} ± 0.07	3.62^{ns} ± 0.16	3.80^{ns} ± 0.38	3.77^{2} ± 0.59	3.58^{2} ± 0.18	3.62^{2} ± 0.19
Difference (%)	10.85	15.17	13.56	-	-	9.88	12.13	8.61	17.68	19.00	18.83
Root length (cm) EDU	12.06 ± 4.19	11.72 ± 1.25	12.05 ± 4.45	-	-	12.05 ± 2.74	12.04 ± 0.39	11.91 ± 1.76	11.71 ± 1.49	11.11 ± 1.55	11.46 ± 1.15
N-TR	11.68^{ns} ± 3.19	10.96^{ns} ± 1.51	11.28^{ns} ± 3.04	14.75 ± 1.75	11.58 ± 3.16	11.38^{ns} ± 1.18	11.42^{ns} ± 2.76	11.52^{ns} ± 0.99	9.08^{2} ± 1.36	7.50^{2} ± 2.07	8.50^{2} ± 2.12
Difference (%)	3.07	6.40	6.40	-	-	5.56	5.15	3.27	22.46	32.49	25.83

Root biomass (gm)											
EDU	0.29 ± 0.01	0.25 ± 0.01	0.23 ± 0.02	-	-	0.27 ± 0.02	0.26 ± 0.02	0.27 ± 0.01	0.67 ± 0.14	0.58 ± 0.19	0.51 ± 0.19
N-TR	0.26[3] ± 0.02	0.22[3] ± 0.02	0.21[3] ± 0.02	0.65 ± 0.06	0.34 ± 0.03	0.24[3] ± 0.01	0.22[3] ± 0.03	0.24[3] ± 0.03	0.58ns ± 0.08	0.40ns ± 0.13	0.44ns ± 0.09
Difference (%)	10.34	12.00	8.69	-	-	11.11	15.38	11.11	13.43	31.03	13.72
Pods per plant											
EDU	11.89 ± 1.64	9.38 ± 0.78	9.12 ± 0.33	-	-	8.50 ± 0.89	8.48 ± 1.09	8.44 ± 0.54	15.80 ± 2.45	14.57 ± 1.13	15.33 ± 1.41
N-TR	6.86[1] ± 1.92	6.39[1] ± 1.60	6.21[1] ± 0.45	15.42 ± 1.44	7.75 ± 0.98	5.92[1] ± 0.82	5.75[1] ± 1.17	5.73[1] ± 1.09	14.33ns ± 1.50	12.29ns ± 1.49	13.17ns ± 1.17
Difference (%)	42.30	31.87	31.91	-	-	30.35	32.35	32.10	9.30	15.65	14.09
Pod length (cm)											
EDU	6.14 ± 0.21	6.09 ± 0.36	6.09 ± 1.17	-	-	6.12 ± 0.54	6.08 ± 0.47	6.04 ± 0.32	4.36 ± 0.68	4.27 ± 0.58	4.26 ± 0.67
N-TR	5.87ns ± 0.62	5.85ns ± 0.30	5.46ns ± 0.80	5.85 ± 0.16	5.57 ± 0.17	5.52ns ± 0.66	5.50ns ± 0.69	5.53ns ± 0.11	3.90ns ± 0.80	3.16ns ± 0.31	3.62ns ± 0.86
Difference (%)	4.39	3.94	10.34	-	-	9.80	9.54	8.44	10.55	25.99	15.02

Seeds per pod EDU	8.35 ± 0.53	8.08 ± 0.81	8.06 ± 1.14	-	-	8.18 ± 0.55	8.15 ± 1.03	8.08 ± 2.06	9.42 ± 1.74	8.60 ± 1.07	9.12 ± 1.45
N-TR	8.21^{ns} ± 1.26	7.55^{ns} ± 0.79	7.53^{ns} ± 1.51	7.60 ± 1.54	7.47 ± 1.21	7.26^{ns} ± 0.75	7.15^{ns} ± 0.75	7.03^{ns} ± 0.63	8.58^{ns} ± 1.65	7.57^{ns} ± 1.72	8.23^{ns} ± 1.802
Difference (%)	1.68	6.55	6.57	-	-	11.25	12.16	13.12	8.92	11.98	9.75
Seed weight per plant (gm) EDU	3.71 ± 0.35	3.11 ± 0.14	2.86 ± 0.32	-	-	3.02 ± 0.16	2.98 ± 0.39	3.02 ± 0.26	4.64 ± 0.31	4.15 ± 0.41	4.28 ± 0.22
N-TR	3.05^{ns} ± 0.46	2.67^{ns} ± 0.35	2.57^{ns} ± 0.60	3.82 ± 0.28	3.39 ± 0.40	2.51^{ns} ± 0.43	2.61^{ns} ± 0.61	2.57^{ns} ± 0.26	3.58^{2} ± 0.28	2.71^{2} ± 0.56	3.03^{2} ± 0.12
Difference (%)	17.80	14.15	10.14	-	-	16.89	12.42	14.90	22.84	34.70	29.20
Total chlorophyll (mg/gm) EDU	3.12 ± 0.016	3.06 ± 0.018	3.01 ± 0.008	-	-	2.82 ± 0.031	2.92 ± 0.015	3.07 ± 0.031	3.253 ± 0.045	2.422 ± 0.018	2.562 ± 0.006
N-TR	2.88^{1} ± 0.012	2.72^{1} ± 0.006	2.74^{1} ± 0.008	2.75 ± 0.026	2.92 ± 0.002	2.42^{1} ± 0.021	2.62^{1} ± 0.0031	2.83^{1} ± 0.002	2.986^{2} ± 0.007	1.094^{2} ± 0.008	1.736^{2} ± 0.02 32.20
Difference (%)	9.61	11.11	8.97	-	-	14.18	10.27	8.14	8.20	54.83	

Ascorbic acid (mg/gm)											
EDU	0.341 ± 0.001	0.312 ± 0.001	0.322 ± 0.002	-	-	0.280 ± 0.031	0.293 ± 0.015	0.317 ± 0.031	0.34066 ± 0.0155	0.34066 ± 0.0155	0.34066 ± 0.0155
N-TR	0.287[2] ± 0.001	0.271[2] ± 0.001	0.273[2] ± 0.002	0.269 ± 0.003	0.293 ± 0.001	0.251[2] ± 0.003	0.261[2] ± 0.003	0.281[2] ± 0.002	0.2967[3] ± 0.0155	0.2527[3] ± 0.0155	0.2307[3] ± 0.0155
Difference (%)	13.29	15.04	15.21	-	-	10.53	10.31	11.35	12.90	25.80	32.26

decrease from EDU
- increase over EDU

S1: Bakoli, S2: S. Collge, S3: Jain Temple, S5: Tilak Bridge, S6: JNU, S7: Badarpur, S8: DPS-Faridabad, S9: IOC

C-Control; E1 set - exposed to five cycles of exposure to 150 $\mu g/m^3$ of ozone for four hours (total exposure of 20 hours) at 10-day interval after each EDU treatment; E2 set - five cycles of exposure to 150 $\mu g/m^3$ ozone daily for 4 hours over five successive days (total exposure of 20 hours) after three EDU treatments.

[1] Significant difference between plants grown without EDU (N-TR) and with EDU treatment at $P \leq 0.01$ level
[2] Significant difference between plants grown without EDU (N-TR) and with EDU treatment at $P \leq 0.05$ level
[3] Significant difference between plants grown without EDU (N-TR) and with EDU treatment at $P \leq 0.1$ level
[ns] Non-significant

A comparison between the performance of plants exposed to ambient ozone at field sites and those subjected to experimental fumigation with ozone shows that the different plant parameters in the fumigated plants were relatively more affected (Table 4.6). In case of the field study, it is observed improvement in the yield parameters at some of the polluted site that may be due to the presence of NO_2 in the ambient atmosphere, which could have enhanced the nitrogen fixing ability and growth in plants of *Phaseolus*.

Table 4.6: A comparison between the percentage differences in average values of different parameters in *Phaseolus aureus* plants grown with and without EDU exposed to 35.72-50.20µg/m³ of ground level ozone and fumigated with 150µg/m³ ozone.

Plant parameter	Field study (% difference) between plants with and without EDU)	Fumigation study (% difference) between plants grown with and without EDU)			Control plants during fumigation study (% difference) between plants grown with and without EDU)
		E1	E2	Average	
Shoot length	5.53	11.29	14.29	12.79	8.04
Shoot biomass	11.70	19.00	18.83	18.92	17.68
Root length	4.98	32.49	25.83	29.16	22.46
Root biomass	11.44	31.03	13.72	22.38	13.43
Pods per plant	33.48	15.65	14.09	14.87	9.30
Pod length	7.74	25.99	15.02	20.51	10.55
Seeds per pod	8.54	11.98	9.75	10.86	8.92
Seed weight per plant	14.38	34.70	29.20	31.95	22.84
Total chlorophyll	10.06	54.83	29.20	42.02	8.20
Ascorbic acid	12.57	25.80	32.26	29.03	12.90

The protection accorded by EDU to *Phaseolus aureus* plants was not uniform in respect of different morphological and biochemical parameters were in the following order:

Pods per plant> Seed weight per plant > Ascorbic acid > Shoot biomass > Root biomass > Total chlorophyll > Seeds per pod > Pod length > Shoot length > Root length.

In case of *Phaseolus aureus* plants fumigated with 150 µg/m³ of ozone, the reduction in different morphological and biochemical parameters was of the following order:

Total chlorophyll > Seed weight per plant > Root length > Ascorbic acid > Pod length > Root biomass > Shoot biomass > Pods per plant > Shoot length > Seeds per pod.

Both in field and fumigation studies, seed weight per plant were highly affected as compared to other plant parameters. It seems that EDU nullifies the adverse effect of ozone on *Phaseolus aureus* plants.

Figure 4.25: A comparison of shoot length between N-Tr and EDU-Tr plants of *Phaseolus aureus* grown at field sites.

Figure 4.26: A comparison of shoot biomass between N-Tr and EDU-Tr plants of *Phaseolus aureus* grown at field sites.
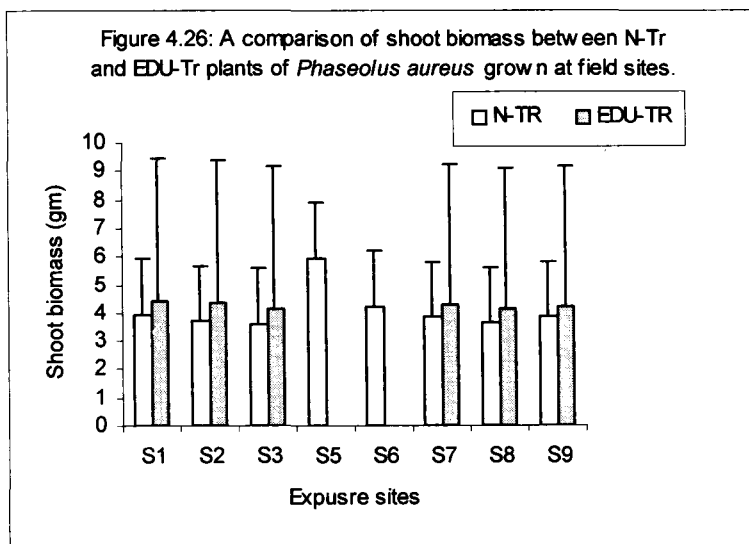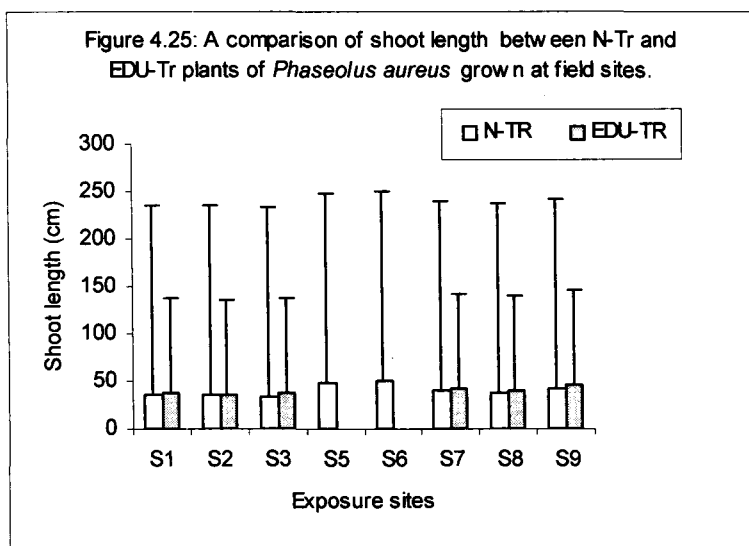
Figure 4.27: A comparison of root length between N-Tr and EDU-Tr plants of *Phaseolus aureus* grown at field sites.
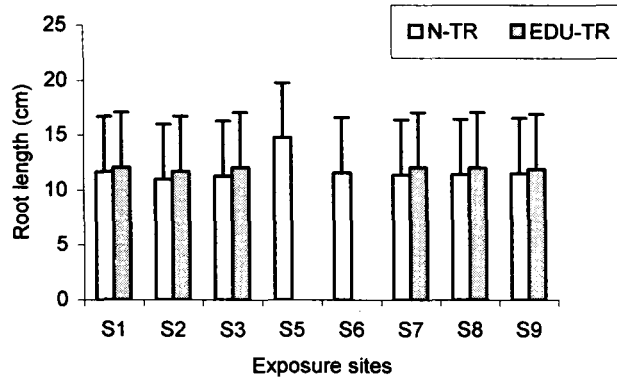
Figure 4.28: A comparison of root biomass of N-Tr and EDU-Tr plants between N-Tr and EDU-Tr plants of *Phaseolus aureus* grown at field sites.
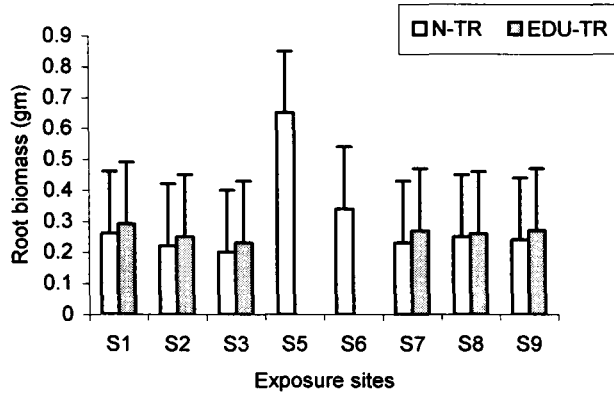
Figure 4.29: A comparison of pods per plant between N-Tr and EDU-Tr plants of *Phaseolus aureus* grown at field sites.

100
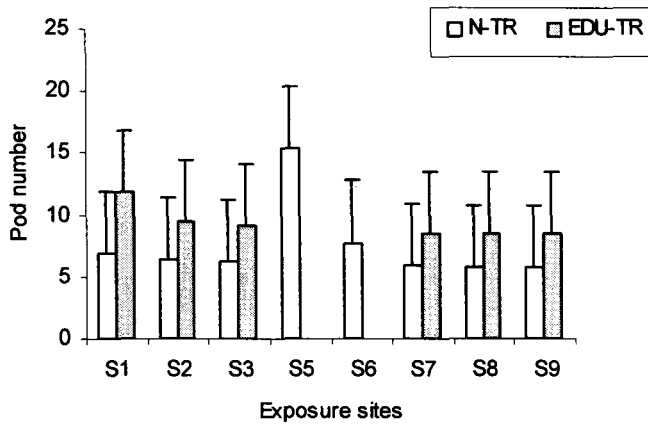
Figure 4.30: A comparison of pod length between N-Tr and EDU-Tr plants of *Phaseolus aureus* grown at field sites.
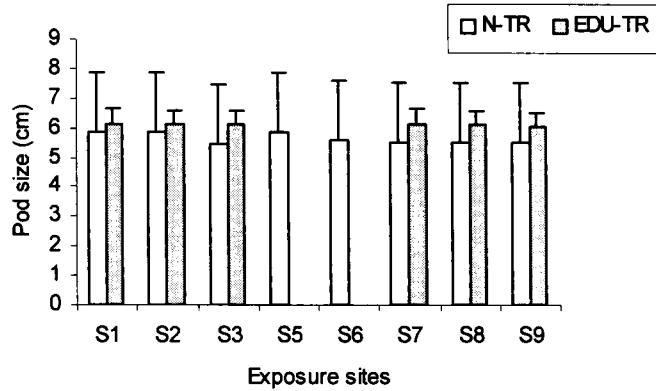
Figure 4.31: A comparison of seeds per pod between N-Tr and EDU-Tr plants of *Phaseolus aureus* grown at field sites.
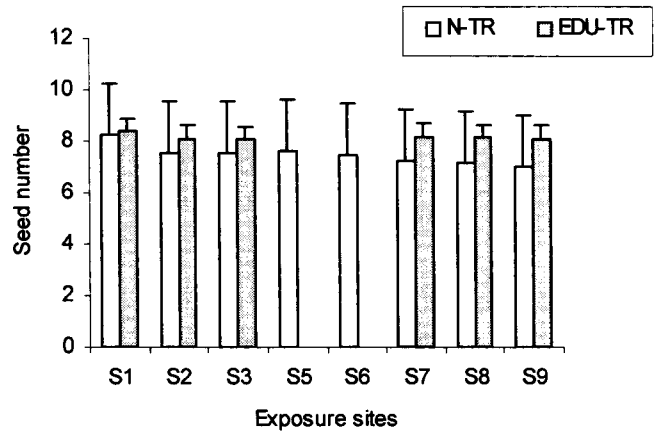
Figure 4.32: A comparison of seed weight per plant between N-Tr and EDU-Tr plants of *Phaseolus aureus* grown at field sites.
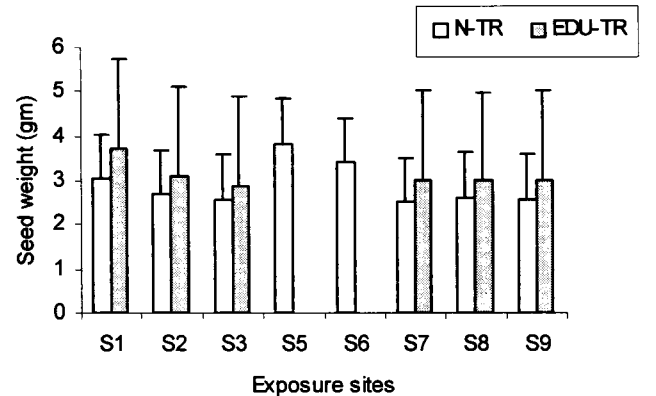
Figure 4.33: A comparison of total chlorophyll content between N-Tr and EDU-Tr plants of *Phaseolus aureus* grown at field sites.
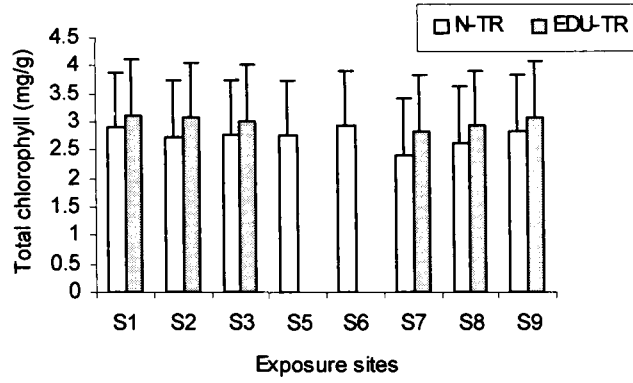
Figure 4.34: A comparison of ascorbic acid content between N-Tr and EDU-Tr plants of *Phaseolus aureus* grown at field sites.
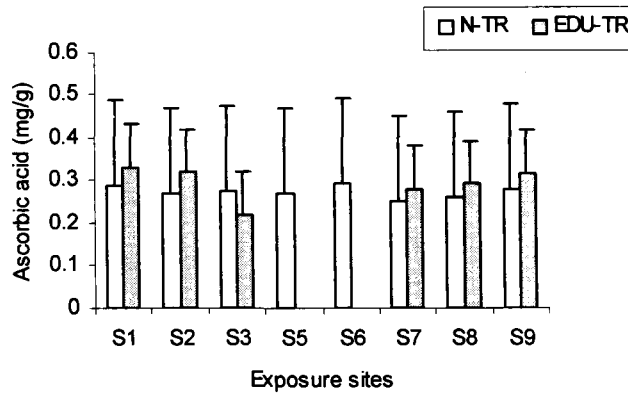
Figure 4.35: A comparison of shoot length between ozone fumigated N-Tr and EDU-Tr plants of *Phaseolus aureus*.

102
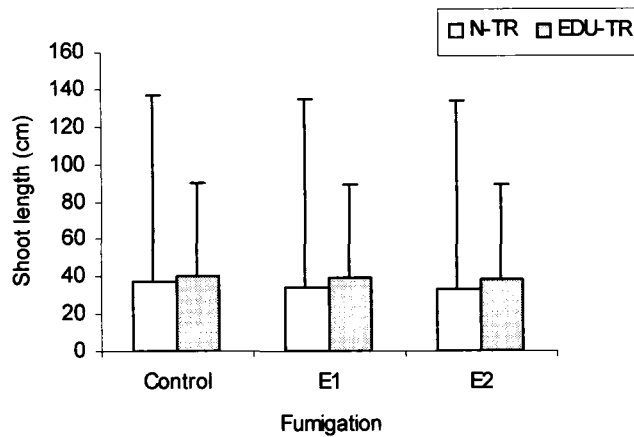
Figure 4.36: A comparison of shoot biomass between ozone fumigated N-Tr and EDU-Tr plants of *Phaseolus aureus*.
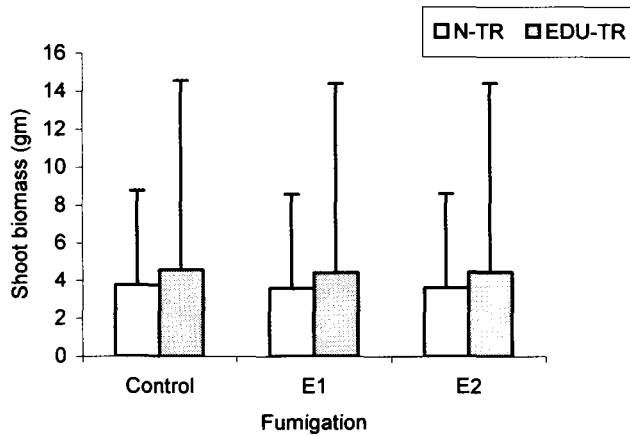
Figure 4.37: A comparison of root length between ozone fumigated N-Tr and EDU-Tr plants of *Phaseolus aureus*.
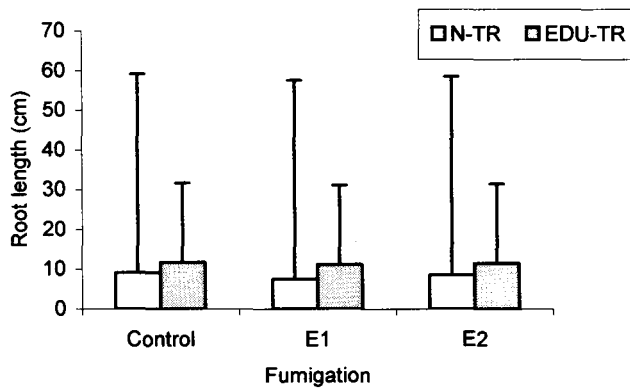
Figure 4.38: A comparison of root biomass between ozone fumigated N-Tr and EDU-Tr plants of *Phaseolus aureus*.
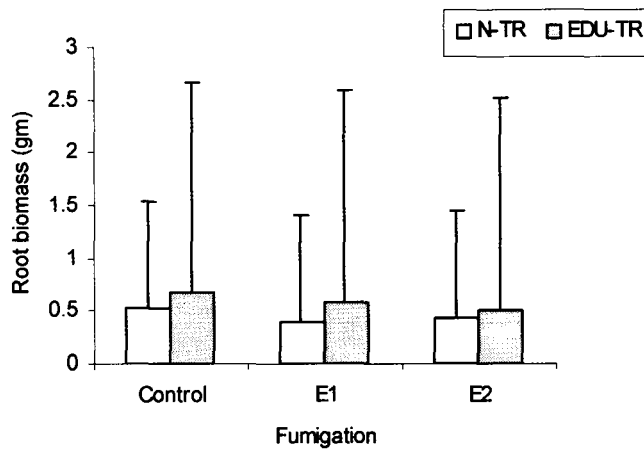
Figure 4.39: A comparison of pods per plant between ozone fumigated N-Tr and EDU-Tr plants of *Phaseolus aureus*.
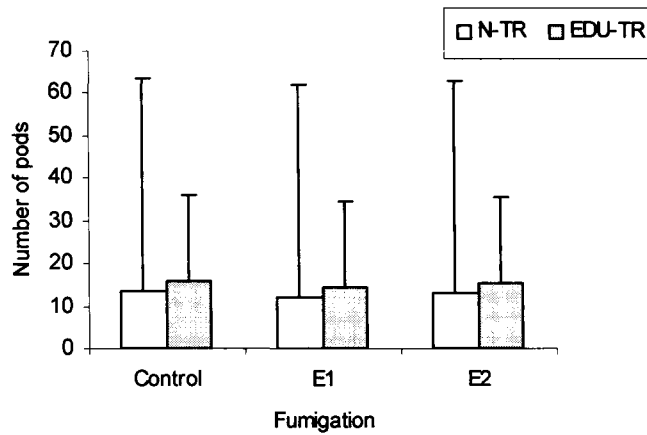
Figure 4.40: A comparison of pod length between ozone fumigated N-Tr and EDU-Tr plants of *Phaseolus aureus*.
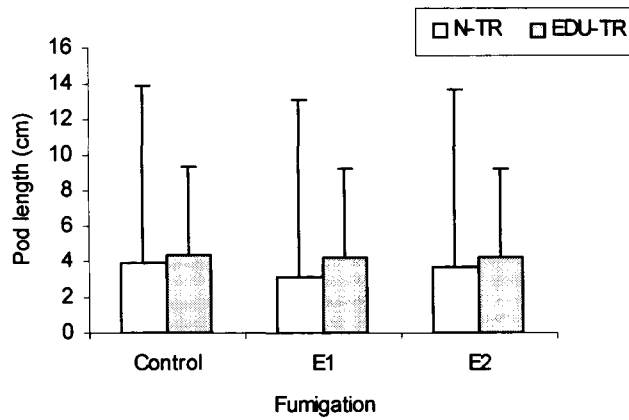
Figure 4.41: A comparison of seeds per pod between ozone fumigated N-Tr and EDU-Tr plants of *Phaseolus aureus*.
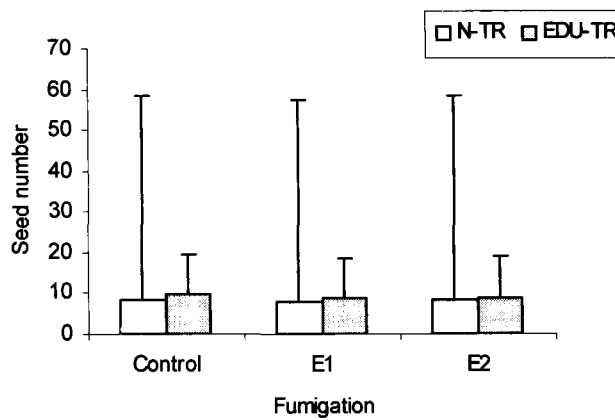
Figure 4.42: A comparison of seed weight per plant between ozone fumigated N-Tr and EDU-Tr plants of *Phaseolus aureus*.
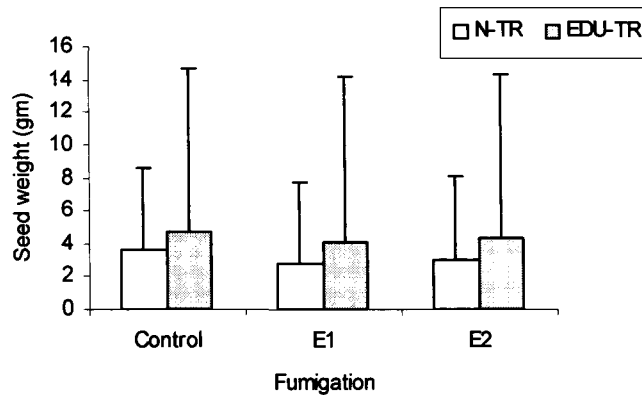
Figure 4.43: A comparison of total chlorophyll content between ozone fumigated N-Tr and EDU-Tr plants of *Phaseolus aureus*.
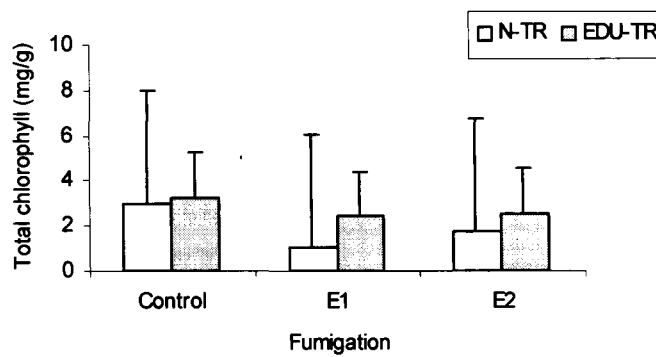
Figure 4.44: A comparison of ascorbic acid content between ozone fumigated N-Tr and EDU-Tr plants of *Phaseolus aureus*.

105
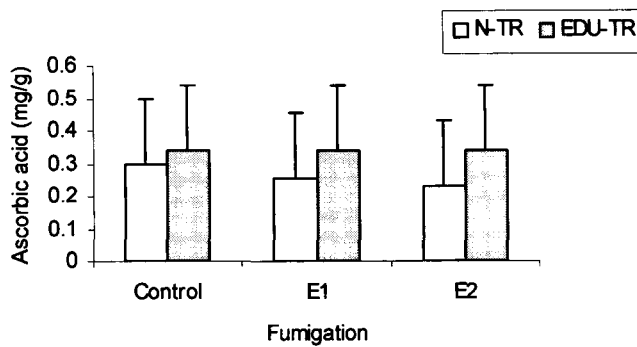
Mustard (*Brassica campestris* var. Pusa Jai Kisan)

Field Study:

Effect of ambient ozone on growth and yield parameters of mustard (*Brassica campestris* var. Pusa Jai Kisan) was evaluated among ethylene diurea (EDU) treated plants and untreated EDU plants under field condition at Delhi-Faridabad. Nine different sites (S1, S2, S3, S4, S6, S7, S9, S10 and S11) were chosen in Delhi and Faridabad representing different levels of anthropogenic activity and traffic density. The ground level ozone concentrations varied between 69.07-158.33μg/m^3 at these nine sites. Observations of growth performances of *Brassica campestris* var. Pusa Jai Kisan plants were made in respect of following morphological and biochemical parameters.

Shoot Length

Initially shoot growth was slow up to 27th day of exposure at all sites. Subsequently, there was a rapid increase in shoot length till 45th days except at site S7, where growth was relatively slow. Between 45th -75th day, growth of shoot length was gradual and beyond 75th day there was no further increase in shoot length.

The average shoot length in 135days old mature plants without EDU at different sites was 88.15 ± 14.24, 71.4 ± 9.57, 77.05 ± 10.46, 77.05 ± 14.24, 84.1 ± 10.32, 66.55 ± 5.21, 93.35 ± 10.46, 78.7 ± 9.24 and 77.7 ± 5.27 cm respectively. The maximum shoot length was 93.35 ± 10.46 cm at site S9 and minimum was 66.55 ± 5.21cm at site S7 (Table 4.7 and Plate 4.5-4.6).

The average shoot length of EDU-treated plants, at different sites was 103.25 ± 14.26, 96.25 ± 11.85, 93.5 ± 13.33, 82.12 ± 8.79, 90.62 ± 7.53, 72.25 ± 13.06, 99.75 ± 9.51, 86.75 ± 9.88 and 85.43 ± 4.37 cm respectively. The maximum shoot length was 103.25 ± 14.26 cm at site S1 and minimum was 72.25 ± 13.06 cm at site S7 (Table 4.7 and Plate 4.5-4.6).

A comparison of shoot length between EDU treated and non-treated plants show shoot length in EDU treated plants was 14.6%, 25.8%, 17.6%, 6.2%, 7.2%, 15.2%, 6.4%, 9.3% and 9.0% more over plants without EDU treatment (Table 4.7 and Figure 4.45).

Plate 4.4: Injury Symptoms on Leaves of Moong (*Phaseolus aureus*) Plant (without EDU), exposed to 150µg/m^3 of Ozone in E1 set.

Plate 4.5: EDU-treated (EDU-Tr) and non-treated (N-Tr) Mustard (*Brassica campestris*) Plants Grown at S-7 (Badarpur) Site.

Plate 4.6: EDU-treated (EDU-Tr) and non-treated (N-Tr) Mustard (*Brassica campestris*) Plants Grown at S-10 (CRI-Faridabad) Site.

The difference in shoot length between EDU treated and non-treated plants was statistically significant (P ≤0.05 level) (Table 4.7).

Number of Branches

The average number of branches at maturity in plants without EDU at all the sites was 12.75 ± 4.89, 12.75 ± 5.39, 17.05 ± 2.01, 14.2 ± 2.7, 18.2 ± 4.83, 13.4 ± 2.3, 14.1 ± 3.98, 20.35 ± 3.71 and 15.9 ± 4.01 respectively. The maximum average number of branches was 20.35 ± 3.71 at site S10 and minimum was 12.75 ± 4.89 at site S1 (Table 4.7).

The average number of branches in EDU treated plants, at different sites was 11.75 ± 2.49, 11.37 ± 2.32, 15.87 ± 3.94, 12.37 ± 1.76, 17.12 ± 3.68, 11.5 ± 3.29, 12.62 ± 3.66, 17.87 ± 3.39 and 14.0 ± 3.38 respectively. The maximum average number of branches was 17.87 ± 3.39 at site S9 and minimum was 11.37 ± 2.32 at site S2 (Table 4.7).

A comparison of number of branches in plants between EDU treated and non-treated plants show average number of branches in EDU treated plants was 8.5%, 12%, 7.5%, 14.7%, 6.3%, 16.5%, 11.7%, 12.8% and 13.5% less as compared to the plants grown without EDU treatment (Table 4.7 and Figure 4.46).

The difference in number of branches between EDU treated and non-treated plants was statistically significant (P ≤0.05 level) (Table 4.7).

Shoot Biomass

At maturity the average shoot biomass in plants without EDU at different sites was 5.15 ± 1.53, 4.98 ± 1.2, 4.96 ± 2.08, 4.46 ± 1.9, 4.95 ± 1.35, 3.95 ± 1.08, 5.04 ± 1.44, 4.89 ± 1.82 and 4.87 ± 1.85 g respectively. The maximum average shoot biomass was 5.15 ± 1.53 g at site S1 and minimum was 3.95 ± 1.08 g at site S7 (Table 4.7).

The average shoot biomass of EDU-treated plants, at different sites was 6.16 ± 2.09, 5.96 ± 1.4, 6.02 ± 1.95, 5.8 ± 1.24, 6.12 ± 1.67, 5.72 ± 1.4, 6.01 ± 1.29, 5.92 ± 1.28 and 5.83 ± 0.87 g respectively. The maximum average shoot biomass was 6.16 ± 2.09 g at S1 and minimum was 5.72 ± 1.4 g at site S7 (Table 4.7).

A comparison of shoot biomass between EDU treated and non-treated plants show shoot biomass of EDU-treated plants was 16.90%, 17.28%, 17.61%, 23.02%, 16.74%, 24.09%, 15.42%, 17.40% and 17.03% more over plants of grown without EDU treatment (Table 4.7 and Figure 4.47).

The difference in shoot biomass between EDU treated and non-treated plants was statistically significant ($P \leq 0.01$ level) (Table 4.7).

Root Length

The average root length in plants without EDU at different sites was 17.6 ± 6.43, 17 ± 5.48, 16.46 ± 5.31, 12.33 ± 3.13, 17.6 ± 4.85, 15.37 ± 3.51, 12.14 ± 2.59, 16.7 ± 3.42 and 16.68 ± 3.37 cm respectively. The highest maximum root length was 17.6 ± 6.43 cm at site S1 and minimum was 12.14 ± 2.59 cm at site S7 (Table 4.7).

The root length of EDU-treated plants, at different sites was 19.5 ± 2.32, 17.95 ± 2.25, 18.6 ± 2.43, 17.41 ± 2.42, 19.2 ± 2.68, 17.42 ± 5.33, 19.22 ± 2.47, 18.66 ± 2.83 and 18.65 ± 2.04 cm respectively. The maximum average root length was 19.5 ± 2.32 cm at site S1 and minimum was 17.41± 2.42 cm at site S4 (Table 4.7).

A comparison of root length between EDU treated and non-treated plants show root length in EDU treated plants was 9.74%, 10.96%, 11.50%, 12.31%, 8.33%, 14.32%, 10.20%, 11.23% and 11.10% more over plants of without EDU-treatment (Table 4.7 and Figure 4.48).

The difference in difference in root length between EDU treated and non-treated plants was statistically significant ($P \leq 0.01$ level) (Table 4.7).

Root Biomass

The root biomass in plants without EDU at different sites was 2.04 ± 0.62g, 1.86 ± 0.76g, 2.12 ± 0.78g, 1.68 ± 0.52g, 2.23 ± 0.64g, 1.58 ± 0.45g, 1.9 ± 0.65g, 1.88 ± 0.54g and 1.83 ± 0.50 g respectively. The maximum root biomass was 2.04 ± 0.62g at site S1 and minimum was 1.58 ± 0.45g was at site S7 (Table 4.7).

The root biomass of EDU-treated plants, at different sites were 2.33 ± 0.44, 2.27 ± 0.34, 2.23 ± 0.77, 2.18 ± 0.31, 2.32 ± 0.68, 2.1 ± 0.45, 2.27 ± 0.27, 2.36 ± 0.36 and

2.17 ± 0.17 g respectively. The maximum root biomass was 2.33 ± 0.44 g at site S1 and minimum was 2.1 ± 0.45 g at S7 (Table 4.7).

A comparison of root biomass between EDU treated and non-treated plants show root biomass in EDU treated plants was 15.7%, 16.96%, 17.04%, 22.94%, 15.51%, 22.86%, 16.29%, 16.59% and 17.27% more over plants of without EDU treatment (Table 4.7 and Figure 4.49).

The difference in root biomass between EDU treated and non-treated plants was statistically significant ($P \leq 0.01$ level) (Table 4.7).

Pods per Plant

The number of pods per plant in plants without EDU at different sites was 116.6 ± 34.59, 116.6 ± 36.34, 115 ± 34.67, 94.65 ± 30.27, 123 ± 40.61, 90.05 ± 30.27, 118.4 ± 31.72, 113.9 ± 39.12 and 112.2 ± 32.65 respectively. The maximum average number of pods per plant was 118.4 ± 31.72 at site S9 and minimum was 90.05 ± 30.27 at site S7 (Table 4.7).

The number of pods of EDU-treated plants, at different sites (site 1-9) was 165.38 ± 24.91, 133.38 ± 39.12, 134.75 ± 35.04, 112.88 ± 29.91, 138.75 ± 31.64, 107.88 ± 34.25, 134.63 ± 29.44, 130.75 ± 37.6 and 127.5 ± 30.3 respectively. The highest average number of pods per plant was 165.38 ± 24.91 at site S1 and the lowest was 107.88 ± 34.25 was at site S7 (Table 4.7).

A comparison of number of pods per plant between EDU treated and non-treated plants show number of pods per plant was 10.33%, 12.63%, 14.32%, 16.15%, 11.1%, 16.73%, 12.07%, 12.81% and 12.03% more over plants grown without EDU-treatment (Table 4.7 and Figure 4.50).

The difference in number of pods per plant between plants grown with EDU and without EDU treatments was statistically significant ($P \leq 0.01$ level) (Table 4.7).

Pod length

The pod length in plants without EDU at different sites was 3.99 ± 0.62, 3.74 ± 0.47, 3.81 ± 0.55, 3.62 ± 0.43, 4.04 ± 0.62, 3.54 ± 0.3, 3.85 ± 0.41, 3.73 ± 0.26 and 3.72 ±

0.25 cm respectively. The maximum pod length was 3.99 ± 0.62 cm at site S1 and minimum was 3.54 ± 0.3 cm at site S7 (Table 4.7 and Plate 4.7).

The pod length of EDU-treated plants, at different sites (site 1-9) was 4.72 ± 0.43, 4.51 ± 0.86, 4.36 ± 0.27, 4.47 ± 0.28, 4.53 ± 0.35, 4.45 ± 0.9, 4.55 ± 0.48, 4.46 ± 0.45 and 4.45 ± 0.38 cm respectively. The maximum average pod length was 4.72 ± 0.43 cm at site S1 and minimum was 4.36 ± 0.27 cm at site S4 (Table 4.7 and Plate 4.7).

A comparison of pod length between EDU treated and non-treated plants show pod length in EDU treated plants was 16.31%, 17.07%, 16.7%, 19.01%, 16.59%, 19.77%, 15.82%, 16.37% and 16.4% more over plants grown without EDU treatment (Table 4.7 and Figure 4.51).

The difference in pod length between EDU treated and non-treated plants was statistically significant (P ≤0.01 level) (Table 4.7).

Seeds per Pod

The number of seeds per pod in plants without EDU at different sites were 12.38 ± 1.61, 11.3 ± 2.73, 12.23 ± 3.55, 10.4 ± 1.23, 12.71 ± 2.85, 10.68 ± 1.2, 11.69 ± 1.81, 11.59 ± 1.33 and 11.48 ± 1.65 respectively. The maximum number of seeds per pod was 12.38 ± 1.61 at site S1 and minimum was 10.4 ± 1.23 at site S4 (Table 4.7).

The number of seeds per pod of EDU-treated plants, at different sites was 13.72 ± 1.7, 12.76 ± 2.54, 12.66 ± 2.16, 12.6 ± 1.53, 13.17 ± 1.91, 12.52 ± 1.93, 13.02 ± 1.55, 12.95 ± 1.65 and 12.62 ± 1.73 respectively. The maximum number of seeds per pod was 13.71 ± 1.7 at site S1 and minimum was 12.52 ± 1.93 at S7 (Table 4.7).

A comparison of number of seeds per pod between EDU treated and non-treated plants show number of seeds per pod in EDU treated plants was 9.84%, 10.66%, 10.11%, 17.46%, 10.02%, 17.91%, 10.36%, 10.50% and 10.91% more over plants grown without EDU treatment (Table 4.7 and Figure 4.52).

The difference in number of seeds per pod between EDU treated and non-treated plants was statistically significant (P ≤0.01 level) (Table 4.7).

Seed Weight per Plant

The seed weight per plant without EDU at different sites was 5.24 ± 2.21, 4.87 ± 1.23, 4.84 ± 1.5, 4.18 ± 1.16, 5.17 ± 1.54, 4.08 ± 0.6, 5.05 ±1.0, 4.78 ± 0.75 and 4.78 ± 0.7g respectively. The maximum seed weight per plant was 5.24 ± 2.21g at site S1 and minimum was 4.08 ± 0.6g at site S7 (Table 4.7 and Plate 4.8).

The seed weight of EDU-treated plants, at different sites was 5.47 ± 0.93, 5.28 ± 1.16, 5.22 ± 1.16, 4.97 ± 1.2, 5.44 ± 0.87, 4.86 ± 0.82, 5.34 ± 1.03, 5.18 ± 0.83 and 5.19 ± 0.54 g respectively. The maximum per plant seed weight was 5.47 ± 0.93 g at site S1 and minimum was 4.86 ± 0.82 g at site S7 (Table 4.7 and Plate 4.8).

A comparison of seed weight per plant between EDU treated and non-treated plants show seed weight per plant in EDU treated plants was 4.20%, 7.76%, 7.28%, 15.89%, 4.96%, 16.05%, 5.43%, 7.72% and 7.89% more over plants grown without EDU treatment (Table 4.7 and Figure 4.53).

The difference in seed weight per plant between EDU treated and non-treated plants was statistically significant ($P \leq 0.01$ level) (Table 4.7).

Total Chlorophyll

The total chlorophyll content in 60 days old plants without EDU at different sites was 1.74 ± 0.21, 1.72 ± 0.23, 1.68 ± 0.15, 1.68 ± 0.16, 1.76 ± 0.07, 1.48 ± 0.10, 1.51 ± 0.06, 1.48 ± 0.15 and 1.52 ± 0.07 mg/g respectively. The maximum total chlorophyll content was 1.76 ± 0.07 mg/g at site S1 and minimum was 1.48 ± 0.10 mg/g at site S7 (Table 4.7).

The total chlorophyll content in EDU-treated plants at different sites was 1.88 ± 0.09, 1.86 ± 0.16, 1.82 ± 0.16, 1.81 ± 0.12, 1.89 ± 0.08, 1.84 ± 0.08, 1.82 ± 0.10, 1.80 ± 0.08 and 1.78 ± 0.05 mg/g respectively. The maximum total chlorophyll content in plants was 1.88 ± 0.09 mg/g at site S1 and minimum was 1.78 ± 0.05 mg/g at S11 (Table 4.7).

A comparison of total chlorophyll content between EDU treated and non-treated plants show total chlorophyll content in EDU treated plants was 7.45%, 7.53%, 7.69%, 7.18%, 6.88%, 19.56%, 17.03%, 17.78% and 14.60% more over plants grown without EDU treatment (Table 4.7 and Figure 4.54).

111

The difference in total chlorophyll content between EDU treated and non-treated plants was statistically significant (P ≤0.05 level) (Table 4.7).

Ascorbic Acid

The ascorbic acid content in 60 days old plants without EDU at different sites was 0.84 ± 0.06, 0.82 ± 0.02, 0.76 ± 0.01, 0.75 ± 0.02, 0.85 ± 0.02, 0.67 ± 0.01, 0.75 ± 0.04, 0.74 ± 0.01 and 0.73 ± 0.02 mg/g respectively. The maximum ascorbic acid content was 0.84 ± 0.06 mg/g at site S1 and minimum was 0.67 ± 0.01 mg/g at site S7 (Table 4.7).

In EDU-treated plants, the ascorbic acid content at different sites was 0.94 ± 0.09, 0.92 ± 0.06, 0.87 ± 0.06, 0.86 ± 0.02, 0.98 ± 0.08, 0.82 ± 0.08, 0.88 ± 0.04, 0.86 ± 0.03 and 0.84 ± 0.02 mg/g respectively. The maximum ascorbic acid was 0.94 ± 0.09 mg/g at site S1 and minimum was 0.82 ± 0.08 mg/g at site S7 (Table 4.7).

A comparison of ascorbic acid content between EDU treated and non-treated plants show ascorbic acid content in EDU treated plants was 10.87%, 12.64%, 12.79%, 16.29%, 13.26%, 14.77%, 13.95%, 13.95% and 13.09% more over plants grown without EDU treatment (Table 4.7 and Figure 4.55).

The difference in ascorbic acid content between EDU treated and non-treated plants was statistically significant (P ≤0.01 level) (Table 4.7).

Fumigation Studies

Three sets of plants namely control, E1 and E2 were prepared to carry out the fumigation study. The E1 and E2 sets were fumigated with 150μg/m^3 of ozone and the control set was maintained in the ambient environment. Ground level ozone monitoring was also carried out during February-2003 to find out the background ozone concentration in the ambient environment at JNU. The average hourly ozone concentration was 73.5μg/m^3 and the maximum and minimum concentration was 174.44μg/m^3 and 5.88μg/m^3 respectively. The plant growth and performances of plants exposed to 150μg/m^3 and were made in respect of different morphological and biochemical parameters.

112

Shoot Length

The shoot growth was slow up to 30th day. Subsequently, there was a rapid growth till 50th day. Between 50th -78th day, the growth was gradual and beyond 75th day there was no further increase beyond 78th day.

The shoot length in 135days old mature plants without EDU was 76.4 ± 9.44, 66.4 ± 8.01 and 69.5 ± 14.24 cm respectively. The maximum shoot length was 76.4 ± 9.44 cm in control plants and minimum was 66.44 ± 8.01cm in plants of E1 set (Table 4.7).

In EDU-treated plants, the shoot length was 84.1± 14.36, 80.2 ± 10.61and 81.4 ± 2.30 cm respectively. The maximum shoot length was 84.1 ± 14.36cm in control plants and minimum was 80.2 ± 10.61 cm in plants of E1 set (Table 4.7).

A comparison of shoot length between EDU treated and non-treated plants show shoot length in EDU treated plants was 9.15%, 17.20% and 14.62% more over without EDU treatment (Table 4.7 and Figure 4.56).

The difference in shoot length between EDU treated and non-treated plants was statistically significant (P ≤0.01 level) (Table 4.7).

Number of Branches

The number of branches in plants without EDU was 16.38 ± 1.36, 15.24 ± 1.15 and 15.4 ± 6.16 respectively. The maximum number of branches was 16.38 ± 1.36 in control plants and minimum was 15.24 ± 1.15 in plants of E1 set (Table 4.7).

In EDU-treated plants, the number of branches was 15.28 ± 4.29, 13.2 ± 1.09 and 13.8 ± 1.58 respectively. The maximum number of branches was 15.28 ± 4.29 in control plants and minimum was 13.2 ± 1.09 in plants of E1 set (Table 4.7).

A comparison of number of branches between EDU treated and non-treated show number of branches in EDU treated plants was 7.2%, 15.45% and 11.59% less as compared to plants without EDU treatments (Table 4.7 and Figure 4.57).

The difference in number of branches between EDU treated and non-treated plants was statistically significant (P ≤ 0.1 level) (Table 4.7).

Shoot Biomass

The shoot biomass in plants without EDU was 4.80 ± 1.36g, 3.80 ± 0.435g and 4.40 ± 1.33g respectively. The maximum shoot biomass was 4.80 ± 1.36g in control plants and minimum was 3.80 ± 0.435g in plants of E1 set (Table 4.7).

In EDU-treated plants, the shoot biomass was 6.02 ± 1.75g, 5.28 ± 1.20g and 5.84 ± 0.95g respectively. The maximum shoot biomass was 6.02 ±1.75g in control plants and minimum was 5.28 ± 1.20 g in plants of E1 set (Table 4.7).

A comparison of shoot length between EDU treated and non-treated plants show shoot biomass in EDU treated plants was 20.26%, 28.03% and 24.65% more over plants without EDU treatment (Table 4.7 and Figure 4.58).

The difference in number of branches between EDU treated and non-treated plants was statistically insignificant (Table 4.7).

Root Length

The root length in plant without EDU was 14.21 ± 3.70, 10.24 ± 3.05 and 11.98 ± 1.75 cm respectively. The maximum root length was 14.21 ± 3.70 cm in control plants and minimum was 10.24 ± 3.05 cm in plants of E1 set (Table 4.7).

In EDU-treated plants, the root length was 16.52 ± 4.20, 14.20 ± 4.05 and 15.46 ± 1.15 cm respectively. The maximum root length was 16.52 ± 4.20 cm in control plants and minimum was 14.20 ± 4.05 cm in plants of E1 set (Table 4.7).

A comparison of root length between EDU treated and non-treated plants show root length was 13.98%, 27.89% and 22.51% more over plants without EDU treatment (Table 4.7 and Figure 4.59).

The difference in root length between EDU treated and non-treated plants was statistically significant (P ≤0.1 level) (Table 4.7).

Root Biomass

The root biomass in plants without EDU was 1.86 ± 0.35, 1.42 ± 0.10 and 1.74 ± 0.43 g respectively. The maximum root biomass was 1.86 ± 0.35 g in control plants and minimum was 1.42 ± 0.10 g in plants of E1 set (Table 4.7).

In EDU-treated plants, the root biomass was 2.24 ± 0.26, 2.02 ± 0.09 and 2.18 ± 0.15 g respectively. The maximum root biomass was 2.24 ± 0.26 g in control plants and minimum was 2.02 ± 0.09 g in plants of E1 set (Table 4.7).

A comparison of root biomass between EDU treated and non-treated plants show root biomass in EDU-treated plants was 16.96%, 29.70% and 20.18% more over plants without EDU treatment (Table 4.7 and Figure 4.60).

The difference in root biomass between EDU treated and non-treated plants was statistically significant ($P \leq 0.1$ level) (Table 4.7).

Pods per Plant

The number of pods in plants without EDU was 96.33 ± 16.88, 62.80 ± 15.33 and 78.33 ± 15.19 respectively. The maximum number of pods per plant was 96.33 ± 16.88 in control plants and minimum was 62.80 ± 15.33 in plants of E1 set (Table 4.7).

In EDU-treated plants, the number of pods per plant was 112.15 ± 16.34, 83.67 ± 17.63 and 98.83 ± 12.05. The maximum number of pods per plant was 112.15 ± 16.34 in control plants and minimum was 83.67 ± 17.63 in plants of E1 set (Table 4.7).

A comparison of number of pods per plant between EDU treated and non-treated plants show number of pods per plant in EDU treated plants was 14.10%, 24.94% and 20.74% more over plants without EDU treatment (Table 4.7 and Figure 4.61).

The difference in number of pods per plant between EDU treated and non-treated plants was statistically significant ($P \leq 0.01$ level) (Table 4.7).

Pod Length

The pod length in plants without EDU was 3.67 ± 0.37, 2.87 ± 0.33 and 3.48 ± 0.35 cm respectively. The maximum pod length was 3.67 ± 0.37cm in control plants and minimum was 2.87 ± 0.33 cm in plants of E1 set (Table 4.7).

In EDU-treated plants, the pod length was 4.30 ± 0.31, 3.94 ± 0.29 and 4.26 ± 0.06 cm respectively. The maximum pod length was 4.30 ± 0.31cm in control plants and minimum was 3.94 ± 0.29 cm in plants of E1 set (Table 4.7).

A comparison of pod length between EDU treated and non-treated plants show pod length in EDU treated plants was 14.65%, 27.15% and 18.30% more over plants without EDU treatment (Table 4.7 and Figure 4.62).

The difference in pod length between EDU treated and non-treated plants was statistically significant (P ≤ 0.01 level) (Table 4.7).

Seeds per Pod

The number of seeds per pod in plants without EDU was 10.8 ± 0.14, 9.40 ± 0.52 and 10.2 ± 0.42 respectively. The maximum number of seeds per pod was 10.8 ± 0.14 in control plants and minimum was 9.40 ± 0.52 in plants of E1 set (Table 4.7).

In EDU-treated plants, the number of seeds per pod was 12.8 ± 0.98, 12.2 ± 0.32 and 12.6 ± 0.42. The maximum number of seeds per pod was 12.8 ± 0.98 in control plants and minimum was 12.2 ± 0.32 in plants of E1 set (Table 4.7).

A comparison of number of seeds per pod between EDU treated and non-treated show number of seeds per pod in EDU treated plants was 15.62%, 22.95% and 19.04% more over plants without EDU treatment (Table 4.7 and Figure 4.63).

The difference in number of seeds per pod between EDU treated and non-treated plants was statistically significant (P ≤ 0.01 level) (Table 4.7).

Seed Weight per Plant

The seed weight per plant in plants without EDU was 4.52 ± 0.20, 3.82 ± 0.10 and 4.24 ± 0.72 g respectively. The maximum seed weight per plant was 4.52 ± 0.20 g in control plants and minimum was 3.82 ± 0.10 g in plants of E1 set (Table 4.7).

In EDU-treated plants, the seed weight per plant was 4.82 ± 0.20, 4.54 ± 0.34 and 4.68 ± 0.90 g respectively. The maximum seed weight per plant was 4.82 ± 0.20 g in control plants and minimum was 4.54 ± 0.34 g in plants of E1 set (Table 4.7).

A comparison of seed weight per plant between EDU treated and non-treated plants show seed weight per plant of EDU treated plants was 6.22%, 15.86% and 9.40% more over plants without EDU treatment (Table 4.7 and Figure 4.64).

The difference in seed weight per plant between plants grown with EDU and without EDU treatments was statistically significant (P ≤ 0.01 level) (Table 4.7).

Total Chlorophyll

The total chlorophyll content in 60 days old plants without EDU was 1.448 ± 0.02, 0.941± 0.01 and 0.940 ± 0.02 mg/g respectively. The maximum total chlorophyll content was 0.944 ± 0.20 mg/g in control plants and minimum was 0.940 ± 0.020 mg/g in plants of E2 set (Table 4.7).

In EDU-treated plants, the total chlorophyll content was 1.907± 0.02, 1.716 ± 0.03 and 1.536 ± 0.09 mg/g respectively. The maximum total chlorophyll content was 1.907 ± 0.02 mg/g in control plants and minimum was 1.536 ± 0.34 mg/g in plants of E2 set (Table 4.7).

A comparison of total chlorophyll content between EDU treated and non-treated plants show total chlorophyll content in EDU treated plants was 24.07%, 45.16% and 38.79% more over plants without EDU treatment (Table 4.7 and Figure 4.65).

The difference in total chlorophyll content between EDU treated and non-treated plants was statistically insignificant (Table 4.7).

Ascorbic Acid

The ascorbic acid content in 60 days old plants without EDU was 0.92 ± 0.01, 0.91 ± 0.01 and 0.91 ± 0.02 mg/g respectively. The maximum ascorbic acid content was 0.92 ± 0.01 mg/g in control plants and minimum was 0.91 ± 0.02 mg/g in plants of E2 set (Table 4.7).

In EDU-treated plants, the ascorbic acid was 0.94 ± 0.02, 0.93 ± 0.03 and 0.92 ± 0.02 mg/g respectively. The maximum ascorbic acid content was 0.94 ± 0.02 mg/g in control plants and minimum was 0.92 ± 0.02 mg/g in plants of E2 set (Table 4.7).

A comparison of ascorbic acid content between EDU treated and non-treated plants show ascorbic acid content in EDU treated was 2.12%, 2.15% and 1.08% more over plants grown without EDU treatment (Table 4.7 and Figure 4.66).

The difference in ascorbic acid content between EDU treated and non-treated plants was statistically insignificant.

Table 4.7: Performance of *Brassica campestris* plants with and without-EDU exposed to ozone at field sites and in fumigation chamber.

Parameters	Field study									Fumigation study		
	S1	S2	S3	S4	S6	S7	S9	S10	S11	C	E1	E2
Shoot length (cm) EDU	103.25 ±14.26	96.25 ±11.85	93.50 ±13.33	82.12 ±8.79	90.62 ±7.53	72.25 ±13.06	99.75 ±9.51	86.75 ±9.88	85.43 ±4.37	84.10 ±14.36	80.20 ±10.61	81.40 ±2.30
N-TR	88.15[2] ±14.24	71.40[2] ±9.57	77.05[2] ±10.46	77.05[2] ±14.24	84.10[2] ±10.32	66.55[2] ±5.21	93.35[2] ±10.46	78.70[2] ±9.24	77.70[2] ±5.27	76.40[1] ±9.44	66.40[1] ±8.01	69.50[1] ±14.24
Difference (%)	14.60	25.80	17.60	6.20	7.20	15.20	6.40	9.30	9.00	9.15	17.20	14.62
No. of branches EDU	11.75 ±2.49	11.37 ±2.32	15.87 ±3.94	12.37 ±1.76	17.12 ±3.68	11.50 ±3.29	12.62 ±3.66	17.87 ±3.39	14.00 ±3.38	15.28 ±4.29	13.20 ±1.09	13.80 ±1.58
N-TR	12.75[2] ±4.89	12.75[2] ±5.39	17.05[2] ±2.01	14.20[2] ±2.70	18.20[2] ±4.83	13.40[2] ±2.30	14.10[2] ±3.98	20.35[2] ±3.71	15.90[2] ±4.01	16.38[3] ±1.36	15.24[3] ±1.15	15.40[3] ±6.16
Difference (%)	8.50	12.00	7.50	14.70	6.30	16.50	11.70	12.80	13.50	7.20	15.45	11.59
Shoot biomass (g) EDU	6.16 ±2.09	5.96 ±1.40	6.02 ±1.95	5.80 ±1.24	6.12 ±1.67	5.72 ±1.40	6.01 ±1.29	5.92 ±1.28	5.83 ±0.87	6.02 ±1.75	5.28 ±1.20	5.84 ±0.95
N-TR	5.15[1] ±1.53	4.98[1] ±1.20	4.96[1] ±2.08	4.46[1] ±1.90	4.95[1] ±1.35	3.95[1] ±1.08	5.04[1] ±1.44	4.89[1] ±1.82	4.87[1] ±1.85	4.80[ns] ±1.36	3.80[ns] ±0.435	4.40[ns] ±1.33
Difference (%)	16.90	17.28	17.61	23.02	16.74	24.09	15.42	17.40	17.03	20.26	28.03	24.65

Root length (cm)												
EDU	19.50 ± 2.32	17.95 ± 2.25	18.60 ± 2.43	17.41 ± 2.42	19.20 ± 2.68	17.42 ± 5.33	19.22 ± 2.47	18.66 ± 2.83	18.65 ± 2.04	16.52 ± 4.20	14.20 ± 4.05	15.46 ± 1.15
N-TR	17.60[1] ± 6.43	17.00[1] ± 5.48	16.46[1] ± 5.31	12.33[1] ± 3.13	17.60[1] ± 4.85	15.37[1] ± 3.51	12.14[1] ± 2.59	16.70[1] ± 3.42	16.68[1] ± 3.37	14.21[3] ± 3.70	10.24[3] ± 3.05	11.98[3] ± 1.75
Difference (%)	9.74	10.96	11.50	12.31	8.33	14.32	10.20	11.23	11.10	13.98	27.89	22.51
Root biomass (g)												
EDU	2.33 ± 0.44	2.27 ± 0.34	2.23 ± 0.77	2.18 ± 0.31	2.32 ± 0.68	2.10 ± 0.45	2.27 ± 0.27	2.36 ± 0.36	2.17 ± 0.17	2.24 ± 0.26	2.02 ± 0.09	2.18 ± 0.15
N-TR	2.04[1] ± 0.62	1.86[1] ± 0.76	2.12[1] ± 0.78	1.68[1] ± 0.52	2.23[1] ± 0.64	1.58[1] ± 0.45	1.90[1] ± 0.65	1.88[1] ± 0.54	1.83[1] ± 0.50	1.86[3] ± 0.35	1.42[3] ± 0.10	1.74[3] ± 0.43
Difference (%)	15.70	16.69	17.04	22.94	15.51	22.86	16.29	16.59	17.27	16.96	29.70	20.18
Pods per plant												
EDU	165.38 ± 24.91	133.38 ± 39.12	134.75 ± 35.04	112.88 ± 29.91	138.75 ± 31.64	107.88 ± 34.25	134.63 ± 29.44	130.75 ± 37.60	127.50 ± 30.30	112.15 ± 16.34	83.67 ± 17.63	98.83 ± 12.05
N-TR	116.60[1] ± 34.59	116.60[1] ± 36.34	115.00[1] ± 34.67	94.65[1] ± 30.27	123.00[1] ± 40.61	90.05[1] ± 30.27	118.40[1] ± 31.72	113.90[1] ± 39.12	112.20[1] ± 32.65	96.33[1] ± 16.88	62.80[1] ± 15.33	78.33[1] ± 15.19
Difference (%)	10.33	12.63	14.32	16.15	11.10	16.73	12.07	12.81	12.03	14.10	24.94	20.74

Pod length (cm) EDU	4.72 ± 0.43	4.51 ± 0.86	4.36 ± 0.27	4.47 ± 0.28	4.53 ± 0.35	4.45 ± 0.90	4.55 ± 0.48	4.46 ± 0.45	4.45 ± 0.38	4.30 ± 0.31	3.94 ± 0.29	4.26 ± 0.06
N-TR	3.99[1] ± 0.62	3.74[1] ± 0.47	3.81[1] ± 0.55	3.62[1] ± 0.43	4.04[1] ± 0.62	3.54[1] ± 0.30	3.85[1] ± 0.41	3.73[1] ± 0.26	3.72[1] ± 0.25	3.67[1] ± 0.37	2.87[1] ± 0.33	3.48[1] ± 0.35
Difference (%)	16.31	17.07	16.70	19.01	16.59	19.77	15.82	16.37	16.40	14.65	27.15	18.30
Seeds per pod EDU	13.72 ± 1.70	12.76 ± 2.54	12.66 ± 2.16	12.60 ± 1.53	13.17 ± 1.91	12.52 ± 1.93	13.02 ± 1.55	12.95 ± 1.65	12.62 ± 1.73	12.80 ± 0.98	12.20 ± 0.32	12.60 ± 0.42
N-TR	12.38[1] ± 1.61	11.30[1] ± 2.73	12.23[1] ± 3.55	10.40[1] ± 1.23	12.71[1] ± 2.85	10.68[1] ± 1.20	11.69[1] ± 1.81	11.59[1] ± 1.33	11.48[1] ± 1.65	10.80[1] ± 0.14	9.40[1] ± 0.52	10.20[1] ± 0.42
Difference (%)	9.84	10.66	10.11	17.46	10.02	17.91	10.36	10.50	10.91	15.62	22.95	19.04
Seed weight per plant (g) EDU	5.47 ± 0.93	5.28 ± 1.16	5.22 ± 1.16	4.97 ± 1.20	5.44 ± 0.87	4.86 ± 0.82	5.34 ± 1.03	5.18 ± 0.83	5.19 ± 0.54	4.82 ± 0.20	4.54 ± 0.34	4.68 ± 0.90
N-TR	5.24[1] ± 2.21	4.87[1] ± 1.23	4.84[1] ± 1.50	4.18[1] ± 1.16	5.17[1] ± 1.54	4.08[1] ± 0.60	5.05[1] ± 1.00	4.78[1] ± 0.75	4.78[1] ± 0.70	4.52[1] ± 0.20	3.82[1] ± 0.10	4.24[1] ± 0.72
Difference (%)	4.20	7.76	7.28	15.89	4.96	16.05	5.43	7.72	7.89	6.22	15.86	9.40

Totalchlorophyll (mg/g)												
EDU	1.88 ± 0.09	1.86 ± 0.16	1.82 ± 0.16	1.81 ± 0.12	1.89 ± 0.08	1.84 ± 0.08	1.82 ± 0.10	1.80 ± 0.08	1.78 ± 0.05	1.907 ± 0.02	1.716 ± 0.03	1.536 ± 0.09
N-TR	1.74[2] ± 0.21	1.72[2] ± 0.23	1.68[2] ± 0.15	1.68[2] ± 0.16	1.76[2] ± 0.07	1.48[2] ± 0.10	1.51[2] ± 0.06	1.48[2] ± 0.15	1.52[2] ± 0.07	1.448[ns] ± 0.02	0.941[ns] ± 0.010	0.940[ns] ± 0.02
Difference (%)	7.45	7.53	7.69	7.18	6.88	19.56	17.03	17.78	14.60	24.07	45.16	38.79
Ascorbic acid (mg/g)												
EDU	0.94 ± 0.09	0.92 ± 0.06	0.87 ± 0.06	0.86 ± 0.02	0.98 ± 0.08	0.82 ± 0.08	0.88 ± 0.04	0.86 ± 0.03	0.84 ± 0.02	0.94 ± 0.02	0.93 ± 0.03	0.92 ± 0.02
N-TR	0.84[1] ± 0.06	0.82[1] ± 0.02	0.76[1] ± 0.01	0.75[1] ± 0.02	0.85[1] ± 0.02	0.67[1] ± 0.01	0.75[1] ± 0.04	0.74[1] ± 0.01	0.73[1] ± 0.02	0.92[ns] ± 0.01	0.91[ns] ± 0.01	0.91[ns] ± 0.02
Difference (%)	10.87	12.64	12.79	16.29	13.26	14.77	13.95	13.95	13.09	2.12	2.15	1.08

decrease from EDU
-increase over EDU

S1: Bakoli, S2: S. Collge, S3: Jain Temple, S4: Libaspur, S6: JNU, S7: Badarpur, S9: IOC, S10: CRI, S11: AIIMS

C-Control; E1 set - exposed to five cycles of exposure to 150 $\mu g/m^3$ of ozone for four hours (total exposure of 20 hours) at 10-day interval after each EDU treatment; E2 set - five cycles of exposure to 150 $\mu g/m^3$ ozone daily for 4 hours over five successive days (total exposure of 20 hours) after three EDU treatments.

[1] Significant difference between plants grown without EDU (N-TR) and with EDU treatment at $P \leq 0.01$ level
[2] Significant difference between plants grown without EDU (N-TR) and with EDU treatment at $P \leq 0.05$ level
[3] Significant difference between plants grown without EDU (N-TR) and with EDU treatment at $P \leq 0.1$ level
[ns] Non-significant

A comparison between the performance of plants exposed to ambient ozone at field sites and those subjected to experimental fumigation with ozone shows that the different plant parameters in the fumigated plants were relatively more affected (Table 4.8).

Table 4.8: A comparison between the percentage differences in average values of different parameters in *Brasssica campestris* plants grown with and without EDU exposed to 69.07-158.33µg/m³ of ground level ozone and fumigated with 150µg/m³ ozone.

Plant parameter	Field study (% difference) between plants with and without EDU)	Fumigation study (% difference) between plants grown with and without EDU)			Control plants during fumigation study (% difference) between plants grown with and without EDU)
		E1	E2	Average	
Shoot length	12.37	17.20	14.62	15.91	9.15
No. of branches	*11.61	*15.45	*11.59	*13.52	*7.20
Shoot biomass	17.99	28.03	24.65	26.34	20.26
Root length	11.07	27.89	22.51	25.20	13.98
Root biomass	17.90	29.70	20.18	24.94	16.96
Pods per plant	13.13	24.94	20.74	22.84	14.10
Pod length	17.04	27.15	18.30	22.72	14.65
Seeds per pod	11.97	22.95	19.04	21.00	15.62
Seed weight per plant	8.57	15.86	9.40	12.63	6.22
Total chlorophyll	11.74	45.16	38.79	41.88	24.06
Ascorbic acid	13.34	2.15	1.08	1.62	2.12

decrease from EDU.
*increase over EDU.

The protection accorded by EDU *Brassica campestris* plants was not uniform in respect of different morphological and biochemical parameters were in the following order:

Shoot biomass > Root biomass > Pod length > Ascorbic acid > Pods per plant > Seeds per pod > Total chlorophyll > Root length > Shoot length > Seed weight per plant.

In case of plants fumigated with 150 µg/m³ of ozone, the reduction in different morphological and biochemical parameters was of the following order:

Total chlorophyll > Root biomass > Shoot biomass > Root length > Pod length > Pods per plant > Seeds per pod > Shoot length > Seed weight per plant > Ascorbic acid.

Both in field and fumigation studies, seed weight per plant was least affected as compared to other parameters. It seems that EDU nullifies the adverse effect of ozone on *Brassica campestris* plants.

Figure 4.45: A comparison of shoot length between N-Tr and EDU-Tr plants of *Brassica campestris* grown at field sites.

Figure 4.46: A comparison of number of branches per plant between N-Tr and EDU-Tr plants of *Brassica campestris* grown at field sites.
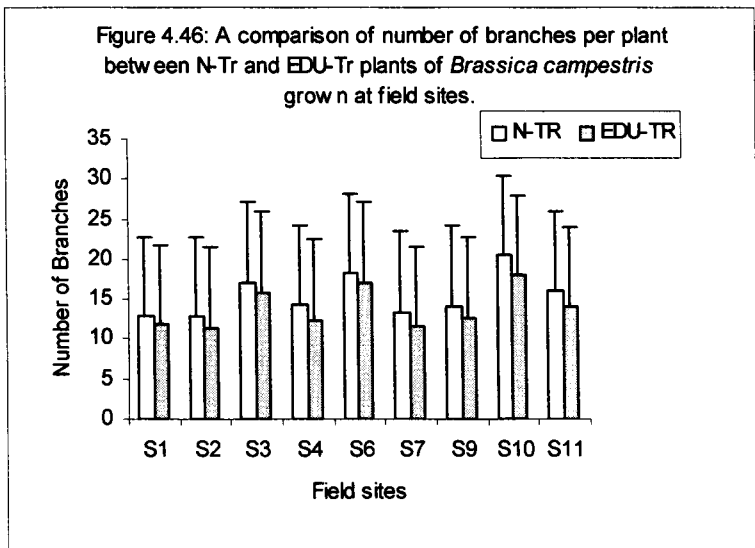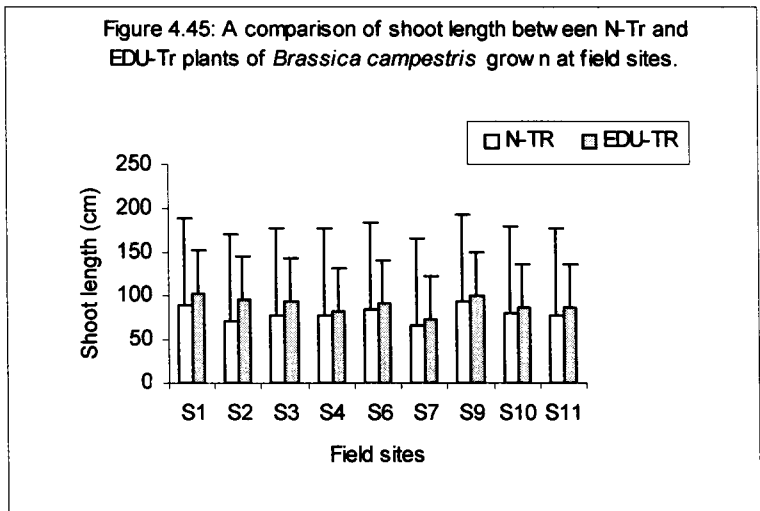
Figure 4.47: A comparison of shoot biomass between N-Tr and EDU-Tr plants of *Brassica campestris* grown at field sites.
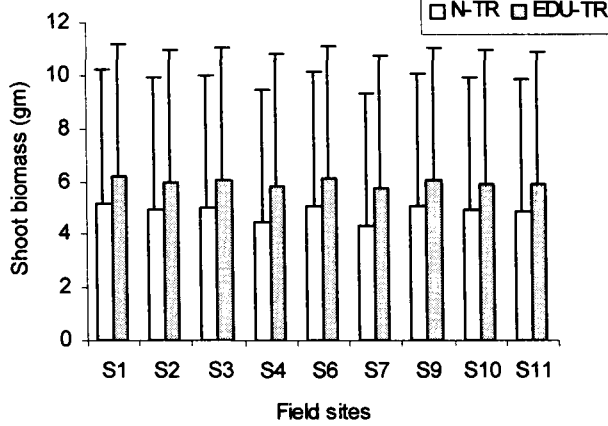
Figure 4.48: A comparison of root length between N-Tr and EDU-Tr plants of *Brassica campestris* grown at field sites.
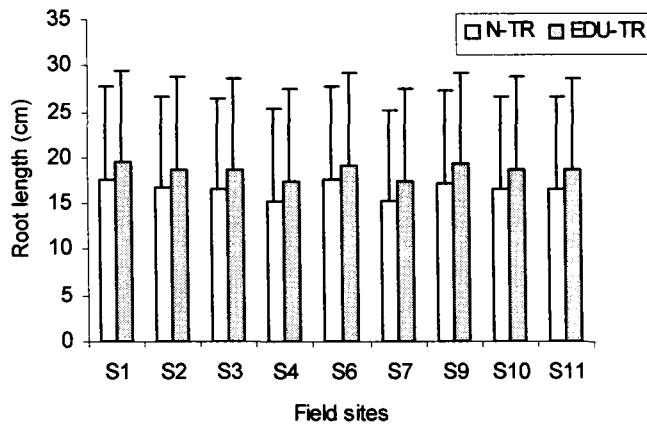
Figure 4.49: A comparison of root biomass between N-Tr and EDU-Tr plants of *Brassica campestris* grown at field sites.

125
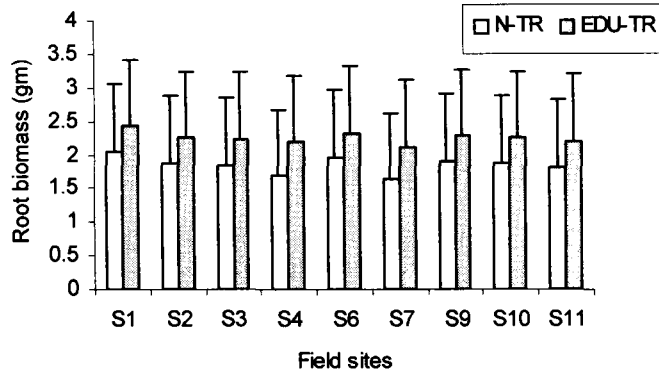
Figure 4.50: A comparison of pods per plant between N-Tr and EDU-Tr plants of *Brassica campestris* grown at field sites
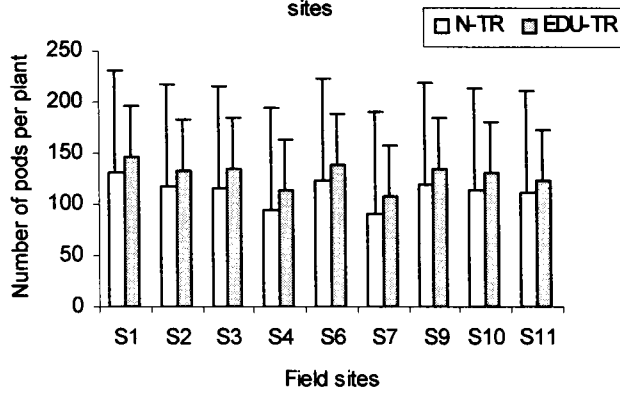
Figure 4.51: A comparison of pod length between N-Tr and EDU-Tr plants of *Brassica campestris* grown at field sites.
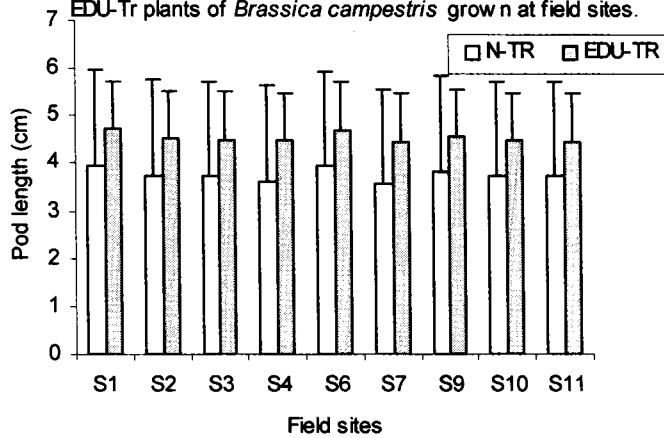
Figure 4.52: A comparison of seeds per pod between N-Tr and EDU-Tr plants of *Brassica campestris* grown at field sites.
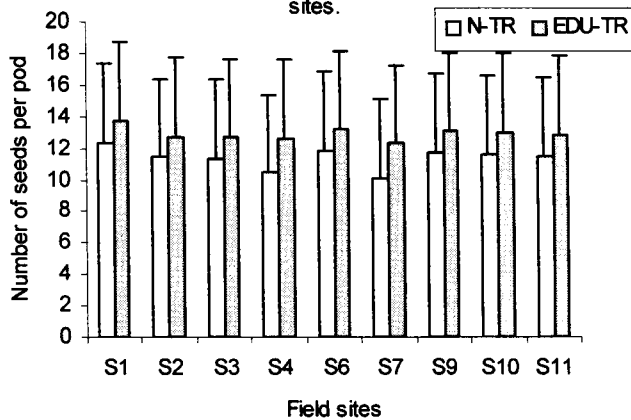
Figure 4.53: A comparison of seed weight per plant between N-Tr and EDU-Tr plants of Brassica campestris grown at field sites.
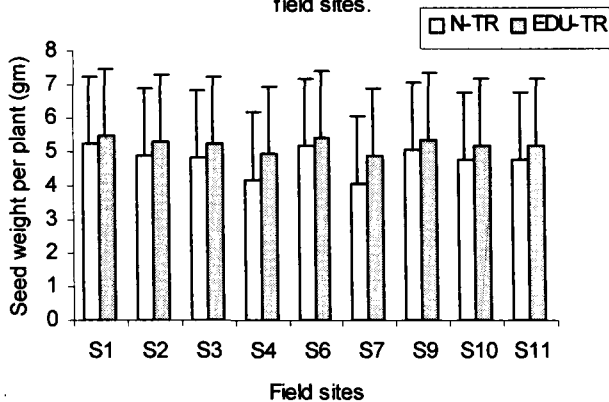
Figure 4.54: A comparison of total chlorophyll content between N-Tr and EDU-Tr plants of *Brassica campestris* grown at field sites.
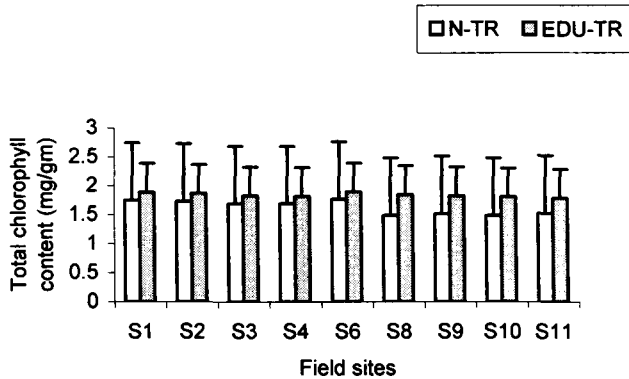
Figure 4.55: A comparison of ascorbic acid content between N-Tr and EDU-Tr plants of *Brassica campestris* grown at field sites.

Figure 4.56: A comparison of shoot length between ozone fumigated N-Tr and EDU-Tr plants of *Brassica campestris*.

Figure 4.57: A comparison of number of branches per plant between ozone fumigated N-Tr and EDU-Tr plants of *Brassica campestris*.

Figure 4.58: A comparison of shoot biomass between ozone fumigated N-Tr and EDU-Tr plants of *Brassica campestris*.
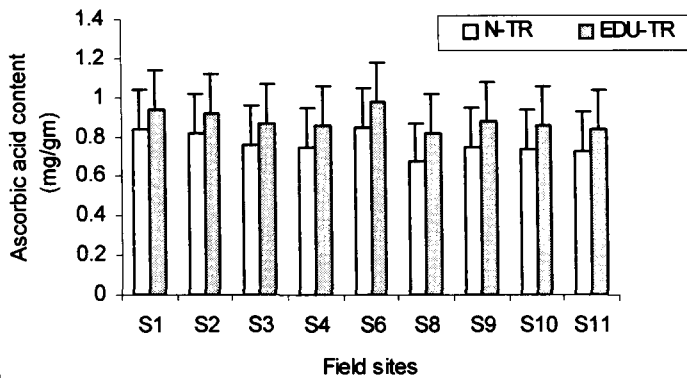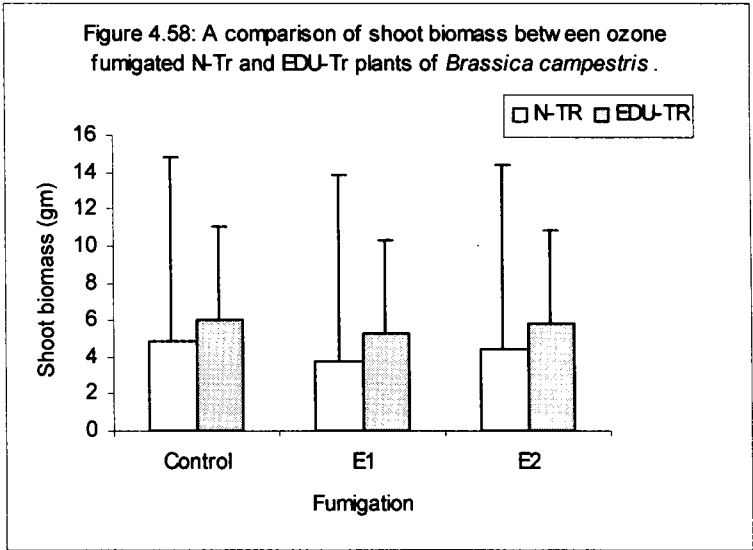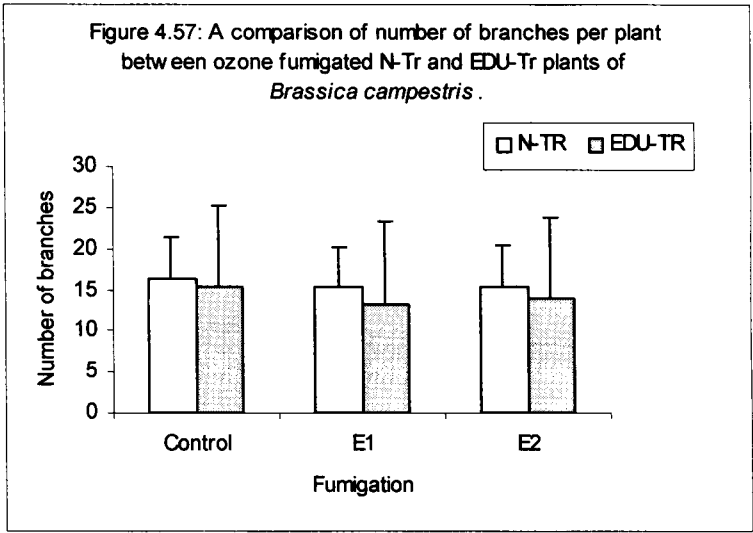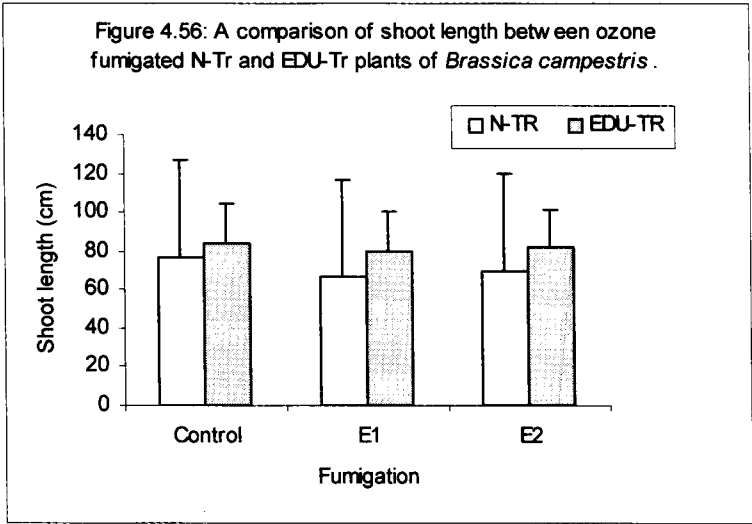
Figure 4.59: A comparison of root length between ozone fumigated N-Tr and EDU-Tr plants of *Brassica campestris*.
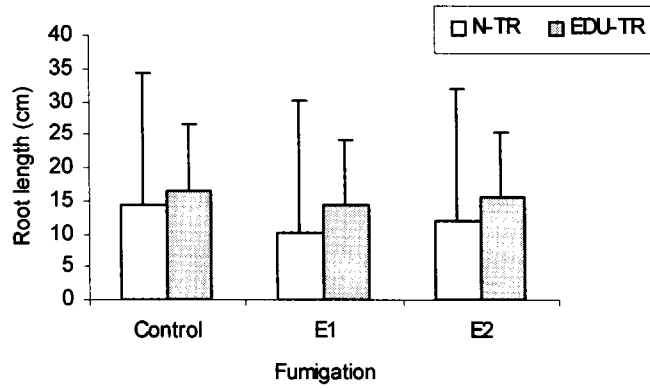
Figure 4.60: A comparison of root biomass between ozone fumigated N-Tr and EDU-Tr plants of *Brassica campestris*.
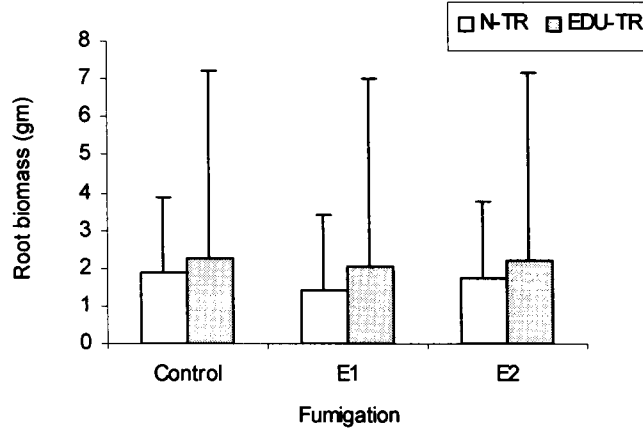
Figure 4.61: A comparison of pods per plant between ozone fumigated N-Tr and EDU-Tr plants of *Brassica campestris*.

129
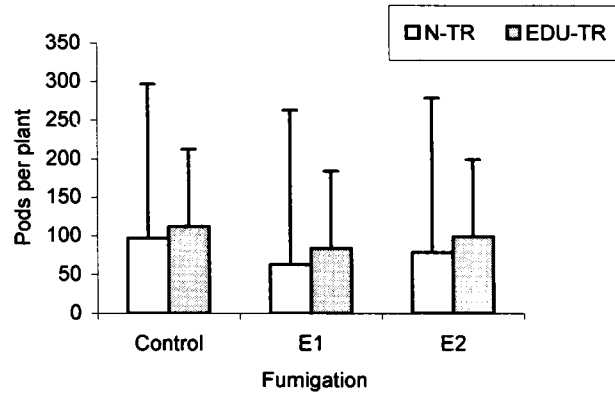
Figure 4.62: A comparison of pod length between ozone fumigated N-Tr and EDU-Tr plants of *Brassica campestris*.
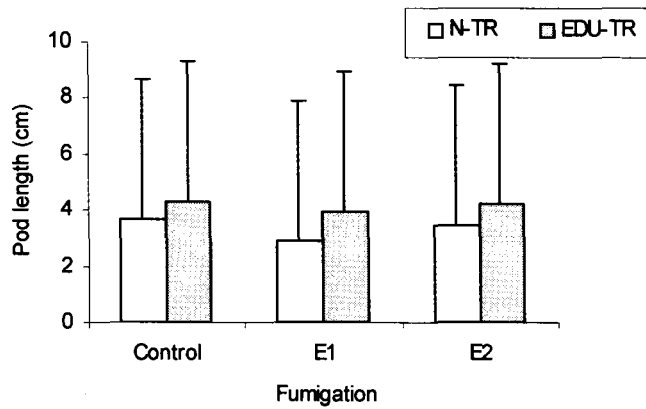
Figure 4.63: A comparison of seeds per pod between ozone fumigated N-Tr and EDU-Tr plants of *Brassica campestris*.
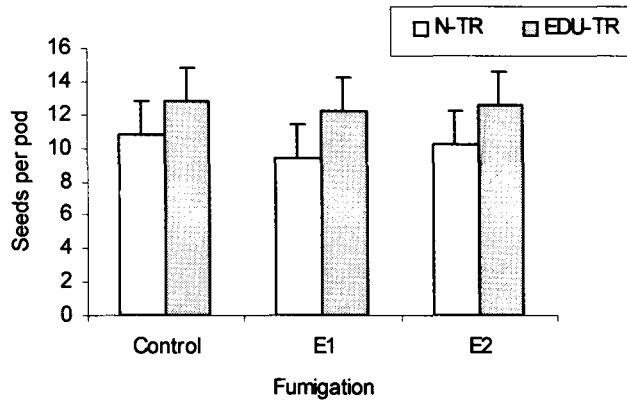
Figure 4.64: A comparison of seed weight per plant between ozone fumigated N-Tr and EDU-Tr plants of *Brassica campestris*.

Figure 4.65: A comparison of total chlorophyll content between ozone fumigated N-Tr and EDU-Tr plants of *Brassica campestris*.

Figure 4.66: A comparison of ascorbic acid content between ozone fumigated N-Tr and EDU-Tr plants of *Brassica campestris*.

131
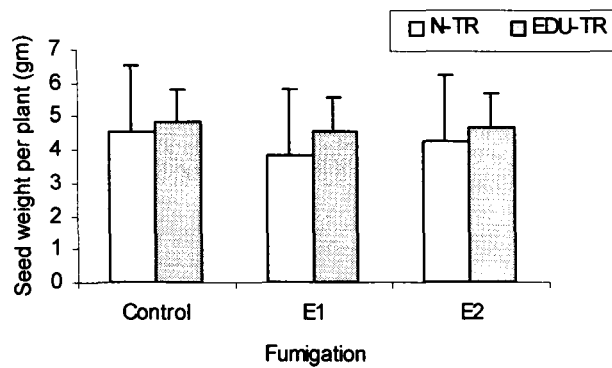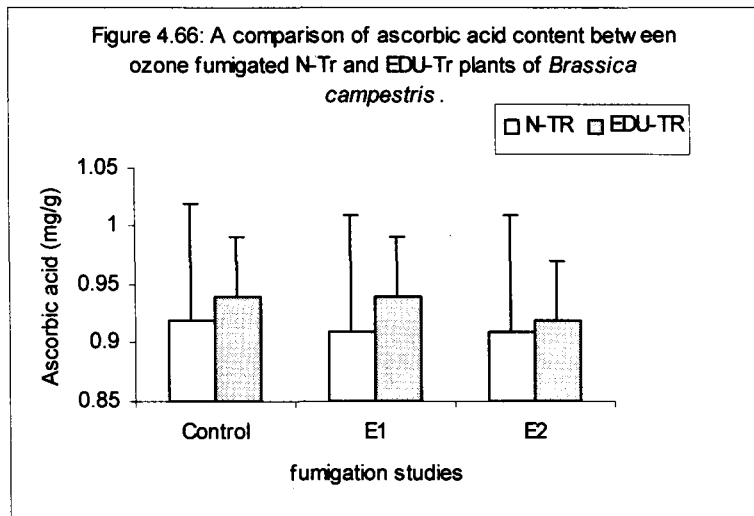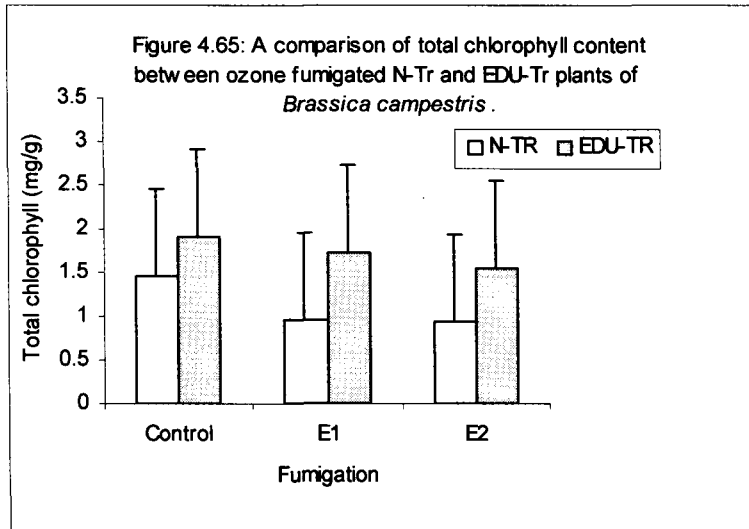
Plate 4.7: A Comparison of Pod Length between EDU-treated (EDU) and non-treated (N-Tr) Mustard (*Brassica campestris*) Plants Grown at Different Field Sites.
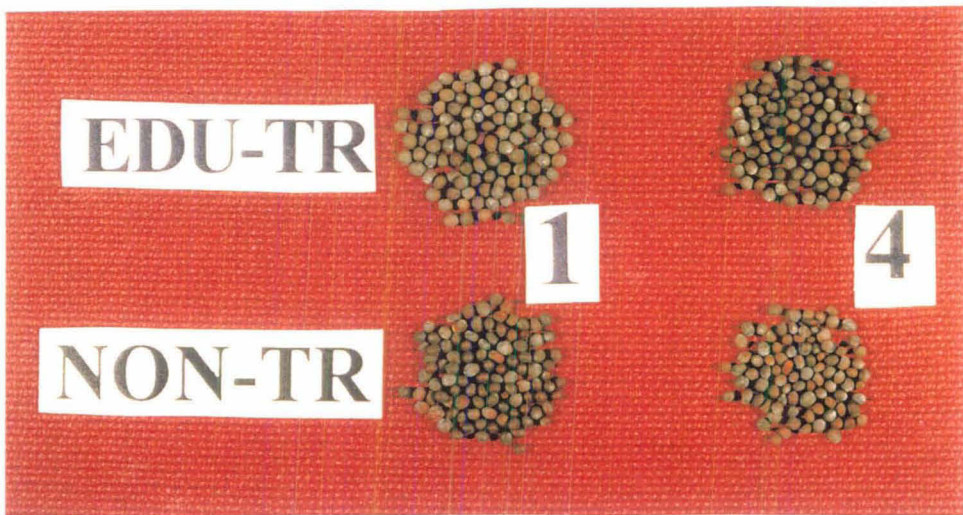
Plate 4.8: A Comparison of Seeds between EDU-treated (EDU-TR) and non-treated (N-TR) Mustard (*Brassica campestris*) Plants Grown at S-1 (Bakoli) and S-4 (Libaspur) Sites.

Plate 4.9: EDU-treated (EDU) and non-treated (Non-EDU) Paalak (*Spinacia oleracea*) Plants Grown at S-6 (JNU) Site.

Paalak (*Spinacia oleracea* var. all green)

Field Studies:

Effect of ambient ozone on growth and yield parameters of paalak (*Spinacia oleracea* var. all green) was evaluated among ethylene diurea (EDU) treated plants and untreated EDU plants under field condition at Delhi-Faridabad. Six different sites (S1, S2, S3, S5, S6 and S9) were chosen in Delhi and Faridabad representing different levels of anthropogenic activity and traffic density. The ground level ozone concentrations varied between 35.72-50.20μg/m^3 at these six sites. Observations of growth performances of *Spinacia oleracea* plants were made in respect of following morphological and biochemical parameters.

Leaf Number

The leaf number in 90 days old matured plants without EDU at different sites was 11.96 ± 1.9, 9.0 ± 0.94, 11.38 ± 0.61, 12.67 ± 0.66, 11.58 ± 1.62 and 12.39 ± 1.21 respectively. The maximum leaf number was 12.39 ± 1.21 at site S9 and minimum was 9.0 ± 0.94 at site S2 (Table 4.9).

In EDU-treated plants, the average leaf number at different sites was 13.44 ± 0.83, 10.89 ± 1.16, 12.22 ± 1.37 and 13.22 ± 1.99 respectively. The maximum leaf number was 13.44 ± 0.83 at site S1 and minimum was 10.0 ± 1.16 at site S2 (Table 4.9).

A comparison of leaf number between EDU treated and non-treated plants show leaf number in the EDU-treated plants was 11.01%, 17.35%, 6.87% and 6.78% more over plants without EDU treatment (Table 4.9 and Figure 4.67).

The difference in leaf number between EDU treated and non-treated plants was statistically significant (P ≤0.05 level) (Table 4.9).

Number of Senescent Leaves

The number of senescent leaves in plants without EDU at different sites was 0.35 ± 0.1, 0.47 ± 0.09, 0.59 ± 0.05, 0.34 ± 0.03, 0.33 ± 0.03 and 0.53 ± 0.02 respectively. The maximum number of senescent leaves was 0.59 ± 0.05 at site S5 and minimum was 0.33 ± 0.03 at site S6 (Table 4.9).

In EDU-treated plants, the number of senescent leaves per plant at sites was 0.27 ± 0.04, 0.34 ± 0.04, 0.43 ± 0.06 and 0.36 ± 0.05 respectively. The maximum number of senescent leaves was 0.43 ± 0.06 at site S3 and minimum was 0.27 ± 0.04 at site S1 (Table 4.9).

A comparison of number of senescent leaves between EDU treated and non-treated plants show number of senescent leaves in EDU-treated plants was 29.6%, 38.23%, 40.47% and 47.22% less as compared to plants without EDU treatment (Table 4.9 and Figure 4.68).

The difference in number of senescent leaves between EDU treated and non-treated plants was statistically significant (P ≤0.05 level) (Table 4.9).

Leaf Area

The average leaf area in plants without EDU at different sites was 22.08 ± 3.39, 19.35 ± 1.49, 19.28 ± 2.75, 22.57 ± 1.54, 22.5 ± 3.77 and 20.16 ± 1.66 cm^2 respectively. The maximum leaf area was 22.57 ± 1.54 cm^2 at site S5 and minimum was 19.35 ± 1.49 cm^2 at site S2 (Table 4.9).

In EDU-treated plants, the average leaf area at different sites was 26.63 ± 3.2, 26.2 ± 2.25, 21.13 ± 1.86 and 26.89 ± 2.19 cm^2 respectively. The maximum leaf area was 26.89 ± 2.19 cm^2 at site S9 and minimum was 26.2 ± 2.25 cm^2 at site S2 (Table 4.9).

A comparison of leaf area between EDU treated and non-treated plants show leaf area in the EDU-treated plants was 17.08%, 26.14%, 8.75% and 25.02% more over plants without EDU treatment (Table 4.9 and Figure 4.69).

The difference in leaf area between EDU treated and non-treated plants was statistically insignificant (Table 4.9).

Root Biomass

The average root biomass in plants without EDU at different sites was 0.60 ± 0.02, 0.57 ± 0.02, 0.59 ± 0.04, 0.78 ± 0.1, 0.62 ± 0.04 and 0.60 ± 0.03 g respectively. The maximum root biomass was 0.78 ± 0.1g at site S5 and minimum was 0.57 ± 0.02 g at site S2 (Table 4.9).

In EDU-treated plants, the average root biomass at different sites was 0.68 ± 0.09, 0.58 ± 0.06, 0.65 ± 0.04 and 0.63 ± 0.06 g respectively. The maximum root biomass was 0.68 ± 0.09g at site S1 and minimum was 0.58 ± 0.06 g at site S2 (Table 4.9).

A comparison of root biomass between EDU-treated and non-treated plants show root biomass in the EDU-treated plants was 13.33%, 1.72%, 9.23% and 4.46% more over plants without EDU treatment (Table 4.9 and Figure 4.70).

The difference in root biomass between EDU treated and non-treated plants was statistically insignificant (Table 4.9).

Plant Biomass

The average plant biomass (shoot and root) in plants grown at different sites was 1.57 ± 0.12, 1.52 ± 0.06, 1.50 ± 0.08, 2.47 ± 0.21, 1.84 ± 0.21 and 1.83 ± 0.2 g respectively. The maximum plant biomass was 0.78 ± 0.1g at site S5 and minimum was 1.50 ± 0.08 g at site S2 (Table 4.9).

In EDU-treated plants, the average plant biomass at different sites was 1.85 ± 0.16, 1.76 ± 0.18, 1.70 ± 0.08 and 2.47 ± 0.42 g respectively. The maximum plant biomass was 2.47 ± 0.42 g at site S9 and minimum was 1.70 ± 0.08 g at site S3 (Table 4.9).

A comparison of plant biomass between EDU treated and non-treated plants show plant biomass in the EDU-treated plants was 15.14%, 13.64%, 11.76% and 26.32% more over plants without EDU treatment (Table 4.9 and Figure 4.71).

The difference in plant biomass between EDU treated and non-treated plants was statistically significant ($P \leq 0.1$ level) (Table 4.9).

Total Chlorophyll

The average total chlorophyll content in 55 days old plants without EDU at different was 0.7264 ± 0.0034, 0.7132 ± 0.0005, 0.7142 ± 0.0004, 0.6764 ± 0.0054, 0.7342 ± 0.0026 and 0.7162 ± 0.0002 mg/g respectively. The maximum total chlorophyll content was 0.7342 ± 0.0026 mg/g at site S5 and minimum was 0.7132 ± 0.0005 mg/g at S2 (Table 4.9).

In EDU-treated plants, the total chlorophyll content at four different sites was 0.7945 ± 0.0003, 0.7869 ± 0.0004, 0.7941 ± 0.0002 and 0.7929 ± 0.0004 mg/g respectively. The maximum total chlorophyll content was 0.7945 ± 0.0003 mg/g at site S1 and minimum was 0.7869 ± 0.0004 mg/g at S2 (Table 4.9).

A comparison of total chlorophyll content between show total chlorophyll content in the EDU-treated plants was 8.57%, 9.37%, 10.06% and 9.67% more over plants without EDU treatment (Table 4.9 and Table 4.72).

The difference in total chlorophyll content between EDU treated and non-treated plants was statistically insignificant (Table 4.9).

Ascorbic Acid

The average ascorbic acid content in 55 days old plants without EDU at different sites was 0.1848 ± 0.015, 0.1678 ± 0.015, 0.1768 ± 0.012, 0.1658 ± 0.016, 0.1982 ± 0.014 and 0.1758 ± 0.017 mg/g respectively. The maximum ascorbic acid content was 0.1982 ± 0.014 mg/g at site S6 and minimum was 0.1658 ± 0.016 mg/g at S5 (Table 4.9).

In EDU-treated plants, the ascorbic acid content at different sites was 0.1968 ± 0.016, 0.1857 ± 0.015, 0.1948 ± 0.016 and 0.1948 ± 0.015 mg/g respectively. The maximum ascorbic acid content was 0.1968 ± 0.016 mg/g at site S1 and minimum was 0.1857 ± 0.015 mg/g at S2 (Table 4.9).

A comparison of ascorbic acid content between EDU treated and non-treated plants show ascorbic acid content in the EDU-treated plants was 6.10%, 9.64%, 9.24% and 9.75% more over plants without EDU treatment (Table 4.9 and Figure 4.73).

The difference in ascorbic acid content between EDU treated and non-treated plants was statistically insignificant (Table 4.9).

Fumigation Study

Three sets of plants namely control, E1 and E2 were prepared to carry out the fumigation study (Plate 4.8). The E1 and E2 sets were fumigated with 150μg/m^3 of ozone and the control set was maintained in the ambient environment. Ground level ozone monitoring was also carried out during February-2003 to find out the background

ozone concentration in the ambient environment at JNU. The average hourly ozone concentration was 73.5μg/m^3 and the maximum and minimum concentration was 174.44μg/m^3 and 5.88μg/m^3 respectively. The plant growth and performances of plants exposed to 150μg/m^3 and were made in respect of different morphological and biochemical parameters.

Leaf Number

The average number of leaves in plants without EDU was 16.70 ± 9.87, 22.17 ± 8.79 and 19.77 ± 12.51 respectively. Minimum number of leaves per plant was 16.70 ± 9.87 in control plants and the maximum was 22.17 ± 8.79 in plants of E1 set (Table 4.9).

In EDU-treated plants, the average leaf number was 17.18 ± 8.61, 15.40 ± 8.20 and 16.12 ± 5.64 respectively. The maximum number of leaves per plant was 17.18± 8.61 in control plants and minimum was 15.40 ± 8.20 in plants of E1 set (Table 4.9).

A comparison of leaf number between EDU treated and non-treated plants show leaf number in EDU-treated was 2.79%, 43.96% and 22.64% less as compared to plants without EDU treatment (Table 4.9 and Figure 4.74).

The difference in leaf number between EDU treated and non-treated plants was statistically insignificant (Table 4.9).

Number of Senescent Leaves

The number of senescent leaves in plants without EDU was 3.24 ± 1.77, 6.83 ± 1.72 and 4.33 ± 1.87 and respectively. Minimum number of senescent leaves per plant was 3.24 ± 1.77 in control plants and maximum was 6.83 ± 1.72 in plants of E1 set (Table 4.9).

In EDU-treated plants, the number of senescent leaves was 2.18 ± 1.08, 4.60 ± 1.33 and 2.50 ± 0.76 respectively. Minimum number of senescent leaves per plant was 2.18 ± 1.08 in control plants and maximum was 4.60 ± 1.33 in plants of E1 set (Table 4.9).

A comparison of number of senescent leaves between EDU and non-treated plants show number of senescent leaves in EDU-treated was 48.62%, 73.20% and 69.72% less as compared to plants without EDU treatment (Table 4.9 and Figure 4.75).

The difference in number of senescent leaves between EDU treated and non-treated plants was statistically insignificant (Table 4.9).

Leaf Area

The leaf area in plants without EDU was 43.60 ± 21.00, 24.11 ± 8.25 and 36.00 ± 15.73 cm^2 respectively. The maximum leaf area was 43.60 ± 21.00 cm^2 in control plants and minimum was 24.11 ± 8.25 cm^2 in plants of E1 set (Table 4.9).

In EDU-treated plants, the leaf area was 53.55 ± 24.00, 36.6 ± 11.52 and 49.60 ± 13.64 cm^2 respectively. The maximum leaf area was 53.55 ± 24.00 cm^2 in control plants and minimum was 36.60 ± 11.52 cm^2 in plants of E1 set (Table 4.9).

A comparison of leaf area between EDU treated and non-treated plants show leaf area in EDU treated plants was 18.58%, 34.12% and 27.42% more over plants without EDU treatment (Table 4.9 and Figure 4.76).

The difference in leaf area between EDU treated and non-treated plants was statistically significant (P ≤0.1 level) (Table 4.9).

Root Biomass

At maturity the average root biomass in plants without EDU was 0.60 ± 0.42, 0.28 ± 0.045 and 0.42 ± 0.12 g respectively. The maximum root biomass per plant was 0.60 ± 0.42 g in control plants and minimum was 0.28 ± 0.045g in plants of E1 set (Table 4.9).

In EDU-treated plants, the average root biomass per plant varied between 0.65 ± 0.09, 0.39 ± 0.087 and 0.49 ± 0.19 g respectively. The maximum root biomass per plant was 0.65 ± 0.32g in control plants and minimum was 0.39 ± 0.087g in plants of E1 set (Table 4.9).

A comparison of root biomass between EDU treated and non-treated plants show root biomass in EDU treated plants was 7.69%, 28.20% and 14.28% more over plants without EDU treatment (Table 4.9 and Figure 4.77).

The difference in root biomass between EDU treated and non-treated plants was statistically significant (P ≤0.05 level) (Table 4.9).

Plant Biomass

The plant biomass in plants grown without EDU was 2.37 ± 1.54, 1.02 ± 0.29 and 1.58 ± 0.58 g respectively. The maximum plant biomass per plant was 2.37 ± 1.54 g in control plants and minimum was1.02 ± 0.29 g in plants of E1 set (Table 4.9).

In EDU-treated plants, the total plant biomass per plant varied between 2.77 ± 1.53, 1.48 ± 0.49 and 2.19 ± 0.70 g respectively. The maximum plant biomass per plant was 2.77 ± 1.53 g in control plants and minimum was 1.48 ± 0.49 g in plants of E1 set (Table 4.9).

A comparison of plant biomass between EDU treated and non-treated plants show plant biomass in EDU treated plants was 14.44%, 31.08% and 27.85% more over plants without EDU treatment (Table 4.9 and Figure 4.78).

The difference in plant biomass between EDU treated and non-treated plants was statistically significant (P ≤0.1 level) (Table 4.9).

Total Chlorophyll

The total chlorophyll content in 55days old plants without EDU was 1.0849 ± 0.0009, 0.6863 ± 0.0054, and 0.9623 ± 0.0012 mg/g respectively. The maximum total chlorophyll content per plant was 1.0849 ± 0.0009 mg/g in control plants and minimum was 0.6863 ± 0.0054 mg/g in plants of E1 set (Table 4.9).

In EDU-treated plants, the total chlorophyll content was 1.5378 ± 0.0024, 1.2245 ± 0.0004 and 1.4443 ± 0.0006 mg/g respectively. The maximum total chlorophyll content was 1.5378 ± 0.0024 mg/g in control plants and minimum was 1.2245± 0.0004 mg/g in plants of E1 set (Table 4.9).

A comparison of total chlorophyll between EDU treated and non-treated plants show total chlorophyll content in EDU treated plants was 29.45%, 43.95% and 33.37% more over plants without EDU treatment (Table 4.9 and Figure 4.79).

The difference in total chlorophyll content between EDU treated and non-treated plants was statistically insignificant (Table 4.9).

Ascorbic Acid

The ascorbic acid content in 55 days old pants without EDU was 0.1648 ± 0.0155, 0.1538 ± 0.0154 and 0.1868 ± 0.0154 mg/g respectively. Minimum ascorbic acid content per plant was 0.1538 ± 0.0154 mg/g in E1set of plants and maximum was 0.1868 ± 0.0154 mg/g in plants of E2 set (Table 4.9).

In EDU-treated plants, the average ascorbic acid content varied between 0.1868 ± 0.0154, 0.1868 ± 0.0154 and 0.2088 ± 0.0155 mg/g respectively. Minimum ascorbic acid content was 0.1868 ± 0.0154 mg/g in control plants and maximum was 0.2087 ± 0.01554 mg/g in plants of E1 set (Table 4.9).

A comparison of ascorbic acid content between EDU treated and non-treated plants show ascorbic acid content in EDU treated plants was 11.77%, 17.66% and 10.53% more over plants without EDU treatments (Table 4.9 and Figure 4.80).

The difference in ascorbic acid content between EDU treated and non-treated plants was statistically insignificant (Table 4.9).

Table 4.9: Performance of *Spinacia oleracea* plants with and without-EDU exposed to ozone at field sites and in fumigation chamber.

Parameters	Field study						Fumigation study		
	S1	S2	S3	S5	S6	S9	C	E1	E2
Leaf number EDU	13.44 ± 0.83	10.89 ± 1.16	12.22 ±1.37	-	-	13.22 ± 1.99	17.18 ± 8.61	15.40 ± 8.20	16.12 ± 5.64
N-TR	11.96^2 ± 1.90	9.00^2 ± 0.94	11.38^2 ± 0.61	12.67 ± 0.66	11.58 ±1.62	12.39^2 ± 1.21	16.70^{ns} ± 9.87	22.17^{ns} ± 8.79	19.77^{ns} ± 12.51
Difference (%)	11.01	17.35	6.87	-	-	6.78	2.79	-43.96	-22.64
No. of senescent leaves EDU	0.27 ± 0.04	0.34 ± 0.04	0.43 ± 0.06	-	-	0.36 ± 0.05	2.18 ± 1.08	4.60 ± 1.33	2.50 ± 0.76
N-TR	0.35^2 ± 0.10	0.47^2 ± 0.09	0.59^2 ± 0.05	0.34 ± 0.03	0.33 ± 0.03	0.53^2 ± 0.02	3.24^{ns} ± 1.77	6.83^{ns} ± 1.72	4.33^{ns} ± 1.87
Difference (%)	-29.60	-38.23	-40.47	-	-	-47.22	-48.62	-73.20	-69.72
Leaf area (cm^2) EDU	26.63 ± 3.20	26.20 ± 2.25	21.13 ± 1.86	-	-	26.89 ± 2.19	53.55 ± 24.00	36.60 ± 11.52	49.60 ± 13.64
N-TR	22.08^{ns} ± 3.39	19.35^{ns} ± 1.49	19.28^{ns} ± 2.75	22.57 ± 1.54	22.50 ± 3.77	20.16^{ns} ± 1.66	43.60^3 ± 21.00	24.11^3 ± 8.25	36.00^3 ± 15.73
Difference (%)	17.08	26.14	8.75	-	-	25.02	18.58	34.12	27.42

	Col1	Col2	Col3	Col4	Col5	Col6	Col7	Col8	Col9
Root biomass (gm) EDU	0.68 ± 0.09	0.58 ± 0.06	0.65 ± 0.04	-	-	0.63 ± 0.06	0.65 ± 0.09	0.39 ± 0.087	0.49 ± 0.19
N-TR	0.60^{ns} ± 0.02	0.57^{ns} ± 0.02	0.59^{ns} ± 0.04	0.78 ± 0.10	0.62 ± 0.04	0.60^{ns} ± 0.03	0.60^{2} ± 0.42	0.28^{2} ± 0.045	0.42^{2} ± 0.12
Difference (%)	13.33	1.72	9.23	-	-	4.46	7.69	28.20	14.28
Plant biomass (gm) EDU	1.85 ± 0.16	1.76 ± 0.18	1.70 ± 0.08	-	-	2.47 ± 0.42	2.77 ± 1.53	1.48 ± 0.49	2.19 ± 0.70
N-TR	1.57^{3} ± 0.12	1.52^{3} ± 0.06	1.50^{3} ± 0.08	2.47 ± 0.21	1.84 ± 0.21	1.83^{3} ± 0.20	2.37^{3} ± 1.54	1.02^{3} ± 0.29	1.58^{3} ± 0.58
Difference (%)	15.14	13.64	11.76	-	-	26.32	14.44	31.08	27.85
Total chlorophyll (mg/g) EDU	0.7945 ± 0.0003	0.7869 ± 0.0004	0.7941 ± 0.0002	-	-	0.7929 ± 0.0004	1.5378 ± 0.0024	1.2245 ± 0.0004	1.4443 ± 0.0006
N-TR	0.7264^{ns} ± 0.0034	0.7132^{ns} ± 0.0005	0.7142^{ns} ± 0.0004	0.6764 ± 0.0054	0.7342 ± 0.0026	0.7162^{ns} ± 0.0002	1.0849^{ns} ± 0.0009	0.6863^{ns} ± 0.0054	0.9623^{ns} ± 0.0012
Difference (%)	8.57	9.37	10.06	-	-	9.67	29.45	43.95	33.37

Ascorbic acid (mg/g)									
EDU	0.1968 ± 0.016	0.1857 ± 0.015	0.1948 ± 0.016	-	-	0.1948 ± 0.015	0.1868 ± 0.0154	0.1868 ± 0.0154	0.2088 ± 0.0155
N-TR	0.1848^{ns} ± 0.015	0.1678^{ns} ± 0.015	0.1768^{ns} ± 0.012	0.1658 ± 0.016	0.1982 ± 0.014	0.1758^{ns} ± 0.017	0.1648^{ns} ± 0.0155	0.1538^{ns} ± 0.0054	0.1868 ± 0.0154
Difference (%)	6.10	9.64	9.24	-	-	9.75	11.77	17.66	10.53

decrease from EDU
- increase over EDU

S1: Bakoli, S2: S. Collge, S3: Jain Temple, S5: Tilak Bridge, S6: JNU, S9: IOC

C-Control; E1 set - exposed to five cycles of exposure to 150 $\mu g/m^3$ of ozone for four hours (total exposure of 20 hours) at 10-day interval after each EDU treatment; E2 set - five cycles of exposure to 150 $\mu g/m^3$ ozone daily for 4 hours over five successive days (total exposure of 20 hours) after three EDU treatments.

[1] Significant difference between plants grown without EDU (N-TR) and with EDU treatment at $P \leq 0.01$ level
[2] Significant difference between plants grown without EDU (N-TR) and with EDU treatment at $P \leq 0.05$ level
[3] Significant difference between plants grown without EDU (N-TR) and with EDU treatment at $P \leq 0.1$ level
[ns] Non-significant

A comparison between the performance of plants exposed to ambient ozone at field sites and those subjected to experimental fumigation with ozone shows that the different plant parameters in the fumigated plants were relatively more affected (Table 4.10). In case of the fumigation study the leaf number were increased as compared to field studies. This may be due to higher pulses of ozone in the fumigation chamber to sustain the ozone stress.

Table 4.10: A comparison between the percentage differences in average values of different parameters in *Spinacia oleracea* plants grown with and without EDU exposed to 35.72-50.20μg/m^3 of ground level ozone and fumigated with 150μg/m^3 ozone.

Plant parameters	Field study (% difference) between plants with and without EDU)	Fumigation study (% difference) between plants grown with and without EDU)			Control plants during fumigation study (% difference) between plants grown with and without EDU)
		E1	E2	Average	
Leaf number	10.52	43.96	22.64	33.30	2.87
No. of senescent leaves	*38.88	*73.20	*69.72	*71.46	*48.62
Leaf area	19.72	34.12	27.42	30.77	18.58
Fresh leaf weight	15.04	31.67	30.12	30.89	23.64
Root biomass	7.19	28.20	14.28	21.24	7.69
Plant biomass	16.72	31.08	27.85	29.46	14.44
Total chlorophyll	9.42	43.95	33.37	38.66	29.45
Ascorbic acid	7.93	17.66	10.53	14.10	11.77

decrease from EDU.

*increase over EDU.

The protection accorded by EDU to *Spinacia oleracea* plants in respect of different morphological and biochemical parameters was in the following order:

No. of senescent leaves > Plant biomass > Leaf area > Fresh leaf weight > Leaf number > Total chlorophyll > Ascorbic acid > Root biomass.

In case of plants fumigated with 150 μg/m^3 of ozone, the reduction in different morphological and biochemical parameters was of the following order:

No. of senescent leaves > Leaf number > Leaf area > Fresh leaf weight > Root biomass > Plant biomass >Ascorbic acid >Total chlorophyll.

Both in field and fumigation studies, fresh weight of leaves were moderately affected as compared to other parameters. It seems that EDU nullifies the adverse effect of ozone on *Spinacia oleracea* plants.

Figure 4.67: A comparison of leaf number between N-Tr and EDU-Tr plants of *Spinacia oleracea* grow n at field sites.

Figure 4.68: A comparison of number of senescent leaves between N-Tr and EDU-Tr plants of *Spinacia oleracea* grow n at field sites.
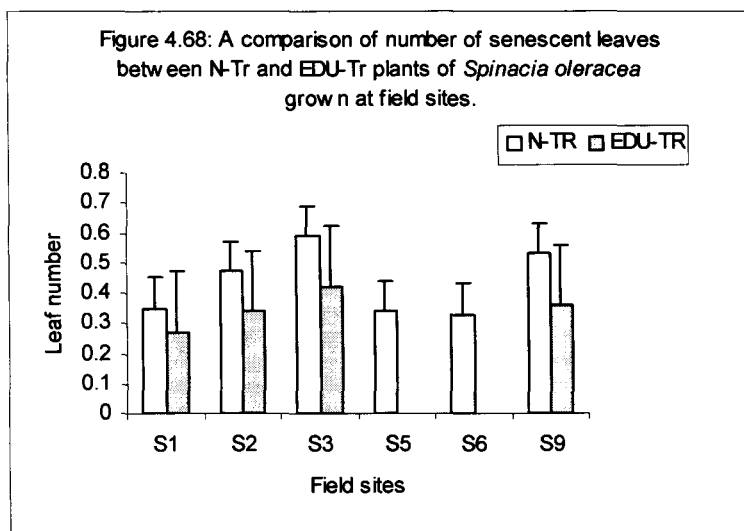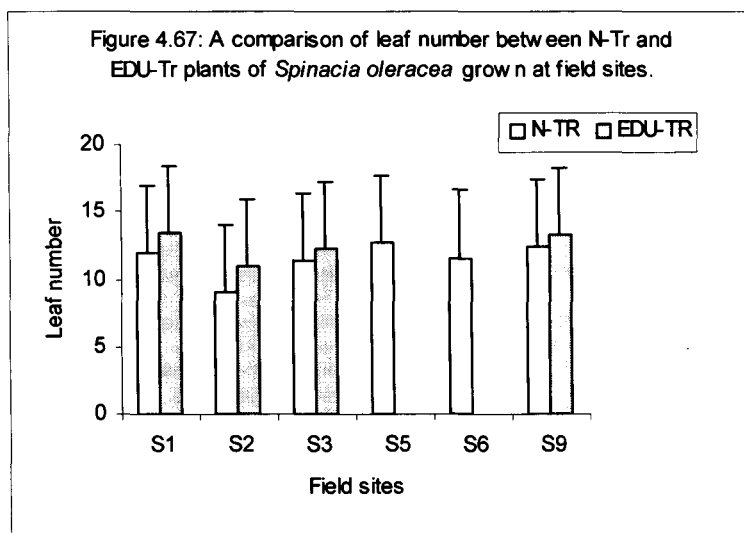
Figure 4.69: A comparison of leaf area between N-Tr and EDU-Tr plants of *Spinacia oleracea* grown at field sites.
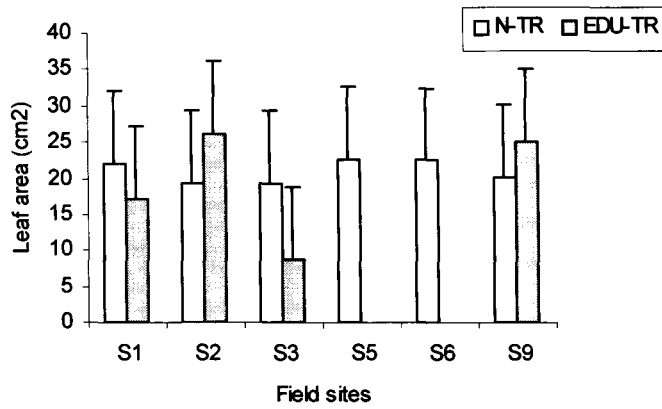
Figure 4.70: A comparison of root biomass between N-Tr and EDU-Tr plants of *Spinacia oleracea* grown at field sites.
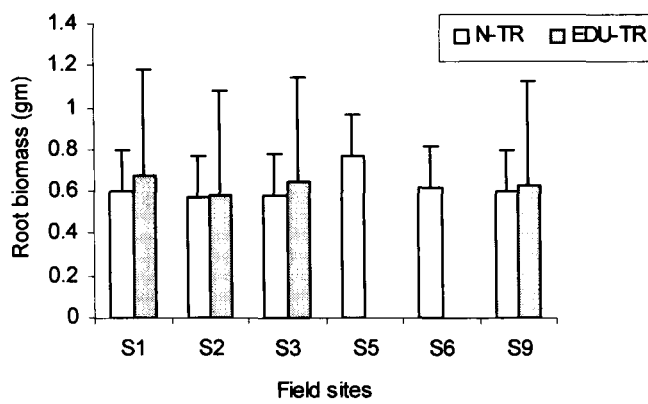
Figure 4.71: A comparison of plant biomass between N-Tr and EDU-Tr plants of *Spinacia oleracea* grown at field sites.
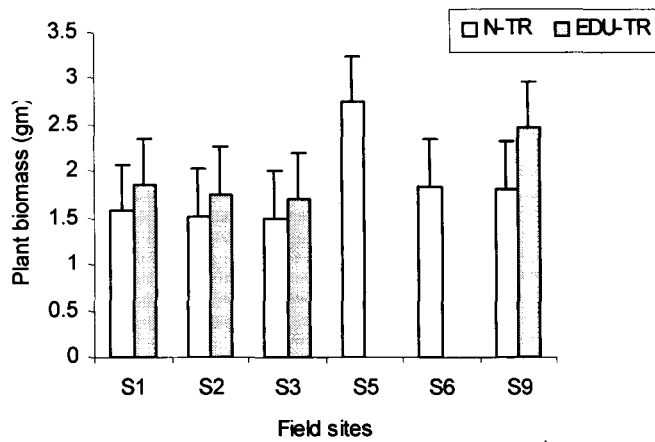
Figure 4.72: A comparison of total chlorophyll content between N-Tr and EDU-Tr plants of *Spinacia oleracea* grown at field sites.
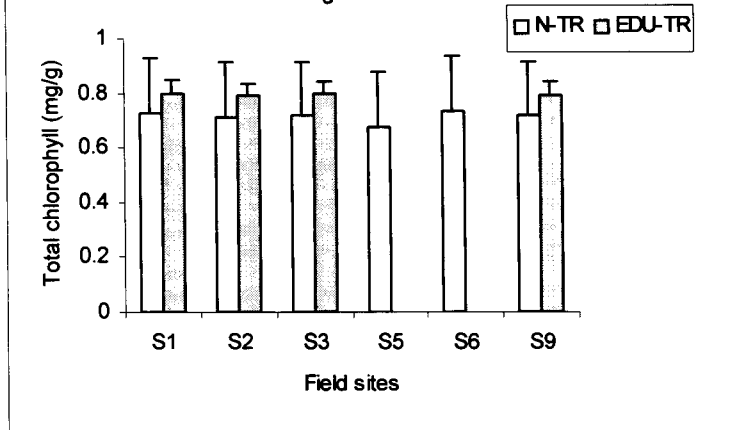
Figure 4.73: A comparison of ascorbic acid content between N-Tr and EDU-Tr plants of *Spinacia oleracea* grown at field sites.
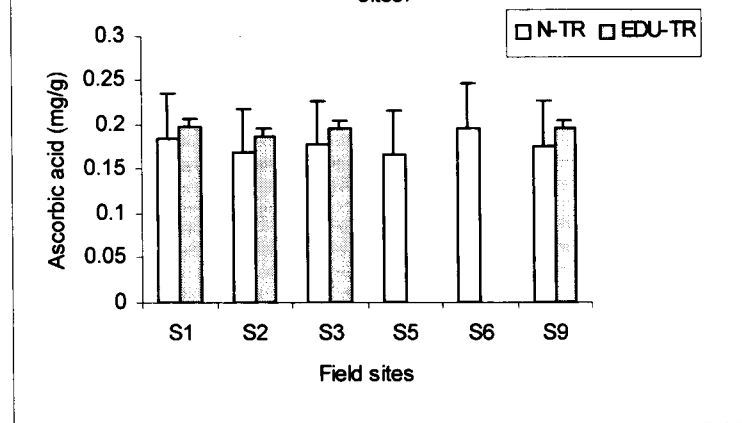
Figure 4.74: A comparison of leaf number between ozone fumigated N-Tr and EDU-Tr plants of *Spinacia oleracea*.

146
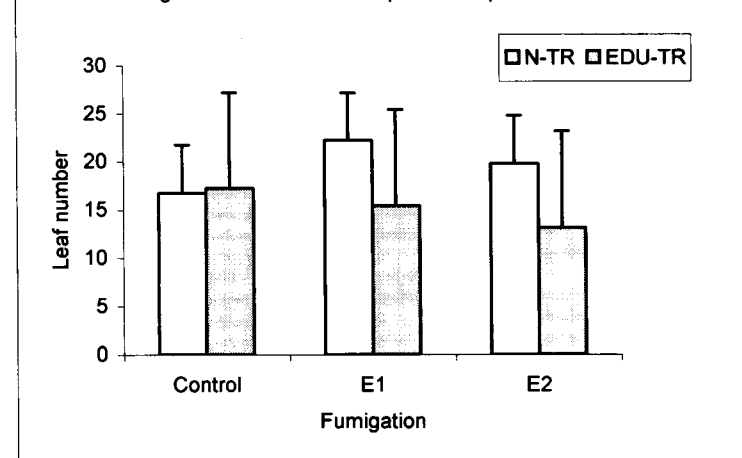
Figure 4.75: A comparison of number of senescent leaves between ozone fumigated N-Tr and EDU-Tr plants of Spinacia oleracea.
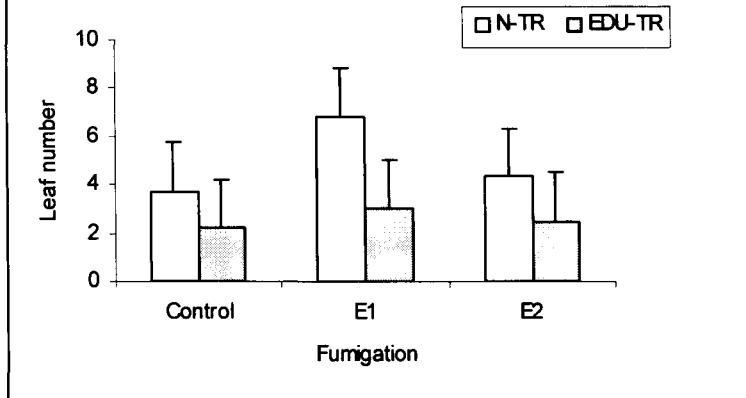
Figure 4.76: A comparison of leaf area between ozone fumigated N-Tr and EDU-Tr plants of *Spinacia oleracea.*
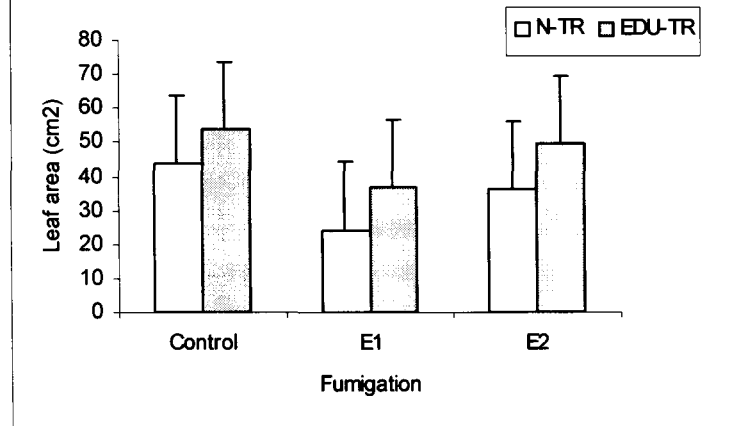
Figure 4.77: A comparison of root biomass between ozone fumigated N-Tr and EDU-Tr plants of *Spinacia oleracea.*
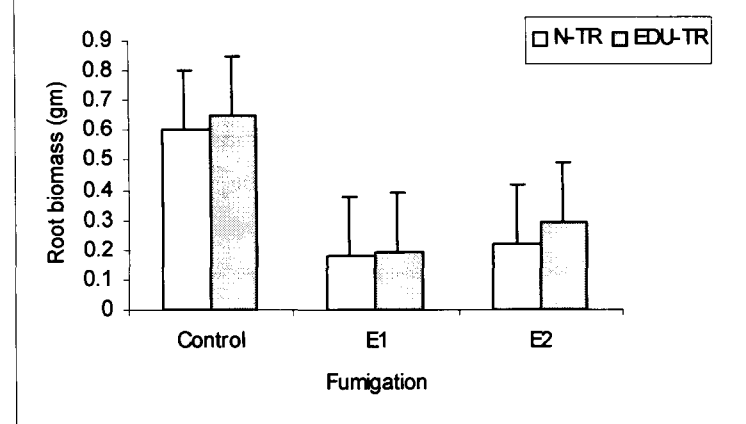
Figure 4.78: A comparison of plant biomass between ozone fumigated N-Tr and EDU-Tr plants of *Spinacia oleracea*.
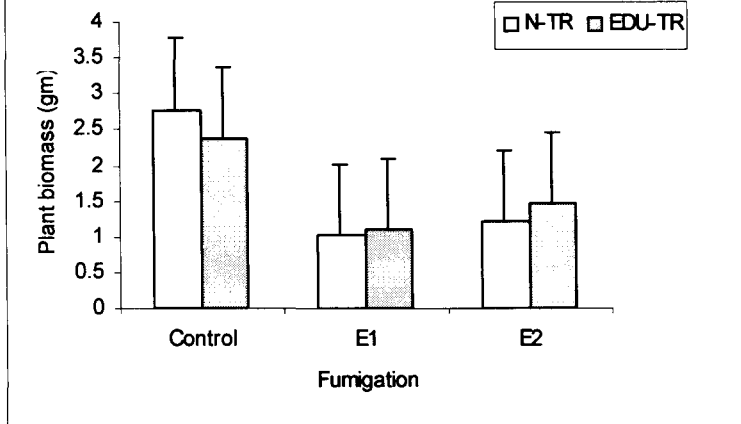
Figure 4.79: A comparison of total chlorophyll content between ozone fumigated N-Tr and EDU-Tr plants of *Spinacia oleracea*.
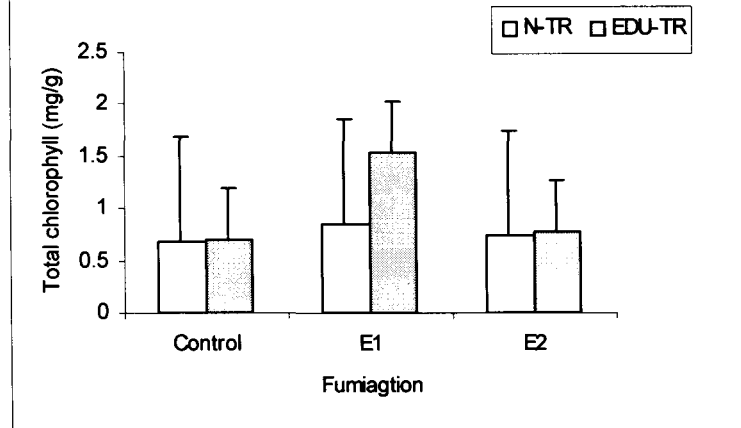
Figure 4.80: A comparison of ascorbic acid content between ozone fumigated N-Tr and EDU-Tr plants of *Spinacia oleracea*.

148
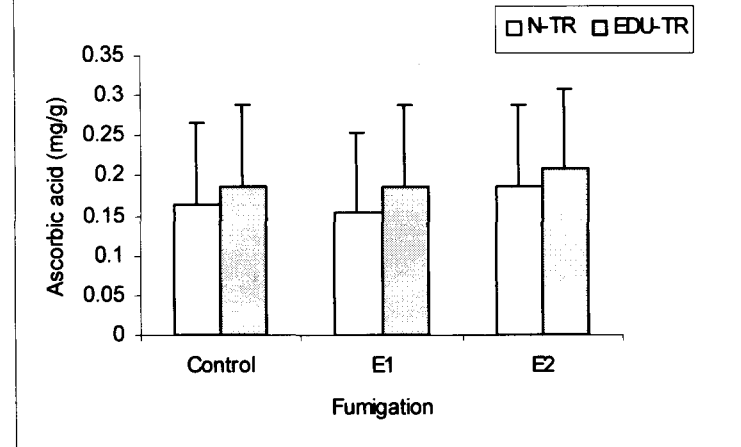
Chapter-V

Discussion

Discussion

It may be observed that there was considerable inter-site-variation in the ground level ozone which was 38.46µg/m^3 at Bakoli (S1), 37.77µg/m^3 at S. College (S2), 35.72µg/m^3 at J. Temple (S3), 44.15µg/m^3 at Tilak Bridge (ITO) (S5), 38.21µg/m^3 at JNU (S6), 50.20µg/m^3 at Badarpur (S7), 41.67µg/m^3 at DPS-Faridabad (S8) and 38.75µg/m^3 at IOC-Faridabad (S9) during May to July, 1998 and from January to April, 1999 ozone levels were 87.57µg/m^3 at Bakoli (S1), 83.01µg/m^3 at S. College (S2), 69.07µg/m^3 at J. Temple (S3), 91.70µg/m^3 at Libaspur (S4), 110.4µg/m^3 at JNU (S6), 158.33µg/m^3 at Badarpur (S7), 70.05µg/m^3 at IOC-Faridabad (S9), 89.41µg/m^3 at CRI-Faridabad (S10) and 85.38µg/m^3 at AIIMS-Faridabad (S11). The variation observed in the ozone concentration at different field sites appears to be on account of site-specific variation in anthropogenic activities, traffic conditions, availability of ozone forming precursors (OFP) and wind speed.

The average hourly ozone concentration was 40.62 µg/m^3 May to July, 1998 and 93.89 µg/m^3 January to April, 1999. The ground level ozone concentration during January to April, 1999 increased over May to July, 1998 by more than 131%. The hourly ozone concentration decreased during May to July, 1998 (Figure 5.1) and increased subsequently from January to April, 1999 (Figure 5.2) exhibiting strong seasonality. High wind turbulence during May and June and washing out of pollutants by rain in the month of July may be responsible for the low ozone concentration during this period. During the January to April, 1999, high atmospheric stability and poor dispersive capacity significantly reduces the dispersal of ozone and its precursors and these conditions seems to be responsible for the higher ozone values from January onwards.

A comparison of ground level ozone concentration recorded at individual sites with the ozone standards prescribed by different agencies show that the hourly ozone concentration at different sites during January to April, 1999 exceeded 1-hr standard prescribed by WHO (76 ppb), Canada (82 ppb), EU (80 ppb) and Japan (60 ppb) (see Table 5.1 and Figure 5.3 –5.4). Almost at all sites ozone levels exceeded 40 ppb which represents the ozone standard of EU for vegetation (see Table 5.1). The ozone values at S4 and S10s site were violated the 1-hr Japanese standard on about 25% and 8% occasions respectively. At site S7, which is one of the most polluted sites, the 1-hr

ozone standard prescribed by WHO, Canada, EU and Japan were violated on 40%, 25%, 31% and 80% occasions respectively.

Table 5.1: Percentage exceedence of ozone levels at individual sites over the ozone standards prescribed by different agencies (after USEPA, 1996; UNDP, 1998; Taylor, 2001).

Field sites	Exceedence (%) of WHO-1hr standard (76 ppb)	Exceedence (%) of Canada-1hr standard (82 ppb)	Exceedence (%) of USEPA-1hr standard (120 ppb)	Exceedence (%) of EU-1hr population standard (80 ppb)	Exceedence (%) of 1-hr Japanese standard (60 ppb)	Exceedence (%) of EU-8hr vegetation standard (40ppb)
S1	-	-	-	-	-	53.33
S2	-	-	-	-	-	46.67
S3	-	-	-	-	-	37.50
S4	-	-	-	-	25.00	57.14
S5	-	-	-	-	-	-
S6	-	-	-	-	-	36.17
S7	40.00	25.00	-	31.25	80.00	80.00
S8	-	-	-	-	-	-
S9	-	-	-	-	-	21.43
S10	-	-	-	-	8.33	35.29
S11	-	-	-	-	-	44.44

- not exceeded

A comparison of the average ground level ozone concentration with the values reported by earlier workers show that the ground level ozone has steadily increased. The hourly ground level concentration during January-April, 1999 had increased by 4.4 % over the 1997 values (Varshney and Rout, 1998) and 12% over the year 1998 (NAAQMS, 2001) (see Table 5.2).

It would be useful to compare the ozone values across different stations of India but such comparison is difficult in the absence of a proper ozone monitoring network in the country. However, a comparison between values of ground level ozone concentration at Delhi during January to April, 1999 and the ozone values reported different centres in the country show that ozone levels at Delhi were relatively high. Although it is not an ideal comparison because ozone values are not for the same year, but it does provide some idea of the ozone status in comparative terms.

150

Table 5.2: Values of ground level ozone reported for different locations in India.

Ozone monitoring stations	Ozone concentration		Reference
	Lowest and highest concentration ($\mu g/m^3$)	Remarks	
Delhi	20-273	Urban and peri-urban areas, August, 1989- August, 1991	Varshney and Agrawal, 1992
	69.5-303.3	Urban and Per-urban areas, January-February, 1993	Singh et al., 1997
	46-65	Urban and peri-urban areas, August to October, 1996	Varshney and Rout, 1998
	88-90	Urban and peri-urban areas, March to June, 1997	Varshney and Rout, 1998
	26-82	Urban traffic cross sections, 1998	NAAQMS, 2001
	20-104	Urban traffic cross sections, 1999	NAAQMS, 2001
Varanasi	20 – 152	Urban areas, 1990-92	Pandey et al., 1992
Ahemedabad	18 – 110	Urban and rural areas, 1993-1994	Naja and Lal, 1996
Pune	2 – 68	Urban areas, 1992	Khemani et al., 1992
Chandigarh	58-114	Urban areas, April-December, 1984 and November 1990-March 1992	CSIO, 1992
Agra	60.37	September, 1999- June, 2001	Carmichael et al., 2003
Bhubaneswar	61.54	September1999- June, 2001	Carmichael et al., 2003
Berhampur (Orissa)	46.45	September, 1999- June, 2001	Carmichael et al., 2003
Cochin	23.13	September, 1999- June, 2001	Carmichael et al., 2003

Table 5.3: Ozone and ozone forming precursors at different sites during January to April, 1999.

Different field sites	O_3 concnetration ($\mu g/m^3$)	TVOC concentration (ppmv)*	NO_2 concentration ($\mu g/m^3$)**
S1	87.57	5.25	30
S2	83.01	7.70	61
S3	69.07	7.35	40
S4	91.70	9.80	110
S6	110.4	5.005	20
S7	158.33	13.30	119
S9	70.05	10.19	43
S10	89.41	11.90	104
S11	85.38	12.25	103

* After Padhy, 1999; ** Varshney and Singh, 2002.

Figure 5.1: Ground level ozone concentration at Delhi-Faridabd during May to July, 1998 .
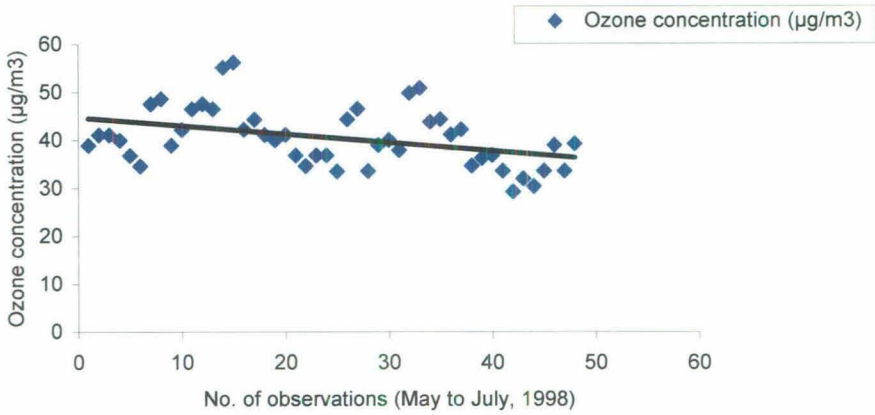
Figure 5.2: Ground level ozone concentration at Delhi-Faridabd during January to April, 1999.
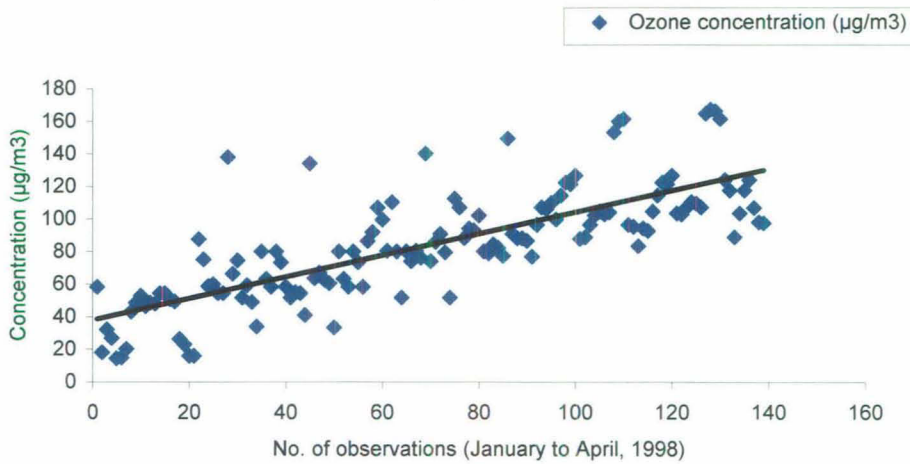
Figure 5.3: A comparison of monthly variation of ozone concentration at field sites in Delhi-Faridabad (1 hr. avg) with various standards prescribed by different agencies.
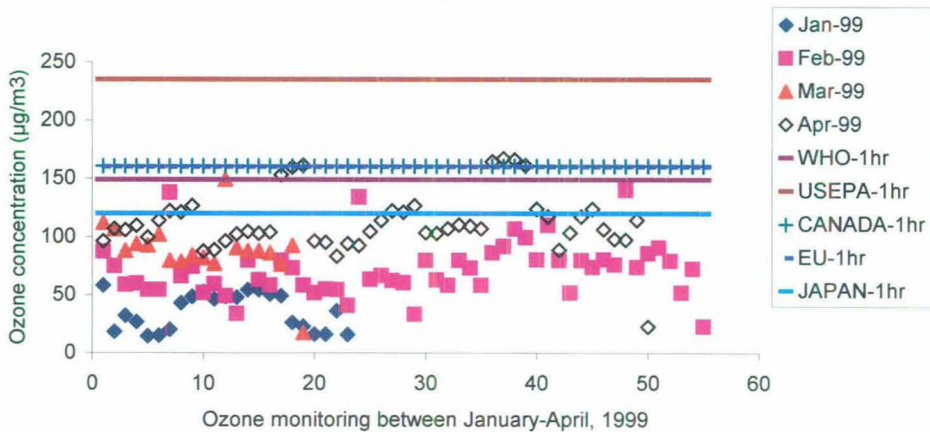
Figure 5.4: A comparison (1 hr. avg) of ozone levels at different sites in Delhi-Faridabad with ozone standards prescribed by various agencies.

Figure 5.5: A comparison of O_3, TVOC and NO_2 concentrations at different Delhi - Faridabad sites.
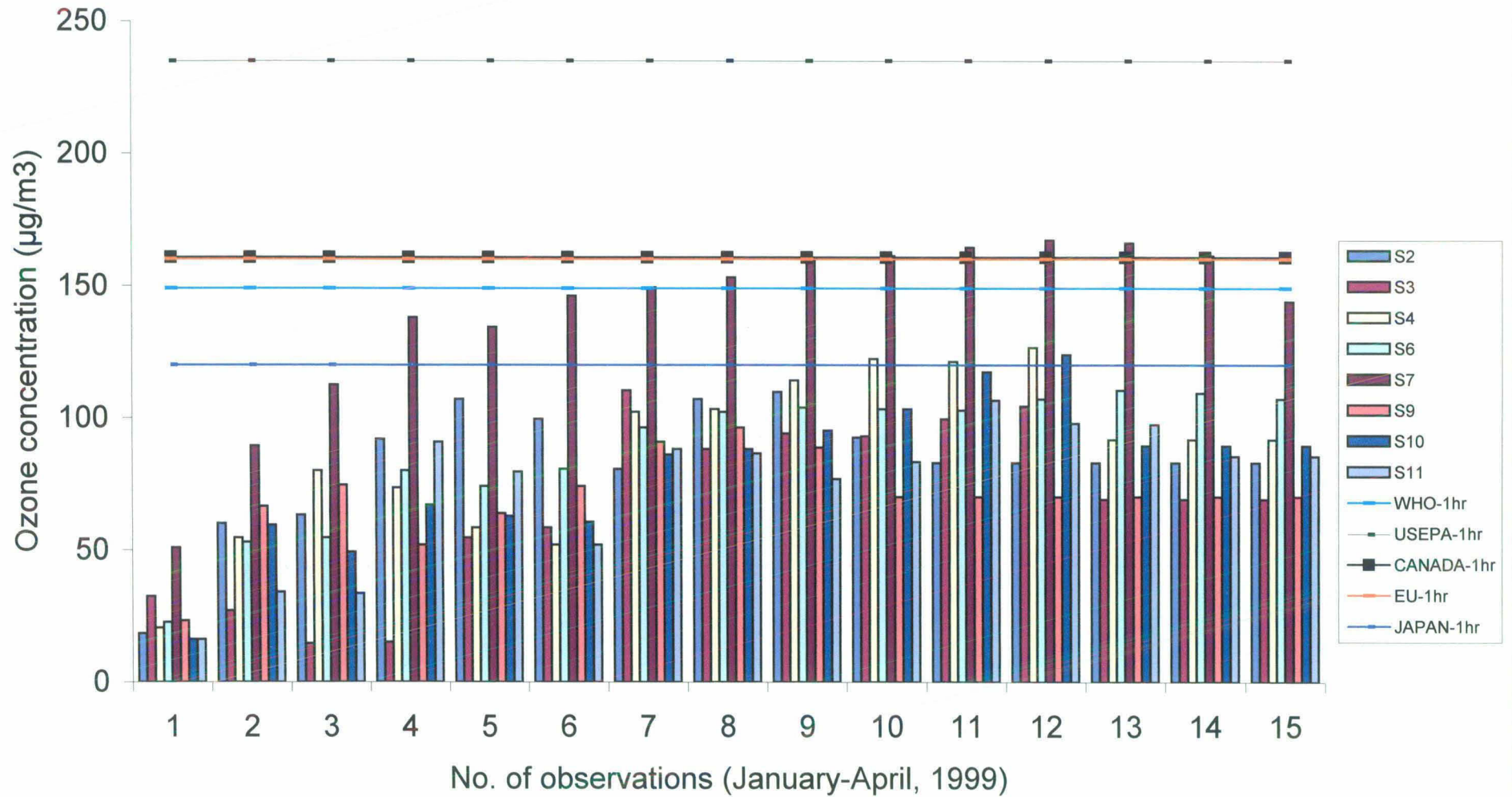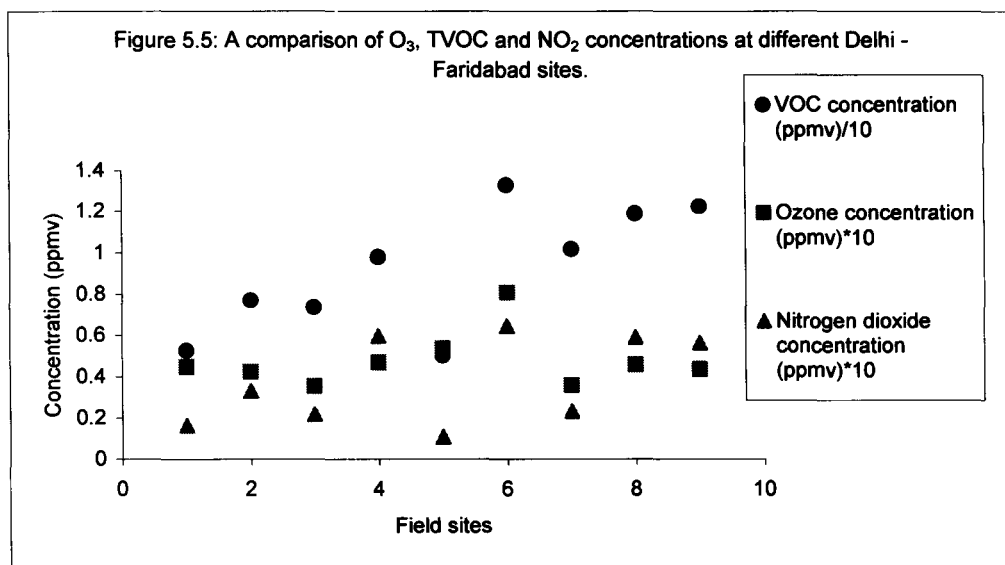
Ozone forming precursor (OFP) such as: volatile organic compounds (VOCs) and NO_X and its relative ratio (ratio of VOCs and NO_X) determines *in situ* formation of ground level ozone. Total volatile organic compounds (TVOC) measured by Padhy, (1999) during January-April, 1999 was 5.25ppmv at Bakoli (S1), 7.70ppmv at S. College (S2), 7.35ppmv at J. Temple (S3) and 9.80ppmv at Libaspur (S4), 5.005ppmv at JNU (S6), 13.30 ppmv at Badarpur (S7), 10.19 ppmv at IOC (S9), 11.90 ppmv at CRI (S10) and 12.25 ppmv at AIIMS (S11). The ambient NO_2 values measured at the same sites in another study during January to April, 1999, were 30μg/m³ at Bakoli, 61μg/m³ at S. College (S2), 40μg/m³ at J. Temple (S3) and 110μg/m³ at Libaspur (S4), 20μg/m³ at JNU (S6), 119μg/m³ at Badarpur (S7), 43 μg/m³ at IOC (S9), 104μg/m³ at CRI (S10) and 103μg/m³ at AIIMS (S11) (Varshney and Singh, 2002) (Table 5.3 and Figure 5.5).

The regression equation developed between O_3, NO_2 and TVOC shows that NO_2 and TVOC have strong affinity to form tropospheric ozone. The regression equation between NO_2 (Y) and TVOC (X) is Y = 0.0061X – 0.0178 (R^2= 0.7492), which is statistically significant and strongly correlated (see Figure 5.6). The regression equation between O_3 (X) and NO_2 (Y) is Y = - 0.4684X + 114.35 (R^2= 0.1003), and between O_3 (Y) and TVOC (X) is Y =-0.0002X + 0.0498 (R^2= 0.0028) and found statistically not significant and weekly correlated (see Figure 5.7 and 5.8). The statistical relationships between O_3, NO_2 and TVOC fully satisfy the reaction kinetics of ozone formation.

Figure 5.6: Relationship between TVOC and Nitrogen dioxide at different sites.

$$y = 0.0061x - 0.0178$$
$$R^2 = 0.7492$$
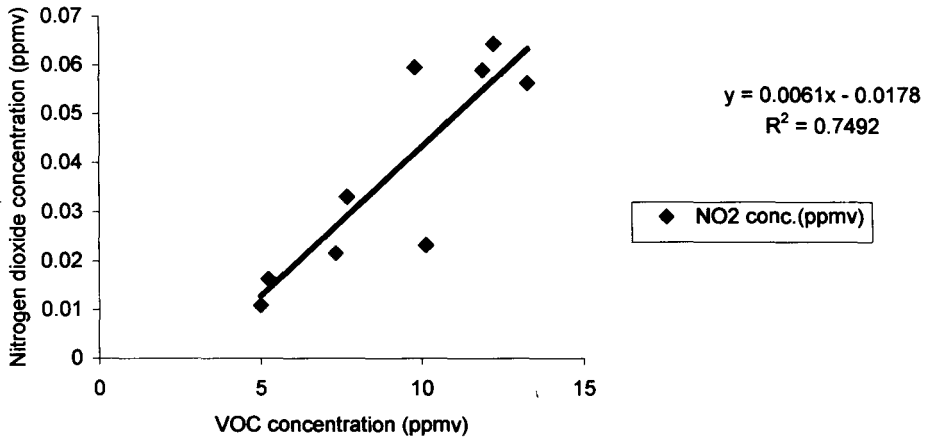
Figure 5.7: Relationship between Ozone and Nitrogen dioxide at different sites.

$$y = -0.4684x + 114.35$$
$$R^2 = 0.1003$$
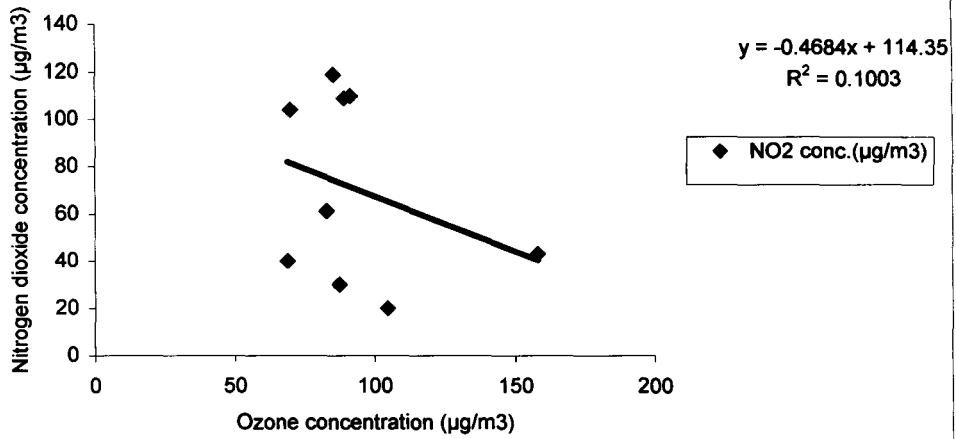
Figure 5.8: Relationship between Ozone and TVOC at different sites.

$$y = -0.0002x + 0.0498$$
$$R^2 = 0.0028$$
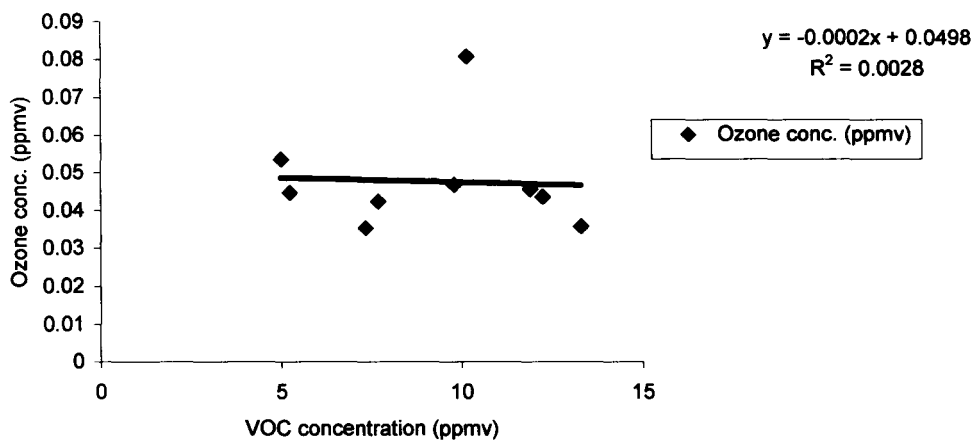
The response of four agricultural crops viz: wheat (*Triticum aestivum*), moong (*Phaseolus aureus*), mustard (*Brassica campestris)* and paalak *(Spinacia oleracea*) to ozone and EDU are discussed below:

Performance of *Triticum aestivum* plants grown with and without EDU at eight sites show that the EDU treated plants were better as compared to plants grown without EDU (Table 4.3 and Plate 4.1-4.3). The percentage difference in the performance of EDU treated and non-treated plants at individual sites shows that the difference in culm length was between 6.45-8.89%; shoot biomass 13.35-27.78%; root length 6.84-11.65%; root biomass 31.35-43.36%; spikes per plant 4.17-12.50%; spike length 6.51-13.09%; grains per spike 22.61-28.95%; grain weight per plant 6.22-14.39%; total chlorophyll 8.68-17.78% and ascorbic acid content 11.45-18.29%. Plants with and without EDU from sites with high pollution load (e.g., site-4 and site-7) exhibited significant reduction in culm length, shoot biomass, root length, root biomass, spikes per plant, spike length, grains per spike, grain weight per plant, total chlorophyll and ascorbic acid content as compared to the performance of plants at low pollution sites (Table 4.2 and 4.3). Statistical relationships have been worked out to determine the correlation between the ground level ozone and the percentage reduction of different parameters in EDU untreated plants of *Triticum*.

The regression equations were developed between the ground level ozone concentration (X) and percentage reduction in different parameters (Y) of *Triticum*. A good correlation (co-effiecient of correlation: $r \geq \pm 0.5$) was observed between ground level ozone concentration and the percentage reduction in spike length, grains per spike, grain weight per plant, root length, root biomass, culm number, spikes per plant, culm length and ascorbic acid, total chlorophyll and shoot biomass found to be weekly correlated (co-effiecient of correlation: $r < \pm 0.5$) (Table 5.4 and Figures 5.9 to 5.19). The difference between EDU treated and non-treated plants in respect of culm length, shoot biomass, root length, root biomass, grains per spike, grain weight per plant, total chlorophyll and ascorbic acid was statistically significant at $P \leq 0.01$ level. The difference with regard to spikes per plant and spike length were also statistically significant at $P \leq 0.05$ level (Table 4.3).

Table 5.4: The relationship between average ground level ozone concentration (X) and average reduction in different parameters (Y) of *Triticum aestivum* plants grown at field sites in Delhi-Faridabad.

Relationship	Equation	r = value
O_3 with Culm length	Y = 0.017x+5.7935	+0.5743
O_3 with Culm number	Y = 0.0633x+12.328	+0.5973
O_3 with Shoot biomass	Y = 0.0684x+14.42	+0.3667
O_3 with Root length	Y = 0.0369x+5.1931	+0.6255
O_3 with Root biomass	Y = 0.0748x+30.496	+0.6176
O_3 with Spikes per plant	Y = 0.0609x+2.001	+0.5925
O_3 with Spike length	Y = 0.0732x+0.9427	+0.8020
O_3 with Grains per spike	Y = 0.0546x+19.725	+0.7408
O_3 with Grain weight per plant	Y = 0.0831x+0.8219	+0.7136
O_3 with Total chlorophyll	Y = 0.0547x+7.6906	+0.4079
O_3 with Ascorbic acid	Y = 0.0572x+7.8689	+0.4721

Plants grown without EDU were greatly reduced in comparison to the plants received EDU treatments both in E1 and E2 sets. Between E1 and E2 the performance of E2 plants was better in respect of each parameter (see Table 4.3). Based on results of this experiment it appears that two or more prophylactic treatments of EDU were more effective in preventing ozone damage in *Triticum* plants.

Figure 5.9: Relationship between ambient ozone and reduction (%) in culm length in *Triticum aestivum.*

$y = 0.017x + 5.7935$
$R^2 = 0.3299$
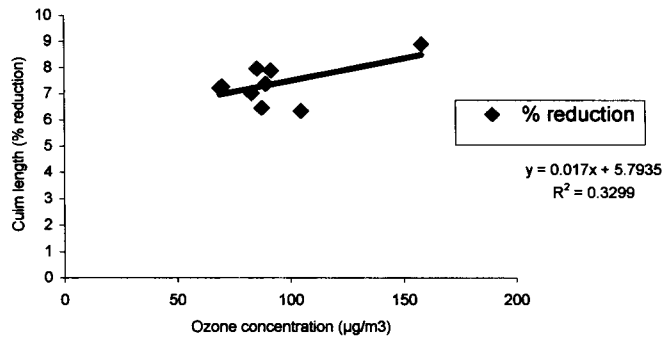
Figure 5.10: Relationship between ambient ozone and reduction (%) in culm number in *Triticum aestivum.*

$y = 0.0633x + 12.328$
$R^2 = 0.3567$
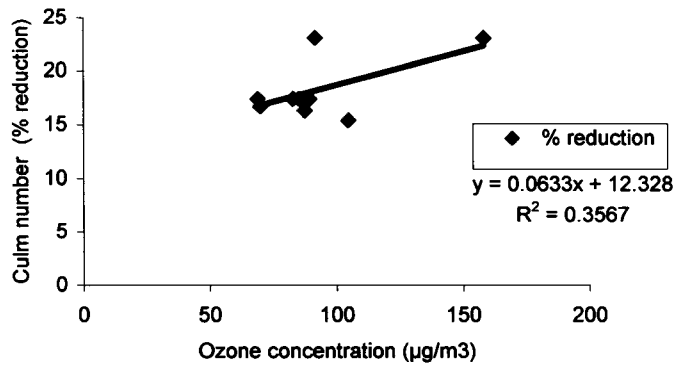
Figure 5.11: Relationship between ambient ozone ambient ozone and reduction (%) in shoot biomass in *Triticum aestivum.*

$y = 0.0684x + 14.42$
$R^2 = 0.1345$
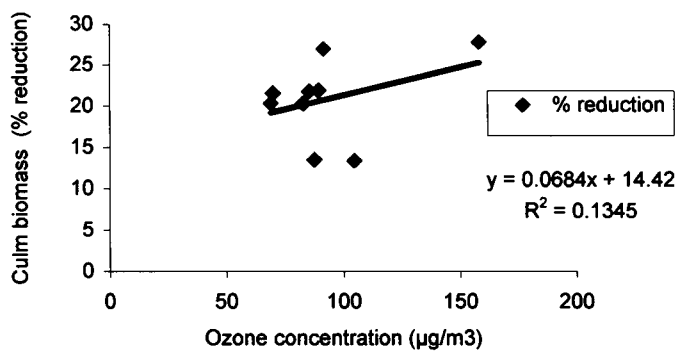
Figure 5.12: Relationship between ambient ozone ambient ozone and reduction (%) in root length in *Triticum aestivum*.

$y = 0.0369x + 5.1931$
$R^2 = 0.3913$
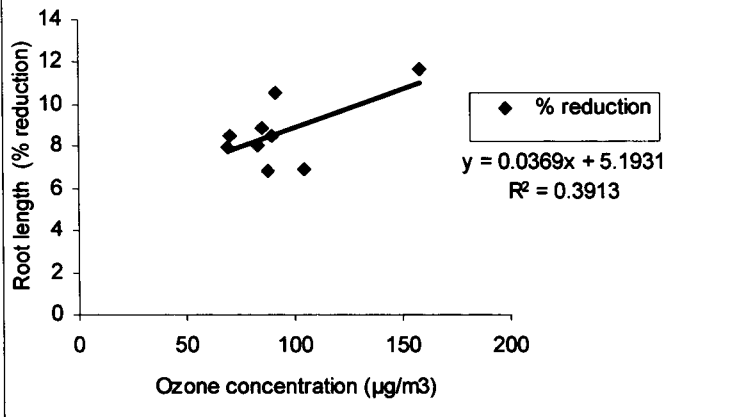
Figure 5.13: Relationship between ambient ozone and reduction (%) in root biomass in *Triticum aestivum*.

$y = 0.0748x + 30.469$
$R^2 = 0.3815$
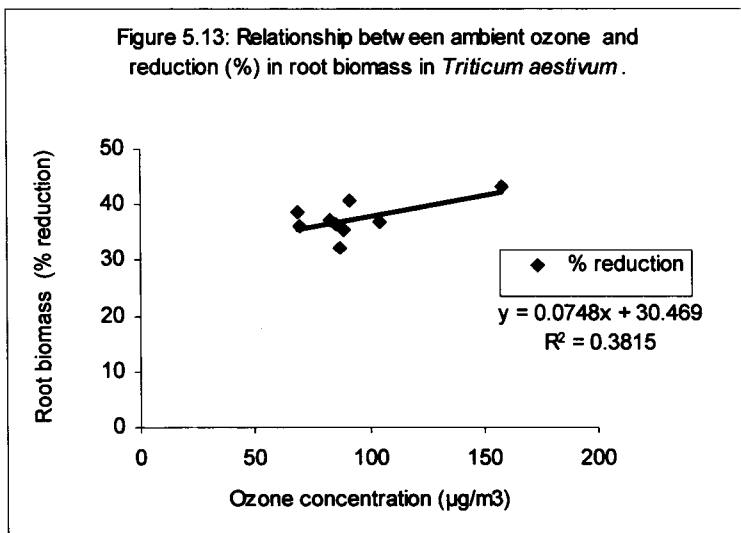
Figure 5.14: Relationship between ambient ozone and reduction (%) in spikes per plant in *Triticum aestivum*.

$y = 0.0609x + 2.001$
$R^2 = 0.3511$

159
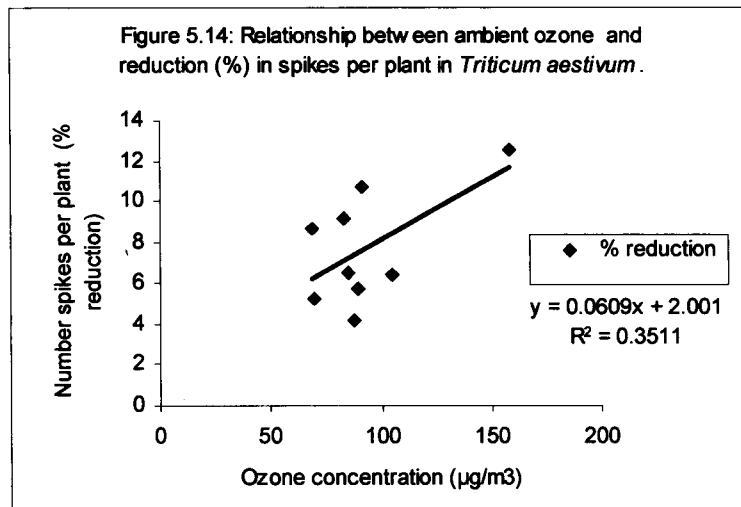
Figure 5.15: Relationship between ambient ozone and reduction (%) in spike size in *Triticum aestivum*.

y = 0.0732x + 0.9427
R^2 = 0.6432
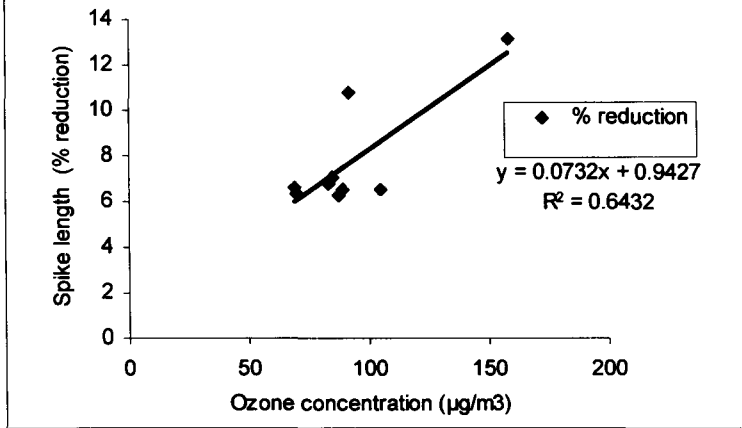
Figure 5.16: Relationship between ambient ozone and reduction (%) in grains per spike in *Triticum aestivum*.

y = 0.0546x + 19.725
R^2 = 0.5488

Figure 5.17: Relationship between ambient ozone and reduction (%) in grain weight per plant in *Triticum aestivum*.
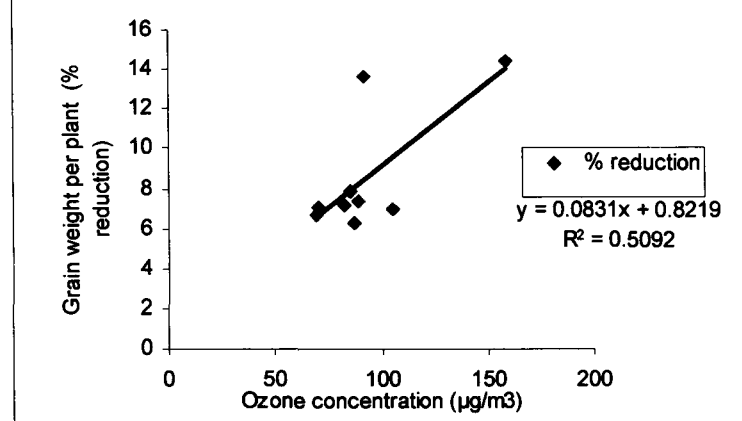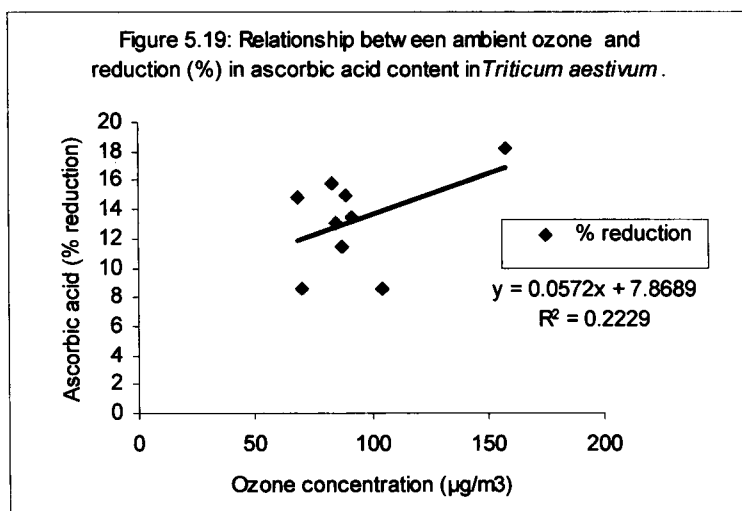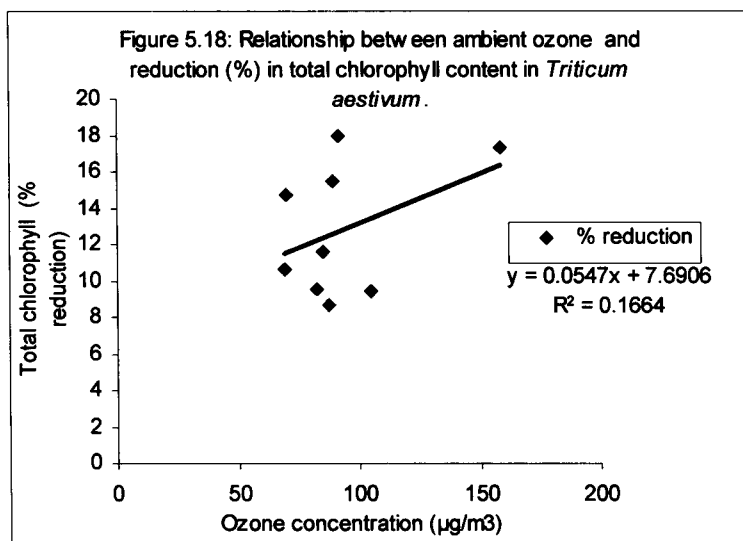
y = 0.0831x + 0.8219
R^2 = 0.5092

160

Figure 5.18: Relationship between ambient ozone and reduction (%) in total chlorophyll content in *Triticum aestivum*.

$y = 0.0547x + 7.6906$
$R^2 = 0.1664$

Figure 5.19: Relationship between ambient ozone and reduction (%) in ascorbic acid content in *Triticum aestivum*.

$y = 0.0572x + 7.8689$
$R^2 = 0.2229$

The performance of *Phaseolus aureus* plants grown with and without EDU at field sites show that the EDU treated plants were better as compared to plants grown without EDU (Table 4.5). The percentage difference in the performance of EDU treated plants at individual sites shows that the difference in shoot length was 2.32-10.11%; shoot biomass 8.61-15.17%; root length 3.07-6.40%; root biomass 8.69-15.38%; pods per plant 30.35-42.30%; pod length 3.94-10.34%; seeds per pod 1.68-13.12%; seed weight per plant 10.14-17.80%; total chlorophyll 8.14-14.18% and ascorbic acid 10.31-15.21%. Plants grown with and without EDU at high pollution sites (e.g., site-7) exhibited significant reduction in shoot length, shoot biomass, root length, root biomass, pods per plant, pod length, seeds per pod, seed weight per plant, total chlorophyll and ascorbic acid content as compared to performance of plants at low pollution sites. Statistical relationships have been worked out to determine the

correlation between the ground level ozone and the percentage reduction of different parameters in EDU untreated plants of *Phaseolus*.

The regression equations were developed between the ground level ozone concentration (X) and percentage reduction in different parameters (Y) of *Phaseolus*. A good correlation (co-effiecient of correlation: $r \geq \pm 0.5$) was observed between ground level ozone concentration and percentage reduction in total chlorophyll and ascorbic acid, week correlation with shoot length, seed weight per pod, shoot biomass, seeds per pod, pod length and pods per plant and root length and root biomass found to be weekly correlated (co-effiecient of correlation: $r < \pm 0.5$) (Table 5.5 and Figures 5.20 to 5.29). The difference between EDU treated and non-treated plants in respect of shoot length, pods per plant and total chlorophyll was statistically significantly at $P \leq 0.01$ level, the difference with regard to root biomass and ascorbic acid content were also statistically significant at $P \leq 0.05$ level and shoot biomass, root length, pod length, seeds per pod and seed weight per plant were found to be statistically insignificant (Table 4.5).

Table 5.5: The relationship between average ground level ozone concentration (X) and average reduction in different parameters (Y) of *Phaseolus aureus* plants grown at field sites in Delhi-Faridabad.

Relationship	Equation	r = value
O_3 with Shoot length	Y = -0.2839x+17.007	-0.4943
O_3 with Shoot biomass	Y = -0.2134x+20.328	-0.4548
O_3 with Root length	Y = 0.0154x+4.3524	+0.0536
O_3 with Root biomass	Y = 0.1239x+15.6293	+0.1766
O_3 with Pods per plant	Y = -0.266x+44.233	-0.3133
O_3 with Pod length	Y= 0.1929x-0.056	+0.3499
O_3 with Seeds per pod	Y = 0.394x-7.4596	+0.4461
O_3 with Seed weight per plant	Y = 0.2637x+3.7213	+0.4799
O_3 with Total chlorophyll	Y = 0.3817x-5.3715	+0.8228
O_3 with Ascorbic acid	Y = -0.3312x+25.963	-0.7539

In fumigation studies, observations on the growth and performance of plants were recorded on maturity. Plants grown without EDU were greatly reduced in comparison to the plants received EDU treatments both in E1 and E2 sets (Table 4.5). Based on the results of this experiment it appears that two or more prophylactic EDU treatments are effective in preventing ozone damage in *Phaseolus* plants (Plate 4.4).

Figure 5.20: Relationship between ambient ozone and reduction (%) in shoot length in *Phaseolus aureus*.

$y = -0.2839x + 17.007$
$R^2 = 0.2443$

Figure 5.21: Relationship between ambient ozone and reduction (%) in shoot biomass in *Phaseolus aureus*.

$y = -0.2134x + 20.328$
$R^2 = 0.2069$

Figure 5.22: Relationship between ambient ozone and reduction (%) in root length in *Phaseolus aureus*.

$y = 0.0154x + 4.3524$
$R^2 = 0.0029$

Figure 5.23: Relationship between ambient ozone and reduction (%) in root biomass in *Phaseolus aureus*.

$y = 0.1293x + 5.6293$
$R^2 = 0.0312$
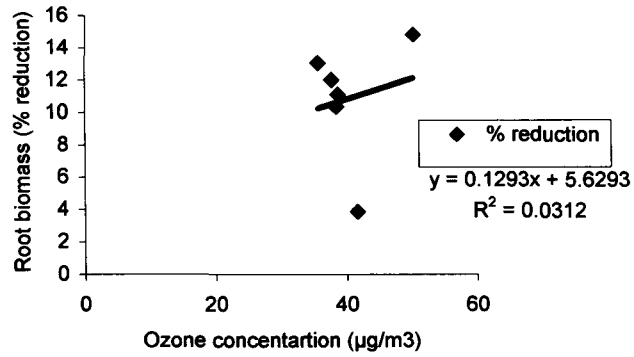
Figure 5.24: Relationship between ambient ozone and reduction (%) in pods per plant in *Phaseolus aureus*.

$y = -0.266x + 44.233$
$R^2 = 0.0981$
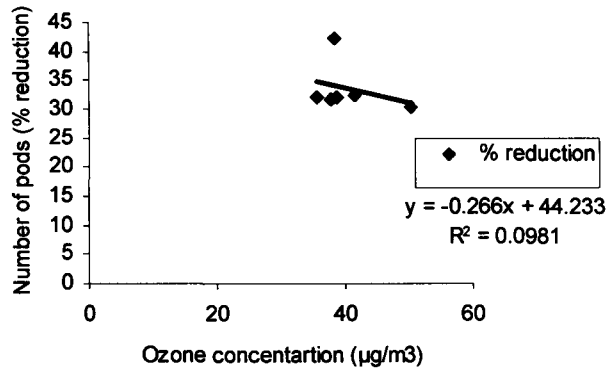
Figure 5.25: Relationship between ambient ozone and reduction (%) in pod size in *Phaseolus aureus*.
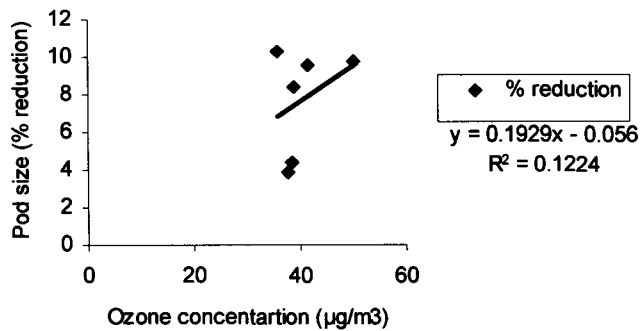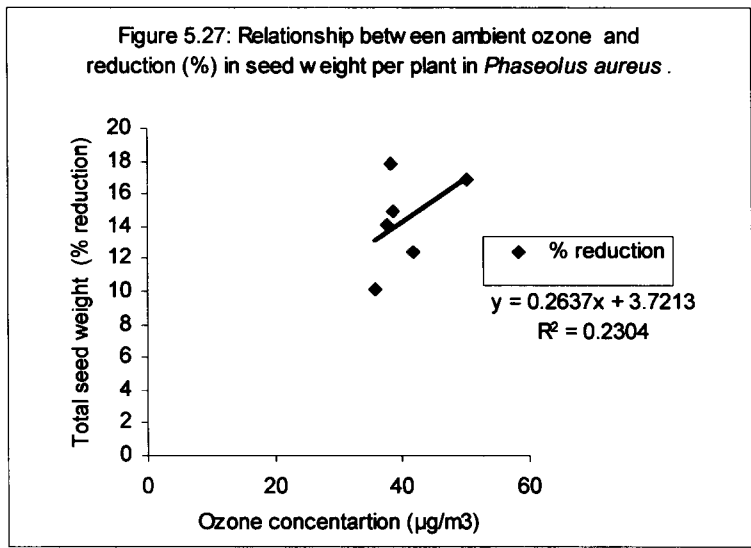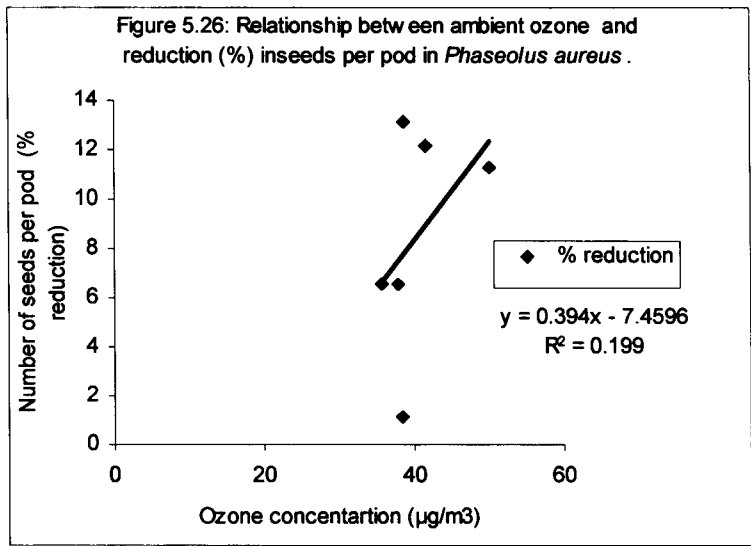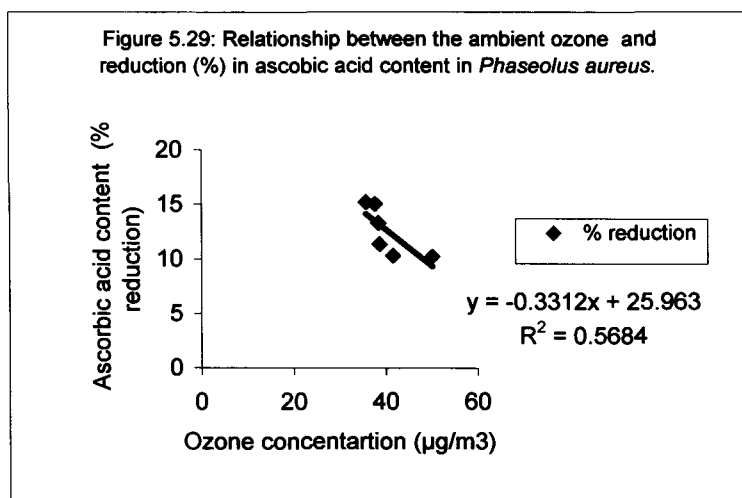
$y = 0.1929x - 0.056$
$R^2 = 0.1224$

164

Figure 5.26: Relationship between ambient ozone and reduction (%) in seeds per pod in *Phaseolus aureus* .

y = 0.394x - 7.4596
R² = 0.199

Figure 5.27: Relationship between ambient ozone and reduction (%) in seed weight per plant in *Phaseolus aureus* .

y = 0.2637x + 3.7213
R² = 0.2304

Figure 5.28: Relationship between the ambient ozone and reduction (%) in total chlorophyll content in *Phaseolus aureus* .

y = 0.3817x - 5.3715
R² = 0.677

Figure 5.29: Relationship between the ambient ozone and reduction (%) in ascobic acid content in *Phaseolus aureus*.

Performance of *Brassica campestris* plants grown with and without EDU at field sites show that the EDU treated plants were better as compared to the plants grown without EDU (Table 4.7 and Plate 4.5-4.8). The percentage difference in the performance of EDU treated and non-treated plants at individual sites shows that the difference in shoot length was between 6.20-25.80%; number of branches 6.30-16.50%; shoot biomass 15.42-24.09%; root length 8.33-14.32%; root biomass 15.51-22.94%; pods per plant 10.33-16.73%; pod length 15.82-19.77%; seeds per pod 9.84-17.91%; seed weight per plant 4.20-16.05%; total chlorophyll 6.88-19.56% and ascorbic acid 10.87-16.29%. Plants grown with and without EDU at high pollution sites (e.g., site-7) exhibited significant reduction in shoot length, number of branches, shoot biomass, root length, root biomass, pods per plant, pod length, seeds per pod, seed weight per plant, total chlorophyll and ascorbic acid content as compared to performance of plants at low pollution sites. Statistical relationships have been worked out to determine the correlation between the ground level ozone and the percentage reduction of different parameters in EDU untreated plants of *Brassica*.

The regression equations were developed between the ground level ozone concentration (X) and percentage reduction in different parameters (Y) of *Brassica*. A good correlation (co-effiecient of correlation: $r \geq \pm 0.5$) was observed between ground level ozone concentration and the percentage reduction in pod length, number of seeds per pod, shoot biomass, seed weight per plant, root biomass and root length and pods per plant, number of branches per plant, total chlorophyll, shoot length and ascorbic acid content were found to be weekly correlated (co-effiecient of correlation: $r < \pm 0.5$) (Table 5.6 and Figures 5.30 to 5.40). The difference between EDU treated and non-

166

treated plants in respect of shoot biomass, root length, root biomass, pods per plant, pod length, seeds per pod and average seed weight per plant was statistically significant at $P \leq 0.01$ level, the difference with regard to shoot length, number of branches, total chlorophyll were also statistically significant at $P \leq 0.05$ level (Table 4.7).

Table 5.6: The relationship between average ground level ozone concentration (X) and average reduction in different parameters (Y) of *Brassica campestris* plants grown at field sites in Delhi-Faridabad.

Relationship	Equation	r = value
O_3 with Shoot length	Y=0.006x+11.803	+0.0247
O_3 with Number of branches	Y=0.0596x+6.0532	+0.4577
O_3 with Shoot biomass	Y = 0.0836x+10.201	+0.6579
O_3 with Root length	Y = 0.0343x+7.8784	+0.5480
O_3 with Root biomass	Y = 0.0663x+11.719	+0.6110
O_3 with Pods per plant	Y = 0.0408x+9.3217	+0.4994
O_3 with Pod length	Y = 0.0408x+13.244	+0.7859
O_3 with Seeds per pod	Y = 0.0837x+4.1718	+0.6834
O_3 with Seed weight per plant	Y = 0.1016x-0.8981	+0.6164
O_3 with Total chlorophyll	Y = 0.0801x+4.2745	+0.3984
O_3 with Ascorbic acid	Y = 0.0151x+11.934	+0.1735

In fumigation studies, observations on the growth and performance of plants were recorded on maturity. Plants grown without EDU were greatly reduced in comparison to the plants received EDU treatments both in E1 and E2 sets (Table 4.7). Based on the results of this experiment it appears that two or more prophylactic EDU treatments are effective in preventing ozone damage in *Brassica* plants.

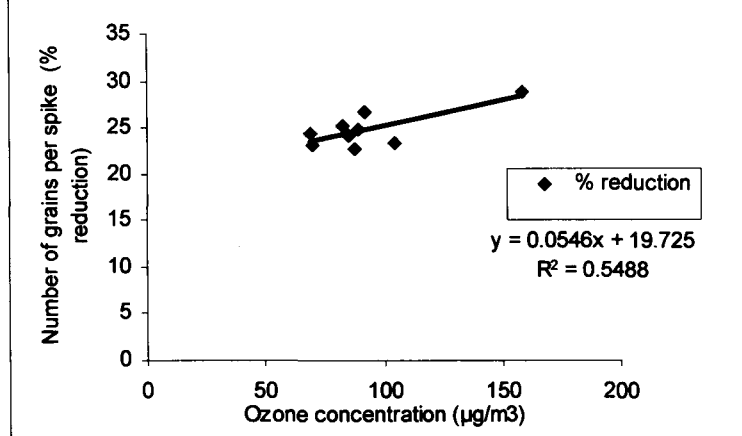**Figure 5.30:** Relationship between ambient ozone and reduction (%) in shoot length in *Brassica campestris* .

Shoot length (% reduction)

y = 0.006x + 11.803
R² = 0.0006

Ozone concentration (µg/m3)
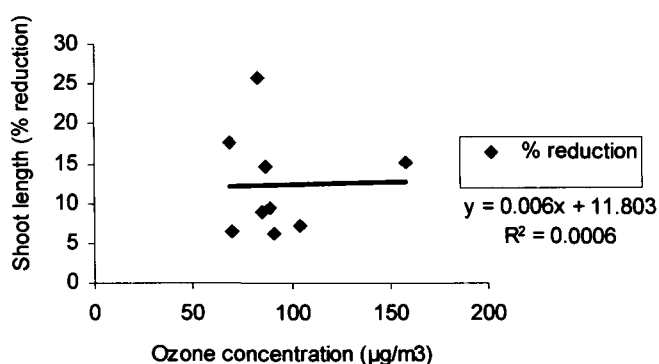
♦ % reduction

Figure 5.31: Relationship between ambient ozone and reduction (%) in number of branches in *Brassica campestris* .

Number of branches (% increase)

y = 0.0596x + 6.0532
R² = 0.2095

Ozone concentration (µg/m3)
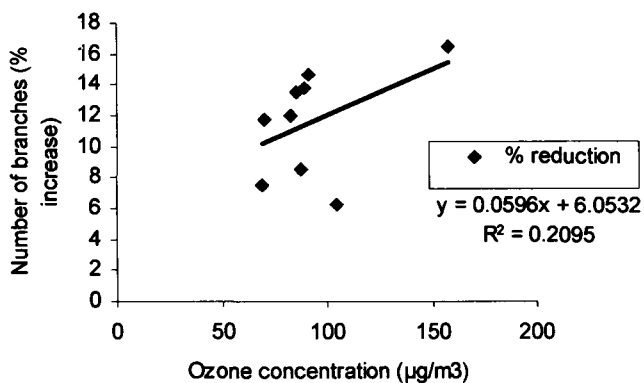
♦ % reduction

Figure 5.32: Relationship between ambient ozone and reduction (%) in shoot biomass in *Brassica campestris* .

Shoot biomass (% reduction)

y = 0.0836x + 10.201
R² = 0.4329

Ozone concentration (µg/m3)

♦ % reduction

168
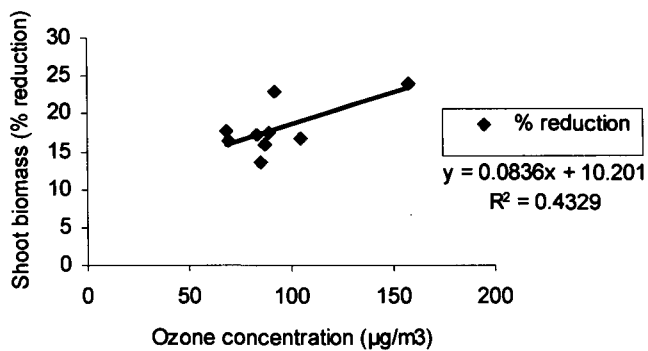
Figure 5.33: Relationship between ambient ozone and reduction (%) in root length in *Brassica campestris*.

y = 0.0343x + 7.8784
R^2 = 0.3003
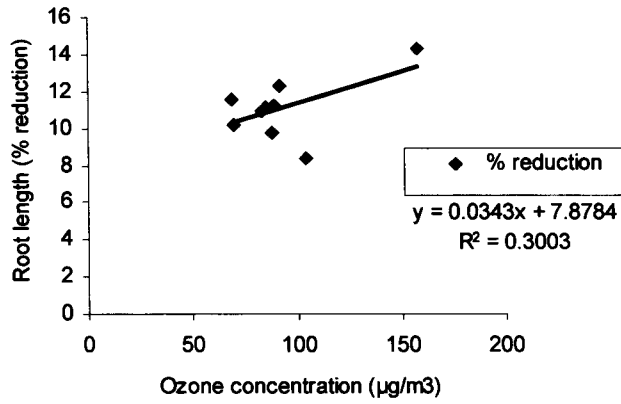
Figure 5.34: Relationship between ambient ozone and reduction (%) in root biomass in *Brassica campestris*.

y = 0.0663x + 11.719
R^2 = 0.3733
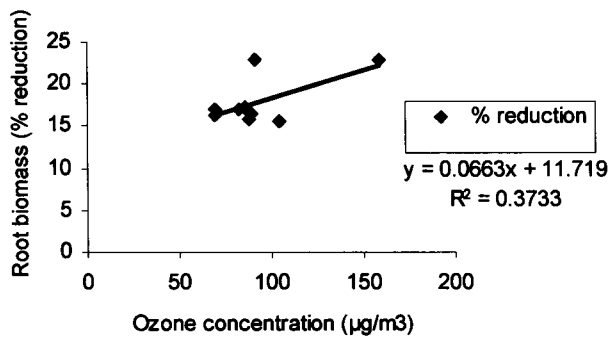
Figure 5.35: Relationship between ambient ozone and reduction (%) in pods per plant in *Brassica campestris*.

y = 0.0408x + 9.3217
R^2 = 0.2495
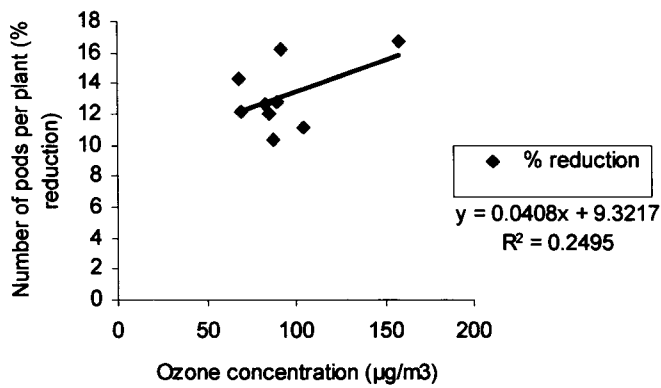
Figure 5.36: Relationship between ambient ozone and reduction (%) in pod size in *Brassica campestris*.
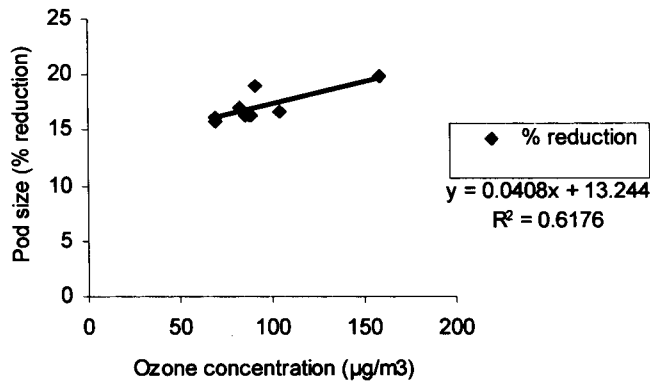
Figure 5.37: Relationship between ambient ozone and reduction (%) in seeds per pod in *Brassica campestris*.
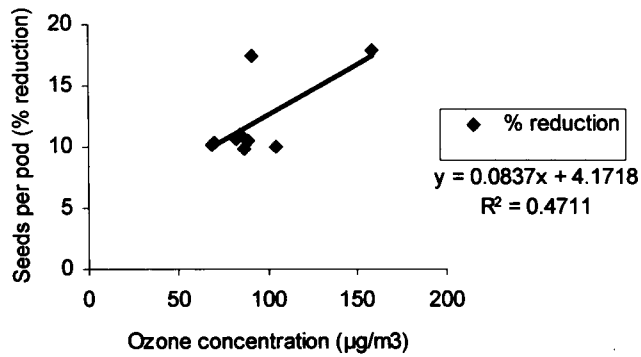
Figure 5.38: Relationship between aambient ozone and reduction (%) in seed weight per plant in *Brassica campestris*.
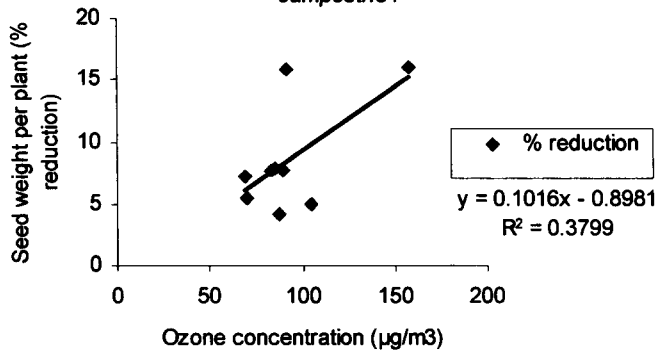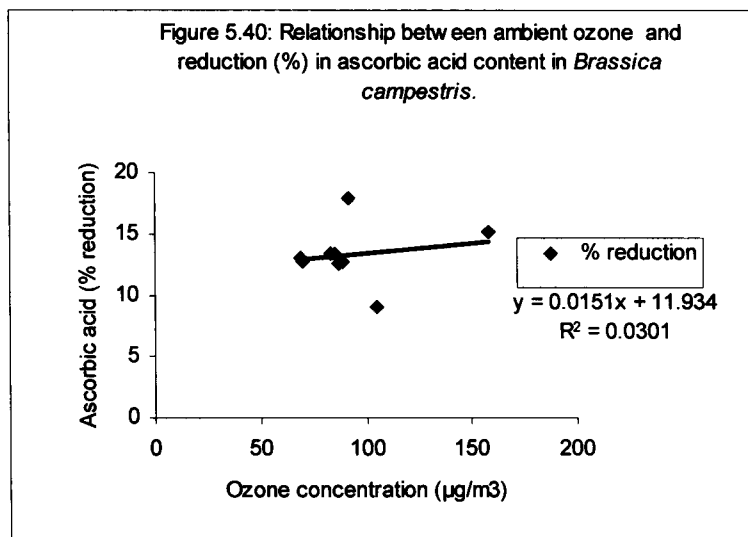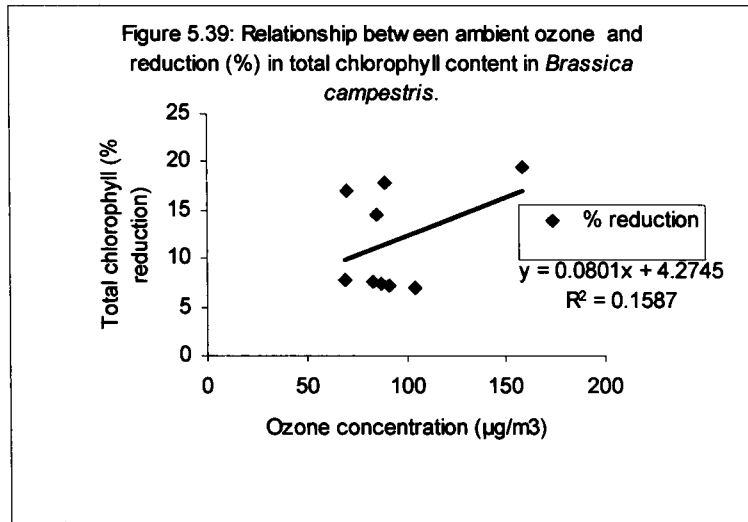
Figure 5.39: Relationship between ambient ozone and reduction (%) in total chlorophyll content in *Brassica campestris.*

$y = 0.0801x + 4.2745$
$R^2 = 0.1587$

Figure 5.40: Relationship between ambient ozone and reduction (%) in ascorbic acid content in *Brassica campestris.*

$y = 0.0151x + 11.934$
$R^2 = 0.0301$

Performance of *Spinacia oleracea* plants grown with and without EDU at field sites show that the EDU treated plants were better as compared to the plants grown without EDU (Table 4.9 and Plate 4.9). The percentage difference in the performance of EDU treated and non-treated plants at individual sites shows that the difference in leaf number was between 6.78-17.35%; number of senescent leaves -47.22 to -29.60%; leaf area 8.75-26.14%; root biomass 1.72-13.33%; plant biomass 11.76-26.32%; total chlorophyll 8.57-10.06% and ascorbic acid content 6.10-9.75%. Plants grown with and without EDU at sites with high pollution load (e.g., site-7) exhibited significant reduction in leaf number, number of senescent leaves, leaf area, root biomass, plant biomass, total chlorophyll and ascorbic acid content as compared to performance of plants at low pollution sites. Statistical relationships have been worked out to determine

the correlation between the ground level ozone and the percentage reduction of different parameters in EDU untreated plants of *Spinacia*.

The regression equations were developed between the ground level ozone concentration (X) and percentage reduction in different parameters (Y) of *Spinacia*. A good correlation (co-effiecient of correlation: $r \geq \pm 0.5$) was observed between ground level ozone concentration and the percentage reduction in leaf area, plant biomass and total chlorophyll and ascorbic acid, root biomass, number of leaves and number of senescent leaves were found to be weekly correlated (co-effiecient of correlation: $r < \pm 0.5$) (Table 5.7 Figure 5.41 to 5.47). The difference between EDU treated and non-treated plant in respect of plant biomass was statistically significant at $P \leq 0.01$. The difference with regard to level and number of senescent leaves were also statistically significant at $P \leq 0.05$ level and root biomass, leaf area, total chlorophyll and ascorbic acid were found to be statistically insignificant (Table 4.9).

Table 5.7: The relationship between average ground level ozone concentration (X) and average reduction in different parameters (Y) of *Spinacia oleracea* plants grown at field sites in Delhi-Faridabad.

Relationship	Equation	r = value
O_3 with Number of leaves	Y = 0.7091x-16.189	+0.1957
O_3 with No. of senescent leaves	Y = -0.2658x+48.896	-0.0499
O_3 with Leaf area	Y = 4.9424x-166.49	+0.7888
O_3 with Root biomass	Y = -1.1644x+51.117	-0.3307
O_3 with Plant biomass	Y = 3.299x-107.57	+0.6882
O_3 with Total chlorophyll	Y = -0.2935x+20.542	-0.6388
O_3 with Ascorbic acid	Y = 0.7115x-18.873	+0.4774

In fumigation studies, observations on the growth and performance of plants were recorded on maturity. Plants grown without EDU were greatly reduced in comparison to the plants received EDU treatments both in E1 and E2 sets (Table 4.9). Based on the

results of this experiment it appears that two or more prophylactic EDU treatments are effective in preventing ozone damage in *Spinacia* plants.

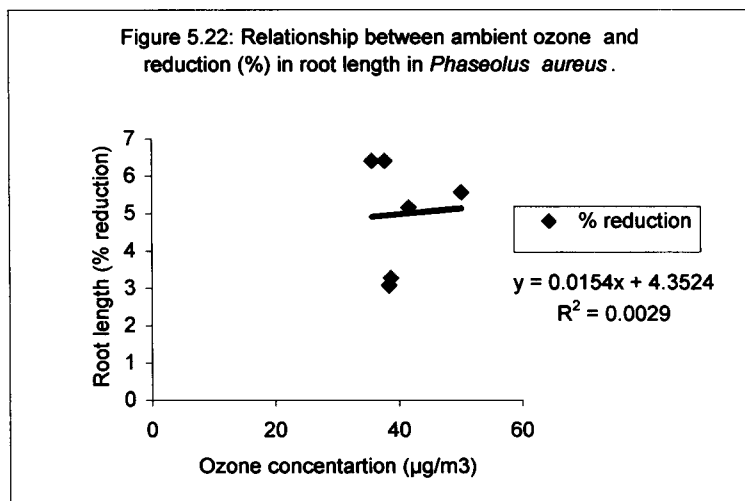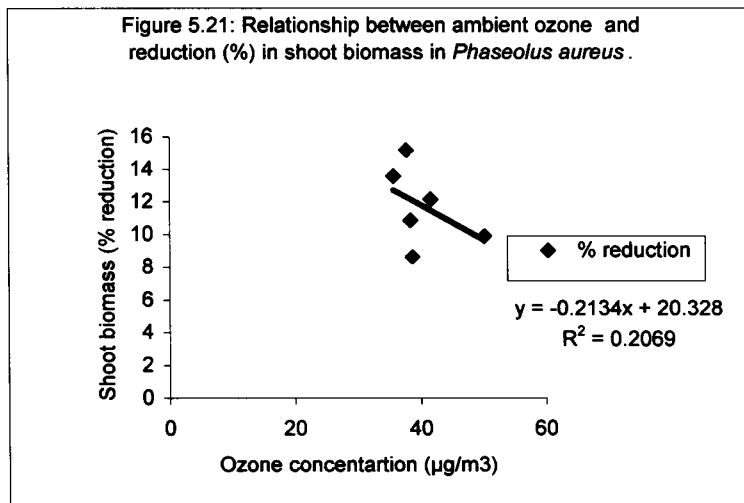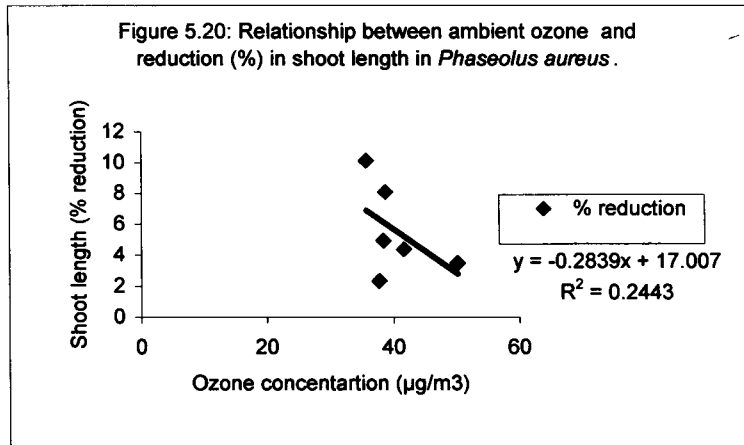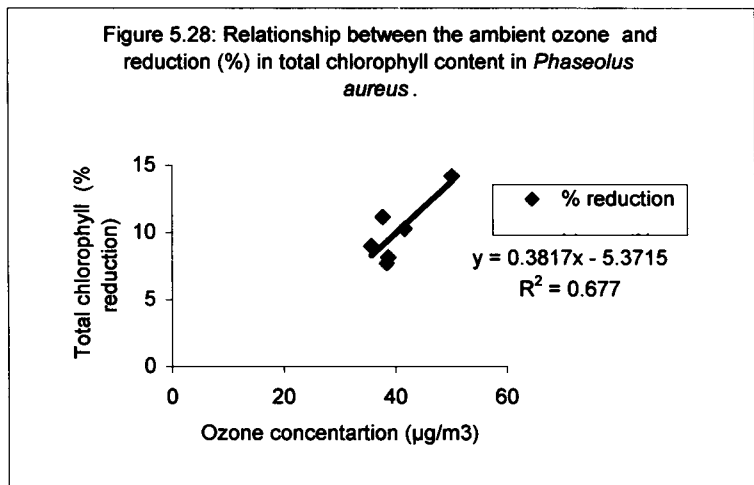**Figure 5.41:** Relationship between ambient ozone and reduction (%) in leaf number in *Spinacia oleracea*.

$$y = 0.7091x - 16.189$$
$$R^2 = 0.0383$$

◆ % reduction

Leaf number (% reduction)
Ozone concentration (μg/m3)

Figure 5.42: Relationship between ambient ozone and reduction (%) in number of senescent leaves in *Spinacia oleracea*.

$$y = -0.2658x + 48.896$$
$$R^2 = 0.0025$$

◆ % loss

Senescent leaves (% reduction)
Ozone concentration (μg/m3)

Figure 5.43: Relationship between ambient ozone and reduction (%) in leaf area of *Spinacia oleracea*.

$$y = 4.9424x - 166.49$$
$$R^2 = 0.6223$$

◆ % reduction

Leaf area (% reduction)
Ozone concentration (μg/m3)

Figure 5.44: Relationship between ambient ozone and reduction (%) in root biomass in *Spinacia oleracea*.

y = -1.1644x + 51.117
R^2 = 0.1094
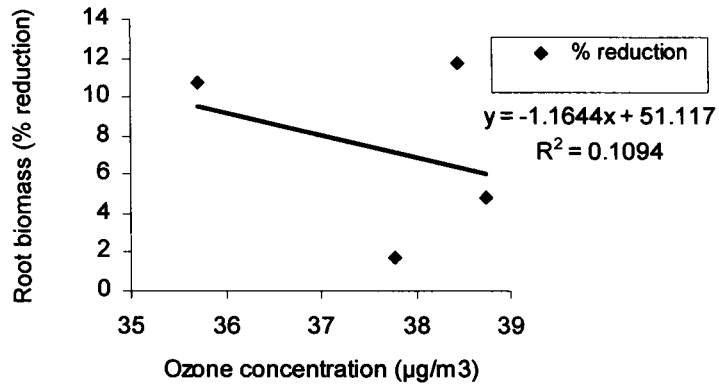
Figure 5.45: Relationship between ambient ozone and reduction (%) in plant biomass in *Spinacia oleracea*.

y = 3.299x - 107.57
R^2 = 0.4736
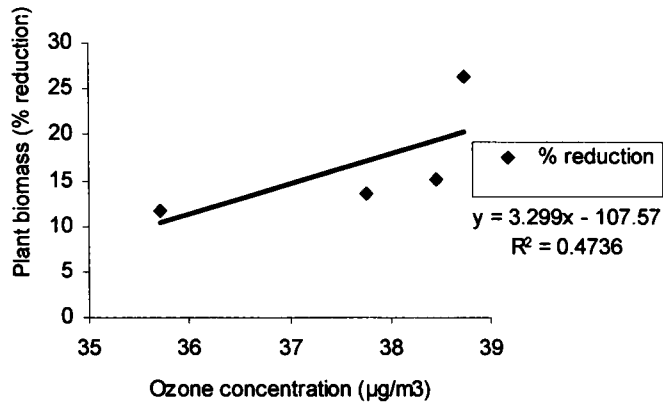
Figure 5.46: Relationship between ambient ozone and reduction (%) in total chlorophyll content in *Spinacia oleracea*.

y = -0.2953x + 20.542
R^2 = 0.4081

Figure 5.47: Relationship between ambient ozone and reduction (%) in ascorbic acid content in *Spinacia oleracea*.
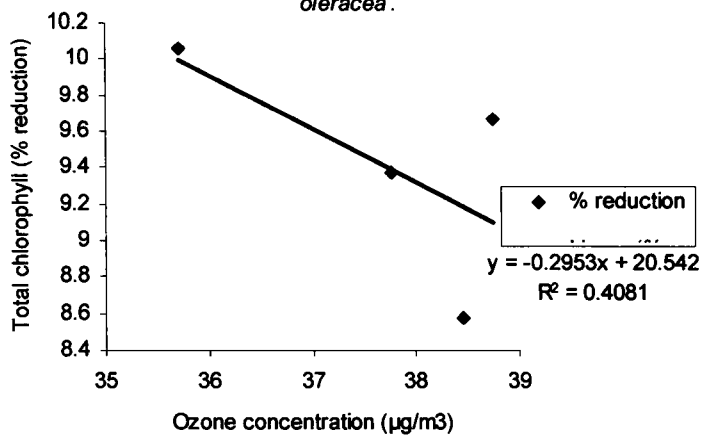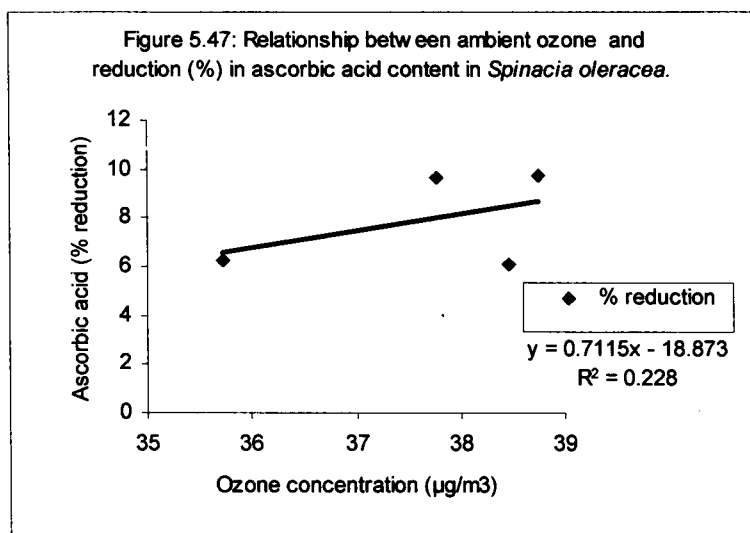
The growth performance of *Triticum, Phaseolus, Brassica* and *Spinacia* plants grown with and without EDU at field sites show that the EDU treated plants were better as compared to the plants grown without EDU. Different parameters were considerably reduced in plants of polluted sites (S-4 and S-7) as compared to plants of low pollution sites (S-1, S-6 and S-9).

Both in field and under fumigation shoot length was highly affected in *Brassica campestris* moderately in *Triticum aestivum*, and least in *Phaseolus aureus* (Table 5.8 to 5.9 and Figure 5.48).

In field grown plants, root length was highly affected in *Brassica campestris*, moderately in *Triticum aestivum*, and least in *Phaseolus aureus*. In fumigated plants root length was greatly affected in *Phaseolus aureus*, moderately in *Triticum aestivum* and least in *Brassica campestris*. The poor root development in *Phaseolus* appears to be on account of pulses of ozone exposure under fumigation regime may have affected root growth and nitrogen fixation more adversely (Table 5.8 to 5.9 and Figure 5.49).

Shoot biomass in field grown plants was most affected in *Triticum aestivum*, moderately in *Brassica campestris* and *Spinacia oleracea*, and least in *Phaseolus aureus*. In ozone fumigated plants shoot biomass was also most affected in *Triticum aestivum*, moderately in *Brassica campestris* and *Phaseolus aureus* and least in *Spinacia oleracea*, which was quite understandable because *Spinacia oleracea* unlike other plants, has a rosette habit lacking an erect stem (Table 5.8 to 5.9 and Figure 5.50).

In field grown plants root biomass was highly affected in *Triticum aestivum,* moderately in *Brassica campestris* and *Phaseolus aureus,* and least in *Spinacia oleracea.* The fumigated plants also exhibited similar trend. The fibrous root system of *Triticum* was more affected as compared to other crop plants (Table 5.8 to 5.9 and Figure 5.51).

The present study shows that the performance of different morphological parameters in EDU treated plants was relatively better as compared to plants grown without EDU. These observations are in line with the information available in literature. For example, the biomass of EDU treated tomato plants was 42% more over the non-treated plants reported by Legassicke and Ormrod (1981), similarly Varshney and Rout, (1998) also reported 24% increase in biomass in EDU treated tomato plants over non-treated plants. In case of tobacco biomass of EDU treated plants increased by 17% over non-treated (Bisessar and Palmer, 1984). Hassan *et al.* (1995) have observed that the EDU treatment suppressed the adverse effect of ozone on shoot development and biomass both in radish and turnip. In fumigated plants of *Phaseolus vulgaris,* the shoot biomass of EDU treated plants was 54% more as compared to the plants grown without EDU treatment (Brunschon-Harti *et al.,* 1995a).

In the field-exposed plants, the total chlorophyll content was most affected in *Phaseolus aureus,* moderately in *Brassica campestris* and *Triticum aestivum,* and least in *Spinacia oleracea.* In fumigated plants of *Triticum aestivum* reduction in total chlorophyll content in was less as compared to other plants (Table 5.8 to 5.9 and Figure 5.52).

The ascorbic acid content in field exposed plants of *Brassica campestris* and *Triticum aestivum* was more affected as compared to *Phaseolus aureus* and *Spinacia oleracea* (Table 5.8 to 5.9 and Figure 5.53). The ascorbic acid content in plants grown at highly polluted sites-7 declined considerably in both with EDU and non treated plants in the following order: *Brassica campestris, Triticum aestivum, Phaseolus aureus* and *Spinacia oleracea* as compared to other sites having low pollution load. The ascorbic acid content in fumigated plants grown with EDU was more as compared to plants grown without EDU. A close relationship has been suggested between endogenous level of ascorbic acid and plant susceptibility to ozone (Lee *et al.,* 1984; 1990, 1992; 1996; Chen *et al.,* 1990; Hausladen and Kunert, 1990).

In field grown plants, the average seed weight per plant was most affected in *Phaseolus aureus*, least in *Brassica campestris* and moderately in *Triticum aestivum*. In fumigated plants also the adverse effect of ozone on seed weight followed the similar trend. (Table 5.8 to 5.9 and Figure 5.54). The performance of different yield parameters in EDU treated plants was relatively better as compared to plants grown without EDU and the trend agrees with the information available in literature. For example, in navy bean plants exposed to high ozone levels and treated with EDU, seed weight increased by 36% (Hofstra *et al.,* 1978); 24% in white bean (Temple and Bisessar, 1979); 35% in potato (Bisessar, 1982); 30% in tomato (Legassike and Ormrod, 1984); 20% in tobacco (Bisessar and Palmer, 1984); 17% in peanuts (Ensing *et al.,* 1985); 30% in radish; 17% in turnip (Hassan *et al.,* 1995) and 16-31% in soybean (Varshney and Rout, 2003).

Table 5.8: A comparative percentage difference in the performance of plants exposed to ground level ozone in field with and without EDU treatment plants.

	Species			
	Triticum	*Phaseolus*	*Brassica*	*Spinacia*
Ozone concentration	69.07-158.33μg/m³		(35.72-50.20μg/m³)	
Plant parameters	Performance (% difference)			
Culm / Shoot length	7.38	5.53	12.37	-
Number of Culms/ Branches per plant	18.23	-	*11.61	
Shoot biomass	20.78	11.70	17.99	16.72
Root length	8.64	4.98	11.07	-
Root biomass	37.48	11.44	17.90	7.19
Grains per spike/Seeds per pod	24.81	8.47	11.97	-
Grain weight/Seed weight per plant	8.58	14.38	8.57	-
Total chlorophyll	12.79	10.06	11.74	9.42
Ascorbic acid	13.20	12.57	13.34	7.93

decrease from EDU.

*increase over EDU.

Table 5.9: A comparative percentage difference in the performance of plants exposed to 150μg/m³ of ozone with and without EDU treatment plants in experimental fumigation study.

Plant parameters	Species			
	Triticum	*Phaseolus*	*Brassica*	*Spinacia*
Culm /Shoot length	31.45	12.79	15.91	-
Number of Culms/ Branches per plant	22.50	-	*13.52	
Shoot biomass	30.40	18.91	26.34	29.46
Root length	14.06	29.16	25.20	
Root biomass	25.67	22.38	24.94	21.24
Grains per spike/Seeds per pod	26.20	10.86	21.00	-
Grain weight/Seed weight per plant	25.82	31.95	12.63	-
Total chlorophyll	21.67	43.52	41.88	38.66
Ascorbic acid	2.425	29.03	1.62	14.10

decrease from EDU.
*increase over EDU.

On the basis of the performance of different plant parameters of *Phaseolus* and *Spinacia* appear relatively more sensitive to ozone as compared to *Triticum* and *Brassica*. Studies carried out under NCLAN have also shown that dicot species (soybean, cotton and peanut) were more sensitive to ozone and suffered greater yield loss as compared to monocot species (sorghum, field corn and winter wheat) (see Table 2.12).

The four crop plants represent the following order according to their ozone sensitivity:

Phaseolus aureus > *Spinacia oleracea* > *Triticum aestivum* > *Brassica campestris*

Figure 5.48: A comparison of culm length/shoot length in *Triticum*, *Phaseolus* and *Brassica* plants in field and experimental fumigation studies.

178
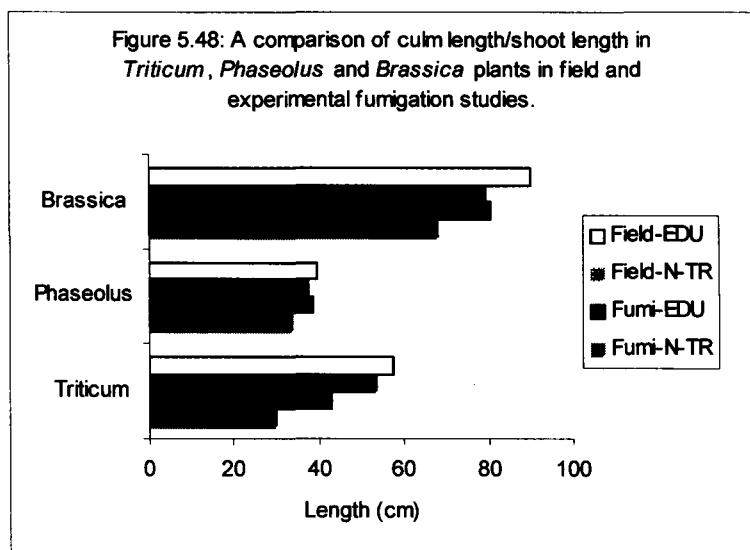
Figure 5.49: A comparison of root length in *Triticum*, *Phaseolus* and *Brassica* plants in field and experimental fumigation studies.
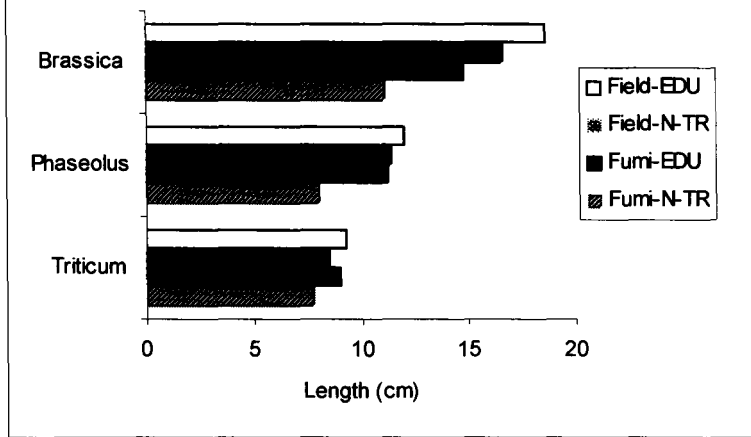
Figure 5.50: A comparison of shoot biomass in *Triticum*, *Phaseolus*, *Brassica* and *Spinacia* plants in field and experimental fumigation studies.
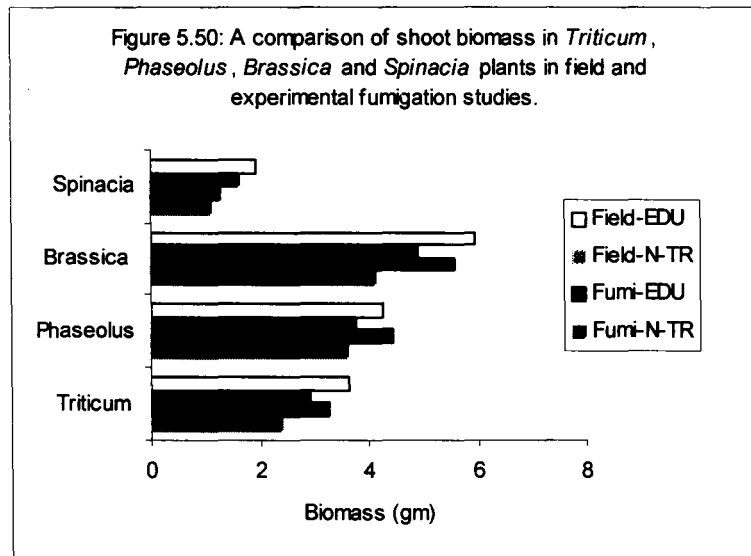
Figure 5.51: A comparison of root biomass in *Triticum*, *Phaseolus*, *Brassica* and *Spinacia* plants in field and experimental fumigation studies.
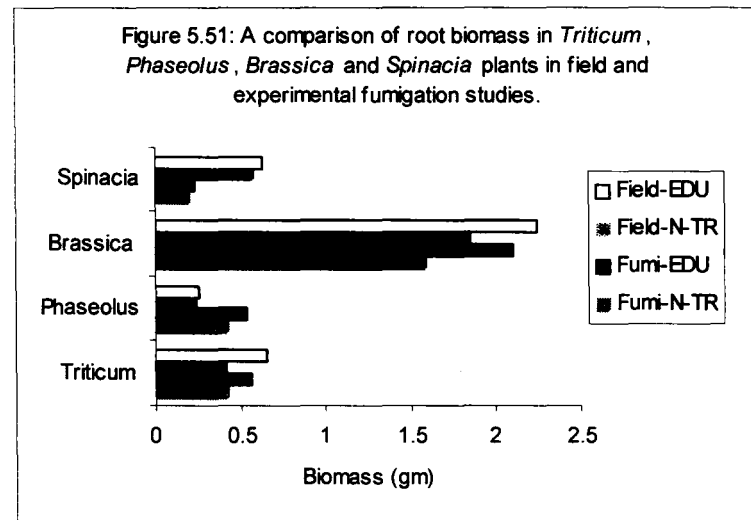
Figure 5.52: A comparison of total chlorophyll content in *Triticum*, *Phaseolus*, *Brassica* and *Spinacia* plants in field and experimental fumigation studies
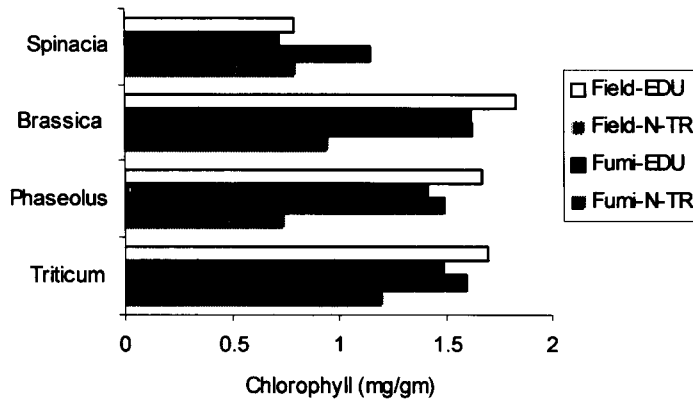
Figure 5.53: A comparison of ascorbic acid content in *Triticum*, *Phaseolus*, *Brassica* and *Spinacia* plants in field and experimental fumigation studies
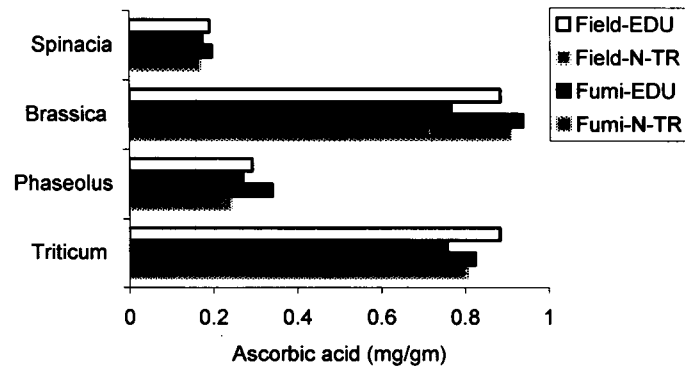
Figure 5.54: A comparison of seed weight per plant in *Triticum*, *Phaseolus* and *Brassica* plants in field and experimental fumigation studies.

180
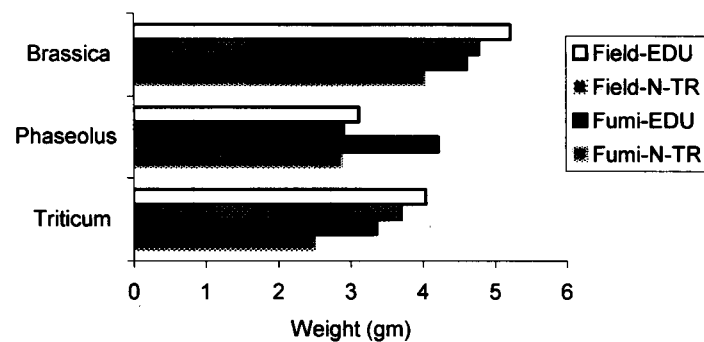
Values of ground level ozone concentration at different field sites invariably exceeded or closely approached the critical ozone level (see Table 5.1) based on AOT40 index (accumulated exposure over a threshold of 40ppb), which was estimated at 90 $\mu g/m^3$ and 80 $\mu g/m^3$ for wheat and field bean respectively for Europe.

A comparison of the performances of field grown plants with ozone fumigated plants show that different parameters of fumigated plants were relatively more affected than the field grown plants. It seems that the protective potential of EDU is more in plants exposed to pulses of ozone as compared to plants continuously exposed to ozone in the field. It has been observed that environmental variables such as temperature, relative humidity and presence of other pollutants influence plants' response to ozone (Guderian et al., 1985). It is also observed that environmental conditions may also influence the protective potential of EDU against ozone injury to plants (Regner-Joosten et al., 1994; Gatta et al., 1997).

Among different parameters, grain/seed weight per plant, spike/pod length, grains per spike/seeds per pod and total chlorophyll in Triticum, Phaseolus and Brassica plants, and leaf area, plant biomass and total chlorophyll in Spinacia oleracea, exhibit a good correlation with ground level ozone. The parameters viz., grain/seed weight per plant, spike/pod length, grains per spike/seeds per pod and total chlorophyll for Triticum, Phaseolus and Brassica and leaf area, plant biomass and total chlorophyll for Spinacia may be used for screening ozone sensitivity of crop cultivars.

On the basis of the results of this study it may be suggested that two or more prophylactic treatments of EDU may prove more beneficial in protecting Triticum, Phaseolus, Brassica and Spinacia oleracea from ozone damage.

181

Chapter-VI

Crop Loss from Ground Level Ozone and its Economic Implications

Crop Loss from Ground Level Ozone and its Economic Implications

Agriculture is the lifeblood of Indian economy. It contributes nearly 25% to Gross Domestic Product (GDP) and about 70% of population is dependent on agriculture for their livelihood (India, 2003). About 18% of the total value of the country's exports is contributed by agricultural sector, and it also supplies bulk of wage goods and raw material required by non-agricultural sectors (India, 2002).

Agricultural production in India is highly influenced by environmental factors including land degradation, pest outbreak, and water and air pollution. Over past 50years, a number of schemes and projects have been taken up to address the problems of land degradation, salinity, pest outbreak and crop improvement through successive Five-Year Plans, but not much attention has been paid to the growing problems caused by air pollution in context of agricultural crops either by government or by research scientists. The problem of air pollution in relation to agricultural production is a growing cause of concern requiring serious attention.

The discussion in this chapter is devoted to the assessment of the likely impact of ground level ozone, on the yield of agricultural crops and its economic implications.

Ozone Scenario in India: Present and Future

Information on ground level ozone pertaining to India is very scarce, ozone available only for few stations viz: Delhi, Varanasi, Chandigarh, Ahmedabad, Pune, Agra, Bhubaneswar, Berhampur (Orissa) and Cochin. Measurements at Delhi (1989-2000) (Varshney and Aggarwal, 1992; Singh *et al.,* 1997; Varshney and Rout, 1998; NAAQMS, 1999, 2001), Varanasi (1990-92) (Pandey *et al.,* 1992), Chandigarh (April-December1984 and November 1990-March 1992) (CSIO, 1992) Ahmedabad (1993-94) (Naja and Lal, 1996), Pune (1992) (Khemani *et al.,* 1992), Agra, Bhubaneswar, Berhampur (Orissa) and Cochin (September, 1999 to June, 2001) (Carmichael *et al.* 2003) was 53.67µg/m^3; 48.00 µg/m^3; 62.32µg/m^3, 46.15µg/m^3, 31.42µg/m^3, 60.37µg/m^3, 61.54µg/m^3, 46.45µg/m^3 and 23.13µg/m^3 at these nine stations respectively. The overall average concentration of ground level ozone for above nine stations comes to 48.111µg/m^3 (see Table 5.1). So far, no systematic ozone monitoring

in peri-urban and rural areas has been attempted in the country, but the ground level ozone values reported from the nine widely separated stations suggest that the build-up of ground level ozone is fairly widespread in the country. Rapidly growing consumption of fossil fuels is likely to increase emission of NO_X and volatile organic compounds, which are ozone precursors. The sub-tropical climate of the country characterised by high ambient temperature and high solar intensity presents ideal condition for promoting formation of ground level ozone and other photochemical oxidants (Bell *et al.*, 2000; Lelieveld and Dentener, 2000). The impending global warming may further promote the formation of ground level ozone, as evident from the recent reports about high build up of ground level ozone in Europe which has experienced unusually warm weather this year (HT, 2003). The consequential effect of the progressive increase in ground level ozone on crop plants is cause of concern, deserving serious consideration.

Impact of Ground Level Ozone on Crop Yield

Impact of ground level ozone on plants is attracting much attention all over the world, because of ground level ozone reduces crop yield, hence, it viewed as a growing threat to food security.

In order to make a broad assessment of the quantum of crop loss from ozone regression equations based on the results of the studies on *Triticum, Phaseolus, Brassica* and *Spinacia,* were developed. The ground level ozone concentration was $40.43 \mu g/m^3$ and $93.25 \mu g/m^3$ during the summer and the winter seasons respectively. Yield loss in *Phaseolus* and *Spinacia,* grown as summer crops, was about 14% and in *Triticum* and *Brassica* grown as winter crops, was about 8% (Table 6.1). The yield loss observed during this study favourably compare with the yield losses reported in literature from tropical environment (Wahid *et al.*, 1995a, 1995b, 2001; Hassan *et al.*, 1995; Laguette-Rey *et al.,*, 1986; Varshney and Rout, 1998, 2003) (Table 6.2).

Table 6.1: Average hourly ground level ozone concentration and average yield reduction in four crops plants at Delhi-Faridabad.

Season	Average hourly ozone concentration ($\mu g/m^3$)	Crop	Average yield reduction (%)
Summer (May –July, 1998)	40.43	Phaseolus	14.38
		Spinacia	14.37
Winter (January – April, 1999)	93.25	Triticum	8.58
		Brassica	8.57

Studies carried out in Pakistan Punjab on the effect of ozone on crop yield, have shown that in the rural areas of Lahore ground level ozone causes substantial loss to agricultural crops i.e., 40% in wheat at 86 $\mu g/m^3$, 64 % in soybean at 80-150 $\mu g/m^3$ and 40-60% in rice at 143 $\mu g/m^3$ (Wahid et al., 1995a, 1995b, 2001). At Delhi, Varshney and Rout (1998) has reported significant yield loss between 16-31% in soybean at 46-65 $\mu g/m^3$ and 24% biomass reduction in tomato plants grown in the environment having 80-90 $\mu g/m^3$ of ozone (Table 6.2).

Table 6.2: Yield loss in different crop plants from ground level ozone reported in literature.

Crop	Ground level ozone concentration ($\mu g/m^3$)	Yield reduction (%)	Country	Reference
Wheat (Triticum aestivum)	86	40	Pakistan	Wahid et al., 1995a
Rice (Oryza sativa)	143	40-60	Pakistan	Wahid et al., 1995b
Soybean (Glycine max)	80-150	64	Pakistan	Wahid et al., 2001
Radish (Raphanus sativus)	54.8-66.9	30	Egypt	Hassan et al., 1995
Turnip (Brassica rapa)	54.8-66.9	17	Egypt	Hassan et al., 1995
Bean (Phaseolus vulgaris)	686	40	Mexico	Laguette-Rey et al., 1986
Tomato (Lycopersicon esculentum)	88-90	24	India	Varshney and Rout, 1998
Soybean (Glycine max)	46-65	16-31	India	Varshney and Rout, 2003

Ashmore and Marshall (1998) have reported substantial yield reduction in wheat, rice, cotton and groundnut due to ground level ozone within a zone of 80km in the peri-urban areas of Mumbai, Ahmedabad, Pune and Lucknow (Table 6.3). It may be pointed out that the ground level ozone may not be equally severe over the entire area of individual crops but the suffering of individual farmers where ozone levels may exceed the crop tolerance limit, may be extremely high.

Table 6.3: Estimated crop loss ('000 tonnes) from ozone in relation to five Indian cities.

Cities	Wheat yield loss	Rice yield loss	Cotton yield loss	Groundnut yield loss
Mumbai	4.30	204.40	-	3.20
Ahmedabad	96.00	91.00	28.5	28.0
Pune	39.00	55.90	-	9.90
Lucknow	300.10	165.2	-	3.70
Total	439.40	516.50	28.5	44.80

After Ashmore and Marshall, 1998.

In the USA it has been estimated about 5-6 % of the gross value of farm commodities are lost due to ozone pollution (Shriner *et al.,* 1982; Wilson *et al.,* 1984; Adams *et al.,* 1989). In the Netherlands ground level ozone pollution was found to cause considerable loss to legumes, potatoes, cut flowers and fodder crops (Tonneijck, 1989). Sulphur dioxide, hydrogen fluoride and ozone have been shown to reduce crop yield by 5%; and 70% of such reduction was attributed to the ground level ozone pollution (Tonneijck, 1989).

The problem of ground level ozone is fairly widespread in urban, peri-urban areas, around industrial complexes and along high traffic corridors in the country. Presently, information on ground level ozone and the extent to which agricultural areas suffer from ozone pollution is lacking in absence of regular ozone monitoring network rural and peri-urban areas. Under these circumstances, values of ground level ozone reported from widely separated stations viz., Delhi, Varanasi, Chandigarh, Ahmedabad, Pune, Agra, Bhubaneswar, Berhampur (Orissa) and Cochin provide a reasonable idea of the build up of ground level ozone across the country. The average ozone value of the nine stations is 48.111 $\mu g/m^3$. In absence of any better data 48$\mu g/m^3$ was taken as the average value for estimating yield loss. The extent of area of each crop suffering from ozone build up is also not certain. Hence, crop loss scenarios have been developed for

5%, 10%, 20% and total cultivated area of the entire area under cultivation of wheat (*Triticum*), moong (*Phaseolus*) and mustard (*Brassica*) crops for computing yield loss and corresponding economic loss from ground level ozone (Table 6.4).

Estimation for *Spinacia* was not attempted due to non-availability of reliable data on the extent of the cultivated area and production statistics of this vegetable crop.

Wheat (*Triticum aestivum*)

Loss of yield in wheat (*Triticum aestivum*) from 48µg/m^3 of ground level ozone affecting 5%, 10%, 20% or the entire area of wheat crop amounts to 0.1594, 0.3189, 0.6378 and 3.1890 million tonnes, which translates into an economic loss of Rs. 92.4808, 184.962, 369.923 and 1849.616 crores respectively calculated on the basis of minimum support price of Rs. 610/- fixed by the government (Table 6.4 to 6.5).

Moong (*Phaseolus aureus*)

Loss of moong yield in (*Phaseolus aureus*) from 48µg/m^3 of ground level ozone affecting 5%, 10%, 20% or the entire area of moong crop amounts to 0.0450, 0.0901, 0.1802 and 0.9008 million tonnes of yield loss, which translates into an economic loss of Rs.55.8057, 111.6114, 223.223 and 1116.114 crores calculated on the basis of minimum support price Rs. 1320/- fixed by the government (Table 6.4 to 6.5).

Mustard (*Brassica campestris*)

Loss of mustard yield in (*Brassica campestris*) from 48µg/m^3 of ground level ozone affecting 5%, 10%, 20% or the entire area of mustard crop amounts to 0.0114, 0.0228, 0.0457 and 0.2284 million tonnes of yield loss, which translates into an economic loss of Rs. 13.7060, 27.4120, 54.8240 and 274.1202 crores calculated on the basis of minimum support price Rs. 1200/- fixed by the government (Table 6.4 to 6.5).

These are rather conservative guesstimates, as they do not include loss of fodder and crop residues, which are extremely vital inputs in maintaining fertility of agricultural fields. The yield loss on account of ground level ozone across the entire range of agricultural commodities in the country and the corresponding economic loss may be significantly high.

Table 6.4: Crop statistics for wheat, moong and mustard.

Crop area / Production / Support price	Name of crop		
	Wheat (*Triticum aestivum*)	Moong (*Phaseolus aureus*)	Mustard (*Brassica campestris*)
Total area under cultivation (Million hectare)	26.65	6.475	5.50
Total production (Million tonne)	72.30	5.275	5.175
Minimum support price per quintal (Rupees)	610.00	1320.00	1200.00

*Source: ES, 2002-2003.

Table 6.5: Estimated yield and economic loss for wheat (*Triticum aestivum*), moong (*Phaseolus aureus*) and mustard (*Brassica campestris*) from 48 $\mu g/m^3$ of ground level ozone.

Crop	Regression equation (Y = Percentage yield loss and x = concentration of ozone)	Assumed percentage of total crop area suffering from ozone							
		5% of cultivated area		10% of cultivated area		20% of cultivated area		Total cultivated area	
		Yield loss (Million of tonne)	Economic loss (Rs. crore)	Yield loss (Million tonne)	Economic loss (Rs. crore)	Yield loss (Million tonne)	Economic loss (Rs. crore)	Yield loss (Million tonne)	Economic loss (Rs. crore)
Wheat	Y=0.0831x +0.8219	0.1594	92.4808	0.3189	184.962	0.6378	369.923	3.1890	1849.616
Moong	Y= 0.2637x+3.7213	0.0450	55.8057	0.0901	111.6114	0.1802	223.2228	0.9008	1116.1140
Mustard	Y=0.1016x-0.8981	0.0114	13.7060	0.0228	27.4120	0.0457	54.8240	0.2284	274.1202

In the absence of any similar study, it is difficult to compare the guesstimates of crop loss in respect of above three crops. However, a close examination of wheat yield and fertilizer input data for the period from 1991-92 to 2002-03 reveal that wheat yield has not increased with the increase rate of fertilizer input. A significant divergent trend between the percentage increase in fertilizer consumption and percentage increase in wheat yield (Figure 6.1) shows that from 1998-99 to 2002-03 the rate of growth in wheat production has progressively lagged behind the rate of increase in fertilizer consumption.

Figure 6.1: A comparison of per hectare percentage increase in fertlizer consumption and wheat production in India, 1991-92 - 2002-03
(Base year 1990-91)
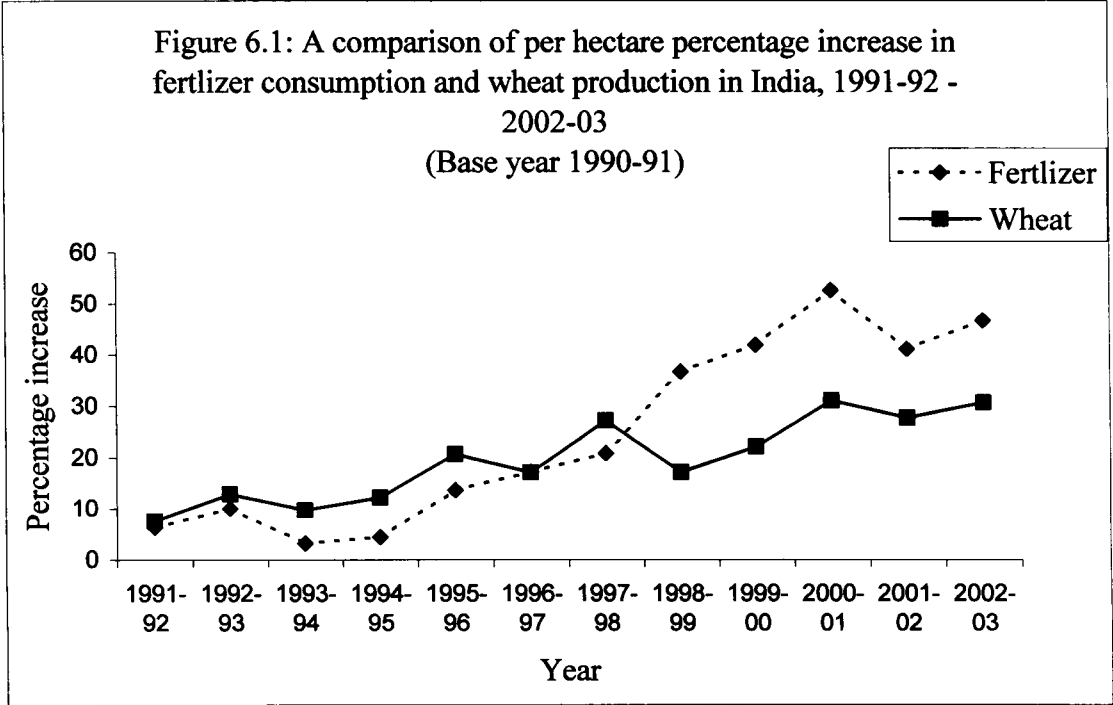
Source: ES, 2002-2003; FAI, 1999.

The exact reasons for the negative wheat yield are not known. However, it appears most likely that due to the adverse environmental conditions including air pollution, annual wheat yield, in spite of increasing use of fertilizers and other agricultural inputs, has stagnated. In future, air pollution especially ground level ozone is likely to increase and may become a serious challenge for increasing agricultural yields in the country.

Chapter-VII

Summary and Conclusions

Summary and Conclusions

Rapid industrialisation, urbanisation and economic development have created serious problems of air pollution in many countries including India. Air pollution kills more than 2.7 million people annually, of which over 90 per cent of such deaths occur in developing countries and two-third of them in Asia (UNDP, 1998). Air pollutants not only affect human health adversely, but also have serious consequences for agricultural and horticultural crops. Agriculture - the main driver of economic growth in developing countries including India, apart from being critically important for food security - is threatened by growing air pollution (Marshall, 2002). Ground level ozone is one of the most damaging phytotoxic gaseous air pollutants known to cause serious damage to agricultural crops, trees and natural ecosystems (Emberson *et al.*, 2001; Mauzerall and Wang, 2001; Oksanen and Holopainen, 2001; Prather *et al.*, 2003).

The present study was undertaken in field and fumigation condition to determine the effectiveness of ethylene diurea (EDU) in preventing ozone damage in wheat (*Triticum aestivum*), moong (*Phaseolus aureus*), mustard (*Brassica campestris*) and paalak (*Spinacia oleracea*).

The important findings are as follows:

Ground Level Ozone at Delhi and Faridabad

1. Measurement of ground level ozone in the ambient environment was carried at eight field sites (Bakoli, S.College, J. Temple, Tilak Bridge, JNU, Badarpur, DPS-Faridabad and IOC) between May to July, 1998. The average hourly ozone concentration was 38.46μg/m^3 at Bakoli (S1), 37.77μg/m^3 at S.College (S2), 35.72μg/m^3 at J.Temple (S3), 44.15μg/m^3 at Tilak Bridge (S5), 38.21μg/m^3 at JNU (S6), 50.20μg/m^3 at Badarpur (S7), 41.67μg/m^3 at DPS-Faridabad (S8) and 38.75μg/m^3 at IOC (S9)

2. During January to April-1999, the ground level ozone measurements were carried out at nine sites (Bakoli, S.College, J. Temple, Libaspur, JNU, Badarpur, IOC, CRI and AIIMS). The average hourly ozone concentration was 87.57μg/m^3 at Bakoli (S1), 83.01μg/m^3 at S.College (S2), 69.07μg/m^3 at

189

J.Temple (S3), 91.70μg/m^3 at Libaspur (S4), 104.74μg/m^3 at JNU (S6), 158.33μg/m^3 at Badarpur (S7), 70.05μg/m^3 at IOC (S9), 89.41μg/m^3 at CRI (S10) and 85.38μg/m^3 at AIIMS (S11).

3. A comparison of ground level ozone concentration recorded at individual sites with the standards prescribed by different agencies show that the hourly ozone concentration at different sites during January to April, 1999 exceeded 1-hr standard prescribed by WHO (76 ppb), Canada (82 ppb), EU (80 ppb) and Japan (60 ppb). Almost at all sites ozone levels exceeded the 8-hr EU standard (40 ppb) for vegetation. The ozone values at S4 and S10s site were violated the 1-hr Japanese standard on about 25% and 8% occasions respectively. At site S7, which is one of the most polluted sites, the 1-hr ozone standard prescribed by WHO, Canada, EU and Japan were violated on 40%, 25%, 31% and 80% occasions respectively.

4. Values of ground level ozone concentration at different field sites invariably exceeded or closely approached the critical ozone level based on AOT40 index (accumulated exposure over a threshold of 40ppb), which was estimated at 90 μg/m^3 and 80 μg/m^3 for wheat and field bean respectively for Europe.

Effect of Ethylene diurea (EDU) on Crop Plants

The present study was carried out with four crops viz., two summer crops (*Phaseolus aureus* var. PS-16 and *Spinacea oleracea* var. all green) and two winter crops (*Triticum aestivum* var. HD-2329 and *Brassica campestris* var. Pusa Jai Kisan) at eleven field sites were spread over Delhi (seven sites) and Faridabad (four sites). Twelve pots of each species (three plants in each pot) were transferred to each field site as per their growing season and one set consisting of twelve pots in respect of each crop was maintained in the ecological garden of SES, JNU, to serve as control for comparison.

Experimental studies on controlled fumigation were carried out with 150 μg/m^3 of ozone as per the treatment schedule. The 30day old plants (E1 set- eight pots each with three plants) and 50day old plants (E2 set- eight pots each with three plants) were chosen to validate field observations. The E2 set was meant to determine the effect of prophylactic treatments of EDU on crop plants against ozone damage.

Plants of four pots in field and fumigation studies were given EDU treatment (600 ml of 400 ppm solution) while the remaining pots were irrigated with equal volume of water as per the treatment schedule (at 10 days interval).

The ground level ozone was monitored during February-2003 to ascertain the background ozone concentration at JNU. The average hourly ozone concentration was 73.5μg/m^3 and the maximum and minimum concentration was 174.44 μg/m^3 and 5.88 μg/m^3 respectively.

Wheat (*Triticum aestivum*)

5. The percentage difference in the performance of EDU treated and non-treated plants at individual sites shows that the difference in culm length was between 6.45-8.89%; shoot biomass 13.35-27.78%; root length 6.84-11.65%; root biomass 31.35-43.36%; spikes per plant 4.17-12.50%; spike length 6.51-13.09%; grains per spike 22.61-28.95%; grain weight per plant 6.22-14.39%; total chlorophyll 8.68-17.78% and ascorbic acid content 11.45-18.29%. The inter-site concentration of ground level ozone varied between 69.07-158.33μg/m^3. Plants with EDU and without EDU from sites with relatively high pollution load (e.g., site-4 and site-7) exhibited significant reduction in culm length, shoot biomass, root length, root biomass, spikes per plant, spike length, grains per spike, grain weight per plant, total chlorophyll and ascorbic acid content as compared to the performance of plants from low pollution sites.

6. The regression equations were developed between the ground level ozone concentration (X) and percentage reduction in different parameters (Y) of *Triticum*. A good correlation (r≥ ±0.5) was observed between ground level ozone concentration and the percentage reduction in spike length (Y = 0.0732x + 0.9427; r = + 0.8020), grains per spike (Y = 0.0546x + 19.725; r = +0.7408), grain weight per plant (Y = 0.0831x + 0.8219; r = +0.7136), root length (Y = 0.0369x + 5.1931; r = +0.6255), root biomass (Y = 0.0748x + 30.496; r = +0.6176), culm number (Y = 0.0633x + 12.328; r = +0.5973), spikes per plant (Y = 0.0609x + 2.001; r = +0.5925), culm length (Y = 0.017x + 5.7935; r = +0.5743) and ascorbic acid (Y = 0.0572x + 7.8689 ; r = +0.4721), total

chlorophyll (Y = 0.0547x + 7.6906; r = +0.4079) and shoot biomass (Y = 0.0684x+14.42; r = +0.3667) found to be weekly correlated (r < ± 0.5).

7. The difference between EDU treated and non-treated plants in respect of culm length, shoot biomass, root length, root biomass, grains per spike, grain weight per plant, total chlorophyll and ascorbic acid was statistically significant at P ≤ 0.01 level. The difference with regard to spikes per plant and spike length were also statistically significant at P ≤ 0.05 level.

8. The percentage difference in the performance of EDU treated and non-treated plants fumigated with 150 μg/m³ of ozone concentration in respect of culm length was 31.45%; shoot biomass 30.40%; root length 14.06%; root biomass 25.67%; spikes per plant 25.82%; spike length 14.32%; grains per spike 26.20%; grain weight per plant 25.82%; total chlorophyll 21.67% and ascorbic acid content 2.425%.

Moong (*Phaseolus aureus*)

9. The performance of *Phaseolus aureus* plants grown with EDU and without EDU at field sites show that the EDU treated plants were better as compared to the plants grown without EDU. The percentage difference in the performance of EDU treated plants at individual sites shows that the difference in shoot length was 2.32-10.11%; shoot biomass 8.61-15.17%; root length 3.07-6.40%; root biomass 8.69-15.38%; pods per plant 30.35-42.30%; pod length 3.94-10.34%; seeds per pod 1.68-13.12%; seed weight per plant 10.14-17.80%; total chlorophyll 8.14-14.18% and ascorbic acid 10.31-15.21%. The inter-site concentration of ground level ozone varied between 35.72-50.20μg/m³. Plants grown with and without EDU with relatively high pollution sites (e.g., site-7) exhibited significant reduction in shoot length, shoot biomass, root length, root biomass, pods per plant, pod length, seeds per pod, seed weight per plant, total chlorophyll and ascorbic acid content as compared to performance of plants from low pollution sites.

10. The regression equations were developed between ground level ozone concentration (X) and percentage reduction in different parameters (Y) of

Phaseolus. A good correlation was observed between ground level ozone concentration and the percentage reduction in total chlorophyll ($Y = 0.3817x - 5.3715$; $r = +0.8228$) and ascorbic acid ($Y = -0.3312x + 25.963$; $r = -0.7539$), week correlation with shoot length ($Y = -0.2839x + 17.007$; $r = -0.4943$), seed weight per pod ($Y = 0.2637x + 3.7213$; $r = +0.4799$), shoot biomass ($Y = -0.2134x + 20.328$; $r = -0.4548$), seeds per pod ($Y = 0.394x - 7.4596$; $r = +0.4461$), pod length ($Y= 0.1929x - 0.056$; $r = + 0.3499$) and pods per plant $Y = -0.266x + 44.233$; -0.3133) and root biomass ($Y = 0.1239x + 15.6293$; $r = +0.1766$) and root length ($Y = 0.0154x + 4.3524$; $r = +0.0536$) found to be weekly correlated.

11. The difference between EDU treated and non-treated plants in respect of shoot length, pods per plant and total chlorophyll was statistically significantly at $P \leq 0.01$ level, the difference with regard to root biomass and ascorbic acid content were also statistically significant at $P \leq 0.05$ level and shoot biomass, root length, pod length, seeds per pod and seed weight per plant were found to be statistically insignificant.

12. The percentage difference in the performance of EDU treated and non-treated plants fumigated with 150 $\mu g/m^3$ of ozone concentration in respect of shoot length was 12.79%; shoot biomass 18.92%; root length 29.16%; root biomass 22.38%; pods per plant 14.87%; pod length 20.51%; seeds per pod 10.86%; seed weight per plant 31.95%; total chlorophyll 42.02% and ascorbic acid 29.03%

Mustard (*Brassica campestris*)

13. The performance of *Brassica campestris* plants grown with EDU and without EDU at field sites show that the EDU treated plants were better as compared to the plants grown without EDU. The percentage difference in the performance of EDU treated and non-treated plants at individual sites shows that the difference in shoot length was between 6.20-25.80%; number of branches 6.30-16.50%; shoot biomass 15.42-24.09%; root length 8.33-14.32%; root biomass 15.51-22.94%; pods per plant 10.33-16.73%; pod length 15.82-19.77%; seeds per pod 9.84-17.91%; seed weight per plant 4.20-16.05%; total chlorophyll 6.88-19.56%

and ascorbic acid 10.87-16.29%. The inter-site concentration of ground level ozone varied between 69.07-158.33μg/m^3. Plants grown with and without EDU with relatively high pollution sites (e.g., site-7) exhibited significant reduction in shoot length, number of branches, shoot biomass, root length, root biomass, pods per plant, pod length, seeds per pod, seed weight per plant, total chlorophyll and ascorbic acid content as compared to performance of plants from low pollution sites.

14. The regression equations were developed between the ground level ozone concentration (X) and percentage reduction (Y) in different parameters of *Brassica*. A good correlation was observed between ground level ozone concentration and the percentage reduction in pod length (Y = 0.0408x + 13.244; r = +0.7859), number of seeds per pod Y = 0.0837x + 4.1718; r = +0.6834), shoot biomass (Y = 0.0836x +10.201; r = +0.6579), seed weight per plant (Y = 0.1016x - 0.8981;r = +0.6164), root biomass (Y = 0.0663x +11.719; r = +0.6110) and root length (Y = 0.0343x + 7.8784;r = +0.5480) and pods per plant (Y = 0.0408x + 9.3217; r = +0.4994), number of branches per plant (Y=0.0596x+6.0532; r = +0.4577), total chlorophyll (Y = 0.0801x + 4.2745; r = +0.3984) ascorbic acid content (Y = 0.0151x+11.934; r= +0.1735) and shoot length (Y= 0.006x +11.803; r = +0.0247) were found to be weekly correlated

15. The difference between EDU treated and non-treated plants in respect of shoot biomass, root length, root biomass, pods per plant, pod length, seeds per pod and average seed weight per plant was statistically significant at P ≤ 0.01 level, the difference with regard to shoot length, number of branches, total chlorophyll were also statistically significant at P ≤ 0.05 level.

16. The percentage difference in the performance of EDU treated and non-treated plants fumigated with 150 μg/m^3 of ozone concentration in respect of shoot length was 15.91%; number of branches -13.52%; shoot biomass 26.34%; root length 25.20%; root biomass 24.94%; pods per plant 22.84%; pod length 22.72%; seeds per pod 21.00%; seed weight per plant 12.63%; total chlorophyll 41.88% and ascorbic acid 1.62%.

Paalak (*Spinacia oleracea*)

17. Performance of *Spinacia oleracea* plants grown with EDU and without EDU at field sites show that the EDU treated plants were better as compared to the plants grown without EDU. The percentage difference in the performance of EDU treated and non-treated plants at individual sites shows that the difference in leaf number was between 6.78-17.35%; number of senescent leaves -47.22 to -29.60%; leaf area 8.75-26.14%; root biomass 1.72-13.33%; plant biomass 11.76-26.32%; total chlorophyll 8.57-10.06% and ascorbic acid content 6.10-9.75%. The inter-site concentration of ground level ozone varied between 35.72-50.20µg/m^3. Plants grown with and without EDU at sites with relatively high pollution load (e.g., site-7) exhibited significant reduction in leaf number, number of senescent leaves, leaf area, root biomass, plant biomass, total chlorophyll and ascorbic acid content as compared to the performance of plants from low pollution sites.

18. The regression equations were developed between the ground level ozone concentration (X) and percentage reduction (Y) in different parameters of *Spinacia*. A good correlation was observed between ground level ozone concentration and the percentage reduction in leaf area (Y = 4.9424x -166.49; r = +0.7888), plant biomass (Y = 3.299x-107.57; r = + 0.6882) and total chlorophyll (Y = -0.2935x + 20.542; r = - 0.6388) and ascorbic acid (Y = 0.7115x-18.873; r = +0.4774), root biomass (Y = -1.1644x + 51.117; r = 0.3307), number of leaves (Y = 0.7091x - 16.189; r = +0.1957) and number of senescent leaves (Y = -0.2658x + 48.896; r = - 0.0499) were found to be weekly correlated.

19. The difference between EDU treated and non-treated plant in respect of plant biomass was statistically significant at P ≤ 0.01. The difference with regard to level and number of senescent leaves were also statistically significant at P ≤ 0.05 level and root biomass, leaf area, total chlorophyll and ascorbic acid were found to be statistically insignificant.

20. The percentage difference in the performance of EDU treated and non-treated plants fumigated with 150 µg/m^3 of ozone concentration in respect of leaf number was 33.30%; number of senescent leaves -71.46%; leaf area 30.77%; root biomass 21.24%; plant biomass 29.46%; total chlorophyll 38.66% and ascorbic acid content 14.10%.

21. On the basis of the performance of different parameters of *Phaseolus* and *Spinacia* were found to be relatively more sensitive to ozone as compared to *Triticum* and *Brassica*. For example, *Phaseolus* and *Spinacia*, grown as summer crops, the yield loss was 14% and in *Triticum* and *Brassica* grown as winter crops, was about 8% grown in environment having 40.43 µg/m^3 and 93.25 µg/m^3 of ozone during summer and winter periods respectively.

The four crop plants represent the following order of ozone sensitivity:

Phaseolus aureus > Spinacia oleracea > Triticum aestivum > Brassica campestris.

22. Among different parameters, grain/seed weight per plant, spike/pod length, grains per spike/seeds per pod and total chlorophyll in *Triticum, Phaseolus* and *Brassica* plants, and leaf area, plant biomass and total chlorophyll in *Spinacia oleracea,* exhibit a good correlation with ground level ozone. The parameters viz., grain/seed weight per plant, spike/pod length, grains per spike/seeds per pod and total chlorophyll for *Triticum, Phaseolus* and *Brassica* and leaf area, plant biomass and total chlorophyll for *Spinacia* may be used for screening ozone sensitivity of crop cultivars.

23. On the basis of the results of this study it may be suggested that two or more prophylactic treatments of EDU may prove more beneficial in protecting *Triticum, Phaseolus Brassica* and *Spinacia oleracea* from ozone damage.

24. EDU was found to be effective in preventing damage from ground level ozone in wheat (*Triticum aestivum*), moong (*Phaseolus aureus*), mustard (*Brassica campestris*) and paalak (*Spinacia oleracea*) at Delhi and Faridabad, and also in experimental plants subjected to ozone exposure in fumigation chambers.

25. The ground level ozone reported from nine widely separated stations in the country viz., Delhi, Varanasi, Chandigarh, Ahmedabad, Pune, Agra, Bhubaneswar, Berhampur (Orissa) and Cochin was $53.67\mu g/m^3$; $48.00\ \mu g/m^3$; $62.32\mu g/m^3$, $46.15\mu g/m^3$, $31.42\mu g/m^3$, $60.37\mu g/m^3$, $61.54\mu g/m^3$, $46.45\mu g/m^3$ and $23.13\mu g/m^3$. The average ozone value for the nine stations is $48.111\ \mu g/m^3$.

26. In the absence of any better data $48\mu g/m^3$ was taken as the average value for estimating yield loss. The extent of area of each crop suffering from ozone build up is also not certain. Hence, crop loss scenarios have been developed for 5%, 10%, 20% and total cultivated area of the entire area under cultivation of wheat (*Triticum*), moong (*Phaseolus*) and mustard (*Brassica*) crops for computing yield loss and corresponding economic loss from ground level ozone.

27. Loss of yield in wheat (*Triticum aestivum*) from $48\mu g/m^3$ of ground level ozone affecting 5%, 10%, 20% or the entire area of wheat crop amounts to 0.1594, 0.3189, 0.6378 and 3.1890 million tonnes, which translates into an economic loss of Rs. 92.4808, 184.962, 369.923 and 1849.616 crores.

28. Loss of yield in moong (*Phaseolus aureus*) from $48\mu g/m^3$ of ground level ozone affecting 5%, 10%, 20% or the entire area of moong crop amounts to 0.0450, 0.0901, 0.1802 and 0.9008 million tonnes of yield loss, which translates into an economic loss of Rs.55.8057, 111.6114, 223.223 and 1116.114 crores.

29. Loss of yield in mustard (*Brassica campestris*) from $48\mu g/m^3$ of ground level ozone affecting 5%, 10%, 20% or the entire area of mustard crop amounts to 0.0114, 0.0228, 0.0457 and 0.2284 million tonnes of yield loss, which translates into an economic loss of Rs. 13.7060, 27.4120, 54.8240 and 274.1202 crores.

The results of the present study are of considerable practical significance. The study convincingly demonstrates that build up of ground level ozone pollution in urban and peri-urban areas of Delhi and Faridabad. The results of this study are in line with the data reported in literature on crop loss from ozone pollution. This has also provided useful information on the role of ethylene diurea (EDU - ozone specific chemical protectant) in protecting crops plants.

In the coming years ground level ozone may become an important factor on account of growing emission of ozone forming precursors due to rapid industrialisation and economic development and shrinking area of agricultural land. Therefore, protection of agricultural crops from ozone damage deserves serious attention. To minimise loss of agriculture production the following actions is suggested for priority action.

1. Develop systematic database on ground level ozone and other air pollutants for agricultural areas.

2. Dose-response study on crop plants covering important cultivars of agricultural crops grown in different agro-climatic zones.

3. Determination of critical levels of air pollutants for individual crops in different agro-climatic zones.

4. Evaluation of different potential plant protectants for effective protection of crop plants from air pollution damage.

5. Reduction of ozone forming precursors by devising appropriate national and regional strategies and policy measures including their effective implementation.

References

References

Adams, R. M., Glyer, J. D., Jhonson, S.L. and McCarl, B. A. (1989). A reassessment of the economic effects of ozone on US agriculture. *J. of Air Pollution Control Association*, **39**, 353-361.

Adedipe N. O. and Ormrod D. P. (1972). Hormonal regulation of ozone phytotoxicity in *Raphanus sativus. Zeitschrift fur Pflanzenphysiologie*, **68**, 254-258.

Adomait, E. J., Ensing, J. and Hofstra, G. (1987). A dose-response function for the impact of O₃ on Ontario-grown white bean and an estimate of economic loss. *Canadian Journal of Plant Science*, **67**, 131-136.

Aggarwal, M. (1993). Characterization of ozone levels in Delhi and evaluation of its phytotoxic effects. Ph. D. Thesis, Submitted to Jawaharlal Nehru University, New Delhi.

Agrawal, M., Nandi, P. K. and Rao, D. N. (1982). Effect ozone and sulphur dioxide pollutants separately and in mixture on chlorophyll and carotenoid pigments of *Oryza sativa. Water, Air and Soil* Pollution, **18**, 449-454.

Air Quality at Major Traffic Intersections of Delhi (NAAQMS/11/1998-99). Central Pollution Control Board, Delhi. March-1999.

Air Quality in Delhi (NAAQMS/17/2000-2001). Central Pollution Control Board, Delhi. March-2001.

Allmendinger, D. G., Miller, V.L. and Jhonson, F. (1954). The control of fluorine scorch of gladiolus with foliar dust and sprays. *Proc. of the American Soc. for Horti. Science*, **56**, 427-432.

Ambient Air Quality - Status and Statistics (1993 and 1994). National ambient Air Quality Monitoring Series: NAAQMS/ 7/1995-96, Central Pollution Control Board, Delhi, 1996.

Amuroso, M., Witz, G. and Brennan, E. (1986). Inhibition of superoxide anion radical production in stimulated phagocytic cells by N-(2-(2-oxy-1-imidazolidinyl)-ethyl)-N'-phenyl urea. *Soc. Toxicol. Ann. Meeting*, (Abstract)

Andreae, M. O. (1991). Biomass burning: Its history, use, and distribution and its impact on environmental quality and global quality. **In**: Levine, J. S. (Ed.) *Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications.* 3-21. MIT Press, Cambridge, Mass., 1991.

Ashmore, M. R. (2002). Effects of oxidants at the whole plant and community level. **In** : J.N.B. Bell and M. Treshow. (Eds) *Air Pollution and Plant Life*, 407-416. John Wiley and Sons. Ltd. England.

Ashmore, M. R. and Bell, J. N. B (1991). The role of ozone in global change. *Annals of Botany*, **67 (Supplement 1)**, 39-48.

Ashmore, M. R., Bell, J. N. B. and Mimmack, A. C. (1988). Crop growth along a gradient of ambient air Pollution, *Environmental Pollution*, **53,** 99-102.

Ashmore, M. R., Bell, J. N. B. and Rutter, J. (1985). The role of ozone in forest damage in Westr Germany. *Ambio*, **14,** 81-87.

Ashmore, M. R. and Marshall, F. M. (1998). Direct impacts of pollutants gases on crops and forests. **In**: Kuylensierna, J. and Hicks, K. (Eds.) Regional Air Pollution in Developing Countries. Background Document for Policy Dialogue, Bangkok, March, 1998.

Ashmore, M. R. and Wilson, R. B. (1993) (Eds.). *Critical Levels of Air Pollutants for Europe*. Department of Environment, London.

Astorino, G., Margani, I., Tripodo, P. and Manes, F. (1995). The response of *Phaseolus vulgaris* L. cv. Lit to different dosages of anti-ozonant ethylenediurea (EDU) in relation to chronic treatment with ozone. *Plant Science*, **111,** 237-248.

Auto Fuel Policy (APR),(2002). Ministry of Petroleum and Natural Gas, Government of India, New Delhi.

Bambawale, O. M. (1986). Evidence of ozone injury to a crop plant in India. *Atmospheric Environment*, **20,** 1501-1503.

Barnes J. D., Davison, A. W. and Booth, T. A. (1988). Ozone accelerates structural degradation of epicuticular wax on Norway spruce needles. *New phytologist*, **110,** 309-318.

Bell, J. N. B., Marshall, F. M., Agrawal, M., Varshney, C. K., Batty, K. and Ashmore, M. R. (2000). Air pollution-an unrecognised threat to the nutrition of the urban poor in the developing world? Air and Noise Pollution, **59,** 59-64.

Bennedict, H.M., Miller, C.J., Smith, J.S. (1973). Assessment of Economic impact of air pollutants on vegetation in the United States: 1969 to 1971, Menlo Park. CA: Stanford research Institute Available fron NITS, Springfield. VA; PB-224818.

Bennett, J. P., Oshima, R. J. and Lippert, L. F. (1979). Effect of ozone and dry matter portitioning in pepper plants. *Environmental and Experimental Botany*, **19,** 33-39.

Bialobok, S. (1984). Controlling atmospheric pollution. **In**: Air Pollution and Plant Life. M. Treshow (Ed). John Wiley and Sons, New York, 1994.

Bielke, S. (1987). Problems associated with long-range transport of air pollution. **In**: S. Sadorani (Ed.) *Regional and Long RangeTransport of Air Pollution*, Elsevier, Amsterdam, 1-42.

Bisessar, S. (1982). Effect of ozone, antioxidant protection and early blight of potato in the field. *Journal of American Society for Horticultural Science*, 107, 597-599.

Bisessar, S. and Palmer, K. (1984). Ozone, antioxidant spray and *Meloidogyne hapla* effects on tobacco. *Atmospheric Environment*, 18, 1025-1027.

Boyd, A. W., Wills, C. and Cyr, R. (1970). New determination of stoichiometric of the iodometric methods for ozone analysis at pH 7.0. *Analytical Chemistry*, 42, 670-672.

Brawn, K. and Fridovich, I (1981). DNA strand scission by enzymatically generated to oxygen radicals. *Arch. Biochem. Biophys.* 206, 414-419.

Brennan, E.G., Clarke, B. B., Greenhalgh-Weidman, B. and Smith, G. (1990). An assessment of the impact of ozone on field grown crops in New Jersey using the EDU method : part-2-soybean (*Glycine max* L. Merr). *Environmental Pollution*, 66, 361-373.

Brennan, E., Leone, I. A. and Clarke, B. (1987). EDU: a chemical for evaluating ozone foliar injury and yield reduction in field grown crops. *International Journal of Tropical Disease*, 5, 35-42.

Brunschon-Harti, S., Fangmeier, A. and Jager, H. J. (1995a). Influence of ozone and ethylene diurea (EDU) on growth and yield of bean (*Phaseolus vulgaris* L.) in open top field chambers. *Environmental Pollution*, 90 (1), 89-94.

Brunschon-Harti, S., Fangmeier, A. and Jager, H. J. (1995b). Effects of ethylene diurea (EDU) and ozone on the antioxidative systems in bean (*Phaseolus vulgaris* L.). *Environmental Pollution*, 90 (1), 95-103.

Byers, D. H. and Saltzman, B. E., (1959). Determination of O_3 in air by neutral and alkaline iodide procedure. *Adv. Chem Ser.*, 21, 93-101.

Carmichael, G. R., Ferm, M., Thongboonchoo, N., Woo, J. H., Chan, L. Y., Murano, K., Viet, P. H., Mossberg, C., Bala, R., Boonjawat, J., Upatum, P., Mohan, M., Adhikary, S. P., Shrestha, A. B., Pienaar, J. J., Brunke, E. B., Chen, T., Jie, T., Guoan, D., Peng, L. C., Dhiharto, S., Harjanto, H., Jose, M., Kimani, W., Kirouane, A., Lacaux, J. P., Richard, S., Barturn, O., Cerda, J. C., Athayde, A., Tavars, T. Cotrina, J. S. and Bilici, E. (2003). Measurements of sulfur dioxide, ozone and ammonia concentrations in Asia, Africa, and South America using passive samplers. *Atmospheric Environment*, 37, 1293-1308.

Carnahan, J., Jenner, E. and Wat, E. (1978). Prevention of ozone injury to plants by a new protectant chemical. *Phytopathology*, 68, 1225-1229.

Central Scientific Instruments Organisation (CSIO). (1992). Ozone concentrations in ground level air in Chandigarh.

Chameides, W. L., Kashibhatla, P. S., Yienger, J. and Levy, H (1994). Growth of continental-scale metro-agro-plexes, regional pollution, and world food production. *Science.* **264**, 74.

Chameides, W. L. and Walker, J.C.G. (1976). A time-dependent photochemical model for ozone near the ground. *J. Geopys. Res.*, **81**, 413-420.

Chanway, C. P. and Runeckles, V. C. (1984). Effect of ethylene diurea (EDU) on ozone tolerance and superoxide dismutase activity in bush bean. *Environmental Pollution*, **35**, 49-56.

Chatfield, R. and Harrison, H. (1976). Ozone in the remote troposphere; mixing versus photochemistry. *J. Geophys. Res.*, **81**, 421-423.

Chen, Y.M., Lucas, P.W. and Wellburn, A.R. (1990). Relationships between foliar injury and changes in antioxidants levels in red spruce exposed to acid mists. *Environmental Pollution*, **66**, 351-360.

Clarke, B. B., Greenhalgh-Weidman, B. and Brennan, E. G. (1990). An assessment of the impact of ambient ozone on field grown crops in New Jersey using the EDU method: part-1-white potato (*Solanum tuberosum*). *Environmental Pollution*, **66**, 351-360.

Clarke, B., Henninger, M. and Brennan, E. (1978). The effect of two antioxidants on foliar injury and tuber production in 'Norchip' potato plants exposed to ambient oxidants. *Plant Disease Reporter*, **62**, 715-717.

Clarke, B., Henninger, M. and Brennan, E. (1983). An assessment of potato losses caused by oxidant air pollution in New Jersey. *Phytopathology*, **73**, 104-108.

Coffey, P. E. and Stasiuk, W. N. (1975). Evidence of atmospheric transport of ozone into urban areas. *Environmental Science and Technology*, **9 (1)**, 59-62

Colbeck, I. and Mackenzie, A. R. (1994). Air pollution by photochemical oxidants. *Air Quality Monographs*, Vol-1, Published by Elseiver Science, Amsterdam, The Netherlands.

Cowling, D. W. and Lockyer, D. R. (1978). The effect of SO_2 on *Lolium perenne* L. grown at different levels of sulphur and nitrogen nutrition. *J. of Exp. Bot.*, **29**, 257-265.

Crutzen, P. J. (1974). Photochemical reaction initiated by and influencing ozone in unpolluted tropospheric air. *Tellus*, **26**, 47-57.

Crutzen, P. J. and Andreae, M. O. (1990). Biomass burning in the tropics: Impact on atmospheric chemistry and biogeochemical cycles. *Science*, **250**, 1669-1678.

Crutzen, P. J. and Carmichael, G. R. (1993). Modeling the influence of fires on atmospheric chemistry. **In**: Crutzen, P.J. and Goldammer, J.G. (Eds.) *Fire in*

the *Environment: The Ecological, Atmospheric, and Climatic Importance of Vegetation Fires*, 89-106. John Wiley, New York.

Crutzen, P. J., Delaney, A., Greenberg, J., Hagenson, P., Heidt, L., Lueb, R., Pollock, W., Seiler, W., Wartburg, A. and Zimmerman, P.H. (1985). Tropical chemical composition measurement in Brazil during the day and dry season. *J. of Atmospheric Chemistry*, **2**, 233-256.

Crutzen, P. J., Lawrence, M. G. and Poschi, U. (1999). On the background Photochemistry of tropospheric ozone. *Tellus*, **51**, 123-146.

Crutzen, P. J. and Zimmerman, P. H. (1991). The changing chemistry of troposphere. *Tellus*, **26 (AB)**, 136-15.

Darley, E.F., Stefens, E.R., Middleton, J.T. and Hanst, P.L (1959). Oxidant plant damage from ozone-olefins reactions. *Int. Air Pollut.*, **1**, 155-162.

Daines, R., Leone, I. and Brennan, E. (1960). Air pollution as it affects agriculture in New Jersey. *New Jersey Agricultural Experiment Station Bulletin*, **794**, 1-14.

Darrall, N. M. (1989). The effects of air pollutants on physiological processes in plants. *Plant, Cell and Environment*, **12**, 1-30.

Danielsen, E. F. (1968). Strtospheric-tropospheric exchange based on radioactivity, ozone and vorticity. *J. Atmos. Sci.*, **25**, 502-518.

deBauer, M. L., Tajeda, T. H. Manning, W. J. (1985). Ozone causes needle injury and tree decline in *Pinus hartwegii* at high altitudes in the mountains around Mexico City. *Journal of Air Pollution Control Association*, **35**, 838.

Derwent, R. G. and Jenkin, M. E. (1991). Hydrocarbons and the long-range transport of ozone and pan across Europe. *Atmospheric Environment*, **25A (8)**, 1661-1678.

Dutch, H.U. (1971). Photochemistry of atmospheric ozone. *Adv. Geophys.*, **15**, 219-322.

Economic Survey, 2001-2002 (ES), (2002). Government of India, Ministry of Finance and Company Affairs, Economic Division, New Delhi.

Economic Survey, 2002-2003 (ES), (2003). Government of India, Ministry of Finance and Company Affairs, Economic Division, New Delhi.

Economic Survey of Delhi 2001-2002 (ESD), (2002). Directorate of Economics and Statistics, Govt. of National Capital Territory of Delhi.

Elstner, E. F. and Osswald, W. (1984). Fichtsternben in "Reinfluftgebieten" struktur resistenzverlust. *Natruw. Undschau*, **37**, 52-61.

Emberson, L. D., Ashmore, M. R., Murray, F, Kuylenstierna, J. C. I., Percy, K. E., Izuta, T, Zheng, Y., Shimizu, H., Sheu, B. H., Liu, C. P., Agrawal, M., Wahid,

A., Abdel-Latif, N. M., van Tienhoven, M., de Bauer, L. I., Domingos M. (2001). Impacts of air pollutants on vegetation in developing countries. *Water, Air and Soil Pollution*, **130**: 107-118

Ensing, J., Hofstra, O. and Roy, R. C. (1985). The impact of ozone on peanut exposed in laboratory and field. *Phytopathology*, **75**, 429-432.

Fabian, P. and Pruchniewicz, P. G. (1977). Meridional distribution of ozone in the troposphere and seasonal variations. *J. Geophys. Res.*, **82**, 2063-2073.

Farage, P. K., Long, S. P., Lechner, E. G. and Baker, N. R. (1991). The sequence of change within the photosynthetic apparatues of wheat following short term approach to ozone. *Plant Physiology*, **95**, 529-535.

Feister, U. and Warmbt, W. (1987). Long-term measurement of surface ozone in German Democratic Republic. *Journal of Atmospheric chemistry*, **5**, 1-21.

Feister, U. and Warmbt, W. (1990). Surface ozone and meteorological predictors on a sub-regional scale. *Atmospheric Environment*, **25A**, 1781-1790.

Fertilizer Statistics (1998-1999). The Fetilizer Statistics of India (FAI), New Delhi, 1999.

Fieldhouse, D.J. (1978). Chemical control of ozone damage on watermelon. *Hortic. Sci.*, **13**, 343.

Finlayson-Pitts, B.J. and Pitts, J.N. (1999). Chemistry of upper and Lower Atmosphere. Academic Press, New York.

Fishman, J. and Crutzen, P.J. (1978). The origin of ozone in troposphere. *Nature*, **274**, 855-858.

Fishman, J., Solmon, S. and Crutzen, P.J. (1979). Observational and theoretical evidence in support of a significant in-situ photochemical sources tropospheric ozone. *Tellus*, **31**, 432-446.

Fletcher, R.A. Adedipe, N.O. and Ormrod, D.P. (1972). Abscisic acids protects bean leaves from ozone induced phytoxicity. *Canadian J. of Bot.*, **50**, 2389-2391.

Flower, D., Cape, J. N., Coyle, M., Smith, R. I., Hjellbrekke, A. G., Simpson, D., Derwent, R. G., Johnson, C. E. (1999). Modelling photochemical oxidant formation, transport, deposition and exposure of terrestrial ecosystems. *Environmental Pollution*, **100**, 43-50.

Foster, K. W., Guerard, J. P., Oshima, R. J., Bishop, J. C. and Timm, H. (1983). Differential ozone susceptibility of centennial russet and white rose potato as demonstrated by fumigation and antioxidant treatments. *American Potato Journal*, **60**, 127-39.

Fox, C. (1873). Ozone and antaozne, *J. & A. Churchil*, London.

Foyer, C., Descouvieres, P. and Kunert, K. (1994). Protection against oxygen radicals: an important defense mechanism studied in transgenic plants. *Plant Cell and Environment*, **17**, 507.523.

Freebairn, H. T. and Taylor, O. C. (1960). Prevention of plant damage from air-borne oxidizing agent. *Proc. of the Nat. Soc. for Horti. Science*, **76**, 693-699.

Furukawa, A., Katese, M., Usijima, T. and Totsuka, T. (1984). Inhibition of photosynthesis of Poplar species and sun flower by ozone. *Res. Rep. Natl. Inst. Environ. Stud. Jap.*, **65**, 77-86.

Gab, S., Hellpointner, E., Turner, W.V. and Korte, F. (1985). Hydroxy-methyl hydroperoxide and bis- (hydroxy-methyl)-peroxide from gas-phase ozonolysis of naturally occurring alkenes. *Letters to Nature*, **316**, 535-536.

Galbally, I. E., Miller, A. J., Hoy, R., Ahmet, D., Joynt, R. C. and Attwood, D. (1986). Surface ozone at rural sites in the Latrobe Valley And Cape Grim, Australia. *Atmospheric Environment*, **20**, 2403-2422.

Galanter, M., Levy II, H. and Carmichael, G. R. (2000). Impacts of Biomass burning on tropospheric CO, NOx and O_3. *Journal of Geophysical research*, **105(D5)**, 6633-6653.

Ganor, E., Beck, Y. and Donagi, A. (1978). Ozone concentration and meteorological condition in Tel-Aviv, 1975, *Atmospheric Environment*, **12**, 1081-1085.

Gatta, L., Mancino, L. and Fredrico, R. (1997). Translocation and persistence of EDU (ethylene diurea) in plants: the relationship of its role in ozone damage. *Environmental Pollution*, **96**, 445-452.

Gorbenkov-Germanov, D. S. and Kozalov, I. V. (1973). Mechanism of the decomposition of ozone in basic aqueous media. *Dokalady Acad. Nauk USSR*, **210**, 851-854. Plenum Publishing Corp., New York.

Gorbenkov-Germanov, D. S. and Kozalov, I. V. (1974). Inter decomposition products of ozone in basic aqueous media investigated by electron spin resonance. *Russian J. of Phy. Chem.*, **48**, 93-95.

Gorbenkov-Germanov, D. S., Vodop'yanova, N. M., Kharina, N. M. and Gorodnov, N. M. (1973). Oxidation of some saturated organic compounds initiated by the catalytic decomposition of ozone in alkaline solution. *Dokalady Acad. Nauk USSR*, **210**, 1121-1123. Plenum Publishing Corp., New York.

Grimes, H. D., Perkins, K. K. and Boss, W. F. (1983). Ozone degrades into hydroxyl radical under physiological conditions. A spin trapping study. *Plant Physio.*, **72**, 1016-1020.

Guderian, R., Tingey, D. T. and Rabe, R. (1985). Effects of photochemical oxidants on plants. **In:** Photochemical oxidants. Guderian, R. (Ed) Springer-Verlag, Berlin, 1985.

Gusten, H., Heinrich, G., Cvitas, T., Klasinc, L., Ruscic, B., Lalas, D. P. and Petrakis, M. (1988). Photochemical formation and transport of ozone in Athens, Greece. *Atmospheric Environment*, **22 (9)**, 1855-1861.

Haagen-Smit, A.J. and Fox, M.M. (1956). Ozone formation in photochemical oxidation of organical substances. *Ind. Eng. Chem. Res.*, **48**, 1484-1487.

Hakola, H., Joffre, S., Latilla, H. and Taalas, P. (1991). Transport, formation and sink processes behind surface ozone variability in North European conditions. *Atmospheric Environment*, **25A (8)**, 1437-1441.

Hartmannsgruber, R.W.A. and Claude, H. (1985). Opposite behaviour of ozone amount in troposphere and lower troposphere during the last years. **In:** C. Zerefos and A. Ghazi (Eds.). *Quadriennal Atmospheric Ozone Symposium.* 1984. Reidel, Dordrecht. 770-774.

Hassan, I.A. Ashmore, M.R. and Bell, J.N.B. (1995). Effect of ozone on radish and turnip under Egyptian field condition. *Environmental Pollution*, **89**, 107-114.

Hausloden, A. and Kunert, K. J. (1990). Effect of artificially enhanced levels of ascorbate and glutathione on the enzyme monohydroascorbate reductase, hydroascorbate reductase and glutathione reductase in spinach. *Plant Physiology*, **69**, 317-322.

Heagle, A. S. (1989). Ozone and crop yields. *Annual Review of Phytopathology*, **27**, 397-439.

Heagle, A.S., Body, D. E. and Pounds, E. K. (1972). Effects of ozone on yield of sweet corn. *Phytopathology.* **62**, 683-687.

Heagle, A. S., Heck, W. W., Lesser, V., Rawlings, J.O. and Mowry, F.L. (1986). Injury and yield response of cotton to chronic doses of ozone and sulphur dioxide. *Journal of Environmental Quality*, **15**, 375-382.

Heath, R. L. (1994). Biochemical mechanisms of pollutant stress. In Heck, W.W. Taylor, O.C. and Tingey, D.T. (Eds). *Assessment of crop loss form air pollutants*, 259-286. Elseiver Applied, New York.

Heck, W. C., Admas, R., Cure, W. W., Heagle, A. S., Heggestad, H. E., Kohat, R. J., Kress, L. W., Rawling, J. O. and Taylor, O. C. (1983). A re-assessment of crop loss from ozone. *Environmental Science and Technology*, **17**, 572A-581A.

Heck, W. W., Taylor, O. C., Adams, R., Bingham, G., Miller, J., Preston, E., and Weinstein, L. (1982). Assessment of crop loss from ozone. *Journal of Air Pollution Control Association*, **32**, 353-361.

Heck, W. W., Taylor, O. C., Cure, W. W., Rawlings, J. O., Zaragoze, L. J., Heagle, A. S., Heggested, H. E., Kohut, R. J., Kress, L. W., Temple, P. J. (1984). Assessing impacts of ozone on agriculture crops: II. Crop yield functions and alternative exposure statistics. *Journal of Air Pollution Control Association*, **34(8)**, 810-816.

Heck, W. W., Taylor, O. C. and Tingey, D. T. (1987). (Eds). *Assessment of Crop Loss from Air Pollutants*. Elsevier Applied Science Publishers, London.

Heck, W. W., Heagle, A. S. and Shriner, D. S. (1986). Effects on vegetation: Native crops, forests. In: A. C. Stern (Ed) *Air Pollution*, New York, Academic Press, Vol 6, 250-274.

Heggestad, H. E. (1988). Reduction in soybean seed yields by ozone air pollution. *APCA Note Book*, **38 (8)**, 1040-1041.

Heggested, H. E. and Bennett, J. H. (1984). Impact of atmospheric pollution on agriculture. In: M. Treshow (Ed) *Air Pollution and Plant Life*, John Willy and Sons Limited, New York, NY, USA.

Hellpointner, E. and Gab, S. (1989). Direction of methyl, hydroxy-methyl and hydroxy-ethyl hydroperoxide in air and precipitation. *Nature*, **337**, 631-634.

Hewitt, C. N., Kok, G. L. and Fall, R. (1990). Hydroperoxides in plants exposed to to ozone mediate air pollution damage to alkene emitters. *Nature*, **344**, 56-58.

Hindustan Times (HT) (1st August, 2003) (HT). Heat wave in Europe. Hindustan Times Ltd. 18-20, Kasturaba Gandhi Marg, New Delhi.

Hofstra, G., Littlejohns, D. A. and Wukasch, R. T. (1983). The efficacy of the antioxidant ethylene diurea (EDU) compared to carboxin and benomyl reducing yield losses from ozone in navy bean. *Plant Disease Reporter*, **62**, 350-352.

Hofstra, G., Wukasch, R. T. and Drexler, D. M. (1978). Ozone injury on potato foliage as influenced by the antioxidant ethylene diurea (EDU) and sulfur dioxide. *Canadian Journal of Plant Pathology*, **5**, 115-119.

Hoigne, J. and Badar, G. (1975). Ozonation of water: Role of hydroxy radicals as oxidising intermediates. *Science*, **190**, 782-783.

Hoigne, J. and Badar, G. (1976). The role of hydroxyl radical reaction in ozonation processes in aqueous solutions. *Water Res.*, **10**, 377-386.

Hough, A. M. and Derwent, R. G. (1990). Changes in the global concentration of tropospheric ozone due to human Activities. *Nature*, **344**, 645-653.

Hov, O. (1990). The role of nitrogen oxides in the long-range transport of photochemical oxidants. *The Science of the Total Environment*, **96**, 101.

India, 2002 - A Reference Annual. Publication Division, Ministry of Information and Broadcasting, Government of India, New Delhi.

India, 2003 - A Reference Annual. Publication Division, Ministry of Information and Broadcasting, Government of India, New Delhi.

International Cooperative Programme on Effects of Air Pollution on Natural Vegatation and Crops (ICP). (2002). Mills, G. (U.K.), Sanz, M. J. (Spain), Fischer, R. (Germany). UNECE, Geneva, 2002.

Johnson, W. B. and Viezee, W. (1981). Stratospheric ozone in lower troposphere-I. Presentation and interpretation of air craft measurements. *Atmospheric Environment*, **15**, 1309-1323.

Junge, C. E. (1962). Global ozone budget and exchange between stratosphere and troposphere,. *Tellus*, **14**, 363-377.

Kanbour, F. I., Faiq, S.Y., Taic, A., Messih, A., Kitto, N. and Badar, N. (1987). Variation in ozone concentration in the ambient air of Baghdad. *Atmospheric Environment*, **21**, 2673-2679.

Karenlampi, L. and Skarby, L., (1996) (Eds). Critical levels of ozone in Europe: Testing and finalising the concepts. UN-ECE Workshop Report. University of Kuopio, Department of Ecology and Environmental Science, Kuipio, Finland.

Kender, W. J. and Forsline, P. J. (1983). Remedial measures to reduce air pollution losses in horticulture. *Hortic. Science*, **18**, 680.

Kendrick, J. B. Jr., Darley, E. F. and Middleton, J. T. (1954). Chemical protection of plants from ozonated olefin (smog) injury. *Phytopatho.*, **44**, 494.

Kersteins, G. and Lendzian, K. J. (1989). Interaction between ozone and plant cuticle. I. Ozone deposition and permeability. *New Phytologist*, **112**, 13-19.

Khemani, C. J., Momin, G. A., Rao, P. S. P., Vijaykumar, R. and Safari, P. D. (1992). Study of surface ozone at urban and forested sites in India *Atmospheric Environment*, **29**, 2021 –2024.

Kickert, R. N. and Krupa, S. V. (1990). Forest responses to tropospheric ozone and global climate change: An anlysis. *Environmental Pollution*, **68**, 29-65.

Kley, D. H., Geiss, H. and Mohenen, V.A. (1994). Tropospheric ozone at elevated sites and precursor emission in the United States and Europe. *Atmospheric Environment*, **28**, 149-158.

Klumpp, A., Klumpp, G. and Domingos, M. (1999). Plants as bioindicators of air-pollution at the Serra-Do-Mar near the industrial-complex of Cubatao, Brazil. *Environmental Pollution*, **85 (1)**, 109-116.

Kostka-Rick, R. and Manning, W. J. (1992). Effects and interactions of ozone and the anti-ozonant EDU at different stages of radish (*Raphanus sativus* L.) development. *Journal of Experimental Botany*, **43 (257)**, 1621-1631.

Kostka-Rick, R. and Manning, W. J. (1993a). Dose-response studies with ethylene diurea (EDU) and radish. *Environmental Pollution*, **79**, 249-260.

Kostka-Rick, R. and Manning, W. J. (1993b). Dose-response studies with the antiozonant ethylenediurea (EDU), applied as a soil drench to growth substrates, on greenhouse grown varieties of *Phaseolus vulgaris* L. *Environmental Pollution*, **82**, 63-72.

Krause, G. H. M., Prinz, B. and Jung, K. D. (1983). Forest effect in West Germany. **In**: D. D. Davis, A. A. Miller and L. Dochinger. (Eds). *Air Pollution and Productivity of the Forest*, Izzak Walton League of America. 297-332.

Krupa, S. V. (1985). **In**: Lee, S.D. (Ed) *Evaluation of the scientific basis of ozone/oxidants*. Air Pollution Control Association, Pittsburgh, PA.

Krupa, S. V. (1997). Global climate change: Processes and products - An overview. *Environmental Monitoring and Assessment*, **46**, 73-88.

Krupa, S. V. and Manning, W. J. (1988). Atmospheric ozone: Formation and effects on vegetation. *Environmental Pollution*, **50**, 101-137.

Krupa, S. V., Grunhage, L., Jager, H.J., Nosal, M., Manning, W. J., Legge, H., and Hanewald, K., (1995). Ambient ozone and adverse crop response: A unified view of cause and effect. *Environmental Pollution*, **87**, 119-126.

Krupa, S. V., Grunhage, L. and Legge, H. (1998). A numerical analysis of the combined open top chamber data from the USA and Europe on ambient ozone and negative crop response. *Environmental Pollution*, 101, 157-160.

Krupa, S. V., McGrath, M.T., Andersen, C.P., Booker, F.L., Burkey, K.O., Chalpeka, A.H., Chevone, B.I., Pell, E.J. and Zilinskas, B.A. (2000). Ambient ozone and plant health. *Plant Disease*, **85 (1)**, 4-11.

Laguette-Rey, H.D., Bauer, L.I., Shibata, J. and Mendoza, N.M. (1986). Impacto de los oxidante ambientalaes en el cultivito de frijole, en montecillos, estado de Mexico. Centro de Fitopatologia.

Lal, S., Naja, M. and Subbaraya, B.H. (2000). Seasonal Variations in surface ozone and its precursors over an urban site in India. *Atmospheric Environment*, **34**, 2713-2724.

Lee, E. H. and Bennett, J. H. (1982). Superoxide dismutase: A possible protective enzyme against ozone injury in snap beans (*Phaseolus vulgaris* L.). *Plant Physiology*, **69**, 1444-1449.

Lee, E. H., Bennett, J. H. and Heggested, H. E. (1981). Retardation of senescence in Red Clover leaf by a new anti-ozonant N-(2-(2-oxy-1-imidazolidinyl)- ethyl)-N'-phenyl urea. *Plant Physiology,* **67**, 347-350.

Lee, E. H. and Chen, C. M. (1982). Studies on the mechanism of ozone tolerance: cytokinin-like activity of N-(2-(2-oxy-1-imidazolidinyl)- ethyl)-N'-phenyl urea, a compound protecting against ozone injury. *Physiologia Plantarum,* **56**, 486-491.

Lee, E. H., Jersey, J. A., Giffod, C. and Bennett, J. H. (1984). Differential ozone tolerance in snap bean: analysis of ascorbic acid in O_3-susceptible and O_3-resistant cultivars by high performance liquid chromatography. *Environmental and Experimental Botany,* **24**, 331-341.

Lee, E. H., Krammer, G. F., Rowland, R.A. and Agrawal, M. (1992). Antioxidants and growth regulators counter the effects of O_3 and SO_2 in crop plants. *Agriculture Ecosystem and Environment,* **38**, 99-106.

Lee, E. H., Rowland, R. A. and Mulchi, C.L. (1990). Growth regulators serve as a research tool to study the mechanism of plant response to air pollution stimuli. **In**: *Mechanism of Plant Perception and Response to Environmental Stimuli* [T. H. Thomas and A.R. Smith (Eds)], 127-137. The British Society of Plant Growth Regulators.

Lee, E. H., Wang, C. Y. and Bennett, J. H. (1981). Soluble carbohydrates in bean leaves transformed into anti-oxidant tolerance tissues by EDU treatment. *Chemosphere,* **10**, 889-896.

Lee, E. H., Saftner, R.A. Wilding, S.J., Clark, H.D. and Rowland, R.A. (1987). Effects of placobutrazol on GA biosynthesis and fatty acid composition. *Proc. of the Plant Growth Regulators Soc. of America,* **14**, 295-302.

Lee, E. H., Upadhyaya, A., Agrawal, M. and Rowland, R.A. (1996). Mechanism of ethylene diurea (EDU) induced ozone protection: re-examination of free radical scavenger systems in snap bean exposed to ozone. *Environmental and Experimental Botany,* **38**, 199-200.

Legassicke, B. and Ormrod, D. P. (1981). Suppression of ozone injury to tomatoes by ethylene diurea in controlled environment and in the field. *Hort. Science,* **16**, 259-266.

Leighton, P. A. (1961). *Photochemistry of Air Pollution.* Academic. San Diego, California.

Lelieveld, J. and Crutzen, P. J. (1994). Role of deep cloud convection in the ozone budget of the troposphere. *Science,* **264**, 1751-1761.

Lelieveld, J. and Dentener, J. (2000). What controls tropospheric ozone? *J. Geophysical Research.* **105 (D3)**, 3531-3551.

Levine, J. S. (1991) (Ed). *Global Biomass Burning: Atmospheric Climate, and Biosphere Implications*. 569, MIT press, Cambridge.

Levy, H (II)., Mahalman, J. D., Moxim, W. L. and Lui, S. C. (1985). Tropospheric ozone: The role of transport. *J. Geophys. Res.*, **90**, 3753-3771.

Levy, H. II., Kashibhatla, P. S., Moxim, W. L., Klonecki, A. A.,Hirsch, A. I., Oltmans, S. J. and Chameides, W. L. (1997). The global impact of human activity on tropospheric ozone. *Geophys. Res. Lett.*, **24**, 791-794.

Liu, S. C., Trainer, M., Fehsenfield, F. C., Parrish, D. D., Williams, E. J., Kashey, D. W., Hubler, G. and Murphy, P. C. (1988). Ozone production in the rural troposphere and the implications for regional and global ozone distribution. *J. Geo. Res.*, **92**, 4191-4027.

Logan J. A. (1985). Tropospheric ozone: seasonal behaviour, trend and anthropogenic influences. *Journal of Geophysical Research*, **90**, 10480-10482.

Low, P. S., Davis, T., Kelley, P. M. and Farmer, G. (1990). Trends in surface ozone at Hohenpeissenberg and Arkona. *Journal of Geophysical Research*, **95**, 22441-22453.

Luo, C., St. John, J. C., Xiuji, Z., Lam, K. S., Wang, T. and Chameides, W. L. (2000). A nonurban ozone air pollution episode over eastern China: Observation and model simulation. *Journal of Geophysical research*, **105(D2)**, 1889-1908.

MacDowall, F. D. H. (1965a). Stages of ozone damage to respiration of tobacco leaves. *Can. J. Bot.*, **43**, 419-427.

MacDowall, F. D. H. (1965b). Predeispositon of tobacco to ozone damage. *Can. J. Bot.*, **45**, 1-12.

Maclachlan, S. and Zalik, S. (1963). Plastid structure, chlorophyll concentration and free amino acid composition of a mutant of barley. *Can. J. Bot.*, **41**, 1053-1062.

Maggs, R., Wahid, A., Shamsi, S. R. A. and Ashmore, M. R. (1995). Effects of ambient air pollution on wheat and rice yield in Pakistan. *Water, Air and Soil Pollution*, **85(2)**, 1311-1316.

Marshall, F. (2002). Effects of air pollutants in developing countries. **In**: J.N.B. Bell and M. Treshow. (Eds) *Air Pollution and Plant Life*, 407-416. John Wiley and Sons. Ltd., England.

Manning, W. J. (1988). EDU: a research tool of assessment of the effects of ozone on vegetation. **In**: *Air Pollution Control Association Annual Meeting*, Dallas, Texas, Reprint No. (2), 88-89.

Manning, W. J. (1999). Use of protective chemicals to assess the effect of ambient ozone on plants. **In**: S.B. Agrawal and M. Agrawal. (Eds) *Environmental Pollution and Plant Responses*, 247-258. Lewis Publishers , Boca Raton, USA.

Manning, W. J., Feder, W. A. and Vardaro, P. M. (1974). Supression of oxidant injury by benomyl: Effects on yields of bean cultivars in the field. *Journal of Environmental Quality*, **3**, 1-3.

Manning, W. J. and Feder, W. A. (1976). **In**: T. A. Mansfield (Ed) *Effects of Air Pollutants on Plants*. Cambridge University Press, Cambridge. 45-60.

Mauzerall, D. L. and Wang, X. P. (2001). Protecting agricultural crops from the effects of tropospheric ozone exposure: Reconcilling science and record setting in the United States, Europe and Asia. *Annual Review of Energy and Environment.* **26**, 699-705.

McLeod, A. and Baker, C. K. (1988). The use of open field system to assess yield response to gaseous pollutants. **In**: W. W. Heck, O. C. Taylor, and D. T. Tingey, (Eds). *Assessment of Crop Loss from Air Pollutants* , Elsevier, London and New York, 211-224.

Mehlhorn, H. and Wellburn, A.R. (1987). Stress ethylene formation determines the plant sensitivity to ozone. *Nature*, **327**, 417-418.

Middleton, J.T., Kendrick, J.B. and Schwalm, H.W. (1950). Injury to herbaceous plants by smog or air pollution. *Plant Disease Reporter*, **34**, 245-252.

Millecan, A. A. (1971). *A survey and assessment of air pollution damage to California vegetation in 1970*. California Department of Agriculture, California, USA.

Miller, J. E., Parmeter, J. R., Flick, B. H. and Martinez, C.W. (1994). Ozone dose response of Ponderosa pine seedlings. *Journal of Air Pollution Control Association*, **34**, 360-363.

Miller, P. R., Pursley, W. A., and Heagle, A. S. (1969). Effect of ethylene diurea on snap beans at a range of ozone concentrations. *Journal of Environmental Quality*, **23**, 1082-1089.

Mills, G., Fumagalli, I., Gimeno, B. S., Velissariou, D. and De Temmerman, L. (2001). Evidence of ozone induced adverse effects on crops in the Mediterranean region. *Atmospheric Environment,* **35**, 2583 – 2587.

Mina, U. (2000). An assessment of ozone phytotoxicity on crop plants. M.Phil. Dissertation, Submitted to Jawaharlal Nehru University, New Delhi.

Mudd, J. B. (1996). Resistance mechanisms in plants against air pollution. **In**: Yunus, M. and Iqbal, M. (Eds). Plant Response to Air Pollution. John Willy & Sons, Chinchester, England.

Naja, M. and Lal, S. (1996). Changes in surface ozone amount and its diurnal and seasonal patterns, from 1954-55 to 1991-93 measured at Ahmedabad (23°N), India. *Geophysical Research Letters*, **23**, 81-84.

Nandi, P. K., Agrawal, M. and Rao, D. N. (1984a). Potassium ascorbate as an antidote to SO_2 phyto-toxicity. *Beitrage zur Biologie der Pflanzen*. **55**, 401-407.

Nandi, P. K., Agrawal, M. and Rao, D. N. (1984b). SO_2 induced effect and their amelioration by $Ca(OH)_2$ solution on *Vigna sinensis* plant. *Scientia Horti.*, **22**, 43-55.

Ogawa, T. and Miyata, A. (1985). Seasonal variation of tropospheric ozone: A summer minimum in Japan. *Journal of Meteorological Society of Japan*, **63**, 937-946.

Oksanen, E. and Holopainen (2001). Response of two birch (*Betula pendula* Roth) clones to different ozone profiles with similar AOT40 exposure. *Atmospheric Environment*, **35**, 5245-5254.

Ollerenshaw, J. H., Lyons, T. and Barnes, J. D. (1999a). Impacts of ozone on the growth and yield of field-grown winter oilseed rape. *Environmental Pollution*, **104**, 53-59.

Ollerenshaw, J.H. and Lyons, T. (1999b). Impacts of ozone on the growth and yield of field - grown winter wheat. *Environmental Pollution*, **106**, 67 – 72.

Ormrod, D. P. and Adedipe, N. O. (1974). Protecting horticultural plants from atmospheric pollutants: A review. *Hort. Science*, **9**, 108-111.

Ormrod, D. P. and Beckerson, D.W. (1986). Polyamines. *Hortic. Sci.*, **21**, 1070.

Padhy, P.K. (1999). Volatile Organic Compounds (VOC) and Air Quality: Measurement and Estimation of VOC Emmission from Anthropogenic and Natural Sources. Ph.D. Thesis, Submitted to Jawaharlal Nehru University, New Delhi.

Papple, D. J. and Ormrod, D. P. (1977). Comparative efficacy of ozone injury suppression by benomyl and carboxin on turf grasses. *J. of American Soc. of Hort. Science*, **102**, 792-796.

Parivesh, Vol II (1), Central Pollution Control Board (CPCB), (1995), June, New Delhi.

Pandey, J. and Agrawal, M. (1993). Protection of plants against air pollutants: role of chemical protectants. *J. of Environ. Manage.*, **37**, 163-174.

Pandey, J., Agrawal, M., Khanam, N., Narayan, D. and Rao, D.N. (1992). Air pollutant concentrations in Varanasi, India. *Atmospheric Environment*, **26 (B)**, 91-104.

Pell, E. J. (1973). *Surevey and assessment of air pollution damage to vegetation in New Jersey*. Published in EPA-R5-022. US Environmental Protection Agency, Washington, DC.

Pell, E. J., Temple, P. J., Friend, E. L., Mooney, H. A. and Winner, W. E. (1992). Compensation as a plant response to ozone and associated stress: an analysis of ROPIS experiment. *Journal of Environmental Quality*, **23**, 429-435.

Pellissier, M., Lacasse, N. L. and Cole, H.(jr) (1972). Effectiveness of benzimutazole, benomyl and thiabendazole in reducing ozone injury in pinto beans. *Phytopathology*, **62**, 580-582.

Photochemical Oxidant Review Group (PROG) (1987). *Ozone in United Kingdom*, Harwell Laboratory.

Pitelka, P. S. (1988). Evolutionary responses of plants to anthropogenic pollutants. *Trends Ecol.*, **3**, 233-236.

Pleijel, H., Skarby, L., Wallin, G. and Selden, G. (1991). Yield and grain quality of spring wheat (*Triticum aestivum* L., cv. Drabant) exposed to different concentrations of ozone in open-top chambers. *Environmental Pollution*, **69**, 151-168.

Pleijel, H., Danielsson. H., Gelang, J., Sild, E. and Selldén, G. (1998). Growth stage dependence of the grain yield response to ozone in spring wheat (*Triticum aestivum* L.). *Agriculture, Ecosystems and Environment*, **70**, 61-68.

Pleijel, H., Danielsson, H., Karlsson, G.P., Gelang, J., Karlsson, P.E. and Selldén, G. (2000). An ozone flux-response relationship for wheat. *Environmental Pollution*, **109**, 453-462.

Postiglione L, Fagnano, M. and Merola, G. (2000). Response to ambient ozone of two white clover (*Trifolium repens* L.cv. "Regal") clones, one resistant and one sensitive, grown in a Mediterranean environment. *Environmental Pollution*, **109**, 525-531.

Prather, M., Gauss, M., Berntsen, T., Isaksen, I., Sundet, J., Bey, I., Brasseur, G., Dentener, F., Derwent, R., Stevenson, D., Grenfell, L., Hauglustaine, D., Horowitz, L., Jacob, D., Mickley, L., Lawrence, M., von Kuhlmann, R., Muller, J,F., Pitari, G., Rogers, H., Johnson, M., Pyle, J., Law, K., van Weele, M. and Wild, O. (2003). Fresh air in the 21st century? *Geophysical Research Letters*, **30(2)**, 72-1-4.

Prince, R. and Ross, F. F. (1972). Sulphur in air and soil. *Water, Air and Soil Pollution.* **1**, 286-302.

Prinz, B. (1988). *Ozone effects on vegetation.* **In**: Tropospheric ozone, (Ed) I.S.A. Isaken, D. Reidel Publishing, Dordrecht, 161-184.

Rao, D. N., Nandi, P. K. and Agrawal, M. (1985). Studies on the amelioration of air pollution effects. *Trends in Plant Research*, **1**, 437-445.

Regener, V. H. (1957). Vertical flux of atmospheric ozone. *J. Geophysical Research*, **62**, 221-228.

Regner-Joosten, K., Manderscheid, R., Bergman, R., Bahadir, M. and Weigel, H. J. (1994). An HPLC method to study the uptake and partitioning of the antiozonant EDU in bean plants. *Agnew. Bot.*, **68**, 151-154.

Reich, P. B. (1983). Effects of low concentrations O_3 on net photosynthesis, dark respiration, and chlorophyll contents in aging hybrid poplar leaves. *Plant Physiology*, **73**, 291-296.

Rodes, C. E. and Holland, D. M. (1981). Variations of NO, NO_2 and O_3 concentrations down wind of a Los Angeles freeway. *Atmospheric Environment*, **15**, 243-250.

Roe, J. H. (1954). Chemical determination of ascorbic acid, dehydro-ascorbic acid, deketo-gluconic acid. Methods in Biochemical Analysis.

Roose, M. L., Bradshaw, A. D. and Roberts, T. M. (1982). Evolution of resistance to gaseous air pollutants. In Unsworth, M. H. and Ormrod, D. P. (Eds) Butterworth Scientific, London. *Effects of Gaseous Air Pollution in Agriculture and Horticulture*, 379-409.

Rout, C. (1997). Studies on EDU as a protectant against injury to plants by ozone. M.Phil. Dissertation, Submitted to Jawaharlal Nehru University, New Delhi.

Rubin, B., Leavitt, J. R. C., Penner, D. and Saettler, A. W. (1980). Interaction of anti-oxidants with ozone and herbicide stress. *Bulletin of Environmental Contamination and Toxicology*, **25**, 623-629.

Rubino, R. A., Bruckman, L. and Magyar, J. (1976). Ozone transport. *Journal of the Air Pollution Control Association*, **26 (10)**, 972-975.

Saettler, A. W. (1981). Yield response of navy bean treated with the antioxidant chemical ethylene diurea. Michigan State University Agricultural Research Station Research Report. **427**.

Sanders, G. E., Skarby, L., Ashmore, M. R. and Fuhrer, J. (1995). Establishing critical levels for the effects of air pollution on vegetation. *Water, Air and Soil Pollution*, **85**, 189-200.

Schulte-Hostede, S., Darrall, N. M., Blank, L. W. and Wellburn, A. R. (1988). *Air Pollution and Plant Metabolism*, Elseiver Applied Science, London, 379.

Schreiber, U., Vidaver, W., Runeckels, V. C. and Rosen, P. (1978). Chlorophyll florescence assay of ozone injury in plants. *Plant Physiology*, **61**, 80-84.

Seinfeld, J. H. (1988). Ozone air quality models: A critical review. *J. Air Pollution Control Assoc.*, **38**, 616- 645.

Seinfeld, J. H. (1989). Urban air pollution: state of the science. *Science*, **243**, 745-752.

Siegel, S. M. (1962). Protection of plants against air borne oxidants: Cucumber seedlings at extreme ozone levels. *Plant Physio.*, **37**, 261-266.

Shamsi, S. R. A. (1996). Effect of ozone on soybean growth and yield in the Pakistan Punjab, Dept. of Botany, University of Punjab, Lahore.

Shriner, D. S., Cure, W. W., Heagle, A. S., Heck, W. W., Johnson, D. W., Olson, R. J., and Skelly, J. M. (1982). An analysis of potential agriculture and forestry impacts of long-range transport of air pollutants, Oak Ridge National Laboratory. **In**: ORNL Report No. 5910.

Shrinivasan, G., Peshin, S.K., Mukhopadhaya, B. and Lal, B. (1997). Variations in ozone concentrations observed over New Delhi. **In**: Proceedings of the IGBP symposium, on *Changes in Global Climate due to Natural and Human Activites*, Bhubaneswar, India, Edited by S.N. Das and R.S. Thakur, 33-35, Allied Publishers, New Delhi.

Singh, A., Sarin, S. M., Shanmugam, P., Sharma, N., Attri, A. K. and Jain, V. K. (1997), Ozone distribution in the urban environment of Delhi during winter months, *Atmospheric Environment*, **31 (20)**, 3421-3427.

Singh, H. B., Ludwig, F. L. and Johnson, W. B. (1978). Tropospheric ozone concentrations and variability in clean remote atmosphere. *Atmospheric Environment*, **28**, 2185-2196.

Singh, H. B., Viezee, W. and Johnson, W. B. (1980). The impact of stratospheric ozone on tropospheric air quality- a critical review. *Proc. APCA Speciality Conference on Ozone/ Oxidant: Interaction with The Total Environment.* Houston, Texas, 118th October, 1979.

Smith, G., Greenhalgh, B., Brennan, E. and Justin, J. (1987). Soybean yield in New Jersey relative to ozone pollution and anti-oxidant application. *Plant Disease*, **71**, 121-125.

Statistical Abstract of Haryana, 2000-2001 (SAH) (2001). Economic and Statistical Organisation, Planning Department, Haryana.

Stevens, C. S. (1987). Ozone formation in the greater Johannesburg region. *Atmospheric Environment*, **21**, 523-530.

Suhre, K., Cammas, J, P., Nedelic, P., Rosset, R., Marenco, A. and Smit, H.G.J. (1997). Ozone rich transients in the upper equatorial Atlantic Atmosphere. *Nature*, **388**, 661-663.

Tate Energy Research Institute, TERI, (1993). Impact of road transportation system on energy and environment-An analysis of metropolitan cities of India. Submitted to Ministry of Urban Development, Govt. of India, New Delhi.

Taylor, G. E. (2001). Risk assessment of tropospheric ozone: Human health, natural resources, and ecology. *Human and Ecology of Risk Assessment*, 7, 1183-1193.

Taylor, J. S., Reid, D. M. and Pharis, R. P. (1981). Mutual antagonism of sulphur dioxide and abscisic acid in their effect on stomatal aperture in broad bean (*Vicia faba* L) epidermal strips. *Plant Physio.*, 68, 1504-1507.

Temple, P. and Bisessar, S. (1979). Response of white bean to bacterial blight, ozone and anti-oxidant protection in the field. *Phytopathology*, 69, 101-103.

Temple, P. J., Taylor, O. C. and Benoit, L. F. (1986). Yield response of head lettuce to ozone. *Environmental and Experimental Botany*, 26, 53-58.

Tingey, D. T., Hogsett, W. E., Lee, E. H., Herstorm, A. A., and Azevedo, S. H. (1991). An evaluation of various alternative ambient ozone standards based on crop yield loss data. **In**: Transactions: tropospheric ozone and environment. (Eds) R.L. Berglund, D.L. Lawson, and D.J. McKee. *Air and Waste management Association*, Pittsburgh, 272-288.

Tiwari, V. S. and Peshin, S. (1995). A prominent maximum in surface ozone concentration during winter months at Pune (India). *Mausam*. 46 (2), 155-162.

Toivonen, P. M. A., Hofstra, G. and Wukasch, R. T. (1982). Assessment of yields losses in white bean due to ozone using the anti-oxidant EDU. *Canadian Journal of Plant Pathology*, 4, 381-386.

Tonneijck, A. E. G. (1989). Evaluation of ozone effects on vegetation in the Netherlands. **In**: T. Schneider, S. D. Lee, G. J. R. Wolters and L. D. Grants (Eds), *Atmospheric Ozone Research and Its Policy Implications*, Elseiver Science Publisher, Amsterdam.

Tonneijck, A. E. G. and van Dijk, C.J. (1997a). Effects of ambient ozone on injury and yield of *Phaseolus vulgaris* L. at four rural sites in the Netherlands as assessed by using ethylene diurea (EDU), *New Phytolgist*, 135, 93-100.

Tonneijck, A. E. G. and van Dijk, C.J. (1997b). Assessing effects of ambient ozone on injury and growth of *Trifolium subterraneum* at four rural sites in the Netherlands with ethylene diurea (EDU), *Agriculture, Ecosystems and Environment*, 65, 79-88.

Tonneijck, A. E. G. and van Dijk, C.J. (2002a). Assessing effects of ambient ozone on injury and yield of bean with ethylene diurea (EDU): Three years plant monitoring at four sites in the Netherlands. *Environmental Monitoring and Assessment*, 77, 1-10.

Tonneijck, A. E. G. and van Dijk, C.J. (2002b). Injury and growth response of subterranean clover to ambient ozone as assessed by using ethylene diurea (EDU): Three years plant monitoring at four sites in the Netherlands. *Environmental Experimental Botany*, 48, 33-41.

UNDP (1998). *Human Development Report*. United Nations Development Program. Oxford University Press, New York.

U.S. Environmental Protection Agency, (USEPA) 1996. *Air Quality Criteria for Ozone and Related Photochemical Oxidants*, EPA/600-90/004bF, National Center for Environmental Assessment, Office of Research and Development, Research Triangle Park, NC.

Varshney, C. K. and Aggarwal, M. (1992). Ozone pollution in the urban atmosphere of Delhi. *Atmospheric Environment*, **26B (3)**, 291-294.

Varshney, C. K., Agrawal, M., Ahmed, K.J., Dubey, P.S. and Raza, S.H. (1997). *Effect of Air Pollution on Indian Crop Plants*. Report submitted to Imperial College Centre for Environmental Technonlogy. Part of UK Department for International Development funded project to assess the impacts of Air pollution on India Crops. Jawaharlal Nehru University, New Delhi.

Varshney, C. K. and Rout, C. (1998). Ethylene diurea (EDU) Protection against ozone injury in Tomato Plants at Delhi. *Journal of Environmental Contamination Toxicology*, **61(2)**, 188-193.

Varshney, C. K. and Rout, Chitrasen. (2003). Response of Soybean (*Glycine max* var. Pusa-16) to ethylene diurea (EDU) in relation to ambient ozone at Delhi (*Under Publication*).

Varshney, C. K. and Singh, A. P. (2002). Measurement of ambient concentrations of NO_2 in Delhi using passive diffusion tube sampler. *Current Science*, **86 (6)**, 731-735.

Volz, A. and Kley, D. (1988). Ozone measurement in the 19th century: An evaluation of of the Montsouris series, *Nature*, **332**, 240-242.

Wahid, A., Maggs, R., Shamsi, S. R. A., Bell, J. N. B. and Ashmore, M. R. (1995a). Air pollution and its impact on wheat yield Pakistan Punjab. *Environmental Pollution*, **88 (2)**, 147-154.

Wahid, A., Maggs, R., Shamsi, S. R. A., Bell, J. N. B. and Ashmore, M. R. (1995b). Effects of air pollution on rice yield in the Pakistan Punjab. *Environmental Pollution*, **90 (3)**, 323-329.

Wahid, A., Milne, E., Shamsi, S. R. A., Ashmore, M. R. and Marshal, F. M. (2001). Effects on oxidants on soybean growth and yield in the Pakistan Punjab. *Environmental Pollution*, **113**, 271-280.

Wang, Y., Jacob, D. J. and Logan, J. A. (1998). Global simulation of tropospheric O_3-NOx-hydrocarbon chemistry. 2. Model evaluation and global ozone budget. *J. Geophys. Res.*, **103**, 10727-10755.

Weidensaul, T. C. (1980). N-(2-(2-oxy-1-imidazolidinyl)- ethyl)-N'-phenyl urea, as a protectant against ozone injury to laboratory fumigated pinto bean plants. *Physiology and Biochemistry*, **70**, 42-45.

Weiss, J. (1935). Investigations on the radical HO_2 in solution. *Trans. Faraday Soc.*, **31**, 668-681.

Westberg, H., Sexton, K. and Roberts, E. (1981). Transport of pollutants along the western shore of lake Michigan. *Journal of Air Pollution Control Association*, **31 (4)**, 385-388..

White, W. H., Anderson, J. A., Blumenthal, D. L., Husar, R. B., Gillani, N. V., Husar, J. D. and Wilson, W. E. (Jr). (1976). Formation and transport of secondary air pollutants: ozone and aerosols in the St. Louis urban plume. *Science*, **194**, 187-189.

Whittaker, B. D., Lee, F. H. and Rowland, R. A. (1990). EDU and ozone protection: foliar glycerolipids and steryl lipids in snap bean exposed to O_3. *Physiologia Plantarum*, **80**, 286-293.

Wild, O. and Akimoto, H. (2001). Intercontinental transport of ozone in and its precursors in a three-dimensional global CTM. *Journal of Geophysical Research*, **106**, 27729-27744.

Wilson, R.G., Mills, J. B., and Wituschek, E. P. (1984). *A Report on the Assessment of Photochemical Oxidants in the Lower Mainland. Greater Vancouver Region Distribution*, Environment Canada.

Wolfenden, J., Woorkey, P. A., Lucas, P. W. and Mansfield, T. A. (1992). Action of pollutants individually and in combination. In: Barker, J.R. and Tingey, D.T. (Eds). *Air Pollution Effects on Biodiversity*, Van Nostrand Reinhold, New York. 72-92.

Wukasch, R. and Hofstra, (1977). Ozone and Botrytis species interaction in onion leaf dieback field studies. *J. American Soc. of Horti. Science*, **102**, 543-546.

Zhang, Y., Shao, K., Tang, X. and Li, J. (1998). The study of urban photochemical smog in China. *Act Scientiarum naturalium Universitatis Pekinensis*. **34**, 392-400.

Zilinskas, B. A. Greenhalgh-Weidman, B. and Brennan, E. (1990). The relationship between EDU and pre-treated and C_2H_4 evolution in ozonated pea plants. *Environmental Pollution*, **65**, 241-249.

Annexure-I

List of Publications

1. Rout, C. and Varshney, C. K. (1996). "Effect of Air Pollutants on Plant Reproductive System". Paper presented in the "International Conference on Plants and Environmental Pollution (ICPEP- 96), held at National Botanical Research Institute (NBRI), Lucknow, India during 26-30th November, 1996.

2. Participated in the National Workshop on "The Impact of Air Pollution on Agriculture in India", 9-10th June, 1997, Organised by WWF-India, New Delhi and Imperial College Centre for Environmental Technology, Imperial College of Science Technology and Medicine, Berks, London, United Kingdom.

3. Varshney, C. K. and Rout, C. (1998). Ethylene diurea (EDU) Protection against ozone injury in Tomato Plants at Delhi. *Journal of Environmental Contamination Toxicology,* **61(2),** 188-193.

4. Varshney, C. K. and Rout, Chitrasen (2003). Response of Soybean (*Glycine max* var. Pusa-16) to ethylene diurea (EDU) in relation to ambient ozone at Delhi. *Current Science* (Under Publication).

Environmental
Contamination
and Toxicology

Ethylene Diurea (EDU) Protection Against Ozone Injury in Tomato Plants at Delhi

C. K. Varshney, C. Rout

School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110 067, India

Air pollution has become an increasingly serious problem in developing countries. Ozone is the most phytotoxic gaseous air pollutant. Ground level ozone measurements carried out at Delhi during 1990 -1992 show that the ambient concentration of ozone varies between 20 to 273 $\mu g\ m^{-3}$, and the one hour WHO ozone standard of 110.74 $\mu g\ m^{-3}$, was violated on many occasions (Varshney and Aggarwal, 1992). Heck *et al.*, 1982 have shown that out of total crop loss caused by air pollution in USA, about 90% of the crop loss is attributed to ozone. Ethylene diurea (EDU) has been shown to be specific in protecting plants against ozone injury because it is an strong anti-oxidant (Carnahan *et al.*, 1978). Exploratory studies have been carried out to evaluate the protective role of EDU against ozone damage in cereals, legumes and vegetables (Astorino *et al.*, 1995; Brennan *et al.*, 1990; Brunschon-Harti, 1995; Clarke *et al.*, 1990; Hofstra *et al.*, 1978; Kostaka-Rick and Manning, 1992,1993; Tonneijck and Vandijk, 1997). In India Bambawale (1986) have shown that the leaf spot disease of potato reported from Punjab in 1978 was primarily due to ozone pollution and foliar spray of EDU was found to reduce about 25-30%leaf spot disease. Higher yield in EDU-treated plants in comparison to un-treated plants has been attributed to the specific protective effect of EDU against ozone damage (Clarke *et al.*, 1990; Saettler, 1981; Smith *et al.*, 1987).

Tomato, an important vegetable fruit crop grown widely in the country, has been shown to suffer adversely from ozone stress (Khan and Khan, 1994). The present study was undertaken to evaluate the performance of tomato plants, with and without EDU treatment, exposed to ambient ozone levels at selected urban and peri-urban sites at Delhi.

MATERIALS AND METHODS

Monitoring of ambient ozone at the following sites was carried out in Delhi (Figure-1) at 15 day interval, during March-June, 1997.

Tilak Bridge is one of the busiest stretch on a main road connecting New Delhi with Old Delhi. The traffic at this site is very heavy. In addition, a thermal power plant in the vicinity makes it one of the most polluted sites in Delhi
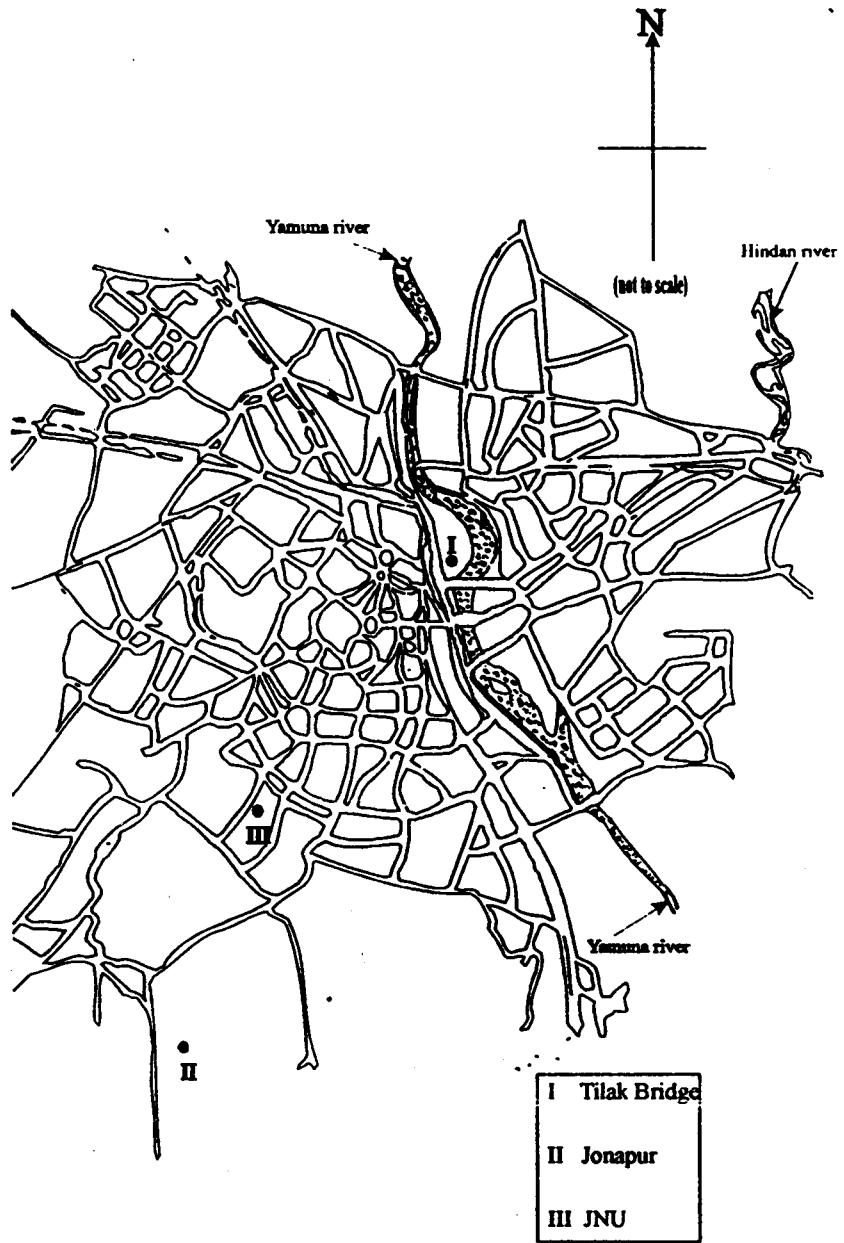

Fig 1. Map of Delhi showing field sites

I   Tilak Bridge

II   Jonapur

III JNU

189

Jonapur is located in peri-urban/rural location lying at the outskirts of Delhi, at approximately 12-15km south of JNU and 15-20km away from traffic dense areas, close to Haryana border (2km).The traffic of Delhi go to Haryana and vice versa through this village. Agricultural activity is still going on around the locality. This area is totally residential but in recent years construction activity has picked up rapidly. This site is not completely free from air pollution.

JNU is located in side of a vast tract of natural vegetation in the southern part of Delhi, is a secluded area, relatively free from pollution, selected to serve as a control site. The natural vegetation of the area is dry deciduous forest which has suffered severely from urbanisation.

Air samples were drawn at hourly interval at a rate of 2 litre per minute using

KIMOTO handy sampler Model HS-7 for 5 hr (from 11.00-16.00 hr) and ozone estimation was carried out using Saltzman (1961) method, with modification suggested by Boyd et al., 1970, having a precision of ±5% from the mean.

Lycopersicon esculentum var. Pusa Ruby (Tomato) plants were raised from seeds in pots in the Ecological Garden, JNU ,during the last week of February 1997. In the third week of March, six pots (two plants in each pot) were transferred to Jonapur (peri-urban) and Tilak Bridge (urban), the field sites and a set of six pots was maintained in the JNU garden to serve as reference. From the last week of March three pots at each site, were given EDU treatment, at twelve day interval, by soil drenching with 400 ppm of aqueous solution of EDU. The remaining three pots at each site were maintained without EDU treatment for comparison and were drenched with water instead of EDU solution.

Plant growth was monitored and the degree of visible injury was recorded at bi-week intervals. The plant parameters studied were, leaf number, shoot length, root length, dry weight of shoot and dry weight of root. The tomato plants were harvested on maturity in Mid-Jun after 82 days of field exposure. To evaluate the effectiveness of EDU treatment on the growth and performance of tomato plants at Delhi, data from all the sites were pooled under two categories namely 1. EDU treated and 2. untreated plants for a better comparison.

RESULTS AND DISCUSSION

The results show that the ground level hourly peak ozone concentration in the ambient environment at three sites in Delhi varied between 113.42-124.42 $\mu g/m^3$ and average hourly ozone concentration ranged between 88.41-89.98 $\mu g/m^3$. The hourly peak ozone value at the Tilak Bridge in the city centre was 113.42 $\mu g/m^3$, was relatively less as compared to the hourly peak ozone value of 124.42 $\mu g/m^3$ at the JNU which lies at the outskirts of the city resembling peri-urban environment.

In general, at all the three sites the performance of EDU treated tomato plants was

In general, at all the three sites the performance of EDU treated tomato plants was better as compared to the untreated plants. However, variation in the performance of the tomato plants from one site to another was found to be related to the inter-site variation in the ambient ozone concentration (Table-1).

Shoot length, root length, shoot biomass and root biomass were less in the plants which did not receive EDU treatment as compared to EDU treated plants. In EDU treated plants the leaf size was bigger as compared to the non-treated plants, however the number of leaves in untreated plants were about 15.70% more as compared to EDU treated plants (Table -2). Data on shoot length, root length, shoot biomass and root biomass given in Table 2-3 show that the performance of EDU treated plants was much better as compared to untreated plants at all the three sites. On an average the shoot length, root length, shoot biomass and root biomass in untreated plants were reduced by 19.10%, 14.50%, 25.60% and 17.96% respectively. It may be observed that the protection provided by EDU treatment was different for different organs in the same plant. In accordance with the degree of EDU protection the four plant organs fall in the following sequence:

Shoot biomass > shoot length > root biomass > root length.

It seems that EDU treatment is not equally effective in respect of different plant organs. In future studies related to EDU effect, it would be interesting to identify the causes and the significance of the variation in the response of different plant organs as observed in this study.

Table 1. Ground level ambient ozone concentration ($\mu g\ m^{-3}$) at different urban and peri-urban at Delhi

Sites	March		April		May		June		Average hourly concentration
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	
Tilak Bridge	87.27	62.14	98.54	78.14	113.42	83.14	97.83	82.15	88.41
Jonapur	97.23	83.42	106.73	91.32	118.47	36.56	98.72	76.46	89.53
JNU	93.12	61.99	113.12	81.47	124.43	80.32	112.82	89.87	89.98

Table 2.Effect of EDU treatment on number of leaves, shoot and root length in tomato plants exposed to ambient air pollution at Delhi

Site	Leaf number			Shoot length (cm)			Root length (cm)		
	EDU	Control	% increase	EDU	Control	% loss	EDU	Control	% loss
Tilak Bridge	72.90	83.50	14.54	63.37	52.07	17.83	19.91	15.30	23.15
Jonapur	48.93	58.22	15.92	62.44	50.23	19.55	16.08	14.43	10.26
JNU	48.37	58.00	16.60	63.25	50.65	19.92	16.28	14.64	10.07

Table 3. Effect of EDU treatment on shoot and root biomass in tomato plants exposed to ambient air pollution at Delhi

Site	Shoot biomass (g / plant)			Root biomass (g / plant)		
	EDU	Control	% loss	EDU	Control	% loss
Tilak Bridge	28.25	21.04	25.53	5.28	4.46	15.53
Jonapur	28.40	20.94	26.27	4.47	3.63	18.79
JNU	28.52	20.54	27.99	4.67	3.76	19.57

REFERENCES

Astorino G, Margani I, Tripodo P, Manes F (1995). The response of *Phaseolus vulgaris* L. cv. Lit to different dosages of anti-ozonant ethylenediurea (EDU) in relation to chronic treatment with ozone. Plant Sci 111: 237-248

Bambawale OM (1986). Evidence of ozone injury to a crop plant in India. Atmos Environ 20: 1501-1503

Boyd AW, Wills C, Cyr R (1970). New determination of stoichiometric of the iodometric methods for ozone analysis at pH 7.0. Anal Chem 42: 670-672

Brennan EG, Clarke BB, Greenhalgh-Weidman B, Smith G (1990). An assessment of the impact of ozone on field grown crops in New Jersey using the EDU method: part-2-soybean (*Glycine max* L. Merr). Environ Pollut 66: 361-373

Brunschon-Harti S, Fangmeier A, Jager HJ (1995). Influence of ozone and ethylene diurea (EDU) on growth and yield of bean (*Phaseolus vulgaris* L.) in open top field chambers. Environ Pollut 90 (1): 89-94

Carnahan J, Jenner E, Wat E (1978). Prevention of ozone injury to plants by a new protectant chemical. Phytopathol 68:1225-1229

Clarke BB, Greenhalgh-Weidman B, Brennan EG (1990). An assessment of the impact of ambient ozone on field grown crops in New Jersey using the EDU method : part-1-white potato (*Solanum tuberosum*). Environ Pollut 66: 351-360

Hofstra G, Littlejohns DA, Wukasch RT (1978).The efficacy of the antioxidant ethylene diurea(EDU) compared to carboxin and benomyl reducing yield losses from ozone in navy bean. Plant Dis Reptr 62, 350-352

Heck WW, Taylor OC, Adams R, Bingham G, Miller J, Preston E, Weinstein L (1982). Assessment of crop loss from ozone. J Air Pollut Contl Asso 32:353-

361

Khan MR, Khan MW (1994). Single and interactive effects of O_3 and SO_2 on tomato. Environ and Exp Bot 34(4): 461-469

Kostka-Rick R, Manning WJ (1992). Effects and interactions of ozone and the anti-ozonant EDU at different stages of radish (*Raphanus sativus* L.) development. J Exp Bot 43 (257): 1621-1631

Kostka-Rick R, Manning WJ (1993). Dose-response studies with the antiozonant ethylenediurea (EDU), applied as a soil drench to growth substrates, on greenhouse grown varieties of *Phaseolus vulgaris* L. Environ Pollut 82: 63-72

Saettler AW (1981). Yield response of navy bean treated with the antioxidant chemical ethylene diurea. Michigan State University Agricultural Research Station Research Report. 427: 7

Saltzman BE (1961). Preparation and analysis of calibrated low concentrations of 16 toxic gases. Anal Chem 33:1100

Smith G, Greenhalgh B, Brennan E, Justin J (1987). Soybean yield in New Jersey relative to ozone pollution and anti-oxidant application. Plant Dis 71: 121-125

Tonneijck AEG, Vandijk CJ (1997). Effects of ambient ozone on injury and yield of *Phaseolus vulgaris* at four rural sites in the Netherlands as assessed by using ethylene diurea(EDU). New Phytol 135: 93-100

Varshney CK, Aggarwal M (1992). Ozone pollution in the urban atmosphere of Delhi. Atmos Environ 26B(3): 291-294