Chapter-VII

Summary and Conclusions
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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/m³ at Bakoli (S1), 37.77µg/m³ at S.College (S2), 35.72µg/m³ at J.Temple (S3), 44.15µg/m³ at Tilak Bridge (S5), 38.21µg/m³ at JNU (S6), 50.20µg/m³ at Badarpur (S7), 41.67µg/m³ at DPS-Faridabad (S8) and 38.75µg/m³ 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/m³ at Bakoli (S1), 83.01µg/m³ at S.College (S2), 69.07µg/m³ at
J.Temple (S3), 91.70μg/m³ at Libaspur (S4), 104.74μg/m³ at JNU (S6), 158.33μg/m³ at Badarpur (S7), 70.05μg/m³ at IOC (S8), 89.41μg/m³ at CRI (S10) and 85.38μg/m³ 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 S10 sites 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/m³ and 80 μg/m³ 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/m³ 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 73.5 μg/m³ and the maximum and minimum concentration was 174.44 μg/m³ and 5.88 μg/m³ 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 69.07-158.33 μg/m³. 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 \((r < \pm 0.5)\).

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 \(P \leq 0.01\) level. The difference with regard to spikes per plant and spike length were also statistically significant at \(P \leq 0.05\) level.

8. The percentage difference in the performance of EDU treated and non-treated plants fumigated with 150 \(\mu\)g/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 35.72-50.20\(\mu\)g/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 µg/m³ 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 69.07-158.33 µg/m³. 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 weakly 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 \(P \leq 0.01\) level, the difference with regard to shoot length, number of branches, total chlorophyll were also statistically significant at \(P \leq 0.05\) level.

16. The percentage difference in the performance of EDU treated and non-treated plants fumigated with 150 µg/m³ 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 35.72-50.20 μg/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 $P \leq 0.01$. 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.
20. The percentage difference in the performance of EDU treated and non-treated plants fumigated with 150 µg/m³ 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/m³ and 93.25 µg/m³ 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.
Crop Loss from Ground Level Ozone and its Economic Implications

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 μg/m³; 48.00 μg/m³; 62.32 μg/m³, 46.15 μg/m³, 31.42 μg/m³, 60.37 μg/m³, 61.54 μg/m³, 46.45 μg/m³ and 23.13 μg/m³. The average ozone value for the nine stations is 48.111 μg/m³.

26. In the absence of any better data 48 μg/m³ 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 μg/m³ 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 μg/m³ 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 μg/m³ 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.