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EFFECTS OF AIR POLLUTION ON YIELD OF MUNGBEAN IN LAHORE, PAKISTAN

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Abstract

Experiments were conducted with two commonly grown mungbean varieties viz., M-28 and 6601, in open top chambers and ambient field conditions with the aim of ascertaining the effects of air pollution on yield. The 8-h daily mean ozone concentrations were 41-73 nl $litre^{-1}$. A considerable reduction of 47.06% and 51.12% in seed yield for M-28 and 6601, respectively were found which are substantially more than might be predicted elsewhere. These reductions in economic yield were due to decrease in both numbers of seed per pod and individual seed weight.

Introduction

The impacts of photochemical pollutants are well documented on the economic yield of major agricultural crops (Wahid *et al*., 1995a,b, 1997; Ashmore *et al*., 1998; Maggs & Ashmore, 1999; Aunan *et al*., 2000). Such effects are currently attributed largely to the secondary photo-oxidant ozone (O_3), which is widespread in major arable productive land areas (Wahid *et al*., 2001). The formation of ozone is influenced by major emissions of its precursors, nitrogen oxides (NOx) and hydrocarbons, of which the motor vehicle is the most important source. However, in some areas nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and other air pollutants are also important in term of crop yield (Emberson *et al*., 2001).

Extensive quantitative studies on economic losses of major agricultural crops arising from air pollution have been obtained from "United States National Crop Loss Assessment Network" (NCLAN) programme and "European Open-top Chambers" (EOTCs) project (Jager *et al*., 1993). In these studies, agricultural crops were grown to maturity in open-top chambers, ventilated with charcoal-filtered or ambient air, supplemented with extra O_3 in some treatments in order to generate dose response relationships (Emberson *et al*., 2003, 2009). Outside plots were also set up to determine any impact on the crops by the chambers themselves. In United States, economic losses of major agricultural crops due to yield depression by air pollution are 3×10^{9} dollars per annum (Murphy *et al*., 1999), while in Europe overall annual losses are 43 million pounds sterling. Both the United States and European studies have shown clear evidence of ambient O_3 pollution reducing yield of major agricultural crops (Maggs *et al*., 1995; Fuhrer *et al*., 1997; Pleijel *et al*., 1998, 1999, 2000; Ashmore *et al*., 1998; Stankowski *et al*., 1998; Maggs & Ashmore; 1999; Meyer *et al*., 2000 and Wahid, 2006a, b).

In contrast to USA and Europe, little information is available about the responses of air pollution on major agricultural crops in developing countries. In Pakistan a number of studies (Wahid *et al.*, 1995a,b; 2001; Wahid, 2006a,b) on wheat, rice and soybean have been carried out that reported 30-70% reduction in yield compared with control plants but extensive information on urban, suburban and rural arable productive areas, phytotoxic pollutant concentration is still not sufficient in Pakistan. At the same time, pollution control is non-existent due to technical, economic and other reasons; consequently the air pollutants emissions are rising in Pakistan. In view of ever increasing air pollution problems during the past few years, and Pakistan being an agricultural country, it is highly desired to take serious notice of this alarming situation and is an urgent need to carry out such studies in Pakistan.

Materials and Methods

Experimental design: The experiment was carried out in the Botanic Garden, GC University Lahore, Pakistan. The open top chambers used in this study were constructed according to the design of Bell & Ashmore (1986), which has been widely used in air filtration studies in England and many other European countries and may also be suitable for developing countries like Pakistan (Wahid *et al.*, 1995a). The open top chambers are 1.5 m in diameter and height, consisting of an aluminum framework with transparent polyethylene walls, with air supplied at three changes per minute *via* vertical manifolds. Four chambers were ventilated with ambient unfiltered air (UFA), while the other four were ventilated with air that had been passed through an activated charcoal filter (FA). Both type of chambers were equipped with prefilters to remove dust. Four open-plots (AA) without any chamber were also used to grow plants in ambient conditions, which make comparison possible to both FA and UFA plants. Small doorway was also present in each chamber, which permit entrance into it for watering and growth assessment purposes. The fans and filters were sheltered in order to minimize any rise in temperature of the air entering the chambers. An 8 feet’s high metal fence was constructed around the entire site for security purposes.

The clay pots of 36 cm diameter were used in this study. The sieve garden soil and sand were mixed in the ratio of 3:1 before filling in the pots. After preparation of pots, they were arranged in rows and were labelled with permanent marker for different treatments. Certified seed of mungbean (*Vigna radiata* (L.) Wilczek) varieties, M-28 and 6601, were obtained from Mutation Breeding Division, NIAB, Faisalabad. Healthy surface sterilized seeds of mungbean were selected and soaked in distilled water for 12 hrs to initiate better germination and for early seedlings development. These pots were placed in the open atmosphere of the wire netting enclosure to save seeds and young seedlings from birds and local villagers. After complete germination, number of seedlings per pot was reduced to 4 carefully by thinning to ensure that 4 plants were of equal size and vigor. Then all the pots were shifted in open-top chambers and in ambient field plots for their respective air treatments.

Microclimatology: Microclimatic measurements i.e., light intensity, air temperature and relative humidity were carried out inside and outside the chambers with the help of portable light and temperature humidity probe at 0800, 1200 and 1600 hrs daily in the center of open-top chamber and in ambient field plot at crop height.

Pollutants concentration measurements: Air pollutants were measured in charcoal filtered air (FA) chambers and unfiltered air (UFA) chambers. Ozone concentrations were determined at crop height using neutral buffered potassium iodide method (Saltzman & Gilbert, 1959) on every alternate day (three time, in a week) between 0900-1700 hrs. NO_2 concentrations were determined by using diffusion tubes method (Atkins *et al.*, 1978) on weekly basis.

Table 1. Mean monthly ambient air temperature, light levels and relative humidity's inside and outside the OTCs. Values are means of values measured daily at 0800, 1200 and 1600 hrs.

Month	Air temperature (°C)			Relative humidity (%)			Light intensity (Lux x 1000)		
	Inside	Outside	Diff.	Inside	Outside	Diff.	Inside	Outside	Diff.
March	24.13	23.01	+1.12	48.16	46.87	+1.29	31.54	32.36	-1.32
April	30.50	29.39	+1.11	38.49	37.26	+1.23	39.46	40.77	-1.31
May	37.38	36.26	+1.12	32.62	31.42	+1.19	41.46	42.75	-1.29
June	40.04	38.95	+1.09	21.06	20.01	+1.05	43.11	44.39	-1.28

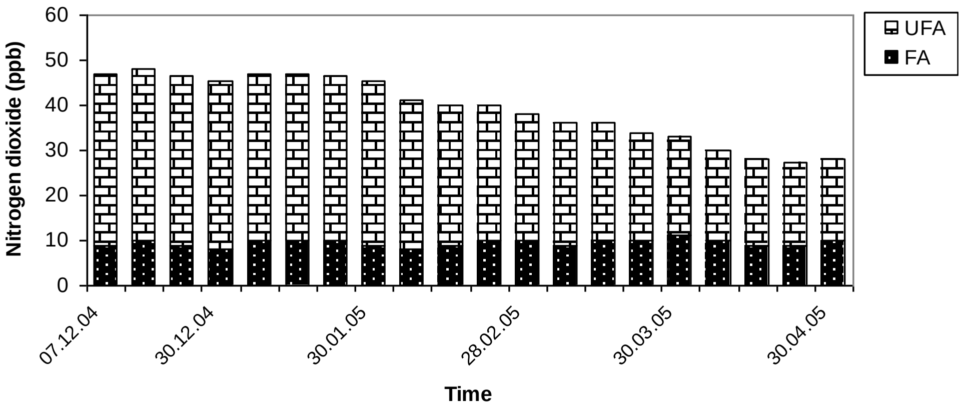

Fig. 1. Weekly mean Nitrogen dioxide concentration (ppb) in filtered and unfiltered air treatments during mungbean growth season.
UFA= Un-filter air, FA= Filter air

Crop measurements: The data for yield and yield components were recorded at the maturity of crop.

Statistical analysis: The collected data were analyzed by analysis of variance technique. Duncan's New Multiple Range test at 5% level of probability was used to test the significant differences of treatment mean (Steel & Torrie, 1960).

Results

The routine measurements recorded show that there are insignificant differences in microclimatic conditions inside and outside the open-top chambers (OCTs). The average light intensity during the crop growing season inside the OTCs reduced by 3.75% while there were a little bit of increase in air temperature (1.11°C) and relative humidity (1.19%) inside the OTCs as compared to ambient air conditions (Table 1) This reduction in light levels and increase in air temperature and relative humidity inside the OTCs were possibly due to polyethylene vertical walls of chambers and also due to heating effect of air blowers of motor.

The air pollutants (O_3+NO_2) concentrations during the experimental period much higher in ambient and unfiltered air (AA+UFA) as compared to the charcoal filtered air (FA). The mean NO_2 concentration ranged from 11.73 nl, l^{-1} in FA treatments to 26.91 nl l^{-1} in UFA treatments (Fig. 1) while on the other hand, O_3 concentration measured for FA was 8.30 nl l^{-1}

and 61.60 nl l^{-1} for UFA during the growing season of crop in OTCs (Fig. 2). The filtration efficiencies of OTCs were 85% and 65% for ozone and nitrogen dioxide, respectively. The concentrations of O_3 and NO_2 at crop height were only 1-2 nl l^{-1} lower than those at 60 cm or 120 cm within the chambers, indicating little depletion of O_3 concentrations by the crop. The ozone levels in UFA were slightly low than those recorded at a similar position in the ambient air plots.

The patterns of reproductive growth were recorded very briefly and data is based on visual record in relation to yield and yield components by the mungbean plants exposed to AA, UFA and FA. Earlier flower setting were noted in AA and UFA exposed plants as compared to FA treated plants by a difference of 7 and 5 days respectively than FA treatment in both varieties. Similar pattern of difference in pod appearance and seed ripening had occurred in AA, UFA and FA treated plants (Table 2).

The growth and developmental pattern of crop showed drastic effects of treatments on chlorophyll contents in terms of chlorophyll a, chlorophyll b, total chlorophyll and chlorophyll a:b ratio in both mungbean varieties. All chlorophyll parameters gradually decreased with rising air pollution. Therefore, high chlorophyll content has been seen in FA as compared to UFA and AA treatments in both the mungbean varieties (Table 3). There was also an accelerated rate of senescence of leaves in UFA and AA when compared to FA, which became apparent from late vegetative stage in 6601 and from start of reproductive stage in M-28. In both varieties the rate of leaf production was slower in AA than in the chambered plants (data not shown).

The results of final destructive harvest revealed highly significant ($p \angle 0.01$) effects of treatments. Large economic yield losses in UFA were seen when compared to FA with total seed weight per plant showing reductions of 47.06% for M-28 and 51.12% for 6601 (Table 4). Reductions in straw weight were similar to reductions in total seed weight, 35.14% for M-28 and 35.76% for 6601. A substantial part of the yield reduction was due to reduction in the number of pods per plant, 23.53% for M-28 and 20% for 6601, respectively, there was largely a reflection of the reduced level of pods in UFA in both varieties. However, for M-28, there was also a 22.99% reduction in the number of seeds per pod in UFA, while the third major yield component, the 100-seed weight, was reduced by 10.06% in UFA in this variety. In contrast, the yield reductions in UFA for their two components were larger in 6601 (25.63% in the number of seeds per pod and 11.56% in 100 seed weight), accounting for the larger overall yield reduction. It is important to note that the difference between filtered and unfiltered air were statistically significant for both varieties and for all major yield components. The percentage reduction in the number of pods per plant was similar to that in the number of seeds per plant, suggesting that the effect of filtration was on pod production rather than number of seeds produced per plant in both varieties.

The yield and yield components measured showed lower values in AA than UFA in both varieties, although differences were small, but statistically significant, compared with those between chamber treatments. Seed yield in AA were significantly reduced compared to UFA, by 16.32% for M-28 and 14.86% for 6601. The reduced yield was due primarily to reductions in the number of seeds per pod rather than in the 100-seed weight or the number of pods per plant. The number of seeds per pod in AA was significantly reduced compared to UFA, by 5.82% for M-28 and 9.16% for 6601.

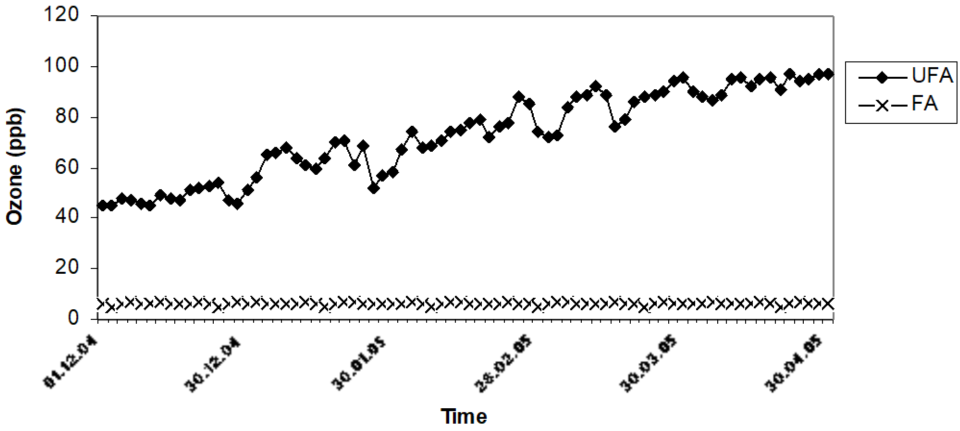

Fig. 2. Weekly mean ozone concentration (ppb) in filtered and unfiltered air treatments during mungbean growth season.

Table 2. Reproductive growth pattern in mungbean in open top chambers and ambient air plots.

Varieties	Air treatment	Flowering	Pod appearance	Seed ripening
M-28	FA	11, May	16, May	21, June
	UFA	6, May	11, May	14, June
	AA	4, May	9, May	13, June
6601	FA	9, May	14, May	19, June
	UFA	4, May	9, May	12, June
	AA	2, May	7, May	11, June

FA= Filter air, UFA= Un-filter air, AA= Ambient air

Table 3. Changes in some chlorophyll characteristics of mungbean under different air treatments at vegetative growth.

Varieties	Air treatment	Chl. a	Chl. b	Total Chl.	Chl. a:b ratio
M-28	FA	0.538	0.448	0.994	1.202
	UFA	0.413	0.387	0.794	1.079
	AA	0.052	0.042	0.125	1.244
6601	FA	0.600	0.592	1.195	1.015
	UFA	0.486	0.413	0.934	1.133
	AA	0.072	0.034	0.165	2.151
Summary of significance of variance sources					
Varieties (V)	1	**	**	**	**
Treatment (T)	2	**	**	**	**
V x T	2	**	**	**	**

**Significant at p<0.05

Table 4. Some yield assays of two mungbean varieties under different air treatments at maturity.

Yield characteristics	Varieties

	M-28			6601		
	FA	**UFA**	**AA**	**FA**	**UFA**	**AA**
Seeds yield per plant (mg)	16286a	8623b	861b	12469a	6095b	5989b
100 seeds wt. (mg)	11060a	9947b	993b	10316a	8623b	8606b
Average no. of seeds per pod	8.70a	6.20b	6.15b	7.92a	5.59b	5.48b
No. of seeds per plant	148a	81b	75b	121a	67b	61b
Average seeds wt. per pod (mg)	959a	668b	648b	819a	587b	568b
No. of pods per plant	17a	13b	12b	15a	12b	11b
Average pod wt. per plant (mg)	1337a	903b	896b	1150a	758b	747b
Average size of pod per plant (cm)	6.0a	4.8b	4.6b	5.6a	4.5b	4.3b
Average straw wt. of pod (mg)	380a	270b	261b	337a	221b	215b
*Straw wt. per plant (mg)	3130a	2010b	1999b	2950a	1895b	1890b

Treatment means followed by different letters within cultivars are significantly different from one another at $p<0.05$
*Straw wt. per plant excluded the pods & seeds wt. per plant

Discussion

Ambient air pollution has shown to be injurious in term of yield losses to a wide range of agricultural crops (Aunan *et al.*, 2000; Emberson *et al.*, 2009). The present study was conducted to assess the impact of ambient air pollution on leguminous crops in OTCs and has revealed the feasibility of using open top chambers, which can be made, easily by using local material in the developing countries like Pakistan. Even under conditions where mean air temperatures approached 44°C towards the end of the experiment, temperature increased within the chambers remained small. In any filtration experiment involving comparisons of plant performance inside chambers, the environmental modification imposed by the chambers are inevitably criticized. In the present study, comparison of UFA with AA showed relatively small differences than comparison of UFA with FA in case of all the growth and yield parameters.

The growth and yield reduction differences detected in AA and UFA may possibly reflect the small increase in temperature inside the chambers. However, another factor may be potentially adverse impacts of dusts, especially during the drier period of the year. Dust levels in the chambers will have been substantially lower than in the ambient air plots.

The routine measurements of the microclimate inside and outside the chambers have shown a very little impact upon the chamber environment. The temperature (1.11°C) and relative humidity (1.19%) increased inside the chambers were very small in comparison to ambient environment. The light intensity (Lux x 1000) values were also comparable to the chamber less ambient conditions in contrast to many other open-top chamber studies (Sanders *et al.*, 1991, 1992; Schenone & Lorenzini, 1992; Wahid *et al.*, 1995a, b) where light levels were much lower inside the chambers. Hence, here the plants growing inside and outside chambers bear more or less similar microclimatic conditions. On the other hand, the ozone concentration in the UFA chamber was also only 1-2 nl litre^{-1} below than AA, while measurements indicated little evidence of a vertical gradient in the chamber at the planting density in this experiment. Despite the OTCs design, overall filtration efficiencies were high, perhaps reflecting the relatively low ambient wide speeds at the site. Thus, overall, the design of these chambers appears highly suitable for such type of studies in regions like Lahore. NO_2 seasonal mean were 26.91 nl litre^{-1} for UFA while 11.73 nl litre^{-1} for FA chambered plants and have impact upon the growth of plants growing in the ambient / field conditions. Ozone is perhaps the most dangerous pollutant in term of crops yield losses and its seasonal mean concentrations were 61.60 nl litre^{-1} for UFA and 8.30 nl litre^{-1} for FA chambered plants. The overall filtration efficiencies for ozone remained higher as compared to NO_2. However, ammonia concentrations at the site may be significant, while the presence of other photo-oxidants associated with high levels of ozone, such as hydrogen peroxide and peroxyacetyl nitrate cannot be excluded. The ozone levels were only measured between 1000-1600 hrs and this could have provided an unreliable estimate of ozone exposure. Data from the mobile laboratory in Lahore consistently show low O_3 concentrations at night, with maximum hourly means typically between 1100 and 1500 hrs. On days with maximum hourly mean concentrations in the range of 60-80 nl litre $^{-1}$, O_3 levels typically exceeded 40 nl litre^{-1} between 0900 and 1800 hrs. Thus there is evidence from the data available that our 6-hrs mean concentration does not provide a reasonable basis of comparison with data from European and American studies using a 7-hrs seasonal mean. Ozone, which is the most dangerous air pollutant, affects or reduced the functional ability of photosynthetic apparatus which results in chlorosis, necrosis and an ultimate senescence / death of leaves (Heath *et al*., 1982, Wahid *et al*., 1995a). The reduction in number and photosynthetic efficiency of leaves may actually affect the carbon allocation to the whole plant resulting in reduced growth and yield as investigated here (Wahid *et al*., 1995b; Wahid *et al*., 2006a, b; Pleijel *et al*., 1998, 1999, 2000; Maggs & Ashmore, 1999).

In the final destructive harvest, the yield losses recorded were very much in line with those obtained by Schenone & Lorenzini (1992) and Sanders *et al*., (1992) in the case of *Phaseolus vulgaris*. Both varieties showed similar reductions in the number of seeds per plant (41% for M-28 and 44% for 6601), which can be related to the reduced number of pod development also shown in both varieties in UFA (23% for M-28 and 20% for 6601). This reduction in pod production in UFA was seen at the time when O_3 concentrations began to increase, but this does not necessarily imply a causal relationship. Both varieties also showed significant reductions in other yield components in UFA, but the reduction in UFA was smaller in 6601, in the case of number of pods per plant (reduced by 20% in 6601, compared with 23% in M-28), seeds weight per plant (reduced by 51% in 6601, compared with 47% in M-28), straw weight per plant (reduced by 36% in 6601, compared with 35% in M-28) and number of seeds per plant (reduced by 45% in 6601, compared with 41% in M-28). These differences are of interest as an initial screening of varieties sensitivity showed 6601 to be more sensitive to ozone than M-28.

In the present study, the reductions in total seed weight were attributed to the combined effects of reductions in three parameters; the number pods per plant, the number of seeds per pod and the 100 seed weight. It is of interest to assess whether the nature of the observed effects is consistent with those observed in fumigation experiments with the major air pollutants at the Lahore site. The reduction in 100 seed weight is consistent with observations of Fuhrer *et al*., (1997), Maggs & Ashmore (1999) and Pleijiel *et al*., (2000).

The ambient levels of ozone and other pollutants at Lahore have a substantially greater impact on yield than would be predicted, on the basis of European and North American studies. The reasons for this are unclear. The large yield effects may also be due to differences in cultivation techniques. The experiment was run according to local agricultural practices, which are in stark contrast to the high intensity, high input agricultural practices seen in Europe and North America. The planting density, irrigation practices and low use of commercial fertilizers, along with the fact that the plants were grown in pots make comparison with other work difficult. Comparisons between field and pot grown crops elsewhere (Skarby *et al*., 1994) have indicated reduced sensitivity to ozone in pot grown plants when compared to those in the field, possibly due to deficiencies in nutrient and water status. This could be offset in the current study by the lower planting density leading to a greater ozone exposure of individual plants.

In developing countries, it is the requirement and urgent need of present time to take serious notice of deteriorating atmospheric quality and potential threat of Phytotoxic pollutants to possible economic yield depressions of major agricultural crops in economic context, otherwise prime productive lands of sub urban and rural arable areas will suffer from increasing depression in agricultural production (Emberson *et al.*, 2009).

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