

**Air Pollution – An Unrecognised Threat to the Nutrition of the Urban Poor in  
the Developing World?**

**Bell, J.N.B<sup>1</sup>., Marshall, F.M<sup>1</sup>., Agrawal, M<sup>2</sup>., Varshney, C.K<sup>3</sup>.,  
Batty, K<sup>4</sup>., & Ashmore, M.R<sup>4</sup>.**

1. T.H. Huxley School of Environment, Earth Sciences & Engineering, Imperial College at Silwood Park, Ascot, Berkshire. SL5 7PY, U.K.
2. Department of Botany, Banaras Hindu University, Varanasi – 221005, India.
3. Department of Environmental Science, Jawaharlal Nehru University, New Delhi-110067, India.
4. Department of Environmental Science, University of Bradford, Bradford BD7 1DP, U.K.

**1. Introduction.**

In the Developed World air pollution damage to vegetation has been recognised since the 16<sup>th</sup> century at least. However, it is only over the last 30 years or so that quantitative estimates have been made of crop yield losses, with the demonstration that vast areas are affected in this manner. Traditionally air pollution has been viewed in terms of sulphur dioxide and particulates associated with coal combustion and smelting. These pollutants were responsible in the past for spectacular adverse effects on vegetation in industrialised areas of Europe and North America. For example, a study of experimental crops exposed along a gradient of increasing levels of SO<sub>2</sub> and particulates in the northern English city of Leeds which was carried out just before World War 1, showed a reduction of yield of up to 70% from a rural area to the most polluted central location (Cohen & Ruston, 1925). Subsequently, concerns over human health, together with a range of socio-economic factors, have resulted in substantial declines in both of these pollutants everywhere in developed countries. However, this has been counteracted to a large extent by the appearance of other pollutants, largely associated with vehicle emissions in the form of nitrogen oxides (NO<sub>x</sub>) and agricultural sources in the form of ammonia (NH<sub>3</sub>). Of particular concern are photo-oxidants, particularly ozone (O<sub>3</sub>), produced by the action of ultra-violet light on NO<sub>x</sub> and volatile organic compounds (VOCs). Paradoxically, while the precursors of O<sub>3</sub> originate largely in cities, concentrations of this pollutant are

usually higher in the neighbouring countryside. The most rigorous study of the impacts of O<sub>3</sub> was conducted in the USA in the 1980s, and suggested that a loss of about \$3 billion was occurring annually as a result of yield reductions in the 11 most important crop species.

While much of the developed world is producing unwanted agricultural surpluses, and thus effects on yield caused by air pollution are invariably no longer viewed as a matter for concern, most developing countries have an urgent need to increase crop production. Thus any effect of air pollution on yield must present an extra threat to food security in addition to the well recognised myriad of constraints, such as salinity and pest/pathogen attack. Furthermore, it is well recognised, although under-researched, that air pollution can reduce the nutritional quality of crops, as well as reducing yield (Skärby, 1984), with the further potential to impact nutrition adversely.

What then is the evidence that this issue of the developed world may be a problem of developing countries? Firstly, emissions of major air pollutants are rising rapidly, with increased industrialisation and levels of motor traffic, usually with minimal or zero controls. Secondly, climatic conditions in many developing countries are particularly conducive to photo-oxidant formation, with high levels of ultra violet radiation (bright sunlight) and temperatures, as well as low wind-speeds. A fraction of the research devoted to air pollution impacts on crops that has been expended in the developed world has been employed in similar studies in developing countries. As a crude estimate we would suggest <0.01%! What can we learn from the small amount of research conducted so far? The indications are that we should be very concerned. As early as 1984, strong evidence was produced of severe O<sub>3</sub> injury on potatoes in the Indian Punjab (Bambawale, 1986). Subsequently, research by Imperial College with the Punjab University, Lahore produced strong evidence for ambient O<sub>3</sub> levels on the periphery of that city reducing yields of rice and wheat by around 40%. (Wahid, *et al.*, 1995a, b). Other research by the same group showed 15-30% reductions in the yield of Egyptian vegetable crops in Alexandria and the nearby Delta (Hassan *et al.*, 1995).

The urban and peri-urban areas of developing countries have the unfortunate combination of being impacted by both the “traditional” pollutants long recognised in the West (i.e. SO<sub>2</sub> and particulates), as well as the “new” pollutants in the form of

NO<sub>x</sub> and O<sub>3</sub>. It is well known that mixtures of these pollutants can not only result in combined adverse effects, but that these are often greater than the sum of their individual impacts. Thus the air pollution regime of many developing country cities would appear to represent a major threat to crops both within the urban area and on its (peri-urban) fringe.

This paper describes an investigation into the above issue, working in the Indian cities of Delhi and Varanasi. It is supported by the UK Department for International Development (former ODA) and is aimed at assessing the impacts of air pollution on the stakeholders of urban and peri-urban agriculture in these cities, as a model for elsewhere in India.

## **2. Materials and Methods.**

As a major part of the research programme, field studies have been conducted over both summer and winter growing seasons with the same crops grown in each city. These studies have employed a gradient approach where experimental plants have been grown to maturity at locations with differing concentrations of air pollutants. This approach has largely been neglected by research workers, yet can yield much valuable information, particularly as the plants are grown outdoors with no alteration of microclimate which results from the use of various types of chambers, and is particularly appropriate for developing countries in view of its low cost and lack of a requirement for sophisticated equipment (Bell & Marshall, 1999). The species grown in the summer of 1998 were moong bean (*Vigna radiata*) and spinach (*Spinacia oleracea*), and those grown in winter 1998/9 were wheat (*Triticum aestivum*) and mustard (*Brassica campestris*), being important urban and peri-urban crops in Delhi and Varanasi in their respective growing seasons.

In Delhi 9 field sites were selected, with 4 of these being upwind towards the NW periphery of the city, 1 in a central area and 4 downwind (SE) in Delhi itself and in the neighbouring towns of Faridabad and Ballabgarh. The NW sites were in an area with relatively little industry, where O<sub>3</sub> might be expected to be the main phytotoxic air pollutant, and the SE sites were located in industrial areas, where a mix of SO<sub>2</sub> and NO<sub>x</sub> was expected in addition to O<sub>3</sub>. In Varanasi the sites were spaced out along a NW-SE transect, where it was anticipated on the basis of earlier work (Pandey *et al.*,

1992) that there would be a gradient of air pollution declining towards the SE. Ten sites were selected with one of these being in a rural location to the SE of the city. All 4 crops were grown to maturity, with a final harvest involving measurements of yield components. In the case of wheat at Varanasi, measurements were made of the nutritional quality of the harvested grain in the form of content of total sugar, reducing sugar, starch, energy and protein. SO<sub>2</sub> and NO<sub>2</sub> were measured along the transects by means of passive samplers and O<sub>3</sub> burdens estimated by means of bio-indicators in the form of an ultra-sensitive tobacco cultivar; in addition 6-hour wet chemistry measurements of SO<sub>2</sub> and NO<sub>2</sub> were made at selected sites in Varanasi.

### **3. Results.**

#### **3.1 Summer Experiment.**

No measurements were available for SO<sub>2</sub> and NO<sub>2</sub> over the summer experiment in Delhi, but O<sub>3</sub> injury was recorded on tobacco at 3 locations. In Varanasi, mean SO<sub>2</sub> concentrations at the 4 sites where wet chemistry measurements were made ranged between 22 gm<sup>-3</sup> and 86 gm<sup>-3</sup>; the corresponding values for NO<sub>2</sub> were 22-112 gm<sup>-3</sup>. These are substantially higher than the Critical Level of 30 gm<sup>-3</sup> annual mean for both pollutants established as the air quality standard to protect crops against yield reduction in Europe. Thus it could be postulated that the atmosphere of Varanasi could have major deleterious effects on the yield of urban agriculture. In the absence of monitoring data for Delhi it is not possible to make any correlation with moong bean and spinach yield. Along the Varanasi transect there was considerable variability in the yield of both crops, amounting to reductions from the highest to the least polluted site of 85% and 77% for SO<sub>2</sub> and NO<sub>2</sub>, respectively, in the case of moong bean, with corresponding figures for spinach of 77% and 78%. Both moong bean and spinach showed significant negative correlations with SO<sub>2</sub> concentration (Fig. 1) but in the case of NO<sub>2</sub> (Fig. 2) this was only significant for bean.

#### **3.2 Winter Experiment.**

During the winter experiment, mean SO<sub>2</sub> and NO<sub>2</sub> levels were 54µgm<sup>-3</sup> and

136 $\mu\text{gm}^{-3}$ , respectively, over the Delhi sites and 79 and 68  $\mu\text{gm}^{-3}$ , respectively, over the Varanasi sites. The corresponding mean values for the sites with the highest concentrations were 86 $\mu\text{gm}^{-3}$  and 197 $\mu\text{gm}^{-3}$  for Delhi and 122 $\mu\text{gm}^{-3}$  and 91 $\mu\text{gm}^{-3}$  for Varanasi. In both cities these are substantially higher than the Critical Levels for both pollutants, thereby indicating a potential threat to crop growth in both cities. An examination of the yield data from the winter experiment reveals variability between the different sites. In Delhi seed weight of both mustard and wheat (Fig. 3) showed negative correlations with both  $\text{SO}_2$  and  $\text{NO}_2$  correlations. However, only the  $\text{NO}_2$  correlation was significant. At Varanasi there were again no significant correlations between the yield of either crop and the prevailing  $\text{SO}_2$  concentration. There was, however, a clear significant negative relationship between  $\text{NO}_2$  concentration and wheat yield (Fig. 4), with indications of a similar relationship for mustard. The slopes of the relationships were much higher at Varanasi than Delhi, which was surprising in view of overall lower  $\text{NO}_2$  concentrations in the former city. Thus wheat seed weight was 12.6% and 28.6% lower at the most polluted compared with the least polluted site in Delhi and Varanasi, respectively.

Almost no  $\text{O}_3$  injury was observed on tobacco at Varanasi, but at Delhi there was a significant positive correlation between injury and reduction in yield of both wheat and mustard from the highest to the lowest yield sites. Thus there is evidence for  $\text{O}_3$  also playing a role in growth reduction.

The measurements of wheat grain quality also showed variation across the sites at Varanasi, and there was a significant negative correlation with both  $\text{SO}_2$  and  $\text{NO}_2$  concentrations for total and reducing sugar, starch and energy content, but no significant relationship with protein content (Fig. 5).

#### **4. Discussion.**

The results of both winter and summer experiments in Delhi and Varanasi have potentially very serious implications for crop yield in urban and peri-urban agriculture in both cities. There is abundant evidence for the yield of 4 important crop species being markedly reduced as a result of the prevailing levels of air pollution. While there clearly may be various confounding factors, particularly variations in

microclimate between sites which may influence the results, the strength of the association between yield reductions and SO<sub>2</sub> or NO<sub>2</sub> concentrations in the ambient air lends strong support to the hypothesis that there is a causal relationship. Furthermore, the tobacco monitoring provides some evidence of O<sub>3</sub> also being involved in yield reduction. In these studies it is not possible to identify with certainty the contribution of the individual pollutants to yield reduction, as many studies in the developed world have shown synergistic, or (less commonly) antagonistic interactions between O<sub>3</sub>, SO<sub>2</sub> and NO<sub>2</sub> in different combinations. While reduction in yield clearly represents a threat to the welfare of the urban poor, perhaps of even greater concern is the fact that the yield that does occur is of significantly lower quality in terms of carbohydrate and energy content. This will pass unnoticed when the crops are consumed or sold, as there will be no external symptoms to indicate reduced nutritional value.

The occurrence of such effects in a medium sized, relatively unindustrialised Indian city suggests that these may be widespread in similar sized urban areas across the Indian sub-continent. Are there, then, any implications for Bangladesh? There is little doubt that air quality has deteriorated seriously in Dhaka over the last few years, yet air pollution monitoring has been limited. A recent study (Kitada & Azad, 1998) has demonstrated widespread elevated levels of both SO<sub>2</sub> and NO<sub>2</sub> in Dhaka, with in some cases these being coincident with areas of urban and peri-urban agriculture. Table 1 shows a comparison of the ranges of concentrations of both these pollutants measured in the present study with those recorded by Kitada & Azad (1998) in Dhaka. It is worth noting that the range for SO<sub>2</sub> exceeds that in the 2 Indian cities, whereas that for NO<sub>2</sub> is towards the lower part of these. However, for both pollutants the Dhaka concentrations exceed the Critical Levels of 30µgm<sup>-3</sup> set as annual or winter means to protect agricultural crops in Europe. The WHO guidelines for protection of human health are higher than the Critical Levels for crops, being 50µgm<sup>-3</sup> and 40-50µgm<sup>-3</sup> for SO<sub>2</sub> and NO<sub>2</sub>, respectively. Thus air pollution control measures designed to protect human health from the direct impacts of air pollution may be inadequate for protection against the indirect impacts which could occur via reduced crop quality and yield.

## **5. Wider Implications of the Study.**

The experimental work described here, forms part of a major interdisciplinary study to assess the scientific and socio-economic implications of environmental threats to urban and peri-urban agriculture in India, with particular emphasis on the livelihoods of the poor. Innovative methods are used to share the emerging experimental findings with a wide range of stakeholders, and to consider them in the context of the constraints faced by the urban poor, and by the authorities charged with environmental and agricultural policy planning and implementation. The study includes in-depth participatory research activities with local communities, and consultation with NGOs, policy makers, planners and others. One major thrust of the policy activities is to consider how air pollution impacts on agriculture can be effectively included in environmental policies and air pollution control strategies, which focus predominantly on the direct impacts of air pollution on human health in urban areas.

## **Acknowledgements.**

This research was funded under the terms of a contract from the UK Department for International Development, whose support is gratefully acknowledged.

## **7. REFERENCES**

- Bambawale, O.M. (1986). Evidence of O<sub>3</sub> to a crop plant in India. *Atmos. Env.*, 20, 1501-3.
- Bell, J.N.B. & Marshall, F.M. (1999). Field studies on impacts of air pollution on agricultural crops. In: *Env. Pollution and Plant Responses*. (Eds. M. Agrawal & Krizek). CRC Press/Lewis Publishers, pp. 99/110.
- Cohen, J.B. & Ruston, A.G. (1925). *A Study of Town Air*. Edward Arnold, London.
- Hassan, I.A., Ashmore, M.R. & Bell, J.N.B. (1995). Effect of ozone on radish and turnip under Egyptian field conditions. *Environ. Pollut.*, 89, 107-14.
- Kitada, T. & Azad, A.K. (1999). Study on the air pollution control system for Dhaka, Bangladesh. *Env. Technology*, 19, 443-459.

- Pandey, J., Agrawal, M., Khanaman, N., Narayan, D. & Rao, D.N. (1992). Air pollution concentrations in Varanasi, India. *Atmos. Environ.*, 26, 91-8.
- Skärby, L. (1984). Changes in the nutritional quality of crops. In: Gaseous Air Pollution and Plant Metabolism. (Eds. M.J. Koziol & F.R. Whatley). Butterworths, London. pp. 351-9.
- Wahid, A., Maggs, R., Shamsi, S.R.A., Bell, J.N.B. & Ashmore, M.R. (1995a). Air Pollution and its impact on wheat yield in the Pakistan Punjab. *Environ. Pollut.*, 88, 147-54.
- Wahid, A., Maggs, R., Shamsi, S.R.A., Bell, J.N.B. & Ashmore, M.R. (1995b). Effects of air pollution on rice yield in the Pakistan Punjab. *Environ. Pollut.*, 90, 323-9.

**Table 1. Range of Winter Air Pollution Concentrations in Delhi, Varanasi and Dhaka.**

	<b>Delhi</b>	<b>Varanasi</b>	<b>Dhaka</b>
<b>SO<sub>2</sub></b>	<b>15-115<math>\mu\text{gm}^{-3}</math></b>	<b>46-125<math>\mu\text{gm}^{-3}</math></b>	<b>43-279<math>\mu\text{gm}^{-3}</math></b>
<b>NO<sub>2</sub></b>	<b>46-355<math>\mu\text{gm}^{-3}</math></b>	<b>31-105<math>\mu\text{gm}^{-3}</math></b>	<b>31-67<math>\mu\text{gm}^{-3}</math></b>
<b>Source</b>	<b>Present Study</b>	<b>Present Study</b>	<b>Kitada &amp; Azad (1998)</b>