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AIR POLLUTION AND ITS IMPACT ON AGRICULTURAL CROPS IN DEVELOPING COUNTRIES – A REVIEW

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ABSTRACT

This review provides an overview of current knowledge of air pollution impacts on very important agricultural cash crops yield and quality in developing countries. Agriculture plays a crucial role in ensuring food security and in the economic growth of developing countries. The need to feed rapidly growing populations has been an important driving force behind efforts to increase agricultural production in developing countries. Increased food production is of particular significance for the poor, the vast majority of whom depend directly on agriculture or other forms of natural resource exploitation for at least part of their livelihoods. More than 850 million people in the developing world are currently undernourished. In addition, the poor may have little or no choice of area in which to farm and are more likely to be living and farming close to industrial pollution sources. Thus, alleviation of constraints on agricultural productivity, including air pollution, remains a high priority for poverty reduction efforts.

Keywords Agricultural crops, O_3, NO_2 and SO_2, Developing countries, Air pollution.

INTRODUCTION

Agricultural practices in both the developed and developing countries have always aimed to eliminate or minimize the numerous constraints on producing maximum yield of crops. These constraints may be abiotic, including nutrient deficiency, metal toxicity, salinity, drought, low and high temperatures, wind and waterlogging. There are also numerous biotic constrains: invertebrates and vertebrates pests; fungal, viral and bacterial pathogens and trampling. Although vast sums of money are spent on overcoming these, there is another constraint that receives much less attention, but with evidence that it is potentially a widespread threat to crop production - air pollution.

In recent years, there has been a decline in interest in effects of air pollution on crops in the developed countries, doubtless largely due to overproduction. The developing countries are certainly not characterized by overproduction, with most countries striving desperately to increase yield of their staple crops to feed rapidly expanding populations. Air pollution has traditionally been viewed as a problem of Western countries, where the bulk of the industry and motor vehicles responsible for the major pollutants residues. However, emissions of some of these pollutants are being reduced as a result of introduction of stringent controls in recognition of their adverse effects on health, vegetation, aquatic ecosystems and materials, as well as a decline of polluting heavy industries. The latter are in fact transferring to the developing world, where rapid industrialization is taking place in many countries but with poor emission controls. At the same time motor traffic is growing at an enormous rate in the developing world, often using old and poorly maintained vehicles that play a major role in contributing to deterioration in air quality. Thus SO_2 and NO_x are increasing rapidly in many developing countries. We know far less about the third ubiquitous pollutant, O_3, because very little monitoring has been carried out in most countries, and most of this is restricted to the cities where concentrations are normally lower than in adjacent agricultural areas. However, it is quite clear that O_3 levels are elevated to potentially phytotoxic concentrations in developing countries (Chameides*et al*. 1994, 1999). This is scarcely surprising in view of the conditions for the production of this secondary pollutant being amply fulfilled in such places. Ozone is a component pf photochemical smog, which was first detected in and around Los Angeles in the 1940s. After intensive research into this new smog phenomenon that not only had unpleasant effects on human health but also damaged vegetation, O_3 was identified as the main culprit in the latter case. Ozone is generated by photochemical reactions on NO_x and volatile organic compounds (VOCs). This requires high levels of emissions of these two categories of pollutants, and a climate with high temperatures, bright sunlight, and relatively still air, all pertinent to Los Angeles from the 1940s onwards (although recognition of the problem has resulted in drastic attempts to control emissions), and also to the present-day developing world. Thus, we have every reason to believe that any problems identified due to air pollution in the developed world will be replicated in developing countries, where any effects on crop yield or quantity have potentially far more serious consequences for human welfare.

Trends in Air Pollutant -- Concentrations and Distributions: Increasing energy demands associated with economic growth and industrialization in Asia, Africa and Latin America have resulted in dramatic increases in air pollution emissions. Problems are compounded by rapid and poorly planned industrial growth in developing countries, the close proximity of industrial complexes and thermal power plants to residential areas (Singh, 1995) and the fact that air pollution control in developing countries is often inadequate for technical and economic reasons. Air pollution kills more than 2.7 million people annually, with more than 90 percent of these deaths in developing countries and two-thirds of them in Asia (UNDP, 1998). Thus it is not surprising that most attention to date has focused on the direct impact of these industrial and urban emissions on human health. However, very little is known about pollutant concentrations in many suburban and rural areas, whereas there may be significant indirect impacts of air pollution on human health, through reduced crop yields, food quality and income.

Sulphur dioxide, one of the major phytotoxic primary pollutants, is emitted mainly from the combustion of coal and fuel oil, with increased emissions associated with the rapidly increasing energy demands in many developing countries. For example, Asian energy demand is doubling every 12 years, and 80 percent of the demand is met by burning fossil fuels, mainly coal (van Aardenne*et al*. 1999). As a result, SO_2 emission in Asia is predicted to increase from 34 x 10^6tonnes in 1990 to 110 x 10^6tonnes by 2020 (van Aardenne*et al*. 1999). In China, coal burning alone accounted for 72 percent of total energy consumption in 1998, causing more than half of the country's SO_2 emissions (Yanjia and Kebin, 1999). China is now the leading emitter of SO_2 in the world. Coal-based power generation has also greatly increased in India over the last decade and now accounts for 64 percent of electricity generation (Agrawal and Singh, 2000). Smelters are another important, but more localized source of sulphur dioxide.Road traffic is a relatively minor contributor in terms of national emissions of SO_2 in the developed world due to the low sulphur content of fuel. However, this is not the case in many developing countries, which have much higher sulphur levels in diesel fuel.

Traffic also plays the major role in emissions of NO_x, with nitric oxide as the principal primary pollutant but being rapidly oxidized to NO_2. All high temperature combustion processes result in the emission of NO_x, with thermal power stations representing the other major source. A global increase in NO_x emissions from 40 x 10^6tonnes in the mid-1980s to 55-66 x 10^6tonnes per year by 2025 has been predicted (Lee *et al*. 1997), with substantially higher percentage increases in some developing countries, such as China. These increases in NO_x are predicted to cause widespread increases in O_3 levels across the developing world.

Ozone levels can be elevated above the natural background of about 40 ppb through a complex series of photochemical reactions also involving both NO_x and volatile organic compounds (VOCs). Motor vehicles, particularly inefficient and poorly tuned engines characteristic of developing countries, are the major source of VOCs. Furthermore, the high temperatures and high light intensity characteristic of many developing country cities favour the production of ozone. Although the precursors for ozone are produced in cities, the levels of this secondary pollutant are often higher on the outskirts of the city, due to local destruction by NO at ground level within the city (UK PORG, 1993). Ozone is a particular cause for concern because elevated ozone levels can be widespread over rural agricultural areas, particularly downwind of cities (UK PORG, 1993). There has been very little coordinated monitoring of ozone levels in rural areas of developing countries, but the limited data available are consistent with this, indicating phytotoxic levels in a number of important agricultural areas (Ashmore and Marshall, 1999).

Agriculture in the Developing Counties: While the impacts of air pollution, and particularly ozone, on agriculture in North American and Western Europe have received considerable attention, there has been little recognition of this issue in the developing countries of Asia, Africa, and Latin America. Here the social and economic significance of air pollution impacts on agriculture may be much greater, bearing in mind the considerable importance of national agricultural production to maintain food security and earn foreign exchange. However, air pollution control in general is argued for in the face of limited resources and a general desire to promote industrial development.

Impacts of air pollution on agricultural crops in developing countries

Ozone: Major field studies on the direct effects of ambient O_3 on crop yield have been carried out in India and Pakistan (Table 1,2,3). Many of these studies have used anti-ozonant chemicals applied to the foliage or as a soil drench. This technique is relatively easy to employ and less costly than chamber filtration systems.

An important experiment was conducted by Wahid *et al*. (2001) in Pakistan. Here the protective effect of EDU on soybean (*Glycine max*) was assessed at a suburban site, a remote rural site and a rural roadside site around the city of Lahore in the pre-monsoon growing season. The decrease in seed weight of the non-treated plants as compared to the untreated plants was 53, 65 and 74 percent for the suburban, remote rural and rural roadside sites, respectively. Oxidant concentrations were also higher at the rural sites. The results suggest that ozone may have widespread impacts on crop yields in the Punjab, which is the most important agricultural area in Pakistan (Table 3).

Table 1.Describing the datacollated about wheat yield response to ozone

Reference	Study site	Experimental type (growth period) – field/pot – O_3 monitoring method	Cultivar (No. of data points)	SO_2 and NO_2 concs. (ppb)	O_3concs. (ppb) averaging period	Yield response (Parameter, rel. yield %)
Agrawal (2005)	India, Varanasi	Fu (Dec–March) – field – wet chemistry	Winter wheat: Malviya 234 (2), HP1209 (2)	-	70, 100; 4-h mean	Yield plant^{-1}, 95–83%
Ambasht and Agrawal (2003a)	India, Varanasi	Fu (Nov–April) – field – wet chemistry	Winter wheat: Malviya 234 (1)	-	70; 4-h mean	Yield plant^{-1}, 91%
Rai et al. (2007)	India, Varanasi	Fi (Dec–March) – field – UV absorption	Winter wheat: Malviya 234 (1)	SO_2 8.4; NO_2 39.9	40; 8-h mean	Yield plant^{-1}, 79%
Tiwari et al. (2005)	India, Varanasi	EDU (300 ppm) (Dec.–March) –field – UV absorption	Winter wheat: Malviya 533 (1), Malviya 234 (1)	-	41; 8-h mean	Yield plant^{-1}, 87–81%
Wahid (2006)	Pakistan, Lahore	Fi (Nov–Feb) – pot – UV absorption	Spring wheat: Inqlab-91 (1), Punjab-96 (1), Pasban-90 (1)	SO_2 16; NO_2 30	72; 8-h mean	Yield plant^{-1}, 82–57%
Wahid and Maggs (1999)	Pakistan, Lahore	Fi (Nov–April) – pot – wet chemistry	Spring wheat: Rawal-87 (1), Punjab-85 (1)	no data	70; 8-h mean	Yield plant^{-1}, 64–52%

Fu: Fumigation; Fi: Filtration; EDU: Ethylenediurea

Table 2. Describing the datacollated about rice yield response to ozone

Reference	Study site	Experimental type (growth period) – field/pot – O_3monitoring method	Cultivar (No. of data points)	SO_2 and NO_2 concs. (ppb)	O_3concs. (ppb) averaging period	Yield response (Parameter, rel. yield %)
Maggs et al. (1995)	Pakistan, Lahore	Fi (May/June to Oct/Nov) – pot – wet chemistry	Basmati 385 (1), IRRI 6 (1)	SO_2 no data; NO_2 22.5	60; 6 h mean of 3 days week_1	Yield plant_1, 63–53%
Wahid et al. (1995b)	Pakistan, Lahore	Fi (July–Nov) – pot – wet Chemistry	Basmati 385 (1), IRRI 6 (1)	SO_2 no data; NO_2 12.6	36; 6 h mean of 3 days week^{-1}	Yield plant$^{-1,}$ 63–58%
Wahid et al. (1997)	Pakistan, Lahore	Fi (July–Nov) – pot – wet Chemistry	Basmati 370 (1), Basmati Pak (1)	no data	57; 8 h mean	Yield plant_1, 71–55%

Fu: Fumigation; Fi: Filtration

Table 3.Describing the datacollated about yield response of various legumes to ozone

Reference	Study site	Experimental type (growth period) – field/pot – O_3monitoring method	Species and cultivar (No. of data points)	Control treatment	O_3concs. (ppb) averaging period	Yield response (Parameter, rel. yield %)
Agrawal (2005)	India, Varanasi	Fu (July–Oct) – field – wet Chemistry	Soybean: PK472 (2), Bragg (2)	-	70, 100; 4-h mean	Yield plant^{-1}, 95–66%
Agrawal et al. (2005)	India, Allahabad	EDU (500 ppm) (July–Sep) – field – wet chemistry	Mung bean: Malviya Jyoti (1)	-	33; 8-h mean of 1 days week^{-1}	Yield plant^{-1}, 70%
Ambasht and Agrawal (2003b)	India, Varanasi	Fu (Nov–March) – field – wet Chemistry	Soybean: Punjab 1 (1)	-	70; 4-h mean	Yield plant^{-1}, 89%
Bajwa et al. (1997)	Pakistan, Lahore	Fi (March–June) – pot – wet Chemistry	Mung bean: M-28 (1)	no data	61; 8-h mean	Yield plant^{-1}, 50%
Wahid et al. (2001)	Pakistan, Lahore	EDU (400 ppm) (Aug–Oct and Feb–May) – pot – wet chemistry	Soybean: NARC-1 (4)	-	40-75; 6-h mean	Yield plant^{-1}, 68–35%
Ahmed (2007)	Pakistan, Lahore	OTCs (March-June) – pot- wet chemistry	Mungbean: NM-92 and NM-51 (2)	-	62; 8-h mean	Yield plant^{-1}, 55%

Fu: Fumigation; Fi: Filtration; EDU: Ethylenediurea

A very limited number of open-top chamber filtration studies have been carried out in developing countries. The most important series of experiments was again in the outskirts of Lahore in Pakistan using two local cultivars each of winter wheat, rice and mungbean repeated for two successive years (Maggs*et al*. 1995; Wahid *et al*. 1995a, b; Ahmed,2007) (Table 1,2,3). The crops were grown in open-top chambers ventilated with ambient or charcoal-filtered air and were subject to local cultivation practices. The four experiments all showed significant reductions in yield in the unfiltered air treatment as compared to filtered air, ranging from 34 to 46 percent. The concentrations of sulphur dioxide at this site were negligible, but a series of closed chamber fumigation studies were carried out to assess the relative contributions of ozone and nitrogen dioxide to the observed yield reductions (Maggs, 1996). These studies, using the same cultivars showed no effect of NO_2 either alone or in combination with O_3, indicating that the yield reductions recorded at Lahore were caused by ambient O_3 alone. These findings were supported by the later study using EDU with soybean (Wahid *et al*. 2001).

Sulphur dioxide: A large number of chamber and field studies have been conducted to investigate the impact of sulphur dioxide on crops in developing countries, particularly in India. Wheat, which appears to be particularly sensitive as compared to other major crop plants, has been studied most extensively. However, the majority of these studies are closed chamber fumigations involving abnormally high concentrations of SO_2, with only a limited number of the fumigations utilizing ambient levels of the pollutant. Field experiments are generally transect studies away from point sources, again due to the complex and costly nature of open-top fumigations systems, which have been widely adopted in industrialized countries. In these transect studies plant material is usually grown in standard soil and containers and exposed for all or part of the growing season along gradients of the pollutant. Results can be complicated by the presence of other pollutants, notably NOx. One important transect study was reported by Singh *et al.* (1990) in which a local wheat cultivar was grown at different distances from a coal-fired power station in Uttar Pradesh, India.

Despite evidence of increasing SO_2 emissions in developing countries, the experimental evidence indicates that phytotoxic impacts on agriculture are largely associated with point sources, and would affect a localized zone in the vicinity of industries located in rural areas. However, this ignores the issue of urban and peri-urban agriculture, which is exposed in many places to high levels of both SO_2 and other pollutants. Urban and peri-urban agriculture is often neglected by policy makers and planners, but there is strong evidence that it plays an increasing role in food supply of rapidly urbanizing populations in the developing world and a very important role in the nutrition of the urban poor (UNDP, 1996).

Nitrogen dioxide: Very little research has been carried out into the impacts of nitrogen dioxide on crop yields in developing countries. Although the study by Maggs *et al*. (1995) indicated that ambient levels of NOx were not having an impact on yields of wheat and rice at suburban sites outside Lahore, this pollutant may indeed be important in and around urban areas. The impact of NOx was also considered in the study described above in which the effect of SO_2 on four crops in Delhi and Varanasi were investigated. In winter, wheat yield was significantly negatively correlated (p< 0.05) with NO_2 concentrations ranging from 31 to 105 μg m^{-3} (Marshall *et al.* 1997). In Delhi the yields of both mustard and wheat were negatively correlated with NO, which ranged from 79 and 197 μg m^{-3} (Marshall *et al.* 1997). The transect study in Varanasi also raised the possibility that urban air pollution was having an impact on the nutritional quality, in addition to the yield of crops. The results showed significant negative relationships with carbohydrate and energy contents and both SO_2 and NO_2 for mungbean and wheat (Table1).

FUTURE RESEARCH PRIORITIES: The limited field experimental data described above clearly indicate that significant crop losses may be occurring in a number of important agricultural areas in the developing countries, with ozone the major cause for concern. However, this issue is little recognized and resources available to investigate it are limited. It is therefore important to be able to identify and illustrate geographical areas where there is a high risk of major crop losses in order to target further research efforts.

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