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A hidden threat to food production:
Air pollution and agriculture in the developing world

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This Gatekeeper Series is produced by the International Institute for Environment and Development to highlight key topics in the field of sustainable agriculture. Each paper reviews a selected issue of contemporary importance and draws preliminary conclusions of relevance to development activities. References are provided to important sources and background material.

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EXECUTIVE SUMMARY

Air pollution is a growing problem in many developing countries. However, attention to date has been on its impact on human health in large cities. But as this paper demonstrates, air pollution in these cities, and in the surrounding countryside, could also have significant impacts on agricultural production. The economic, environmental and social impacts of these effects could be substantial, but the importance of this issue, and its implications for both pollution control and agricultural policy, has not been recognised by many national and international agencies.

This paper examines the current and future importance of air pollution as a constraint to agricultural productivity in developing countries. It asserts that the key pollutants of concern are ground level ozone, given its potential to cause widespread yield loss in sensitive crops; and other pollutants, such as sulphur dioxide and nitrogen dioxide, which also have significant localised effects. A global risk assessment reveals a high risk of crop loss from ozone, and local crop loss due to sulphur dioxide in a number of countries, including China and India. Projecting ozone emissions to 2025, the high risk area expands dramatically, covering the majority of the cultivated areas of India, China, Egypt, South Africa and significant areas in other countries. The implications are that the effectiveness of policies aimed at increasing food production and food security will be increased in many areas if action is taken to reduce the impacts of air pollution.

This global assessment is supported by a case study in India, which explores how these findings can be addressed at a national level through further research and policy change. Potential methods of reducing impacts through changes in agricultural practice are identified, but more field work is needed to evaluate their costs and benefits in different situations. Important links are also identified to plant breeding programmes, pest management programmes, assessments of the impacts on agriculture of global climate change, and the development of sustainable agriculture.

Whilst exploring the potential for changes in agricultural practices to reduce these impacts is one way forward, clearly another avenue to explore is how policy can reduce emissions of the major pollutants and their precursors. There are a number of environmental policy issues, including air quality standards, cost-benefit analysis, urban planning, national land-use planning and local environmental impact assessment, which need to take the issue of air pollution and agriculture into account. More detailed analysis of these policy issues in India identifies scope for new measures which move away from the conventional command and control approach to pollution reduction. Thought should also be given to more creative solutions which can overcome the difficulties of centralised pollution monitoring and control. The issue can be further understood through community based research: the focus of a new project to examine the impacts and policy implications of air pollution on crop yields in urban and peri-urban areas in India.

A HIDDEN THREAT TO FOOD PRODUCTION: AIR POLLUTION AND AGRICULTURE IN THE DEVELOPING WORLD

Fiona Marshall, Mike Ashmore & Fiona Hinchcliffe

Until the middle of this century, air pollution was primarily a problem of urban and industrial regions in the developed nations. In the last three decades, however, changes in the pattern of air pollutant emissions, including increases in those from motor vehicles, have led to greater pollutant impacts in more remote rural areas. Furthermore, the rapid pace of industrial development and urbanisation in many developing countries means that adverse impacts on agriculture are beginning to be felt in many parts of the world outside the industrialised West.

Much of the attention surrounding air pollution in developing countries tends to focus on its impact on human health in large cities, with more limited focus on damage to important historic buildings. However, air pollution in and around these cities, and in the surrounding countryside, could also have significant impacts on agricultural production. The economic, environmental and social impacts of these effects could be very significant, but the importance of this issue, and its implications for both pollution control and agricultural policy, has not been recognised by many national and international agencies.

This paper summarises research conducted by the Imperial College Centre for Environmental Technology (ICCET) and IIED[1]. It outlines the way in which air pollution represents a threat to agriculture in the developing world, presents field based evidence of significant crop yield reductions as a result of air pollution, and discusses approaches to the assessment of the extent and nature of this risk in other regions. A case study from India assesses the risk presented by this problem at a national level, highlights the implications for future research priorities, and outlines the policy context within which both the problem and some potential solutions lie.

1 The research project entitled 'The impacts and costs of air pollution on agriculture in developing countries' was funded by the Environment Research Programme of the British Department for International Development (DFID). The project had a duration of two years from August 1995.

How does air pollution affect agriculture?

There are three major ways in which air pollutants may damage agricultural production (Box 1):

1. *Direct visible injury*, usually to leaf tissue. If extensive, this can affect crop yield, and superficial damage can make the crop look less appealing to consumers, thus lowering its value.
2. *Direct effects on growth and yield*. Experiments with a range of different pollutants have shown that yields are generally reduced with increasing exposure to pollutants, even in the absence of visible injury.
3. *Indirect effects*. Even at relatively low levels, air pollutants may cause a range of subtle physiological, chemical or anatomical changes which will not lead to detectable yield reductions under optimal growth conditions. However, these changes may increase the crop's sensitivity to other stresses, thereby contributing to significant yield losses. Exposure to sulphur dioxide and nitrogen dioxide, for example, consistently leads to increased growth rates of a range of aphid pests (Belled et al., 1993).

Box 1. The nature of the problem

Air pollutants may be conveniently divided into two categories. Primary pollutants, such as sulphur dioxide, nitrogen oxide and particulates, are emitted directly into the atmosphere. They are generally present in high concentrations in urban areas or close to large point sources, such as around thermal power stations, where they may have large effects on local farming communities. Secondary pollutants include tropospheric (ground level) ozone, and are formed by subsequent chemical reactions in the atmosphere. They often spread at high concentrations over hundreds of kilometers away from urban and other sources. Ozone is considered to be the most powerful pollutant in terms of its impacts on crops on a regional and national basis (Fuhrer et al., 1997) Ozone is formed through a series of chemical reactions in the atmosphere which involve emissions of nitrogen oxides and reactive hydrocarbons, of which motor vehicles are the main source. The reactions leading to ozone formation from primary pollutants are favoured by high temperature and light intensities: it is characteristically a pollutant of hot summer days. Complex mixtures of pollutants, which may be particularly significant in urban and peri-urban areas, may cause much larger effects on yields than individual pollutants in isolation.

Despite the extensive evidence available from studies in Europe and the USA, there has been relatively little recognition of this issue in the developing world. Although air pollution in cities such as Mexico City, Delhi and Beijing has received considerable attention, and international urban monitoring networks have been established (WHO/UNEP, 1992), there has been very limited coordinated monitoring of air pollution in the developing world's rural, agricultural areas.

Yet the social and economic implications of yield losses from air pollution in these countries are potentially much greater, due to the need to increase crop productivity to meet the needs of growing populations, and the much greater importance of agriculture in national economies. Furthermore, in many of these regions there is a rapid upward trend in emissions of air pollutants as a result of industrialisation, urbanisation, population growth and increased demand for energy and transport. At the same time, pollution control is often rather inadequate in such countries. It is clear that the pollutant concentrations in major cities of the developing world are already high enough to cause damage to many crops. The high temperatures and longer periods of sunshine common in these countries are also favourable for the production of high concentrations of ozone (Ashmore and Marshall, in press).

Global evidence

Evidence from the USA and Europe

The National Crop Loss Assessment Programme (NCLAN) was initiated in the US in the 1980s with the aim of assessing current economic losses to agriculture by air pollution. This programme looked at yield reductions associated with a given pollutant concentration for major US crops, and combined these with economic models to calculate the benefit of reductions in ozone concentrations. Yield reductions on a national scale were estimated to be about 5%, with the economic benefit of reducing ozone concentrations by 40% estimated to be about three billion dollars annually (Heck et al., 1985). However, these figures are dominated by the response of cereals, which tend to be less sensitive to ozone than other crops, thus disguising the large regional differences which exist.

In Europe, a different approach has been used to estimate effects of ozone on yield. Ozone exposure has been summarised as an index which has a strong linear relationship to yield loss in wheat grown in field experiments at locations across Europe (Fuhrer et al., 1997). The ozone exposure corresponding to a 10% yield loss is exceeded over most of Europe, indicating the large potential for substantial effects on crop production. Detailed continent-wide estimates of actual production losses have not yet been made, although individual filtration studies at Mediterranean sites, where ozone exposures are among the highest in Europe, have shown yield losses above 20% on sensitive crops (Schenone et al., 1992).

Evidence from developing countries

In developing countries, a limited number of experimental studies have recorded yield reductions linked to ambient[2] ozone concentrations (Table 1). This demonstrates the potential for significant effects.

2. The level in the surrounding air

Table 1. Examples of studies showing effects of ozone on tropical crops

Location and reference	Crop	Effect (including approximate yield loss where appropriate)
Indian Punjab (rural); Bambawale, 1986	Potato	Visible leaf injury
Valley of Mexico (rural); Laguette-Rey, 1986	Bean	40% yield loss in sensitive cultivar
Nile delta (rural); Hassan et al., 1995	Radish Turnip	30% yield loss 17% yield loss
Pakistan Punjab (peri-urban); Wahid et al., 1995a and b	Wheat Rice	40% yield loss 40% yield loss
Pakistan Punjab (rural); Shamsi pers. comm.	Soybean	57% yield loss

Some of the most striking results have been obtained in studies in Pakistan, in and around Lahore. Two basic techniques were used:

1. filtration chambers in which the growth and yield of plants with and without the presence of air pollutants can be compared; and
2. the application of a chemical which protects plants against ozone.

The results of these studies (Wahid et al., 1995a and b; Shamsi pers. comm.) suggest that yield loss due to ozone for sensitive crops may be 40% or more in rural areas around the city of Lahore. The results also provide support for the hypothesis that the impacts of ozone on the yield of sensitive crops are greater in the rural areas around major cities in Pakistan than in the cities themselves. They imply that there may be substantial impacts of ozone on agriculture in the Lahore district, and suggest that ozone impacts may also occur over wider areas of the Punjab.

Despite these important experimental findings, there is a large discrepancy in the number of studies in developed and developing countries of crop yield losses due to ozone, and it is clear that the significance of ozone pollution has been poorly recognised in developing countries. For example, an extensive literature review carried out by ICCET in 1997 identified many studies on the effects of ozone on four major crops of the developing world; wheat (35 studies), rice (8 studies), soybean (44 studies) and phaseolus (50 studies) from North America, Europe and Japan, whilst only one or two studies on each crop were available from the developing world.

As there is little systematic data from developing countries concerning the concentration of ozone at which yield loss occurs, any assessment of thresholds for adverse effects of this pollutant must be based on European and American data. These data suggest that for sensitive crops, significant effects (defined as yield losses above 10%) may be seen when

seasonal mean concentrations in the middle of the day exceed 50 parts per billion (ppb) (Ashmore and Marshall, in press). The very limited literature available on rural ozone concentrations in developing countries suggest that this threshold for effects on sensitive crops is exceeded in a number of locations, including the Nile Delta in Egypt (Farag et al., 1993), rural sites in the state of Sao Paulo, Brazil (Kirchhoff et al., 1991), the outskirts of Lahore in Pakistan (Wahid et al., 1995a and b) and the peri-urban zone of New Delhi, India (Varshney and Rout, in prep.).

In contrast to ozone, the effects of sulphur dioxide on crop yields have been widely recognised for some time, and a large number of field and chamber experiments have been conducted in developing countries, especially in India. Although the effects of sulphur dioxide and other primary pollutants are likely to be important mainly in the vicinity of urban and industrial sources, major yield reductions can occur in these areas, which could have a major impact on the livelihood of individual farmers and the local economy. The effects of the mixtures of sulphur dioxide, nitrogen oxides and ozone which occur in peri-urban areas may also be significant.

Identifying agricultural areas at risk from air pollution - a global risk assessment

While the experimental evidence described above does give real cause for concern that agricultural production in developing countries can be severely affected by air pollution, and ozone in particular, these data relate to isolated locations. Priority areas for future investigation can be identified by using simple risk assessment methodologies to estimate the likely nature and extent of this problem in areas where field data are not currently available.

In a recent study carried out by ICCET, a global risk assessment was conducted to identify areas at high, moderate and low risk of crop yield reduction from two major air pollutants, ozone and sulphur dioxide.

As rural air pollution monitoring data is scarce, global data on air pollution emissions were used to indicate potential pollutant concentrations. These concentrations were compared to levels of pollutants associated with crop yield loss in Europe, in order to estimate areas in which significant crop loss might occur.

Figure 1 shows the risk of crop loss due to ozone based on this approach (Ashmore and Marshall, 1997). The high risk areas correspond to the ozone exposure which is estimated to cause a yield reduction above 15% based on European studies using wheat. The intermediate risk areas correspond to the ozone exposure estimated to give a yield reduction of 5-15%. Anything below this is categorised as low risk. The risk category indicates only the potential for yield loss in certain sensitive crops, not the estimated effects over the grid square.

Almost all the areas in developing countries identified as moderate or high risk correspond with agricultural areas. There are significant areas of high risk in northern India, China, Korea and Taiwan, with isolated areas elsewhere. Significant areas of moderate risk are found in Egypt, Malaysia, Thailand, Pakistan, Mexico and Venezuela, as well as further large areas of India and China. Many other isolated squares are observed, mainly around large cities.[3]

Although this risk assessment has many limitations in terms of the datasets and simple methodology used, the categories are not inconsistent with results from field studies indicating the real impacts of ozone on crop yield. Adverse effects on sensitive crops have been shown at locations in western Europe and north America that fall within the high risk category. In developing countries, adverse impacts of ambient ozone have been shown through field studies in Pakistan, Egypt and Mexico as described above; these are all locations appearing as moderate risk.

Figure 2 is a projection for the year 2025. This predicts how yield losses are likely to increase if global nitrogen oxide emissions continue at their current rate (Lee et al., 1997). Whilst emissions are predicted to decrease in many areas of western Europe and north America, very large increases are shown in many developing countries. In India, China and South Africa, the majority of the cultivated area would fall into the high risk category. Many other countries such as Egypt, Malaysia, Bangladesh, the Philippines and Indonesia are predicted to have large areas of cultivated land in the high risk category, whilst other countries such as Mexico, Nigeria and Zimbabwe, have large areas entering the moderate risk category. Figure 2 clearly demonstrates the potentially very serious future problem of ozone induced crop losses in developing countries, unless action is taken to reverse the increasing nitrogen oxide emissions. Similar conclusions have been reached in other studies of future global risk of ozone induced crop yield loss (Chameides et al., 1993)

When this global risk assessment exercise is repeated for sulphur dioxide (again using emission values from GEIA), the pattern of moderate and high risk areas in the developing world are generally comparable to that of ozone, although there is a tendency for these to be in grid squares representing industrial sources or large thermal power plants, rather than high population density. The predicted sulphur emissions for 2025 (source: Stockholm Environment Institute, 1997) lead to a very similar change in the pattern to that of ozone. Some isolated high risk areas for sulphur dioxide damage are apparent which are not indicated on the ozone map; for example, in the South Africa highveld, where many thermal power plants are located and planned, and the industrial area around the Nile delta. In contrast to ozone, the risk of damage to sensitive crops from sulphur dioxide is likely to be limited to localised areas of high emissions within each grid square.

3. It is important to note that the ozone estimates are based on global nitrogen oxide emission inventories (from the Global Emissions and Inventory Activity, GEIA, of the International Geosphere-Biosphere Programme). These do not include emissions from soils and biomass burning, which has been shown to contribute to seasonally elevated ozone levels over parts of southern Africa and eastern South America, and hence there may be some underestimation of risk in these regions.

Figure 1. Risk of ozone impacts on crops, based on emissions of nitrogen oxides in 1985

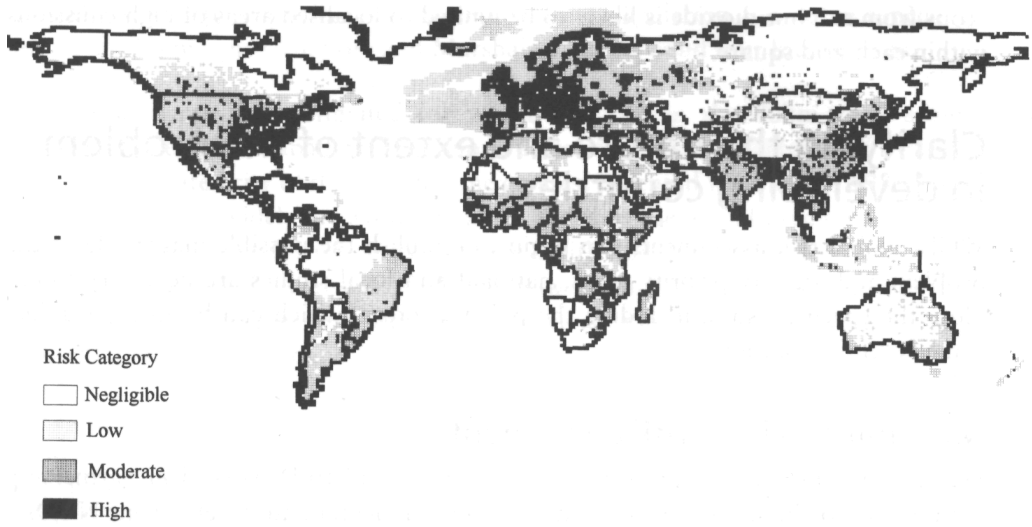
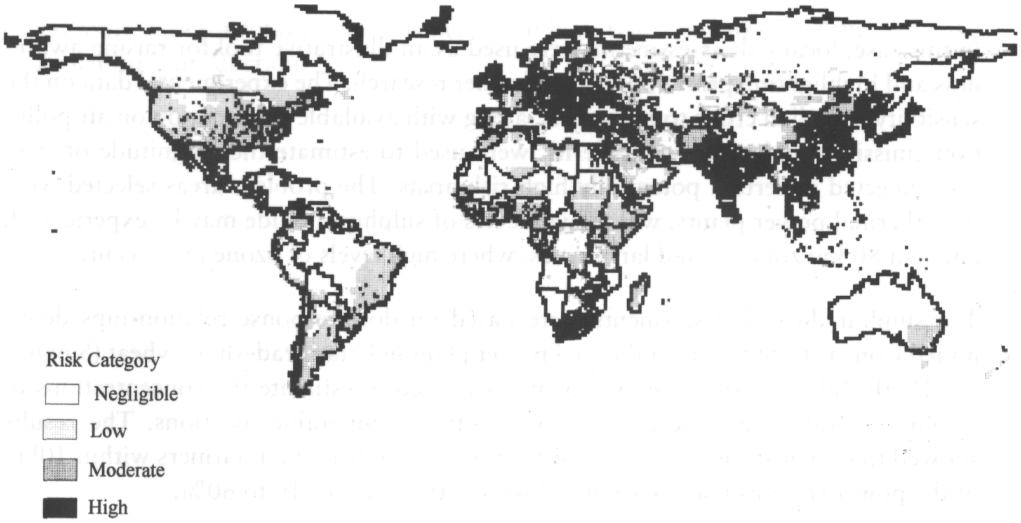


Figure 2. Risk of ozone impacts on crops, based on projected emissions of nitrogen oxides in 2025



Clarifying the nature and extent of the problem in developing countries

Whilst global risk assessments can begin to establish the possible magnitude of the problem and identify priority areas, national and local studies are necessary to explore the specific issues, including the policy context, which can begin to establish some potential solutions.
National and local risk assessments

During a recent research project in India, ICCET and IIED worked in partnership with a team of Indian scientists, and with environmental and development NGOs[4]. This study began with a review of experimental evidence on air pollution effects on crop yields in India, which confirmed that air pollution is a potential threat to crop yields, but that there is a need for a better understanding of the impacts in the field (Varshney *et al*., 1997).

In this case, local risk assessments were used as an illustrative tool for raising awareness and highlighting priority areas for further research. The experimental data on the sensitivity of Indian crops to pollutants, along with available information on air pollution emissions and cropping patterns, were used to estimate the magnitude of crop loss expected in certain potentially high risk areas. The problem areas selected were near thermal power plants, where high levels of sulphur dioxide may be experienced, and in a 80 km zone around large cities, where high levels of ozone may occur.

The sulphur dioxide assessments were based on dose-response relationships determined from a study around a thermal power plant in Uttar Pradesh on wheat (Singh *et al*., 1990). Information on power plants was used to estimate the concentrations of sulphur dioxide experienced by crops in other comparable locations. The results showed that, whilst the losses on a district-wide basis are small, farmers within 10km of the power stations may experience losses in the range of 10 to 60%.

To assess crop losses from ozone, we used the data from Pakistan which shows that wheat, rice and soybean may experience yield losses of 40% or more in rural areas around Lahore (Wahid et al., 1995a and b; Shamsi pers. comm.). This information, supported by data on Lahore's population and nitrogen dioxide emissions, was used to establish a simple empirical relationship between population and ozone concentration in the 80km zone (Ashmore and Marshall, 1997) around four Indian cities.

Crop losses were then estimated for wheat and rice in the 80km zone around Mumbai, Pune, Ahmedabad and Lucknow. These estimates indicated that Mumbai, the most populated city of the four, has the greatest potential yield loss of 40%. However, wheat is not widely grown in the area, and thus the actual predicted crop loss was only 4300 tonnes for wheat as compared with 204,400 tonnes for rice. In contrast, the predicted yield loss

4. Project partners included: Jawaharlal Nehru University, New Delhi; Banares Hindu University, Varanasi; National Botanical Research Institute, Lucknow; Vikram University, Ujjain; Osmania University, Hyderabad; Tata Energy Research Institute, New Delhi; Development Alternatives, New Delhi; World Wide Fund for Nature India, New Delhi.

around Lucknow is only 12%, but as an important wheat and rice growing area, the total predicted crop yield losses were higher -439,400 tonnes for wheat and 516,500 tonnes for rice.

The example from India illustrates the potential for combining cropping data with information on pollutant emissions to make preliminary risk assessments. However, there is considerable diversity in terms of the types of risk assessment and subsequent research and policy activities that are both possible and appropriate for a given country and location. Table 2 summarises the key findings from a review of a further five at risk countries. In each case there is information which would provide the basis for an assessment of risk of damage to crops, but the types of data available, and key policy and research issues of relevance vary considerably. It is also clear that, in all cases, more experimental research is needed in high risk areas to assess the real risks to agricultural production.

Table 2. Summary of key findings, policy issues and research issues in selected 'at risk' countries

Country	*Major findings*	*Key policy and research issues*
Egypt	Limited agricultural area Close proximity to urban areas and industry Field evidence of effects on crops close to industry and of rural ozone	Better data on pollutant impacts Measures to reduce impacts in urban and peri-urban areas Improved capacity for risk assessment
South Africa	Rural monitoring shows levels of SO_2, NO_x and O_3 are above thresholds for effects on agriculture Little recognition of importance of agricultural impacts	Better data on pollutant impacts in areas of high exposure Air quality guidelines need modification to include effects on agriculture Role of biomass burning on ozone formation needs to be determined Implications of planned increase in electric power generation need to be evaluated
Brazil	Only limited data on pollutant emissions and concentrations, except for largest cities Biomass burning, including sugar cane, may be an important additional source Very limited data on impacts of air pollution	More data needed on rural and peri-urban pollutant levels and their impacts Improved capacity for monitoring air pollution
Mexico	Extensive data and analysis of policy for Mexico City, and some effective interventions Little data on rural and peri-urban problems, although evidence of ozone effects around Mexico City	More data needed on rural and peri-urban pollutant levels and their impact Policy assessments for control measures in Mexico City could be extended to consider impact on peri-urban areas
China	Extensive data on air pollutant concentrations and emissions Clear evidence of environmental impacts of sulphur emissions, but little data on crop responses specifically Little recognition of ozone as a problem for agriculture	Measures to reduce environmental impacts of sulphur emissions Better data on ozone levels and effects on agriculture

Factors influencing the impact of air pollutants on crops

In addition to the uncertainties associated with risk assessment models, a number of other factors may influence the relationship between yield loss and pollutant exposure for a particular crop:

- Climate. High atmospheric vapour pressure deficit and high soil moisture deficit both tend to reduce pollutant impact. Thus, impacts are likely to be lower in the dry tropics, and during dry seasons, than in the wet tropics or on irrigated crops, although it should be remembered that when rainfall is high the pollutant concentrations will be low.
- *Variations between cultivars*. There is clear evidence from many studies of large variations between cultivars in sensitivity to air pollution. It is possible that traditional cultivars used in developing countries may differ in their sensitivity from those used in developed countries, while the introduction of modern cultivars may have also caused systematic shifts in sensitivity to air pollution. Greater cultivar sensitivity may be an explanation for the greater effects of ozone found in developing country studies.
- *Interactions with insect pests and pathogens*. In some cases, there is a consistent effect of pollutants increasing pest problems, but in other cases, the effects are more variable. Since pest and pathogen problems are often more serious in developing countries, these interactions may be of great significance in determining effects of pollutants on yield.

Other factors such as salinity and fertiliser inputs are thought to influence the impacts of air pollutants on crops, but the interactions themselves are less well established.

This summary indicates that there is some potential to develop agronomic practices to reduce the impact of air pollution on crop yields. However, while there is experimental data indicating the potential of this approach, very few of the possibilities have been investigated in real farming conditions.

Research priorities

A field level perspective

Whilst this evidence indicates that air pollution may cause significant reductions in crop yields in a number of developing countries, it is also clear that field investigations in high risk areas are essential to establish the magnitude of this problem, and its implications for local communities and national economies.

The following examples of key issues for future research were identified by the group of organisations involved in the Indian scientific review and risk assessment activities described above:

- Estimated yield losses need to be verified in the field, for a wide range of crops, cultivars and agricultural systems, using standard methodologies where possible
- Dose-response relationships need to be developed on the basis of the experiments
- described above
- Ambient air quality standards[5] for ozone should be developed, and current standards for other air pollutants should reflect the impacts on crops in addition to human health.
- Monitoring of major phytotoxic air pollutants, particularly ozone, should be carried out in rural areas, to assess where damaging concentrations are present. This could be linked to data on crop distribution and dose response relationships to determine what the magnitude of crop loss is likely to be.

A policy perspective

In order to inform the policy debate it is essential to provide reliable and timely information concerning the impact of this issue on the communities affected, and on the local and national economy. The perceived importance of this issue in terms of other constraints on crop production and overall livelihood issues are important parameters here. Particular emphasis should be placed on the livelihoods of the poor.

A case study on the impacts of air pollution on agriculture in urban and peri-urban areas of Delhi and Varanasi (Box 2) exemplifies some of the key elements of a new research project that is designed to examine the social and economic implications of this issue alongside conventional field experiments, to develop policy dialogues, and to assess a range of possible solutions.

5. A prescription for air quality based on the maximum concentration of specified pollutants considered tolerable in a particular location.

Box 2. Assessing air pollution and agriculture in urban India: an innovative approach

There is a real and growing concern about the effects of urban air pollution on both human health and architectural heritage in India. By quantifying the impacts on urban agriculture and informing the policy debate, a new research project[6] is aiming to help in the search for effective means of controlling air pollution.

Through an innovative approach to the field work and policy analysis, the project will examine the nature and extent of urban and peri-urban agriculture in India, and the magnitude and impacts of crop losses due to air pollution. It will assess these impacts in the light of other more recognised threats to crop production, with particular emphasis on the livelihoods of the poor. A multidisciplinary policy team will contribute to the wider development challenge of improving communication channels between grassroots organisations, researchers, planners and policy makers. The policy and research aspects of the work will be carried out in parallel, with conventional field trials being established in the vicinity of specific farming communities who will remain partners in all aspects of the research programme:

- Farmers' perceptions of air pollution will be an important aspect of the re search. Participatory methodologies will be used to assess both the importance of urban and peri-urban agriculture, and the significance of crop losses from air pollution to the local community. They will also be used to investigate the extent to which farmers perceive air pollution as a constraint, the trends they perceive and the indicators they would use to monitor its impacts and levels.
- Farmers, community groups and others will be actively involved in the university research activities to quantify yield losses due to air pollution using simple experimental techniques alongside their fields. Local community groups will be involved in monitoring using local pollution monitoring kits and simple biomonitor techniques to assess damage to crops.
- Fora will be created to allow affected communities, researchers, policy makers and planners to exchange information and views. Consumers, polluters and others will also be invited to specific planning meetings, workshops and seminars.

Policy responses to air pollution and agriculture?

There is a wide range of policies and policy mechanisms that are relevant to the issue of air pollution and its impact on agriculture. These need to be examined and understood. Combining forces with other initiatives will lead to greater pressure for appropriate policy change and more effective implementation. For example, there are active campaigns concerned with impacts of air pollution on human health which are receiving considerable attention at a policy level in many developing countries. However, their concentration on a single issue means that the full economic and social benefits of measures to reduce air pollutant emissions, including those for national crop production and the welfare of

6. This project is funded by DFID and co-ordinated by ICCET and IIED. It will be conducted in collaboration with a number of Indian research and development organisations.

subsistence farmers, are not fully captured. Therefore, in order to establish effective policy responses it is essential to create active links between scientific and policy research programmes and existing policy debates.

Within this context, it is suggested that the problem can be tackled at two levels. The first addresses the symptoms of the problem, ie. through understanding and promoting agronomic techniques which can lessen the impacts of certain pollutants. The second addresses the cause of the problem: ie. it attempts to reform policy so that air pollution itself, or projected increases in pollution are reduced. The following examples illustrate some potential measures for addressing this issue at each of these levels.

Agricultural policy

The potential for agricultural practices to reduce sensitivity to air pollution is a key area for future research. For example, breeding programmes could develop culitvars that are resistant to air pollutants and further research could explore the role of fertilizer inputs in modifying pollutant impacts. Agricultural policy support is needed both to promote interventions that have proven success, and to establish research into new interventions and practices. It is also important that existing research takes into account the constraints posed by air pollution (Table 3).

It will also be important for agricultural planners and decision-makers to balance carefully the other benefits and disbenefits of any proposed changes in farming practices, as well as the economic costs. For a given intervention, this balance will obviously depend upon particular producer groups, with the risk that some may benefit only well-resourced farmers. It is essential that interventions are developed with low-income farmers, in the context of the many constraints that they face, including the difficulties in obtaining information and support.

Table 3. Summary of links to agricultural policy areas

Policy or research area	*Links to existing policy assessment or research*	*Major dissemination routes/channels of communication*
Selection and introduction of new cultivars	Pollution tolerance should be evaluated for new introductions Breeding of new cultivars for use in areas of high pollution	National ministries of agriculture National and international agricultural research organisations
Pest management policy	Importance of pollution as factor influencing pest problems in peri-urban and industrial areas	National ministries of agriculture National and international agricultural research and development organisations and agricultural networks Local farmers' groups
Sustainable agriculture	Research into declining yield of high input agricultural systems, should consider air pollution as a potential threat to sustainability. Policies for promoting sustainable agriculture should consider air pollution as a potential threat.	National ministries of agriculture International agencies National research and development organisations International and national agricultural networks Local farmers' groups
Development of national and international databases	Development of validated digitised international databases for assessment of environmental impacts on agriculture	FAO International agencies
Impacts of global change	Capacity building in methods to assess impacts of atmospheric change on agriculture Strategies to adapt local agriculture to predicted climate change to consider impacts of air pollution	National ministries of agriculture environment International agencies

Tackling the problem at source: pollution control

The recent project in India revealed a number of policy approaches to reducing pollution emissions and their impact on agriculture. Clearly strengthening and extending existing legislation has a role to play. However, there is also scope for new measures which move away from the conventional command and control approach to pollution

reduction. Thought should also be given to more creative solutions which can overcome the difficulties of centralised pollution monitoring and control. The issue was discussed with Indian policy makers, researchers, planners and NGOs at a national workshop in Delhi in June 1997 (Ashmore and Marshall, 1997). Specific recommendations included the following:

- Existing legislation should be strengthened, ensuring that it reflects the impacts of air pollution on agriculture. For example, ambient air quality standards need to be set at a level which protects agriculture, and these also need to be incorporated into environmental impact assessments.
- Air quality standards should also reflect what can be borne by a specific region in terms of ecosystem, land use and current pollution load.
- Economic instruments, such as green taxes and tradeable permits, should be considered as a method of internalising some of the costs of pollution abatement, providing incentives for clean technologies, and establishing a fund for promoting pollution control.
- Policy changes that allow for the decentralisation of pollution control enforcement and monitoring should be considered so that some of the monitoring burden can be assumed by concerned individuals (farmers, NGOs and other local networks) and by the use of voluntary tools, eg regular publishing of emissions figures to apply moral pressure. Shared information on emission sources, pollutant levels and evidence of crop damage due to air pollution would be key tools. This could be developed by making the planning of major industrial developments participatory, sharing basic information, negotiating with the communities liable to be most affected, and ensuring that final approval is dependent upon the people's consent.

Table 4 summarises some of these ideas, and also indicates a number of different ways to disseminate findings and promote discussion.

Table 4. Policy routes to tackling air pollution and its impact on agriculture

Policy area	Links to existing policy assessment	Major dissemination routes/channels of communication
Setting and enforcement of national air quality standards	Air quality standards for effects on agriculture agreed locally and added to health-based standards	National governments and pollution control organisations
Cost-benefit analysis	Economic impacts of air pollution on agriculture need to be included in assessment of benefits of pollution control measures	National governments and pollution control organisations World Bank and regional development banks
Regional assessment of transboundary air pollution problems	Assessments have focused on impacts of acidification of soils and freshwater - these need to be extended to direct effects on agriculture, especially of ozone	National governments Regional cooperation programmes Regional development banks
Environmental impact assessment	Impacts of air pollution on local agriculture need to be assessed before major new developments are approved	Local governments and pollution control organisations
National land use planning	Sensitivity of local agriculture to be considered, alongside other factors, in identifying locations for major new developments	National energy and industrial development agencies
Urban planning	Impacts of air pollution emissions and expansion of urban area on peri-urban agriculture	Urban and regional governments National ministries of environment
Global emissions of greenhouse gases	Impacts of air pollution on agriculture considered alongside those of climate change and sea level rise	Intergovernmental Panel on Climate Change National research organisations National ministries of environment

Conclusions and Issues for Future Exploration

This research has produced clear evidence of the current and future significance of air pollution as a constraint to agricultural production in many developing countries. The implications are that the effectiveness of policies aimed at increasing food production and food security will be increased in many areas if action is taken to reduce the impacts of air pollution.

While changes in agricultural practices have some potential to reduce these impacts, the knowledge needed to identify and implement such changes successfully at local level does not currently exist. Therefore, it will be essential to address the underlying causes of air pollution.

The identification and implementation of successful air pollution control policies requires the capacity to make an integrated assessment of the costs and benefits of alternative policy approaches. It is therefore essential that the significance of impacts on agriculture is more widely disseminated, and that it is properly incorporated into agricultural and environmental policy development. Finally, it is vital to identify the links between this issue and other on-going debates on local and regional policy development, as this will be the route to both wider recognition of the significance of air pollution impacts on agriculture and the identification of well-targeted interventions to reduce its impacts.

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