Ozone: a threat to food security in South Asia

Key Findings

- Current day concentrations of ground level ozone (O_3) are commonly reducing crop yields by between 5 and 35 % at agriculturally important locations across South Asia.
- O_3 induced economic crop losses could be in the region of $4 billion per annum for staple crops in South Asia; such losses are likely to impact more on poor and vulnerable people.
- O_3 concentrations are increasing rapidly in South Asia and the situation looks set to worsen considerably in the future under current legislation to control emissions.
- Crop yield losses from current day O_3 concentrations are greater than projected losses due to climate change, indicating that O_3 may be a more immediate problem to food security.
- O_3 impacts depend upon local meteorology and CO_2 concentrations. It will be important to understand the role of climate change in determining O_3 related yield losses.
- O_3 induced yield reductions suggest this pollutant may be an important contributing factor to the recent decline in the growth of crop yields seen across South Asia.
- There are substantial co-benefits in reducing O_3 precursor emissions since O_3 is also an important greenhouse gas and is capable of causing adverse effects on human health.

What is ground level ozone?

Ground level ozone (O_3) is the atmospheric pollutant most likely to threaten global food production due to its high toxicity to arable crops and prevalence over important agricultural regions. O_3 is a secondary pollutant formed from chemical reactions of primary pollutants (nitrogen oxides and volatile organic compounds) occurring under the action of sunlight. These reactions occur continually in polluted air masses which leads to an accumulation of O_3 at distances (sometimes up to thousands of kilometres) downwind from the initial polluting source (i.e urban or industrial areas). **This makes O_3 a pollutant more likely to affect agricultural regions with elevated O_3 concentrations frequently covering broad geographical areas and crossing international boundaries.** Ground level O_3 is also the third most important greenhouse gas behind carbon dioxide and methane and has been shown to adversely affect human health at elevated concentrations. As such there would be substantial co-benefits in emission reductions to control O_3 pollution.

To what extent does ozone decrease crop yields?

Rapid industrialisation and economic growth across much of Asia has resulted in increased emissions of O_3 precursor pollutants and hence elevated O_3 concentrations. Since the mid 1990s, field experiments to assess O_3 effects on crops have been performed in South Asia (Box 1). These studies have clearly demonstrated that current day levels of O_3 are causing substantial yield losses and changes in crop quality to a wide variety of important crops grown in the region such as rice, wheat, soybean, mung bean, spinach, peanut, chickpea and potato. The evidence of such yield losses has resulted in O_3 being considered a serious threat to continued agricultural production across the Asian region. This has lead intergovernmental agreements such as the Malé Declaration, and initiatives including the Atmospheric Brown Clouds Project, to include O_3 in their activities and research programmes.

Box 1. Experimental Evidence

Filtration studies are a common experimental method used in Asia comparing crops grown in "clean" or "filtered" air with those in "ambient" air that may contain pollution. These studies have shown that a large number of local crops and cultivars are extremely sensitive to O_3 at present day concentrations (Figure 1).

Figure 1. The effect of air filtration on Pakistan wheat variety Chak-86 during the 1992-1993 growing season close to Lahore, Pakistan. The plant on the left has been grown under conditions where O_3 has been filtered from the air, the plant on the right under the ambient O_3 concentrations present at the location. (Courtesy of Prof. Abdul Wahid)

How much ozone is out there?

Existing "site-specific" evidence clearly shows that even today, O_3 concentrations are high enough to cause significant losses in arable agricultural yields (Box 2). **Regional O_3 modelling has identified elevated concentrations across north eastern parts of South Asia, encompassing the fertile agricultural lands of the Indo-Gangetic Plain**, which is the most important agricultural region in South Asia and one of the most important agricultural areas in the world (Box 3).

What are the economic impacts?

A provisional economic loss assessment for South Asia has been performed by SEI using European dose-response relationships to estimate yield losses caused by surface O_3 concentrations. Yield losses are converted into production losses (based on Food and Agriculture Organisation (FAO) crop production statistics) from which economic losses are estimated in relation to the crop commodity price. This method follows standard approaches to evaluate reductions in agricultural yields caused by anthropogenic air pollutants (e.g. Wang & Mauzerall, 2004). **Economic losses for South Asia are estimated to be in the region of US$ 3.9 billion per year for 4 staple crops (wheat, rice, soybean and potato) for the Malé countries** of Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka (Figure 4). The largest losses are found in India (US$ 3.1 billion), Pakistan (US$ 0.35 billion) and Bangladesh (US$ 0.4 billion) in the fertile, agriculturally important Indo-Gangetic plain. The implications of these

Box 2. Synthesis of Asian Data

A recent synthesis of comparable experimental data conducted across Asia shows that even with **today's concentrations of O_3, the yield losses experienced by three staple Asian crops (wheat, rice and legumes) range between 5–48 %, 3-47 % and 10-65 % respectively.** Results of this synthesis are shown for wheat in Figure 2. These Asian studies have been carried out using limited resources, and although they clearly demonstrate the effect of O_3, they cannot be used to develop dose-response relationships making it difficult to derive air quality guidelines and perform regional risk assessments. Comparisons suggest that United States and European dose-response relationships (derived from extensive co-ordinated experimental field campaigns) may underestimate the sensitivity of equivalent crops and varieties grown under Asian conditions (Emberson and others, submitted). This means that crop yield and economic loss risk assessments made using United States or European based dose-response relationships may actually underestimate the damage caused by O_3.

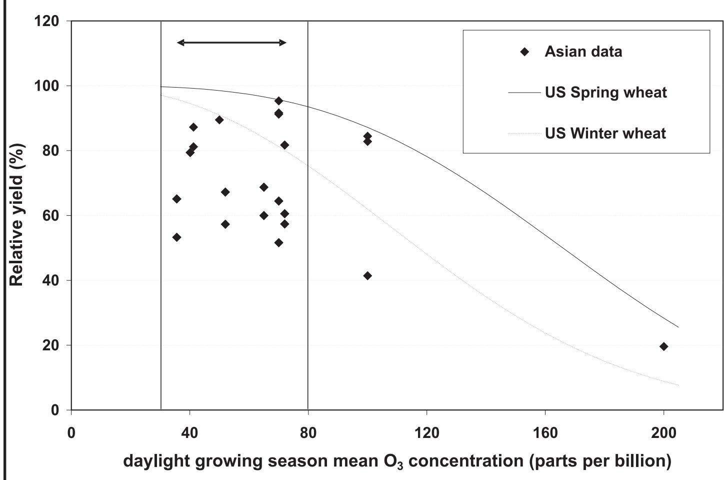

Figure 2. Asian wheat yield loss data (expressed as a percentage of the relative yield that occurred in clean "O_3 free" air) against daylight growing season mean O_3 concentrations. Dose-response relationships from the United States (US) for spring wheat and winter wheat are also shown. The local ambient pollutant concentration range defined by the experimental investigations is indicated by the arrowed vertical lines. (Emberson and others, submitted).

Box 3. Regional Ozone Modelling

Surface O_3 concentrations have been modelled using MATCH (Engardt, 2008), an atmospheric pollution dispersion model used extensively within Malé Declaration activities. Figure 3 shows distributions of modelled surface O_3 expressed as daylight means over growing seasons for both wheat and rice. These distributions suggest that the "site-specific" experimentally derived yield losses may well be indicative of similar losses found across agriculturally important regions of South Asia. Modelling has also identified the spring and summer months as having the highest O_3 concentrations; these periods coincide with peak growing seasons for many important South Asian crops (e.g. wheat and potato).

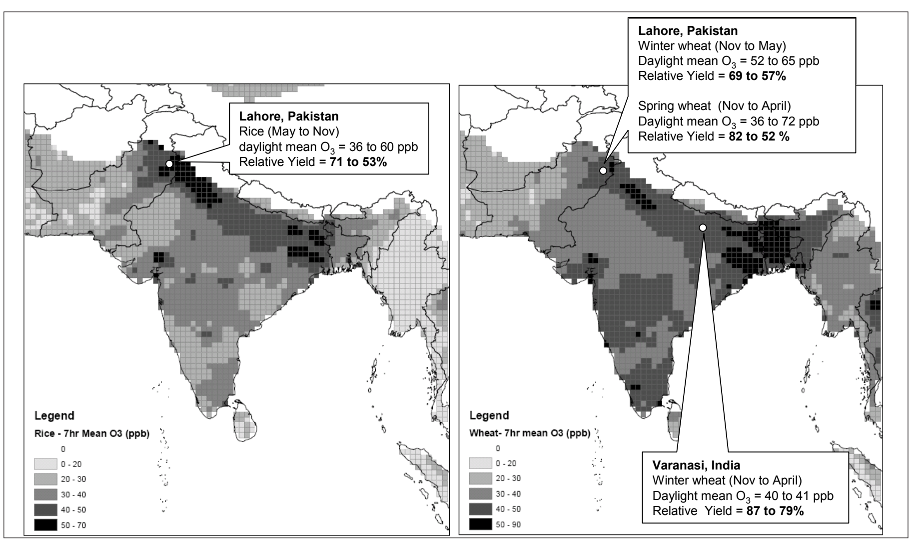

Figure 3. Location of South Asian experimental study sites and associated O_3 concentration and yield losses presented in relation to MATCH modelled surface O_3 concentrations expressed as daylight (7 hour) means over respective growth periods for wheat and rice (Emberson and others, submitted).

economic losses for food security need careful consideration. For example, changes in supply will affect both consumer- and producer-crop price with implications for agricultural livelihoods and consumer accessibility to nutritionally important foodstuffs.

In stark contrast to the gains in crop productivity made during the Green Revolution, evidence suggests that growth in crop yields in South Asia has been in decline over recent years. This has been attributed to a number of different factors including declining soil fertility and climate change. The evidence presented here would suggest that increasing levels of O_3 are an additional and extremely important factor in this deceleration in the growth of crop yields. This has important implications for sustainable agriculture given pressures on cultivated land area e.g. from expansion of crops for bio-energy production, and on agricultural supply given increasing demand from the rapidly expanding Asian population.

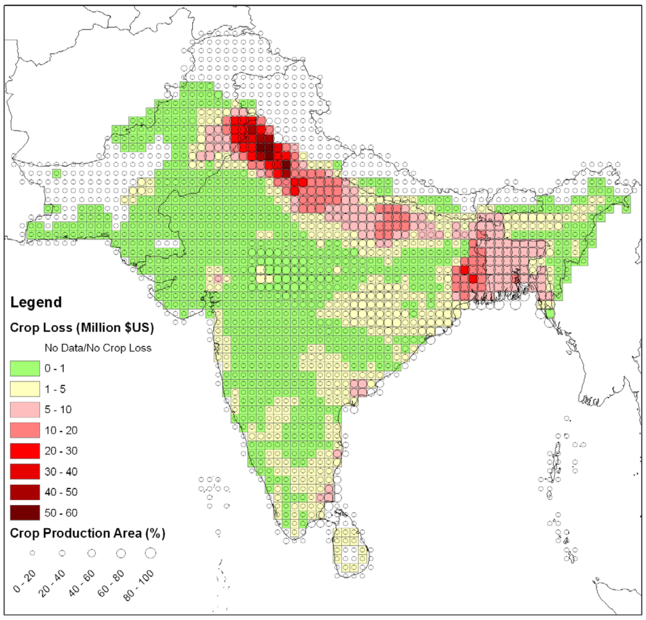

Figure 4. Provisional estimates of economic crop losses (in Millions of $US) for South Asia performed using MATCH modelled O_3 concentrations and European dose-response relationships for wheat, rice, soybean and potato (Mills and others, 2007). The intensity of crop production is defined by the size of the open circles within each MATCH grid.

How is the situation likely to change in the future?

Worryingly for the South Asian region, **projections of future global O_3 trends show that O_3 concentrations will increase rapidly over the next 20 to 30 years** with South Asia projected to experience the highest increase in surface O_3 (average annual increases 7.2 ppb occurring by 2030) of any global region (Dentener and others, 2006; Figure 5). These projections are based on current legislation emission scenarios; this means that **to avoid these increases in O_3, additional policy interventions are likely to be required.**

What's the additional impact of climate change?

Comparing "current day" crop yield losses due to O_3 (commonly ranging between 5-35 %) with those forecast to occur by the end of this century due to climate change (up to 30 %, Cruz and others, 2007) suggests that the **impacts of O_3 may in fact be a more immediate threat to agricultural productivity than climate change in the South Asian region**. It is also likely that the CO_2 fertilization effect, that was hoped might partly negate temperature-induced stress to agro-ecosystem productivity, may well be limited by the impacts of O_3. The interactions between O_3 and climate change are also important since **O_3 impacts on crop yield are influenced by environmental factors, in particular drought, humidity and temperature;** as such changes in climatic conditions could exacerbate future crop yield losses resulting from O_3.

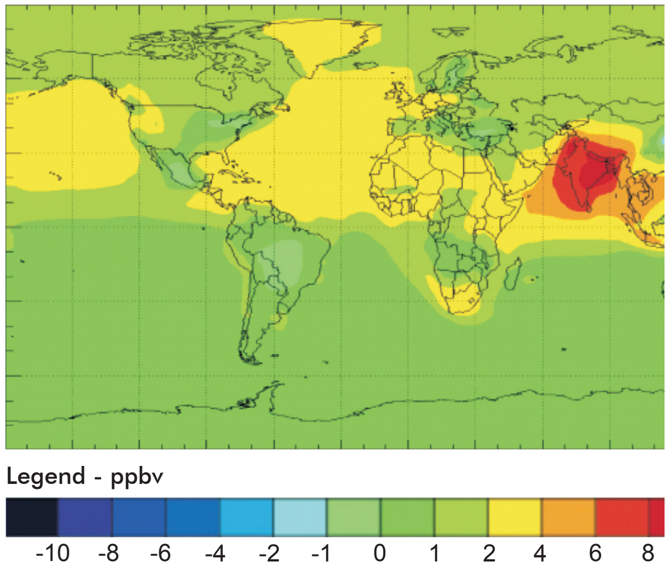

Figure 5. Projected changes in annual surface O_3 assuming enforcement of current emission control legislation between 2000 and 2030. (Adapted from Dentener and others, 2006).

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Acknowledgments: The work presented within this policy brief has been financed by the Swedish International Development Cooperation Agency (Sida) through SEI Institutional Programme Support and funding for the Regional Air Pollution in Developing Countries (RAPIDC) Programme. The content of this brief has been prepared with help from members of the APCEN Network and the Malé Crop Impact Assessment Project co-ordinated by UNEP.

Recommendations

International agreements to curb O_3 precursor emissions
The transboundary nature of O_3 pollution requires international efforts to effectively reduce emissions of nitrogen oxides and volatile organic compounds and hence O_3 impacts on agricultural productivity. Such emission reductions would have co-benefits for climate change and human health.

Co-ordinated experimental campaigns for South Asia
Implementation of cost-effective emission reductions requires risk assessments to identify the geographical distribution and magnitude of crop yield losses. The derivation of Asian dose-response relationships from a pan-South Asian experimental campaign along with complementary monitoring of rural O_3 concentrations would be required to perform and validate these risk assessments. Pilot experimental campaigns are currently being developed across South Asia within the Malé Declaration co-ordinated by UNEP with technical support from APCEN (the Air Pollution Crop Effect Network; http://www.sei.se/apcen/index.html).

Crop breeding programmes to reduce sensitivity in crop varieties
Experimental data has shown that variability in the sensitivity to O_3 of different crop varieties can vary by as much as 50%. If the sensitivities of different cultivars were known, the use of resistant cultivars could provide an important adaptation option against O_3 impacts. Since current evidence suggests that more recently bred crop varieties have a greater sensitivity to O_3 it will be important to ensure that breeding programmes are not inadvertently introducing traits that increase crop vulnerbility to O_3.

Understanding the role of O_3 on food security and poverty
Different crops also show different sensitivities to O_3; many studies suggest that pulses are more sensitive than cereal crops. This could have important implications for food security since disproportionate changes in the supply of these high protein crops may price poorer consumers out of the market of these nutritionally important foodstuffs. Understanding the role O_3 may play on crop consumer price and accessibility of the poorer and hence more vulnerable parts of society is urgently needed to assess the role O_3 may play in food security.

Understanding the interaction between O_3 and climate change
As O_3 concentrations are projected to increase, climate change (due to increases in greenhouse gases and atmospheric aerosols and particulate matter) is likely to be altering crop productivity, crop growth and crop distribution across South Asia. Crop sensitivity to O_3 is strongly dependent upon prevailing environmental conditions. Understanding the implications of, for example, altered precipitation and temperature patterns across the Indo-Gangetic Plain will be important in determining the extent and magnitude of future crop yield losses.

Improved communication between policy makers, stakeholders and scientists
Development of effective policy interventions to reduce the threat to agriculture from ground level O_3 requires improved dialogue between policy makers, stakeholders and scientists. This could include supporting the procurement of scientific evidence appropriate for policy development, enhancing the development and modification of existing policies of relevance to O_3 impacts on agriculture (e.g. agricultural, transport and industrial policies), and utilising opportunities for engagement across policy fields (e.g. to encompass food security and climate change issues).

Published by:
Stockholm Environment Institute
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2008

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