Assessing the Impact of Air Pollution on Agriculture

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Air pollution has long been know to cause damage to agriculture with observations of photo-oxidant injury to agricultural crops being made in the US as early as the 1940s and 1950s (Middleton et al. 1950). A number of different air pollutants have been identified as responsible for causing damage to agriculture, either directly (e.g. by gaseous uptake of the pollutant) or indirectly (through changes in acidity of sensitive soils). Oxides of sulphur and nitrogen (SOx and NOx) are largely responsible for the latter whilst the most important pollutants acting directly are ozone (O_3), suspended particulate matter (SPM), sulphur dioxide (SO_2), nitrogen oxides (NOx) and hydrogen fluorides (HFs) (e.g. Emberson et al., 2003).

This paper will focus on O_3, which as a secondary pollutant, tends to reach higher concentrations some distance from the urban and industrial centres from which the precursor pollutants originate. Hence, high O_3 levels are likely to occur over large expanses of rural areas posing significant risk to agricultural productivity. Global photo-oxidant modelling using business as usual emission scenarios suggest O_3 concentrations will increase significantly in the near future, with “hot spot” areas experiencing annual mean O_3 concentrations of 40ppb, increasing to 55 ppb by 2030, and that by 2100 concentrations will have ***increased*** by approximately 50 ppb over parts of Asia and southern Africa (Prather et al. 2003). Given that current WHO air quality guidelines use a threshold of 40 ppb above which to accumulate potentially damaging levels of O_3 for agricultural crops, the threat to food production would seem to already exist and the implications for the future sustainability of agriculture may be extremely serious.

A number of studies have been conducted to assess O_3 pollution impacts on economic losses to agriculture. Initially, these studies were preformed in the US and Europe where the highest O_3 levels were experienced in recent decades. For example, Adams et al. (1988) estimated economic crop losses due to O_3 in the US as in excess of US \$3 x 10^9 per year. More recently, Holland et al. (2002) estimated crop losses for Europe in excess of US\$ 8 x 10^9. Similar studies have been conducted in China and East Asia, reflecting concern over elevated O_3 levels in these regions. These suggest yield losses of staple crops may currently be in the range of 1 to 10% and predict future losses of 4 to 30% in 2020 (Aunan et al. 2000; Wang & Mauzerall, 2004) with resulting current day economic losses of US \$ 5 x 10^9 rising to US \$ 8.3 x 10^9 in 2030 (Wang & Mauzerall, 2004).

However, all of these studies have a number of limitations which are a reflection of our limited understanding of O_3 impacts rather than the design and execution of the study *per se*. Arguably, the most important of these is the use of concentration- (e.g. AOT40, SUM06, W126) rather than flux- or absorbed dose- based indices. Concentration based indices do not account for environmental conditions which may modify sensitivity to O_3 exposure. For example, crops grown under non-irrigated conditions may well experience drought stress which will reduce stomatal conductance (and hence the exchange of gases between the plant and the atmosphere) resulting in a reduced pollutant absorbed dose. Conversely, conditions that are optimal for stomatal conductance will result in a large pollutant dose even though concentrations may not be particularly high. The use of a flux based approach removes the dose modifying uncertainty aspect from O_3 pollutant risk assessments (e.g. Emberson et al. 2001). As such, flux based risk assessments can be applied with greater certainty under a variety of climatic conditions (i.e. at the global scale and under future climate change conditions). Flux based methods for O_3 have been developed and accepted as air quality tools in Europe under the UNECE Convention on Long-Range Transboundary Air Pollution

(CLRTAP). These methods allow more robust economic loss assessments to be performed (e.g. Karlsson et al. 2005).

Although these flux based methods provide a more mechanistic basis for assessing yield reductions and hence economic losses due to O_3, a number of uncertainties remain when considering application of such methods at the global scale. Perhaps, the most important of these relates to the range of species and cultivars that exist worldwide, currently both concentration- and flux- response relationships only exist for a very limited number of European or North American species and cultivars. Fundamental uncertainties lie in the necessary assumption that the species and cultivars grown across the rest of the world will respond to O_3 similarly to those grown in Europe and North America. Other factors that may alter plant response to air pollutants include those associated with climate, agricultural management practices (e.g. crop rotation, chemical application, irrigation), crop phenology, genetically-based tolerance or resistance and pollutant exposure patterns. As such, there is an urgent need to establish dose-response relationships for locally grown species and cultivars under local environmental conditions and management practice regimes.

Consideration should also be given to the biological response parameter chosen for impact assessment and how best to translate appropriate biological impacts into socio-economic impacts. To date, the focus of all regional O_3 crop loss studies has been on crop yield reductions and subsequent economic losses. However, air pollutants are also know to cause visible injury and can alter the nutritional and chemical quality of grains and fruits (e.g. Soja et al. 2004), ideally such impacts would be considered in a full economic analysis. In addition, the studies tend to have focussed on using traditional market-based methods to quantify pollution costs. In developing country situations, where non-marketable goods (e.g. subsistence crops, bartering of farm produce) may be particularly crucial to particular sectors of society, alternative approaches that provide a more inclusive and equitable assessment of the benefits of improved air quality need to be considered (e.g. Marshall & Wildig, 2003).

Finally, in the future, elevated O_3 levels are likely to co-occur with elevated CO_2 concentrations under altered climatic conditions. In terms of future projections of agricultural productivity many studies cite a "benefit" to crops growing under climate change due to the fertilization effect caused by elevated CO_2. However, a recent review of the literature by Fuhrer (2003) concludes that the benefits will largely be outweighed by the disadvantages wrought by altered climate (e.g. changes in precipitation and temperature) causing additional stresses (e.g. drought and heat stress). These stresses will affect different parts of the globe to varying extents, and the implications for agriculture in air pollution "hot-spot" areas is unknown. Plant breeding programmes could offer ways to alleviate the future risk to food security. However, efforts are currently directed to develop new strains for drought and heat stress tolerance with no consideration of how crops may be affected by air pollution. Given the projected significant increases in air pollutants (particularly O_3) the potential advantages afforded by plant breeding may not be realised if cultivar sensitivity to air pollutants is not considered.

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