How agriculture metrics are developed: agricultural impacts relevant to estimating the impact of BC and methane interventions and relevance for metrics development

Felicity Hayes and Gina Mills
ICP Vegetation Coordination Centre
Centre for Ecology and Hydrology, UK

fhay@ceh.ac.uk

+11 other participating countries in Africa and SE Asia
Impacts of concern for crops, e.g. Indian urban fringes

- Dust particles
- Black carbon
- Aerosols
- Heavy metals
- Sulphur dioxide
- Oxides of nitrogen
- Ammonia
- Acidification
- Ozone
Particulates – Direct effects

Physical effects:

(1) Leaf shading – reduces photosynthesis
(2) Blocking of stomatal pores prevents $CO_2$ absorption and reduces the growth-potential of crops
(3) Leaf temperature rises as heat cannot be dissipated
(4) Stomatal functioning interfered with – increased water loss (wicking effect$^2$)

$^1$ Yamaguchi et al., 2014, $^2$ Burkhardt et al., 2010, Burkhart and Pariyar, 2013
Particulates - Indirect effects

- Aerosols change the quantity and quality of the light reaching plant surfaces
- Decrease in photosynthetically active radiation decreases photosynthesis and growth
- Whilst, an increase in diffuse radiation/PAR can increase photosynthesis
- Net benefit can be an increase in photosynthesis by 10%
- Dynamics of summer Asian monsoons can be affected by aerosols, thereby impacting on crop production
What are the benefits of cleaning the air? (Pakistan)

- Plants grown in ambient air with high levels of SO$_2$, NO$_2$, O$_3$ pollution, Lahore, Pakistan
- Filtering out the pollution dramatically increases growth
Beneficial effects for crops of cleaning the air in India

Crop yield improved by 8 – 26% by filtration

<table>
<thead>
<tr>
<th></th>
<th>Location</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Varanasi</td>
<td>Rai et al, 2007</td>
</tr>
<tr>
<td>2</td>
<td>Varanasi</td>
<td>Sarkar and Agrawal, 2010</td>
</tr>
<tr>
<td>3</td>
<td>Varanasi</td>
<td>Sarkar and Agrawal, 2010</td>
</tr>
<tr>
<td>4</td>
<td>New Delhi</td>
<td>Bhatia et al., 2011</td>
</tr>
<tr>
<td>5</td>
<td>Varanasi</td>
<td>Sarkar and Agrawal, 2012</td>
</tr>
<tr>
<td>6</td>
<td>Varanasi</td>
<td>Singh et al., 2012</td>
</tr>
<tr>
<td>7</td>
<td>New Delhi</td>
<td>Singh et al., 2013</td>
</tr>
<tr>
<td>8</td>
<td>Varanasi</td>
<td>Kumari et al, 2013</td>
</tr>
</tbody>
</table>
Open-top chambers (Spain)

Open-top chambers (Sweden)

Open-top chambers (UK)

Free-air ozone exposure (UK)

Free-air ozone exposure (India)

Free-air ozone exposure (USA)

Free-air ozone exposure (Finland)

Solardomes (UK)

Free-air ozone exposure (USA)
Many crops are ozone-sensitive including wheat, maize, legumes, tomato and lettuce.

There is variation in ozone-sensitivity between cultivars of the same crop.

Threshold for significant yield effects:

- Lettuce
- Barley
- Sugar beet
- Potato
- Tomato
- Alfalfa
- Oilseed Rape
- Maize

M7 ozone conc. for a significant effect on yield:

- Peas and beans
- Rice
- Wheat
- Soybean
Evidence-based policy: Field evidence of effects

Key policy outcome: Revised Gothenburg Protocol

• Recommended use of flux-based approach
• Recognised importance of effects on vegetation as well as health

Locations of effects on vegetation, 1995 - 2004
ICP Vegetation, contributing to the development of the LRTAP Convention Protocols

- The 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg Protocol); amended in 2012 (PM2.5 and black carbon added)
- The 1998 Protocol on Heavy Metals; amended in 2012

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone biomonitoring</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Critical levels: conc based</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Critical levels: flux based</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk/scenario maps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mosses: Heavy metals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mosses: N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mosses: POPs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global outreach activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Critical levels for ozone, an evolving process

<table>
<thead>
<tr>
<th>Year</th>
<th>Workshop</th>
<th>Progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988, 1989</td>
<td>Bad Harzburg, Germany</td>
<td>Annual mean</td>
</tr>
<tr>
<td>1992</td>
<td>Egham, UK</td>
<td>AOT40 introduced</td>
</tr>
<tr>
<td>1993</td>
<td>Bern Switzerland</td>
<td>AOT40 established</td>
</tr>
<tr>
<td>1996</td>
<td>Kuopio, Finland</td>
<td>AOT40 extended</td>
</tr>
<tr>
<td>1999</td>
<td>Gerzensee, Switzerland</td>
<td>First flux-based critical levels considered</td>
</tr>
<tr>
<td>2002</td>
<td>Gothenburg, Sweden</td>
<td>First flux-based critical levels accepted</td>
</tr>
<tr>
<td>2005</td>
<td>Obergurgl, Austria</td>
<td>CLs updated based on new knowledge</td>
</tr>
<tr>
<td>2009</td>
<td>Ispra, Italy</td>
<td>CLs updated based on new knowledge</td>
</tr>
<tr>
<td>2016</td>
<td>Madrid, Spain</td>
<td>CLs and methodology updated,</td>
</tr>
<tr>
<td>2017</td>
<td>Poznan, Poland</td>
<td>Revised CLs finalised</td>
</tr>
</tbody>
</table>
Process required to derive a critical level

Stomatal conductance measurements to parameterise a flux-model (minimum approx. 500)

Experimental data of yield loss

Hourly climate and ozone data from the experiment to run the model

Repeat, preferably a minimum of 4 independent studies covering several countries / climatic regions

Develop a dose-response function

Approval, including thresholds, % yield loss, reference value etc. through a series of workshops and meetings

Climate monitoring inside CEH solardomes
Wheat: POD$_6$SPEC functions

The relationship between the relative yield of wheat and stomatal ozone flux (POD$_6$SPEC) for the wheat flag leaf based on five wheat cultivars from three or four European Countries (Belgium, Finland, Italy, Sweden)
The relationship between the relative a) tomato fruit yield and b) tomato fruit quality and POD$_6$SPEC for sunlit leaves based on data from Italy (IT) and Spain (SP), and c) tuber yield of potato and POD$_6$SPEC for sunlit leaves based on data from four European countries (Belgium, Finland, Germany, Sweden)
## Crops: POD$_6$SPEC and POD$_3$IAM CLs

<table>
<thead>
<tr>
<th>Species</th>
<th>Effect parameter</th>
<th>Biogeographical zones</th>
<th>Potential Effect at CL (% reduction)**</th>
<th>Critical level (mmol m$^{-2}$ PLA)*</th>
<th>REF POD$_6$SPEC (mmol m$^{-2}$ PLA) [Represents pre-industrial ozone burden]</th>
<th>Potential maximum rate of reduction (%) per mmol m$^{-2}$ PLA of POD$_6$SPEC***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>Grain yield</td>
<td>All*</td>
<td>5%</td>
<td>1.3</td>
<td>0.0</td>
<td>3.85</td>
</tr>
<tr>
<td>Wheat</td>
<td>1000 grain weight</td>
<td>All*</td>
<td>5%</td>
<td>1.5</td>
<td>0.0</td>
<td>3.35</td>
</tr>
<tr>
<td>Wheat</td>
<td>Protein yield</td>
<td>All*</td>
<td>5%</td>
<td>2.0</td>
<td>0.0</td>
<td>2.54</td>
</tr>
<tr>
<td>Potato</td>
<td>Tuber yield</td>
<td>All</td>
<td>5%</td>
<td>3.8</td>
<td>0.0</td>
<td>1.34</td>
</tr>
<tr>
<td>Tomato</td>
<td>Fruit yield</td>
<td>All</td>
<td>5%</td>
<td>2.0</td>
<td>0.0</td>
<td>2.53</td>
</tr>
<tr>
<td>Tomato</td>
<td>Fruit quality</td>
<td>All</td>
<td>5%</td>
<td>3.9</td>
<td>0.0</td>
<td>1.29</td>
</tr>
<tr>
<td>Crops</td>
<td>Grain yield</td>
<td>All</td>
<td>5%</td>
<td>7.9</td>
<td>0.1</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* Using different parameterisation for Mediterranean and non-Med regions
** Represents the (POD$_6$SPEC - REF POD$_6$SPEC) required for a 5 % reduction
*** Calculate the % reduction using the following formula:

\[
\text{[(POD6SPEC – REF PODySPEC) \times \text{rate of reduction}]}\]

Note: Specific accumulation time per receptor
There were no significant effects of O₃ profile, it was the total dose that affected yield

Hayes, Mills et al, in prep.
Application example: Assessing the global impact of ozone on wheat yield
Methodology schematic

EMEP MSC-W Chemical transport model

Modelled ozone distribution

Climate zone - timing

Proportion of irrigated wheat

Wheat production

Grid square value for POD33IAM weighted by proportion of production from irrigated and non-irrigated area

Response functions for grain, protein and starch yield

Global production loss, economic value, quality changes, mean of 2010, 2011 and 2012
Based on concentration:

- Ozone concentration-based methods overestimate effects.

Based on stomatal uptake:

- The effects are lower and the distribution is different (e.g. USA).

Mean % wheat yield loss (2010 – 2012)

Mills et al., submitted to PNAS.
Increasing production by increasing irrigation will worsen ozone effects

- Additional % yield loss would occur if irrigation is fully in use as soil moisture would not be limiting ozone uptake
- Some of yield benefits of added irrigation would be lost

Mills et al., submitted to PNAS.
Application example:
Assessing the influence of small changes in climate on ozone uptake
Ozone uptake is increased with temperature

For ozone fluxes, decreases in peak concentrations may be counterbalanced by increased background ozone

A small increase in temperature (2°C) can significantly increase ozone uptake, particularly in spring

Hayes et al, in prep.
Conclusions and Opportunities

Some widely applicable agricultural metrics exist for ozone, e.g. wheat

Agricultural metrics for direct impacts of SLCPs are difficult to establish as air filtration removes many additional pollutants

Flux-based risk assessment allows many of the indirect impacts of SLCPs (e.g. aerosols, direct vs diffuse light) to be incorporated into existing models to predict impacts on photosynthesis and therefore crop growth

Current ICP Vegetation outreach activities include application of risk assessments and evidence collection in other global regions

New data is required for additional crops (particularly Asian and African) in addition to other responses e.g. forage quality

‘New’ flux based functions and critical levels are available at http://icpvegetation.ceh.ac.uk/

Thank you