

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

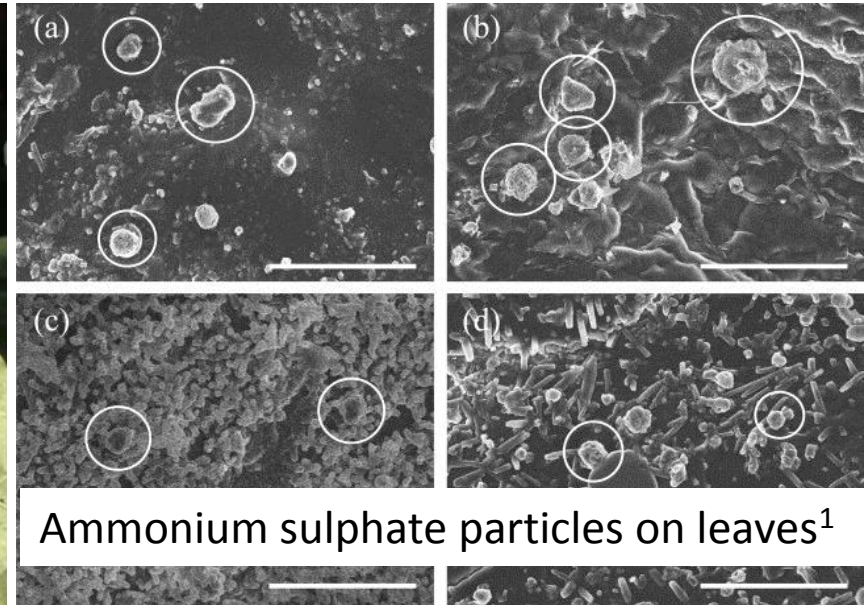
Dust particles
Black carbon
Aerosols
Heavy metals

Sulphur dioxide
Oxides of nitrogen
Ammonia
Acidification

Ozone



Particulates – Direct effects



Physical effects:

- (1) Leaf shading – reduces photosynthesis
- (2) Blocking of stomatal pores prevents CO₂ 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 effect²)

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)



(photos: A. Wahid)

Filtered air

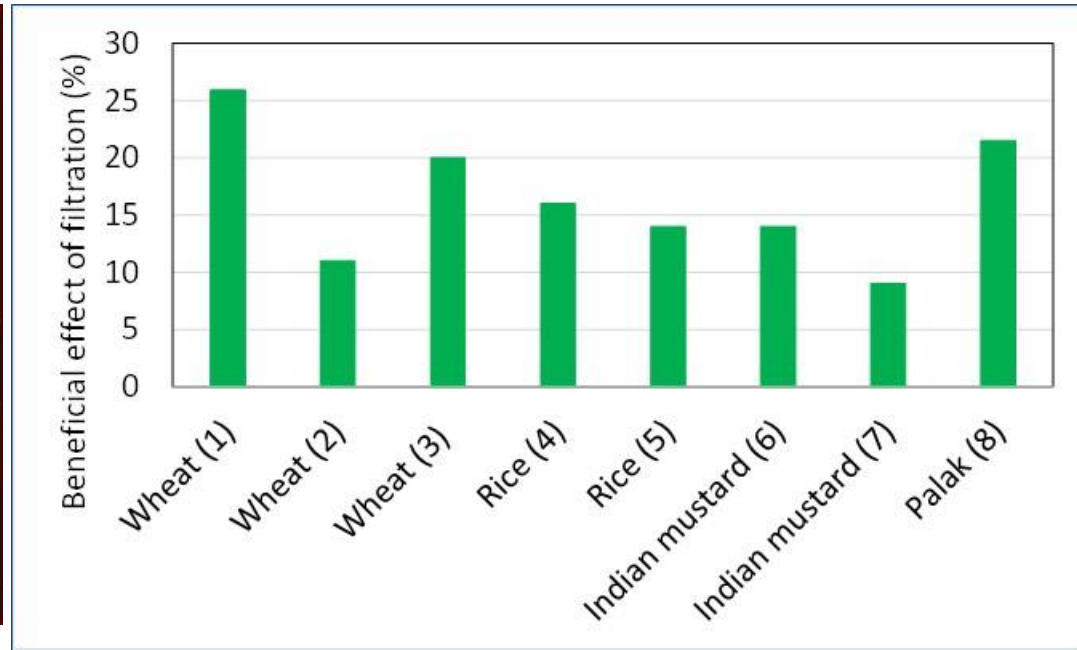
Unfiltered air

Filtered air

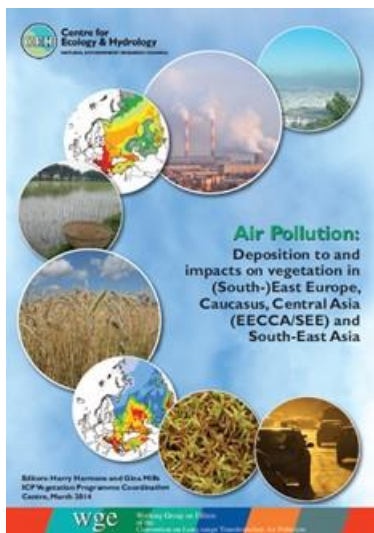
Unfiltered air

- 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



1	Varanasi	Rai et al, 2007
2	Varanasi	Sarkar and Agrawal, 2010
3	Varanasi	Sarkar and Agrawal, 2010
4	New Delhi	Bhatia et al., 2011
5	Varanasi	Sarkar and Agrawal, 2012
6	Varanasi	Singh et al., 2012
7	New Delhi	Singh et al., 2013
8	Varanasi	Kumari et al, 2013



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)



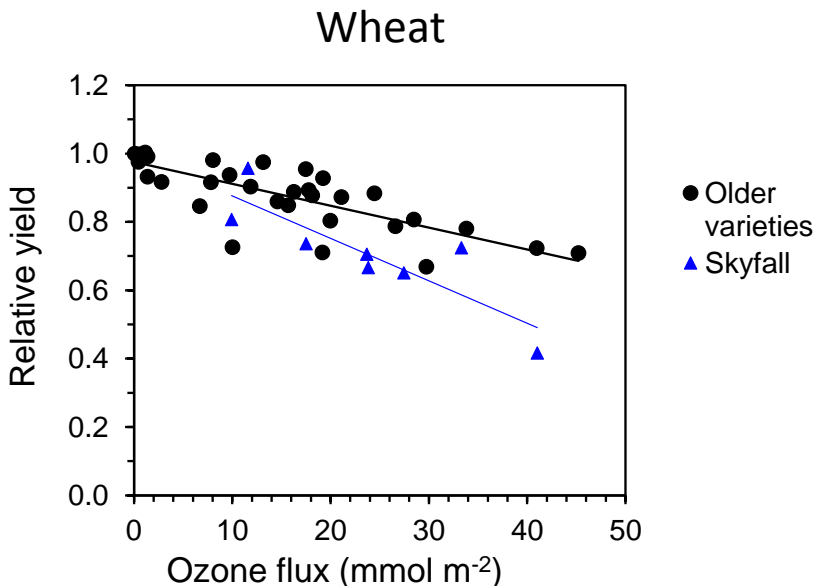
Solardomes (UK)



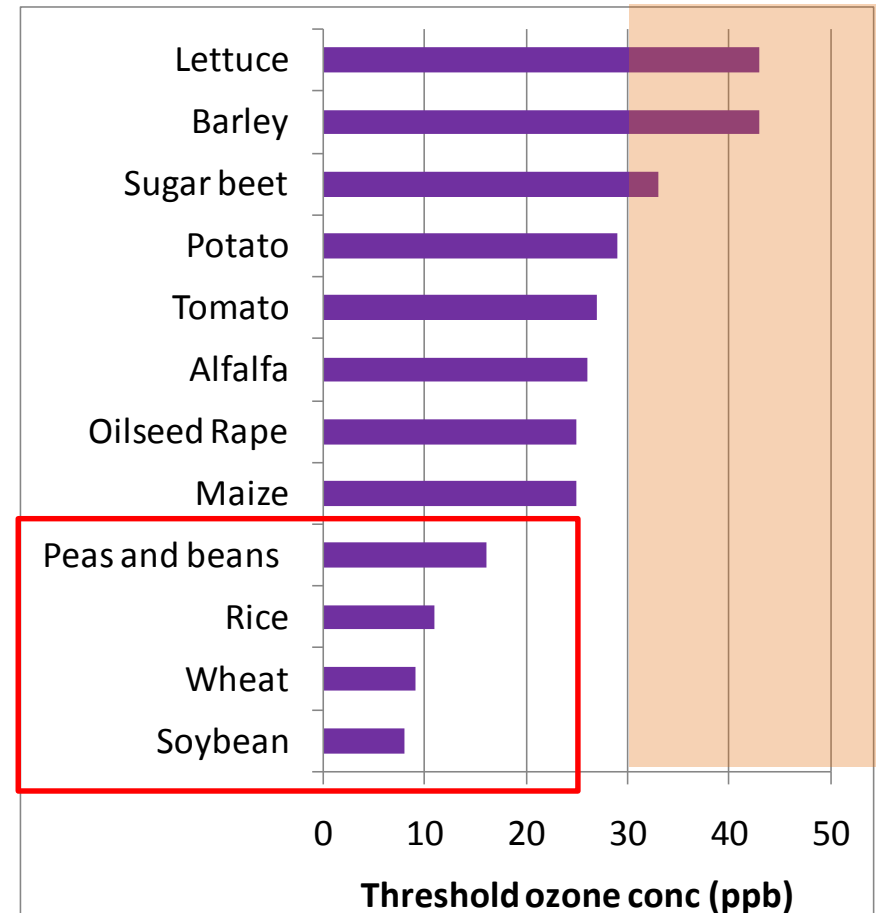
Free-air ozone exposure (USA)

A range of sensitivity to ozone for crops

Many crops are ozone-sensitive including wheat, maize, legumes, tomato and lettuce
There is variation in ozone-sensitivity between cultivars of the same crop

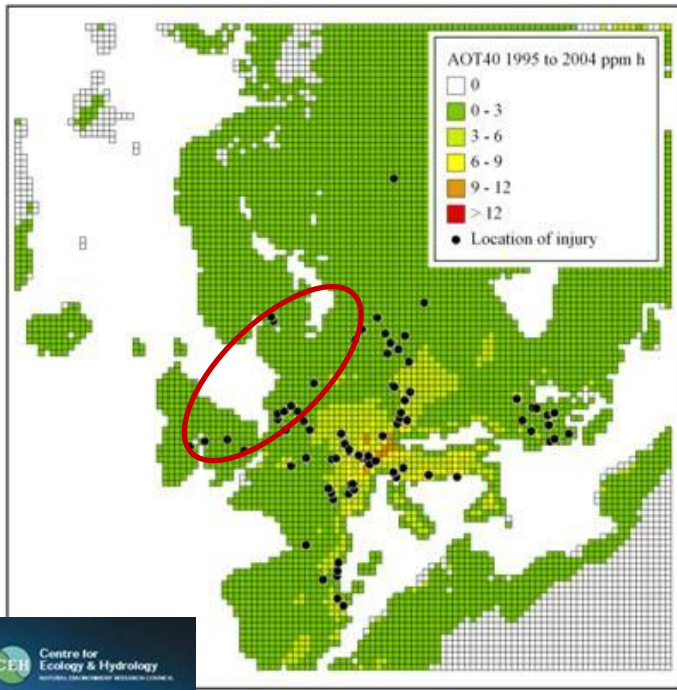


Threshold for significant yield effects

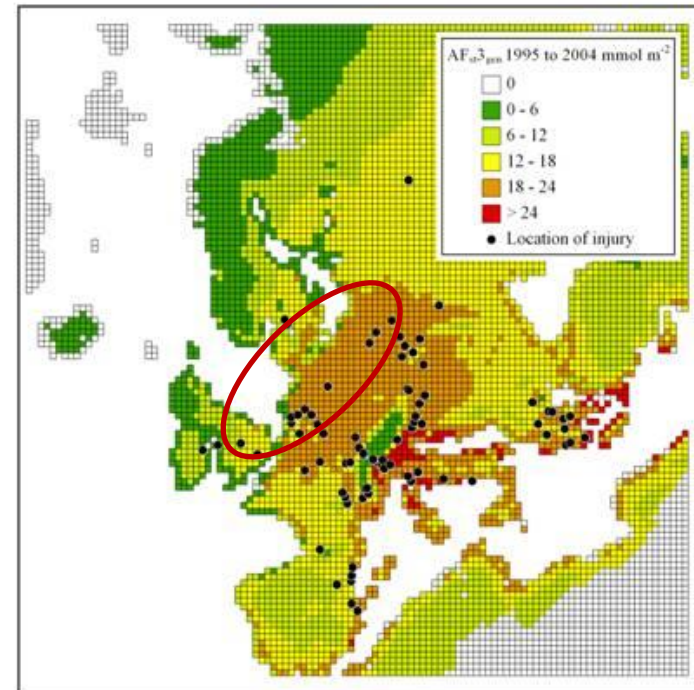


M7 ozone conc. for a significant effect on yield

Evidence-based policy: Field evidence of effects



AOT40

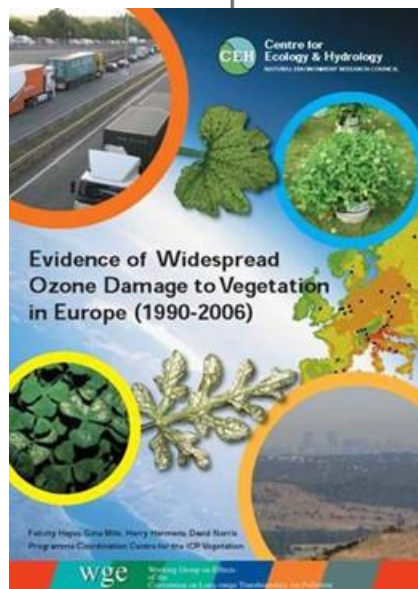


Ozone flux

Locations of effects on vegetation, 1995 - 2004

Key policy outcome: Revised Gothenburg Protocol

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



Critical levels for ozone, an evolving process

Year	Workshop	Progress
1988, 1989	Bad Harzburg, Germany	Annual mean
1992	Egham, UK	AOT40 introduced
1993	Bern Switzerland	AOT40 established
1996	Kuopio, Finland	AOT40 extended
1999	Gerzensee, Switzerland	First flux-based critical levels considered
2002	Gothenburg, Sweden	First flux-based critical levels accepted
2005	Obergurgl, Austria	CLs updated based on new knowledge
2009	Ispra, Italy	CLs updated based on new knowledge
2016	Madrid, Spain	CLs and methodology updated,
2017	Poznan, Poland	Revised CLs finalised

Process required to derive a critical level



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

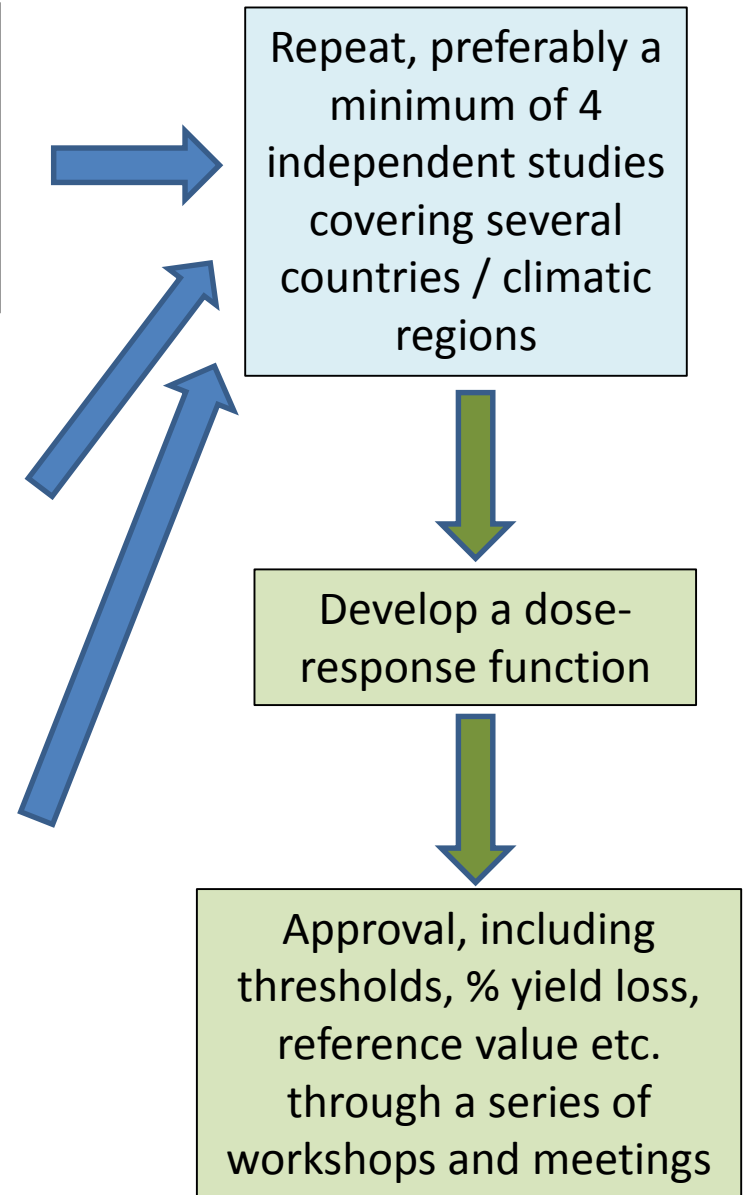


Experimental data of yield loss

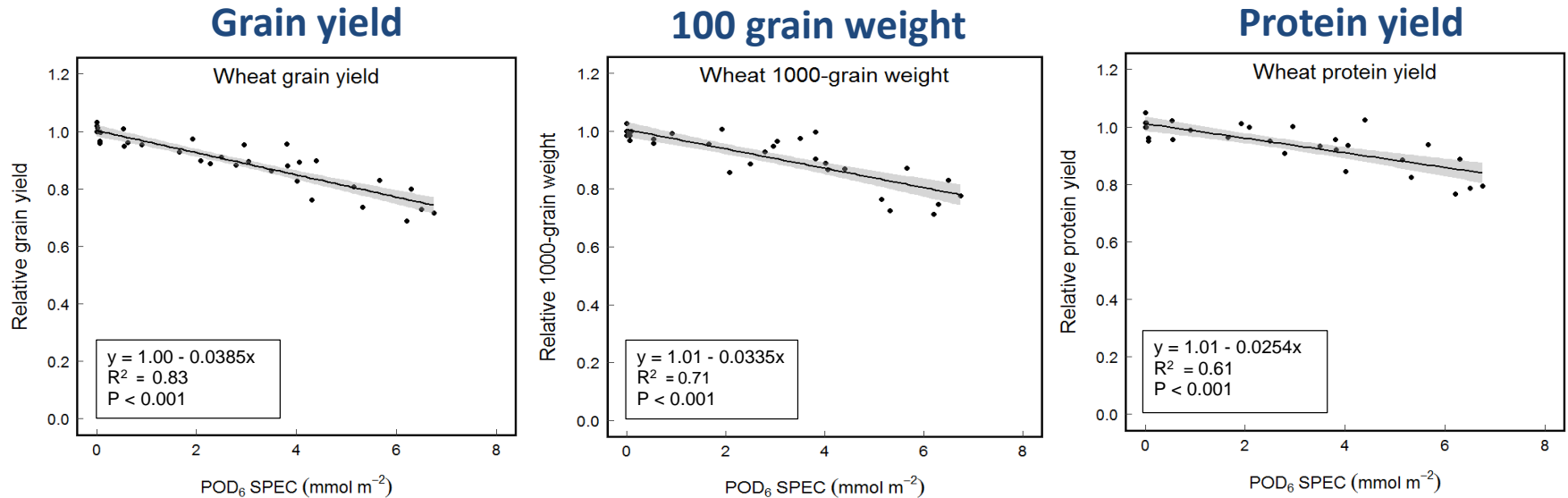


Hourly climate and ozone data from the experiment to run the model

Climate monitoring inside CEH solardomes



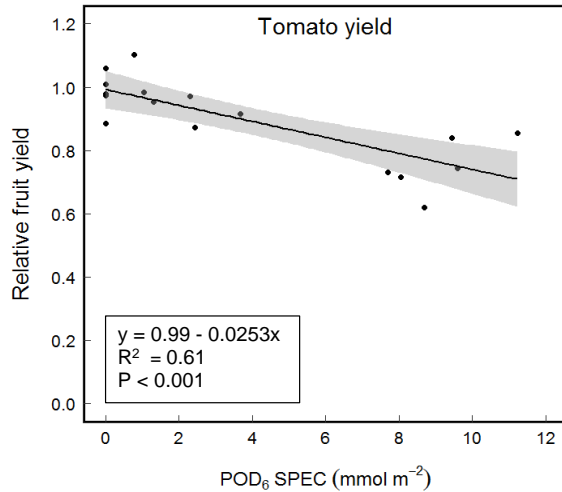
Wheat: POD_6 SPEC functions



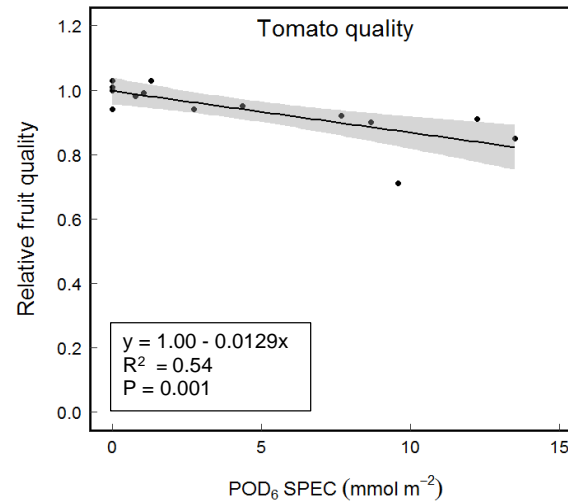
The relationship between the relative yield of wheat and stomatal ozone flux (POD_6 SPEC) for the wheat flag leaf based on five wheat cultivars from three or four European Countries (Belgium, Finland, Italy, Sweden)

Tomato and Potato

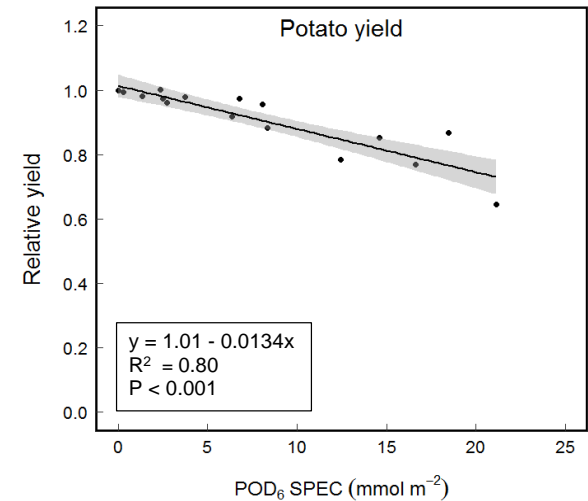
Tomato yield



Tomato quality



Potato yield



The relationship between the relative a) tomato fruit yield and b) tomato fruit quality and POD₆SPEC for sunlit leaves based on data from Italy (IT) and Spain (SP), and c) tuber yield of potato and POD₆SPEC for sunlit leaves based on data from four European countries (Belgium, Finland, Germany, Sweden)

Crops : POD₆SPEC and POD₃IAM CLs

Species	Effect parameter	Biogeographical zones	Potential Effect at CL (% reduction)**	Critical level (mmol m ⁻² PLA)*	REFPOD ₆ SPEC (mmol m ⁻² PLA) [Represents pre-industrial ozone burden]	Potential maximum rate of reduction (%) per mmol m ⁻² PLA of POD ₆ SPEC***
Wheat	Grain yield	All*	5%	1.3	0.0	3.85
Wheat	1000 grain weight	All*	5%	1.5	0.0	3.35
Wheat	Protein yield	All*	5%	2.0	0.0	2.54
Potato	Tuber yield	All	5%	3.8	0.0	1.34
Tomato	Fruit yield	All	5%	2.0	0.0	2.53
Tomato	Fruit quality	All	5%	3.9	0.0	1.29
Crops POD ₃ IAM	Grain yield	All	5%	7.9	0.1	N/A

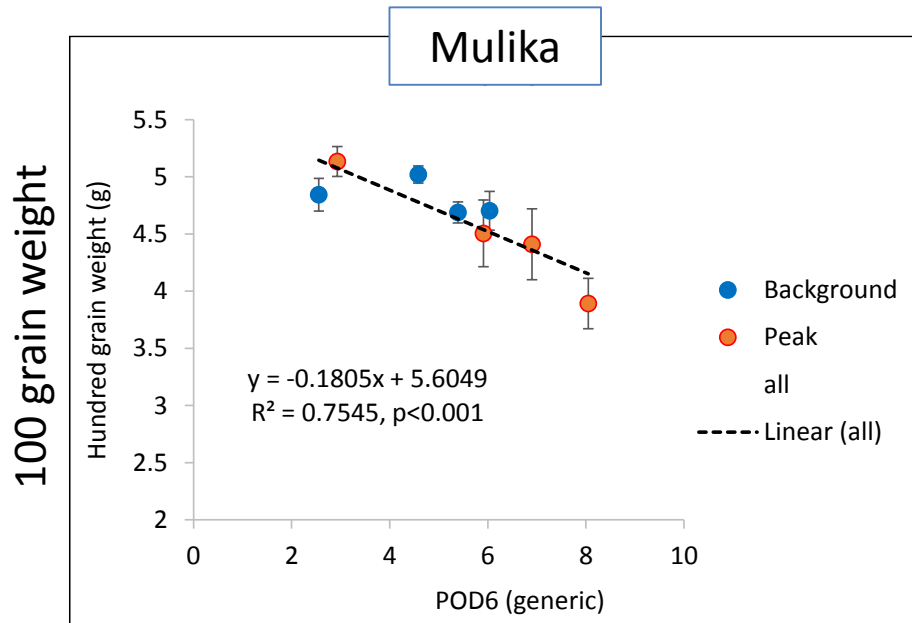
* Using different parameterisation for Mediterranean and non-Med regions

** Represents the (POD₆SPEC - REF POD₆SPEC) required for a 5 % reduction

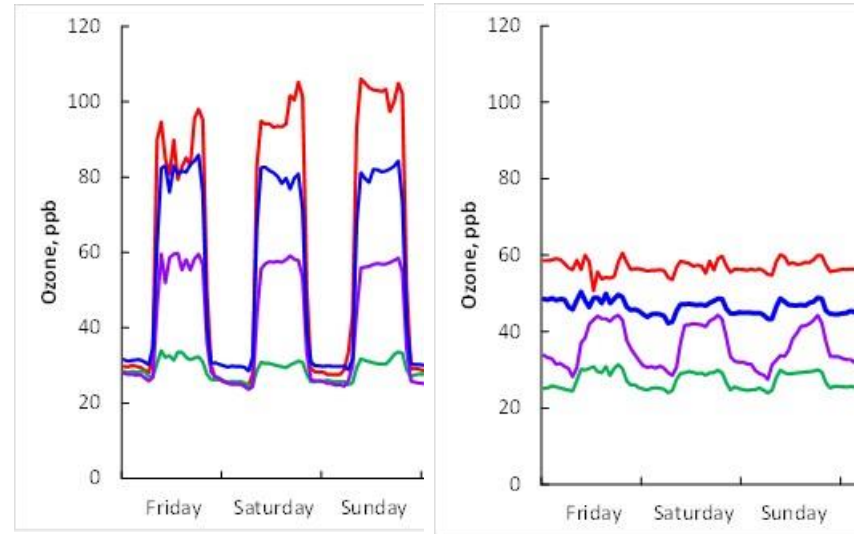
*** Calculate the % reduction using the following formula:

$$[(\text{POD}_{6\text{SPEC}} - \text{REF POD}_{6\text{SPEC}}) * \text{rate of reduction}]$$

Wheat: comparing a 'peaks' to 'background' ozone profile



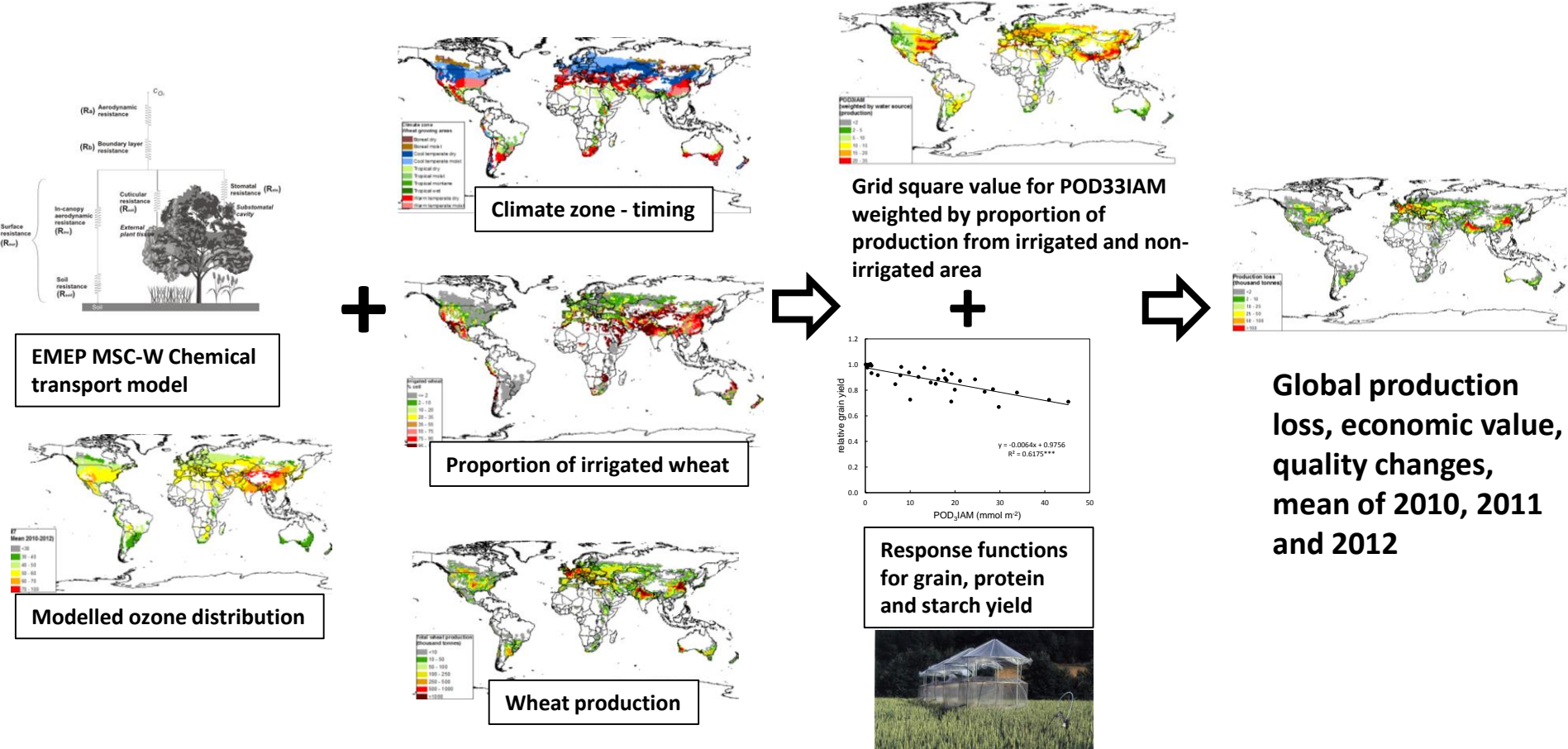
Using paired treatments of episodic vs elevated background treatments

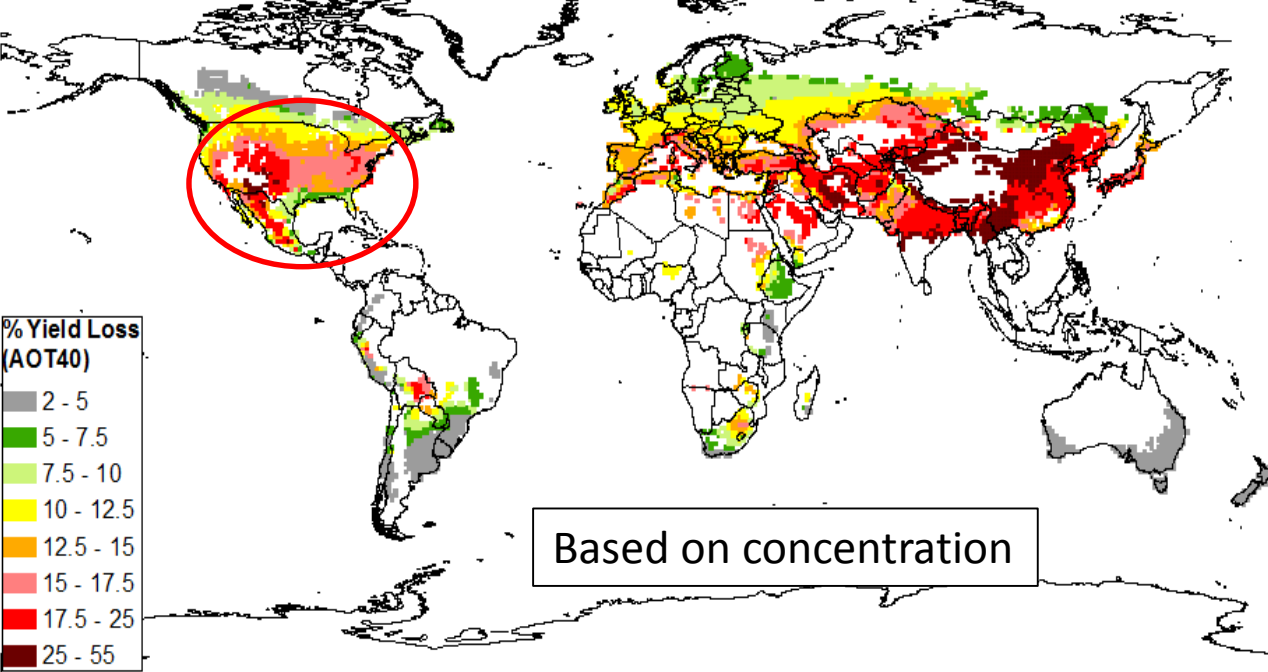


There were no significant effects of O₃ profile, it was the total dose that affected yield

Application example: Assessing the global impact of ozone on wheat yield

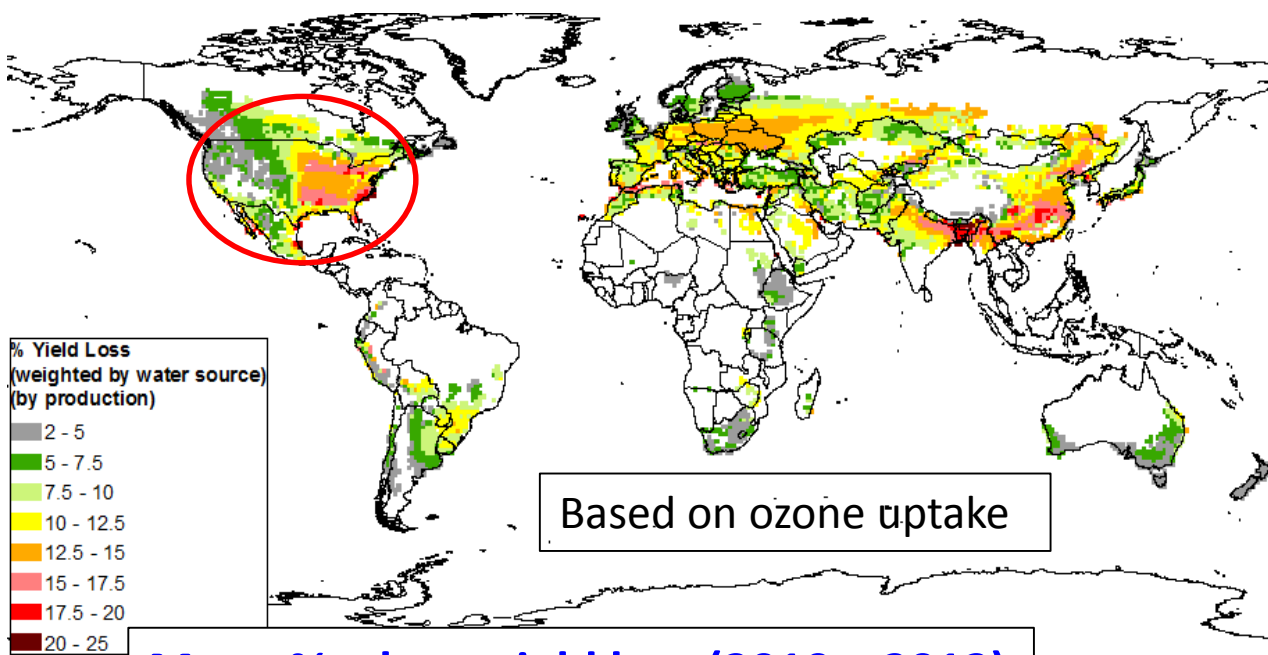
Methodology schematic





➤ Ozone concentration-based methods overestimate effects

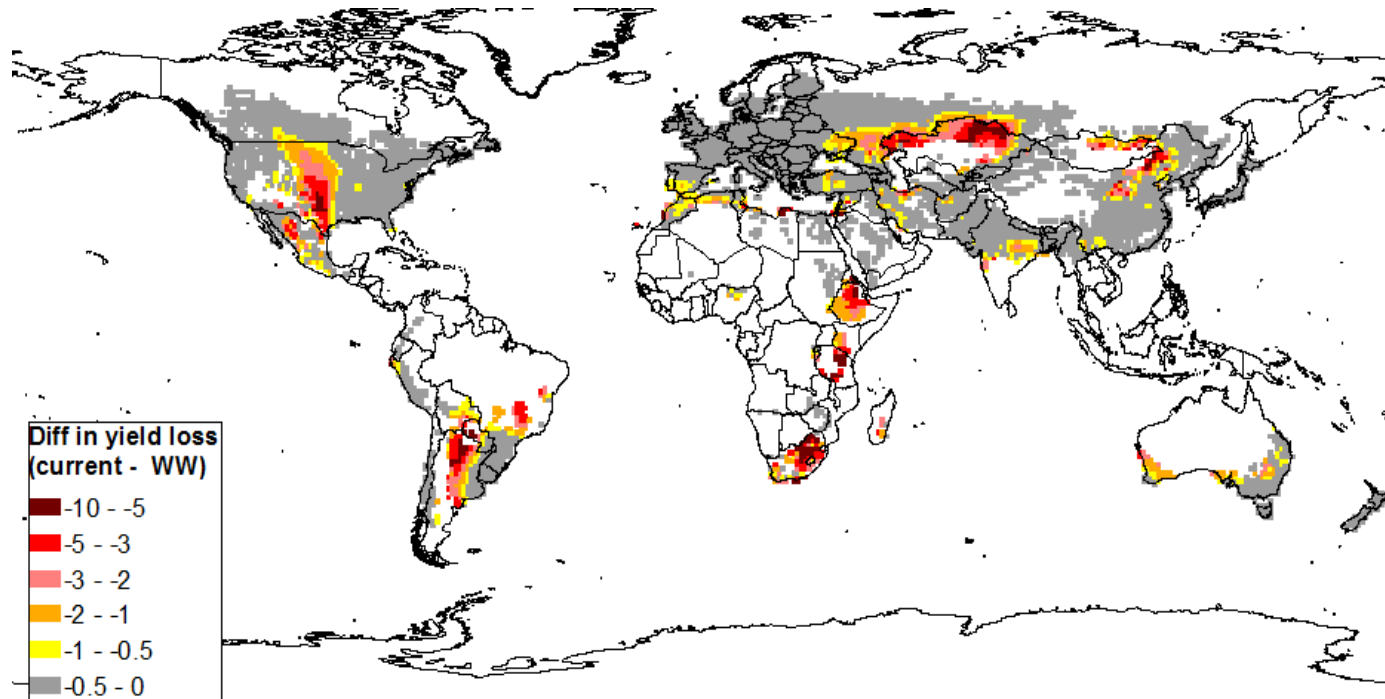
➤ Based on stomatal uptake, the effects are lower and the distribution is different (e.g. USA)



Mean % wheat yield loss (2010 – 2012)

Mills et al., submitted to PNAS.

Increasing production by increasing irrigation will worsen ozone effects

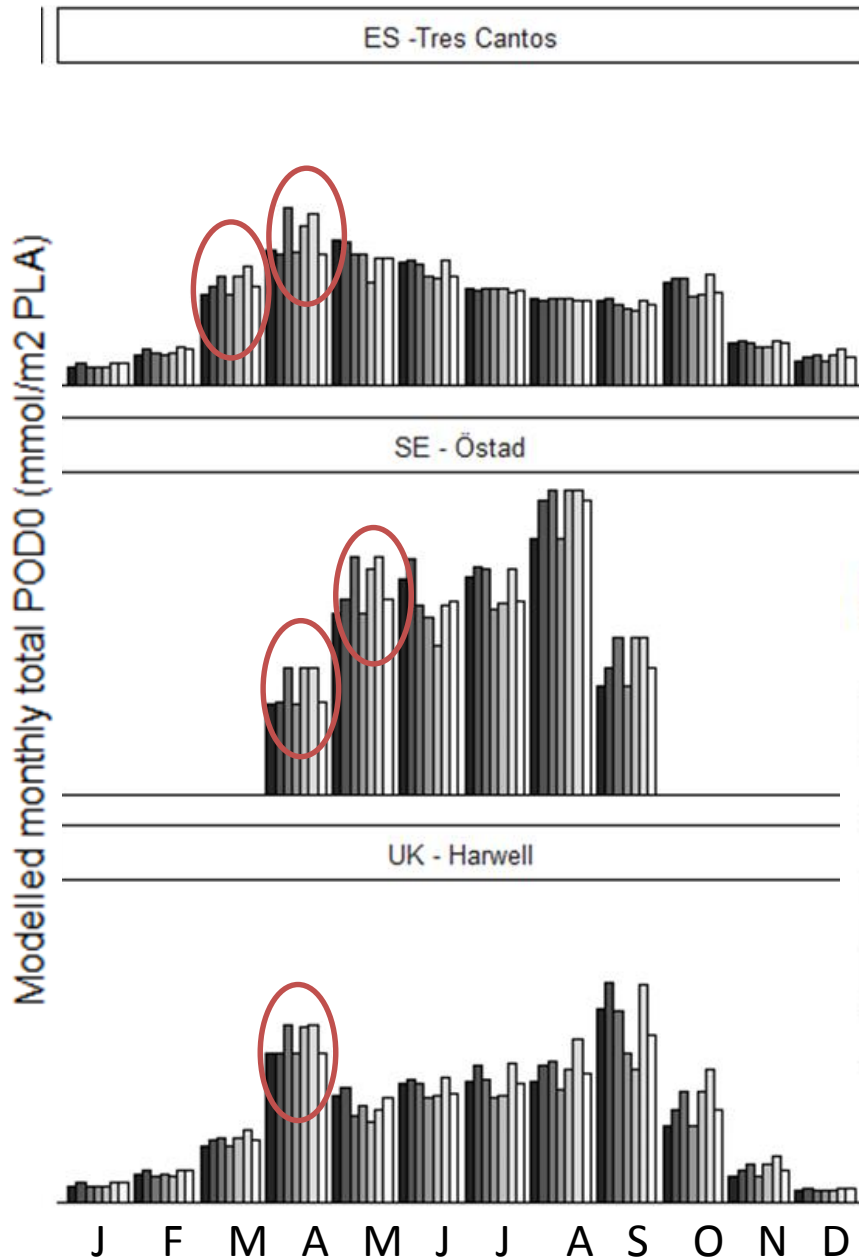


- Additional % yield loss would occur if irrigation is fully in use as soil moisture would not be limiting ozone uptake
- Some of yield benefits of added irrigation would be lost

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

Models

- current
- +background - peaks
- +temp +VPD
- rain
- rain +temp +VPD
- +background - peaks + temp +VPD
- +background - peaks -rain

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