An O_3 flux-based risk assessment for wheat

Ludger Grünhage

Institute for Plant Ecology, University of Giessen, Heinrich-Buff-Ring 26-32, D-35392 Giessen, Germany

Introduction

As a consequence of the discussions about the reasons of the so-called 'Neuartige Waldschäden' (forest die-back) ground-level ozone (O_3) and its impact on human health and vegetation has come into focus more and more within the UNECE (United Nations Economic Commission for Europe) and the European Union since the mid eighties of the last century. While at the first European workshop on critical levels for O_3 to protect vegetation in Bad Harzburg, Germany, 1988 a long-term *critical level* for O_3 was defined as a 7-hour mean of 25 ppb over the vegetation/growing period (UN-ECE 1988), at the second workshop in Egham, UK, 1992 a change to an **A**ccumulated exposure index **O**ver a certain **T**hreshold, AOTx, was recommended (Ashmore & Wilson 1992). At the UNECE workshops in Bern, Switzerland, 1993 and Kuopio, Finland, 1996 *critical levels* for O_3 to protect crops, semi-natural vegetation and forest trees using an AOT40 exposure index were defined (Fuhrer & Achermann 1994, Kärenlampi & Skärby 1996), which are the basis for the current European Convention on Long-Range Transboundary Air Pollution to Abate Acidification, Eutrophication and Ground-level O_3 (UNECE 1999) and the European Directive on Ground-level O_3 (EU 2002).

Because the only adequate tool to ensure effective protection against adverse effects of O_3 on vegetation is the derivation of critical cumulative fluxes/stomatal uptake (*critical loads*) for sensitive vegetation types similar to the *critical loads* for acidification and eutrophication as determined in accordance with the Convention's Manual on Methodologies and Criteria for Mapping Critical Levels/Loads (UBA 1996), a reorientation from cumulative exposure index-based critical levels to flux-based limiting values took place (cf Grünhage & Jäger 2002).

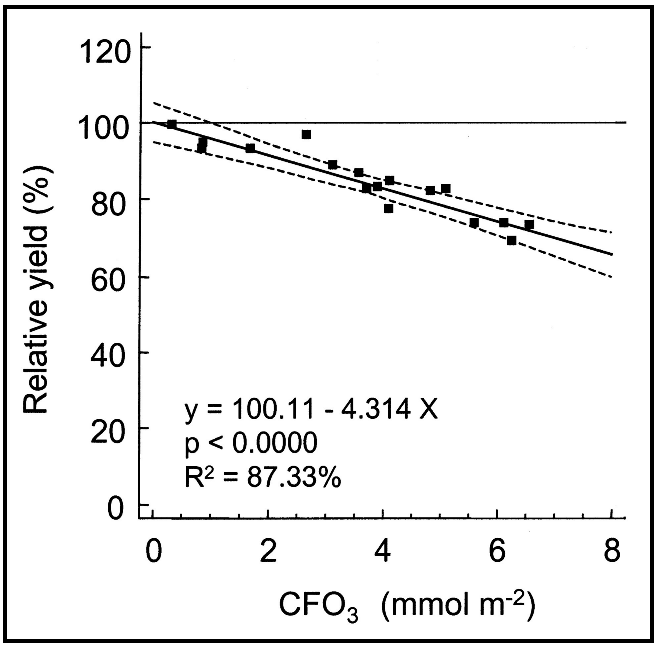

Fig. 1: Relative yield of spring wheat vs cumulative stomatal uptake of O_3 (CFO_3) by the flag leaf during grain filling (Pleijel et al. 2000, modified)

Data base

At present, the data base for the derivation of critical loads for O_3 is extremely insufficient.

For spring wheat, a flux (stomatal uptake) - response (relative yield) relationship was deduced by Pleijel et al. (2000) from 5 open-top chamber experiments with two wheat varieties only (Fig. 1).

Brief model description

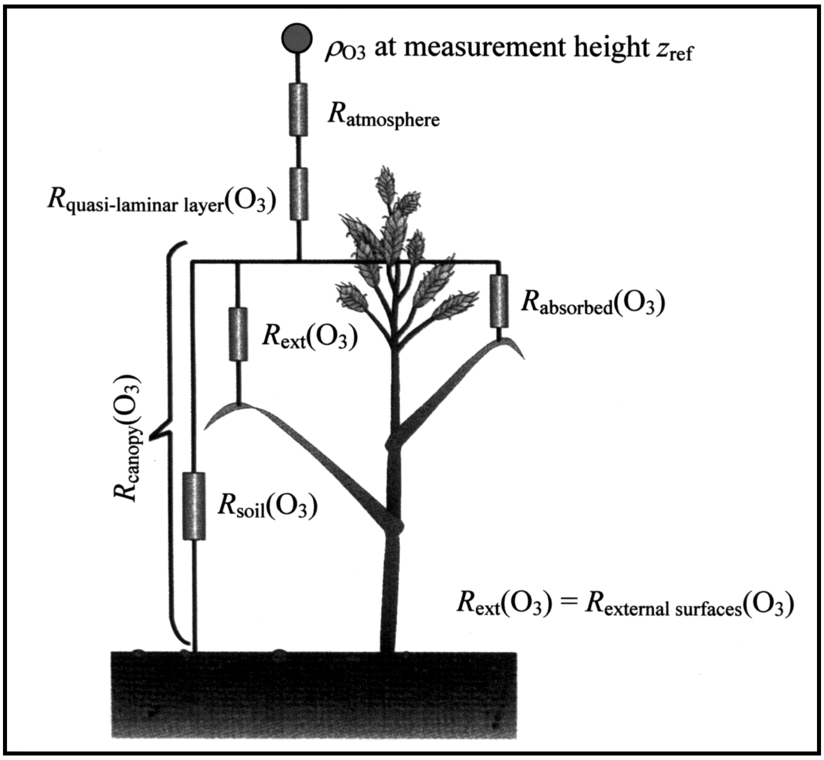

Fig. 2: A deposition resistance analogy for ozone (modified from PORG 1997)

For the estimation of O_3 stomatal uptake, the big-leaf model WINDEP (Worksheet-INtegrated Deposition Estimation Programme; Grünhage & Haenel 2000) was adapted. WINDEP is based on the soil-vegetation-atmosphere-transfer (SVAT) model PLATIN (PLant-ATmosphere INteraction; Grünhage & Haenel 1997).

The resistance network (Fig. 2) allows to partition the total atmosphere-canopy flux $F_{total}(O_3)$ into the fluxes reaching the stomatal caves ($F_{absorbed}$), the external plant surfaces ($F_{external\ plant\ surfaces}$) and the soil beneath the canopy (F_{soil}):

$$F_{total}(O_3) = F_{absorbed} + F_{external\,plant\,surfaces} + F_{soil}$$

The integral of $F_{absorbed}$ over time t is the ***pollutant absorbed dose***, $PAD(O_3)$ [$\mu g \cdot m^{-2}$], (Fowler & Cape 1982):

$$PAD(O_3) = \int_{t_1}^{t_2} \left| F_{absorbed}(O_3) \right| \cdot \mathrm{d}t$$

The calculation of the aforementioned resistances, i.e. the exchange of O_3 between phytosphere and atmosphere near the ground, requires the following measured input parameters:

- ozone concentration ρ_{O3} [$\mu g \cdot m^{-3}$] at a reference height $z_{ref,\,O3}$
- horizontal wind velocity u [$m \cdot s^{-1}$] at a reference height $z_{ref,\,u}$
- global radiation S_t [$W \cdot m^{-2}$]
- air temperature t_a [°C] at a reference height $z_{ref,\,T}$
- air humidity rH [%] at a reference height $z_{ref,\,rH}$
- air pressure p [hPa] at a reference height $z_{ref,\,p}$

Stomatal uptake by the flag leaf was parameterised as described in Pleijel et al. (2000), the development of spring wheat canopy during the grain filling period (phenological stage codes 61 to 87; after Zadoks et al. 1974 and Tottman 1987) as described in Grünhage et al. (1999; Fig. 3) in addition with an up-scaling from leaf to canopy according to eq. (36) in Grünhage et al. (2000).

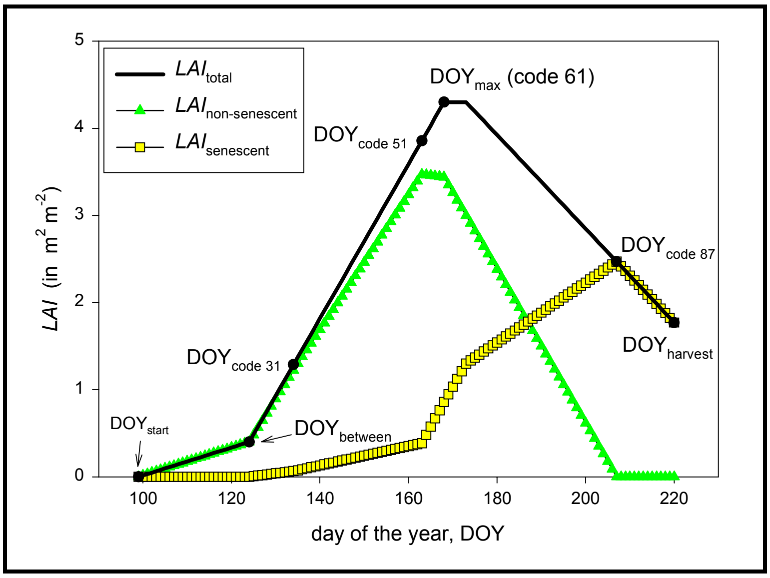

Fig. 3: Mean development of leaf area index (*LAI*) of spring wheat (after Grünhage et al. 1999)
(DOY_{start} = 99; $DOY_{code\ 31}$ = 134; $DOY_{code\ 51}$ = 163; $DOY_{code\ 87}$ = 207; $DOY_{harvest}$ = 220)

The WINDEP model version used can be downloaded from:

http://
www.uni-giessen.de/~gf1034/
ENGLISH/WINDEP.htm

Taking into account the statistical uncertainties indicated by the confidence interval in Fig. 1, stomatal uptake above 1 mmol·m^{-2} O_3 is linked with a yield loss deviating significantly from a 100 % yield. To avoid an overestimation of risk, i.e. yield loss, it seems to be reasonable to subtract this threshold from the modelled O_3 absorbed dose, *PAD*(O_3), which then results in:

$$\textit{relative yield loss} = 100 - \left\{100.11 - \left[\left(4.314\,\mathrm{m}^2\cdot\mathrm{mmol}^{-1}\right)\cdot\left(PAD(\mathrm{O}_3) - 1\,\mathrm{mmol}\cdot\mathrm{m}^{-2}\right)\right]\right\}$$

with *PAD*(O_3) on a unit leaf area basis in mmol·m^{-2}

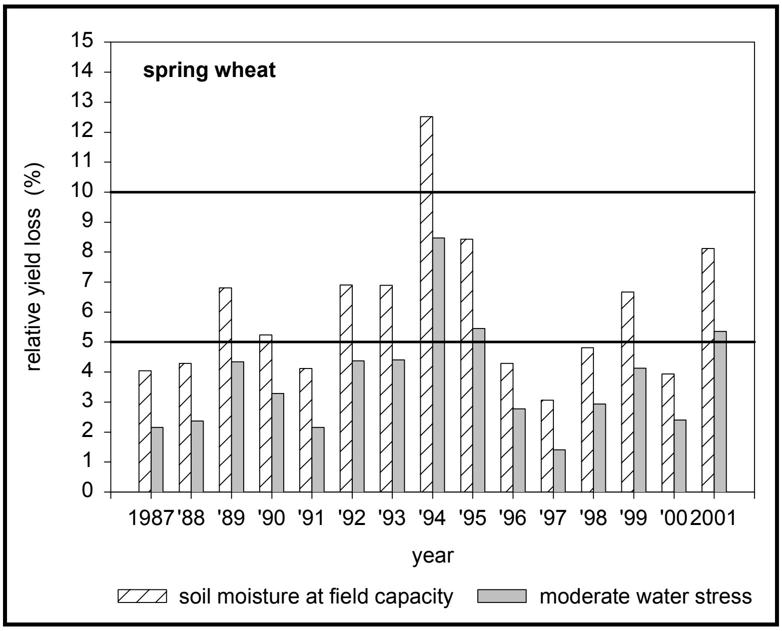

Fig. 4: Temporal variation in potential relative yield loss (%) due to O_3 stomatal uptake under optimal water supply and moderate water stress (Jarvis factor for soil moisture 1 and 0.7) for a representative Hessian agricultural site (fixed growing season; Grünhage & Jäger 2002)

Model application

The big-leaf model was applied for for a representative agricultural site in Hesse in central Germany. As shown in Fig. 4 more than 10 % yield loss due to O_3 stomatal uptake could be estimated for 1994 only. According to the experimental conditions, optimal water supply, i.e. soil moisture at field capacity, was assumed. Moderate water stress reduces the impact of O_3 significantly due to reduced stomatal aperture. Comparisons of diurnal variation of stomatal uptake and AOT40 showed that 36 – 46 % (median: 38 %) of stomatal O_3 absorption (assuming optimal water supply) occurred before noon whereas the AOT40 values were dominated by O_3 concentrations during afternoon (69 – 87 %; median: 79 %).

Remarks

This example demonstrates the applicability of the flux approach for site and local scale risk assessments in principle. On the other hand the application of the aforementioned flux-response relation in a risk assessment for Germany can be criticised due to the small number of experiments with two "old" wheat varieties from the late eighties and mid nineties at one site in Sweden only. Meanwhile, the parameterisation of stomatal conductance was improved for Nordic conditions (Pleijel et al. 2002). Because the parameterisation has not been validated for climate conditions in Central or Southern Europe, a European wide application is questionable.

Another problem arises from the fact that the application of the above mentioned flux-effect relationship needs an up-scaling from the flag leaf to the canopy (bottom-up approach). At the beginning of the grain filling period, the leaf area of the flag leaf exhibits of a fraction between 20 and 25 % of the non-senescent leaf area of the canopy only (Pleijel et al. 2000). Therefore, it is questionable to what extent the flag leaf gas exchange parameterisation is representative of the gas exchange of the whole canopy. Additionally, the parameterisation of non-stomatal O_3 deposition is presently not solved. Because any administrative/political measure on European level must be based on risk evaluations as accurate as possible, flux model parameterisations need a validation in two steps:

- validation of the parameterisation of stomatal conductance via micrometeorological flux measurements of water vapour
- validation of the parameterisation of O_3 stomatal uptake and non-stomatal deposition via micrometeorological O_3 flux measurements

This concept requires a limited number of micrometeorological flux measurements sites distributed over Europe. For Germany, one or two crop sites and two or three extensively managed grassland sites seem to be adequate.

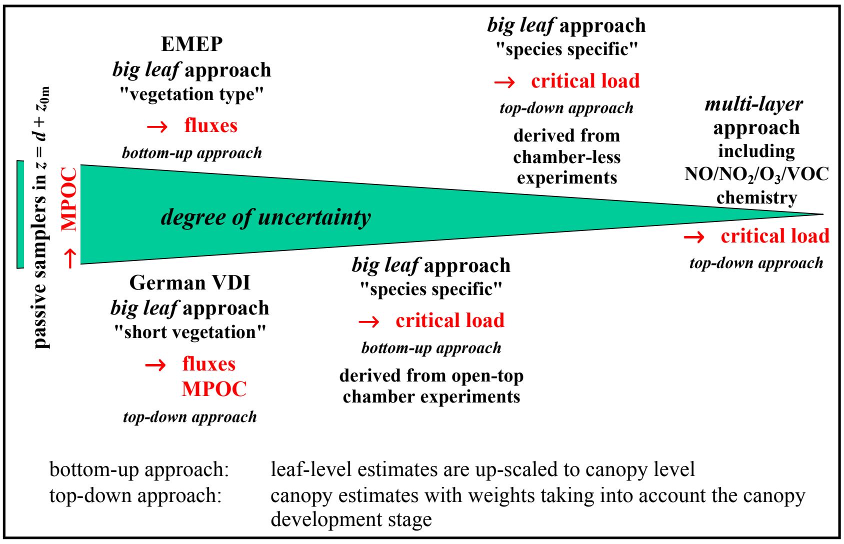

Fig. 5: Conceptual degree of uncertainty in flux-based risk assessments for crops and semi-natural vegetation using measured data (Grünhage et al. 2002)

As mentioned by Grünhage and Jäger (2002) flux-response relationships based on chamber experiments are biased in principle. Therefore, future relationships should be derived from experiments under chamber-less conditions. Here, a top-down approach seems to be more appropriate than a bottom-up approach. Taking into account NO emissions from fertilised arable land and their impacts on O_3 deposition, it might be reasonable to improve gas exchange parameterisations based on the big-leaf approach by multi-layer models at some flux measurements sites (Fig. 5).

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