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ESTIMATION OF THE REDUCTION IN PHOTOSYNTHETIC PARAMETERS (V_{PMAX} , V_{CMAX}) IN THE LEAVES OF MAIZE PLANTS EXPOSED TO INCREASING OZONE CONCENTRATIONS

Bethenod O.¹, Castell J-F.², Roche R.¹, Le Thiec D.³, Leita L.⁴, Repellin A.⁴

¹ INRA and ² AgroParisTech, UMR 1091 EGC, F-78850 Thiverval-Grignon, France. ³ EEF: UMR 1137 INRA/UHP Nancy 1, F54280 Champenoux. ⁴ UPEC, UMR Bioemco 7618, F-94010 Créteil cedex.

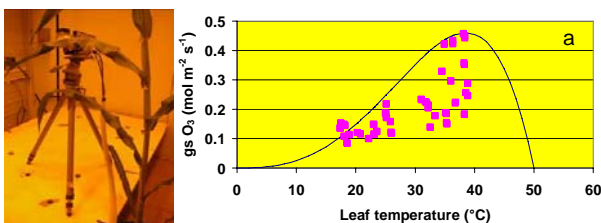
Background: Tropospheric ozone (O_3) is an important gaseous air pollutant with severe phytotoxic effects due to strong oxidizing properties. Current tropospheric O_3 concentrations have become a factor of climate change that mitigates the carbon sink strength of vegetation in a context of increasing atmospheric CO_2 . This is particularly acute in spring and summer, as happened during the 2003 summer heat wave.

Indicators: Over the past two decades, prevention of O_3 effects on European vegetation has driven the development of policies primarily based on the **AOT40 exposure index**. Accumulating evidence suggests that the responses of vegetation to ozone are better related to the **absorbed dose through stomata** than to external concentrations (the absorbed dose being defined as the balance between the O_3 taken up and leaf tissue O_3 -detoxification capacity). However, to date, the detoxification capacity of plants remains an elusive quantity despite the need for detoxification functions (**D**) to be included in photosynthesis models.

	measure	parameter	unit
Hazard	$[O_3]$	AOT 40	ppb.h
Exposure: POD (Phytotoxic Ozone Dose)	O_3 uptake	ΣO_3 Flux	mmol m ⁻² (O_3)
Risk assessment	Effective O_3 flux	$\Sigma(O_3 \text{ Flux}-D)$	mmol m ⁻² (O_3)

The responses to O_3 of crops like winter wheat are well documented unlike those of summer crops like maize and sunflower. Here are shown preliminary results about the vulnerability of maize, a typical summer crop, to O_3 . To estimate the impact of O_3 on maize photosynthetic parameters, a new model for the determination of stomatal conductance (gs) based on a multiplicative Jarvis-Stewart approach and including an original temperature/VPD_i function, was designed (Fig. 1). Phytotoxic Ozone Dose (POD) values were derived from this model ($POD = \Sigma O_3 \text{ Flux} = \Sigma [O_3] \cdot g_{s_{O_3}}$).

Step 1: Parameterisation of leaf stomatal conductance vs leaf vapor pressure deficit (VPD_i), leaf temperature (T_l), light, etc... according to Jarvis functions, as determined from growth chamber studies, using a LiCor 6400 (Massad *et al.* 2007).



A temperature response curve was derived from the experimental data shown on Fig.1a:

$gs(O_3) = gs(O_3)_{opt} \cdot [2(T-T_{min})^a(T_{opt}-T_{min})^a(T-T_{min})^{2a}]/(T_{opt}-T_{min})^2$
where $a = \ln 2 / \ln[(T_{max}-T_{min})/(T_{opt}-T_{min})]$, $gs(O_3)_{opt} = 0.46 \text{ mol m}^{-2} \text{ s}^{-1}$, $T_{opt} = 38.5^\circ\text{C}$ (T_{min} and T_{max} were arbitrarily set at 0°C and 50°C , respectively), ($DO_3/DH_2O = 0.663$).

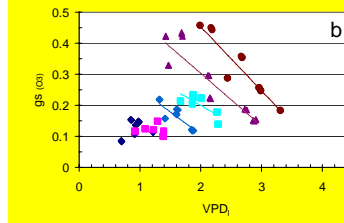


Fig.1: Maize stomatal conductance to O_3 measured in a growth chamber, as a function of:
a/ leaf temperature for $0.7 \text{ kPa} < VPD_i < 3.4 \text{ kPa}$
b/ leaf vapour pressure deficit at various leaf temperatures (\bullet : 38.5°C , \blacktriangle : 35°C , \square : 30°C , \blacklozenge : 25°C , \blacklozenge : 20°C , \blacklozenge : 15°C)

Since growth chamber and field-measured leaf temperatures were below 38.5°C (T_{opt}) (Fig.1b) another fitting curve was established to model the experimental data:

$gs(O_3) = gs(O_3)_{max} \cdot [1/(1-VPD_0)^a \cdot (VPD_i-VPD_0)] \cdot [\exp(a \cdot (T-T_{max}))]$
where leaf $VPD_0 = 4.13 \text{ kPa}$ and $a = 0.09093$, $R^2 = 0.826$, bias = 0.053, and $gs(O_3)_{max}$ fitted value = $0.618 \text{ mol m}^{-2} \text{ s}^{-1}$.

Step 2: Determination of O_3 impact in three experimental setups (Open Top Chamber, Growth Chamber and field Face system).

Leaf photosynthetic parameters were deduced from A/CO_2 curves established, using a LiCor 6400. A mean O_3 concentration of approximately 80 nmol mol^{-1} ($11.5 < AOT40 < 12.4 \text{ ppm h}$) induced a 50% reduction and a 30% reduction in the maximal PEP carboxylation rate (V_{pmax}) and the maximal leaf photosynthesis rate (V_{cmax}), respectively (Table 1).



	Open Top Chamber			Growth Chamber			Field Crop 2008		
AOT40 (ppm h)	0.5	10.0	12.4	0	1.4	11.5	1.2	11.7	17.8
POD ₀ (mmol m ⁻²)	1.5	2.9	3.6	0	1.7	3.5	2.49	4.26	5.04
POD ₆ (mmol m ⁻²)							0.18	1.37	2.13
Slope of A(Ci) curves (mol.m ⁻² .s ⁻¹) used in Vpmax	0.88±0.07	0.81±0.10	0.39±0.05	0.61±0.05	0.58±0.03	0.16±0.01	0.45±0.04	0.34±0.05	0.26±0.03
Vcmax (μmol CO ₂ m ⁻² s ⁻¹)	33.8±2.2	30.0±4.8	22.3±6.3	40.5±1.9	37.9±2.2	31.0±2.8	32.5±2.7	20.8±4.3	21.9±2.6

FACE O_3 system, EGC, Grignon, 2008



Table 1- V_{pmax} , V_{cmax} and O_3 exposure indices (accumulated exposure over a threshold concentration for ozone of 40 nmol mol^{-1} (AOT40) and POD_0) for maize leaves located near the ear. In the OTC and field experiments, stomatal conductance (gs) was determined according to a new model. In the growth chamber experiment, gs values were measured.

Concluding remarks: (i) In all three experimental setups, O_3 -induced reductions in V_{cmax} were equivalent. (ii) To include leaf O_3 detoxification capacity in POD values, a $6 \text{ nmol m}^{-2} \text{ s}^{-1}$ threshold was arbitrarily set. However, further field experiments are required to accurately determine maize O_3 scavenging capacities, either as a threshold O_3 flux or as a more complex function. (iii) gs_{max} is observed at 38.5°C in maize (at 25°C in maize and wheat, EMEP). Since gs is lower in maize than in wheat for the same T_l and $[CO_2]$ values, maize POD values were lower than those generally found in wheat. (iv) As a consequence, field-grown maize yield parameters were not affected in this experiment. POD values could better explain why, in Atlantic central Europe, the yield of winter wheat is reduced by 15% for an $8 \text{ nmol mol}^{-1} \text{ h}$ AOT40, while little change occurs in maize yield in response to increasing AOT40 values (Mills *et al.*, 2007).

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Massad R., Tuzet A. and Bethenod O., 2007. Plant, Cell and Environment, 30, 9, 1191-1204. Mills G., *et al.*, 2007. Atmospheric Environment, 41, 2630-2643.