And Vegetation?
Uptake and effects of a paradigmatic pollutant on plants

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Air Week 2014, *Università di Brescia,* Brescia (I), 10 November 2014

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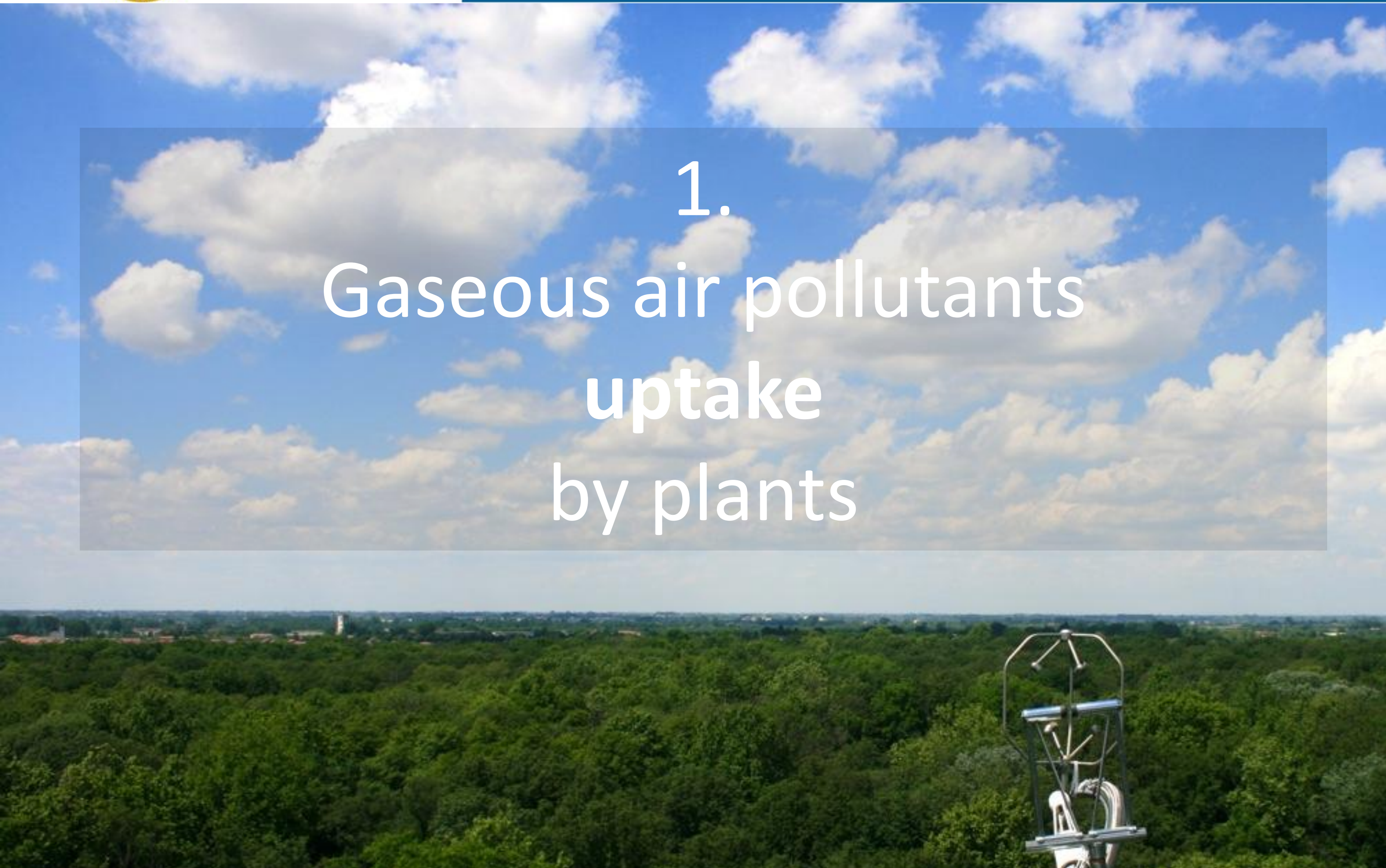
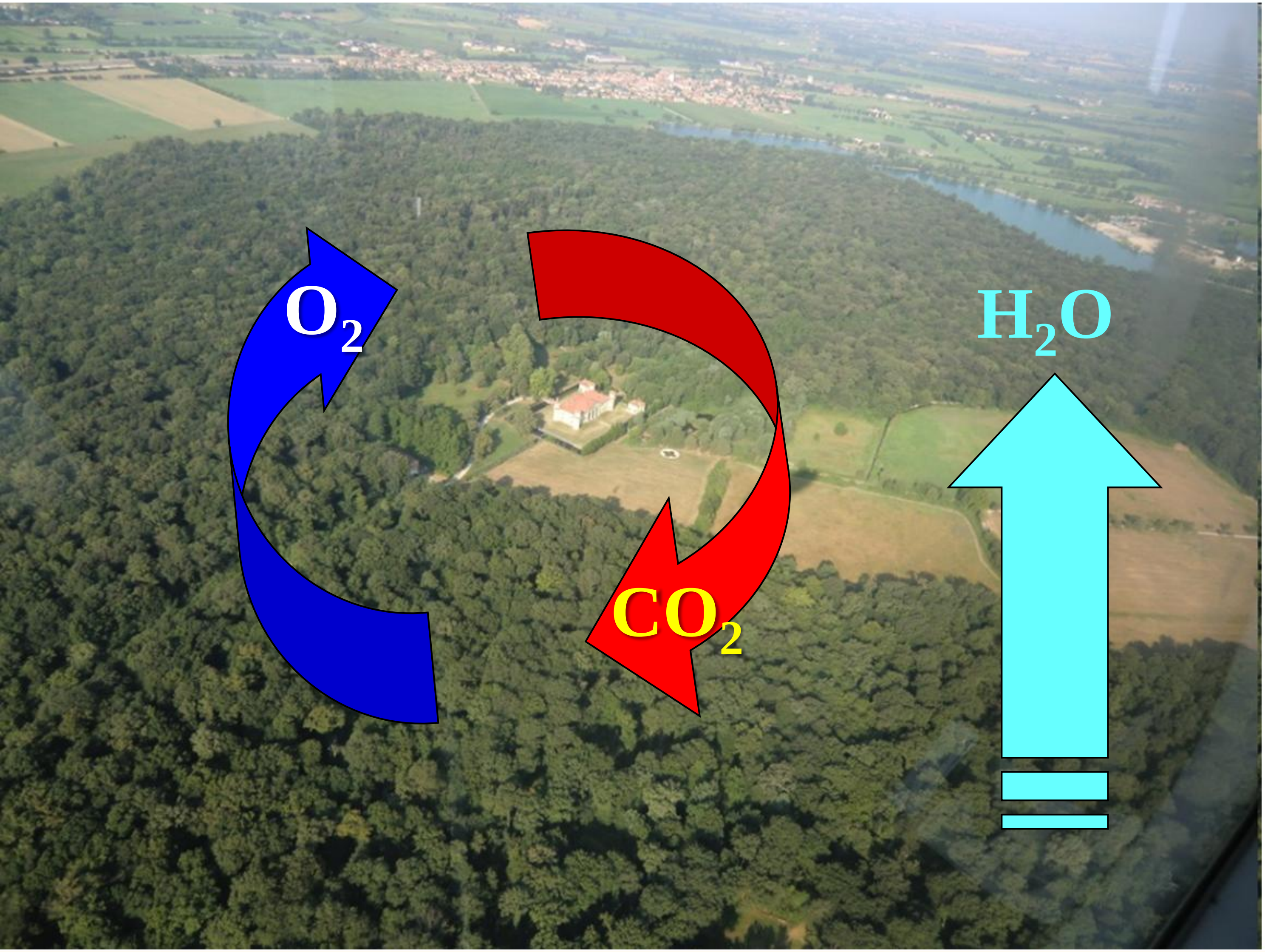
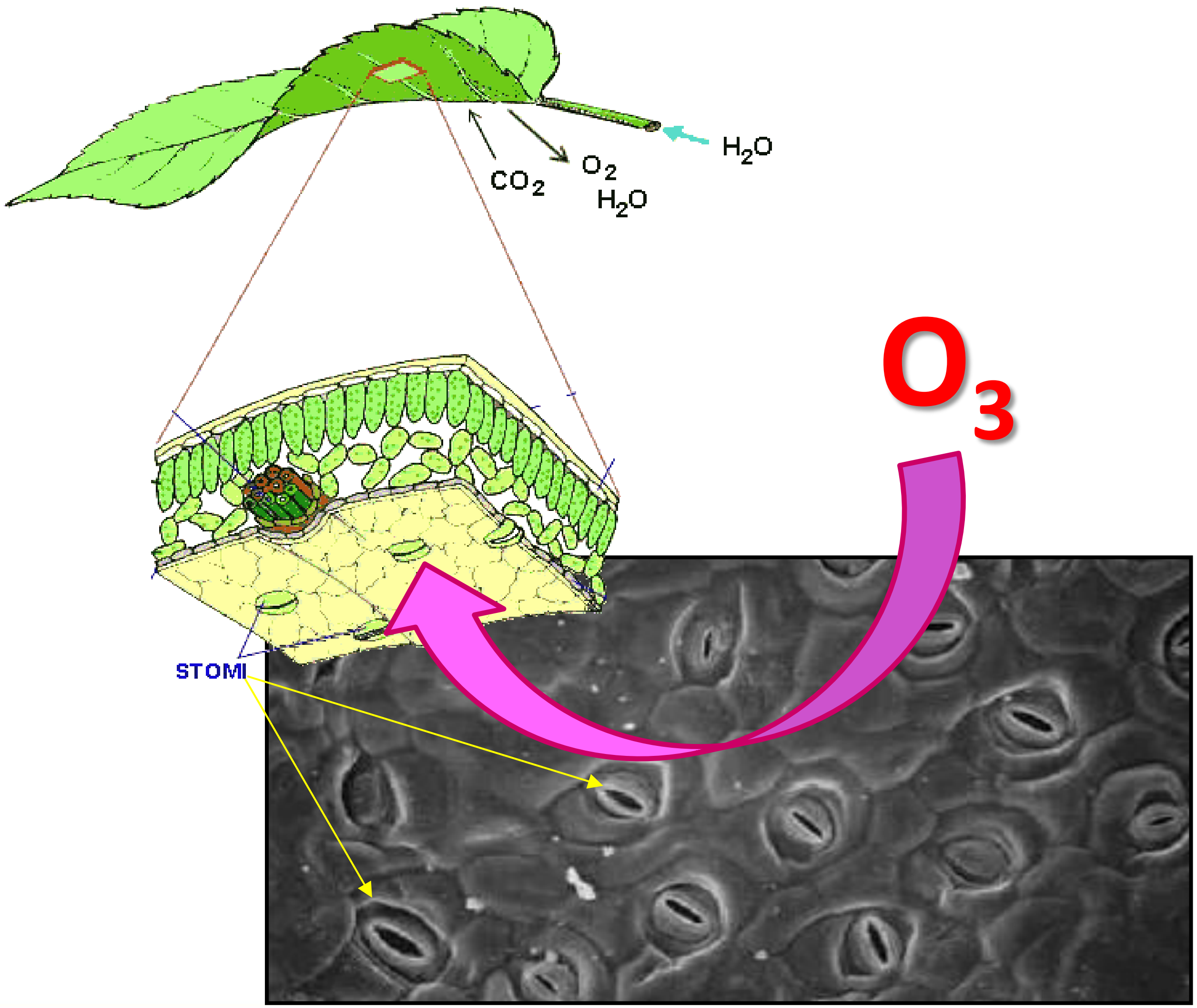
1. Gaseous air pollutants **uptake** by plants



Ecosystems exchange gasses with the atmosphere



Key role of stomates in plants' gas exchange



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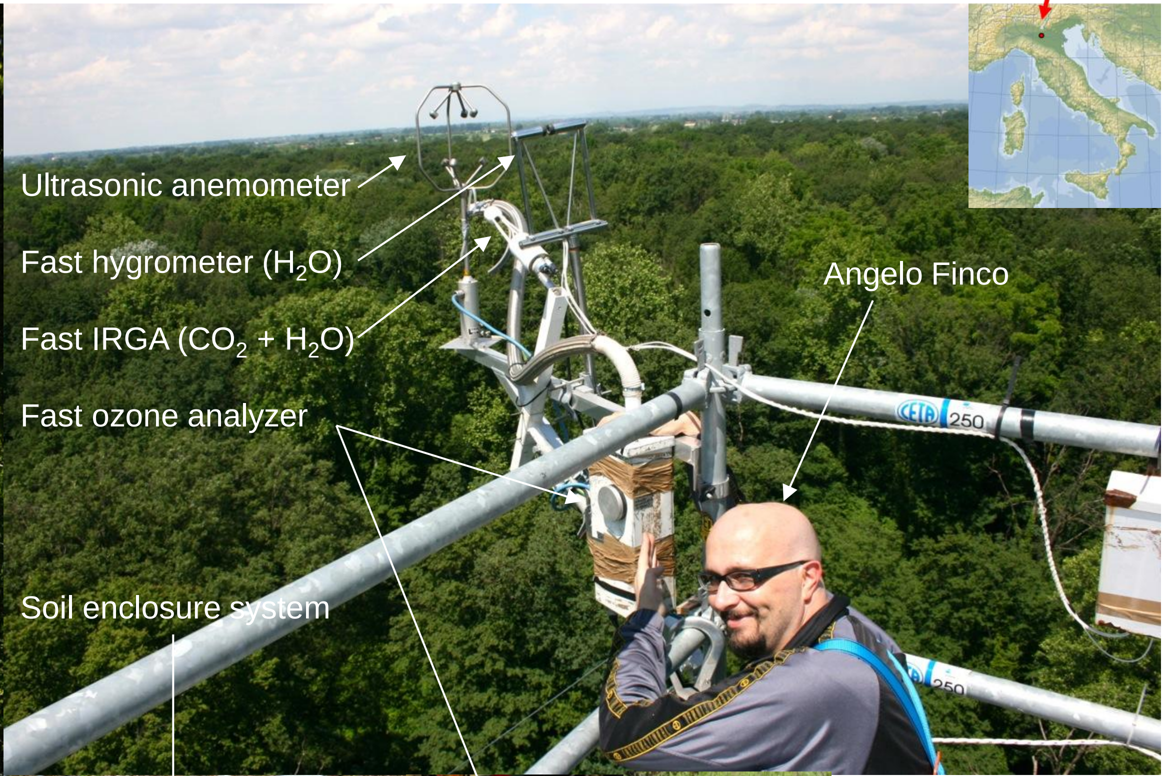
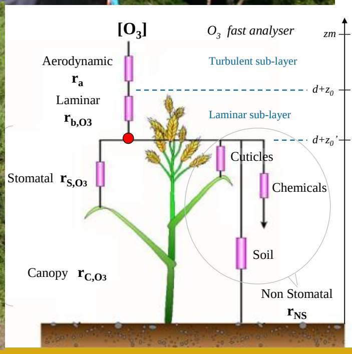
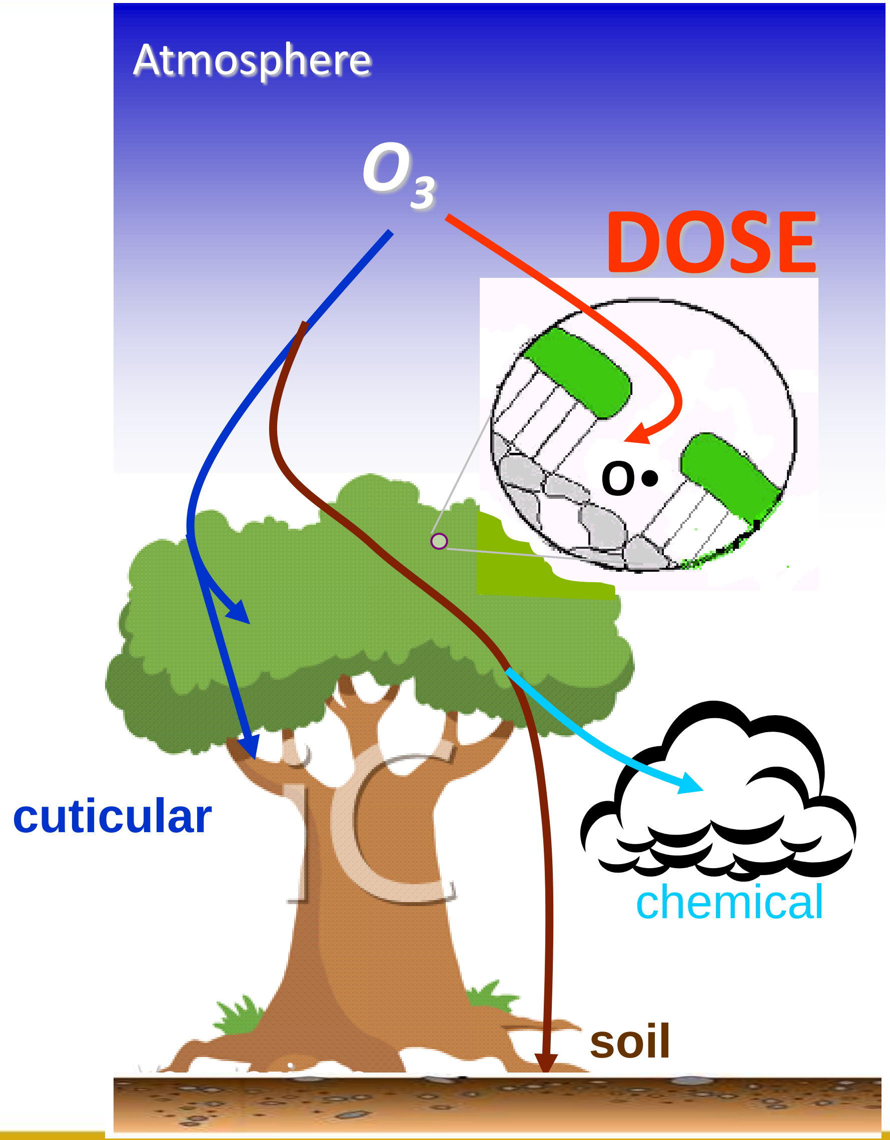
Measurements of gas exchange at ecosystem level



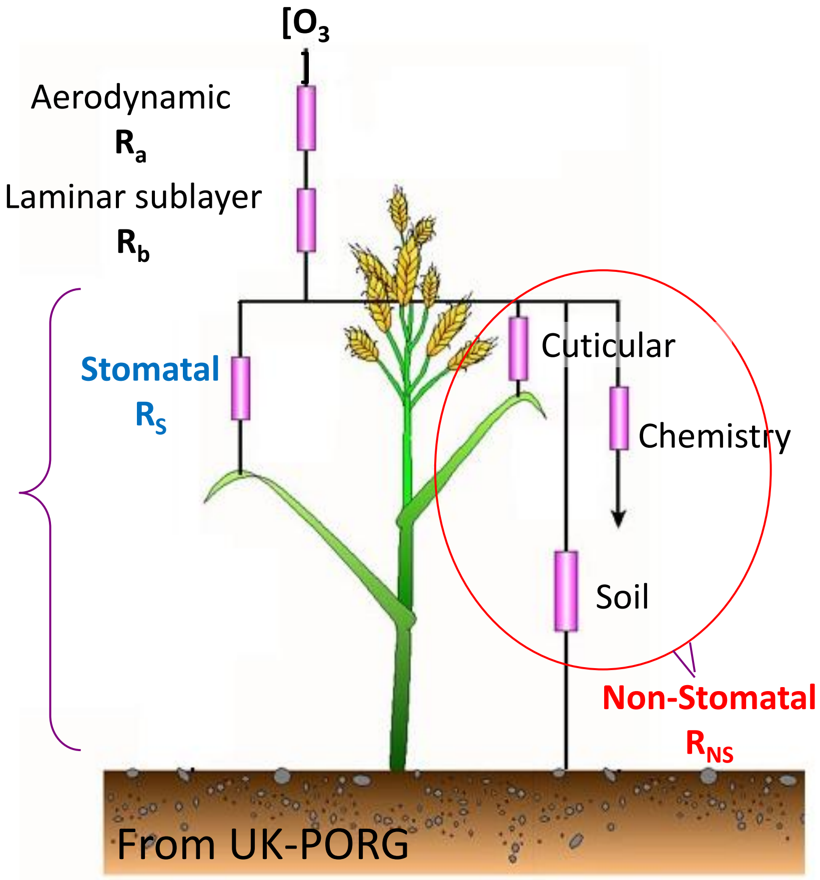


Ozone deposition pathways to a forest ecosystem

O_3 uptaken through stomata are only a part of the ozone deposited to the ecosystem



Derivation of the bio-available O_3 conc. and the ozone dose taken up through stomata



Stomatal uptake at our forest ecosystem

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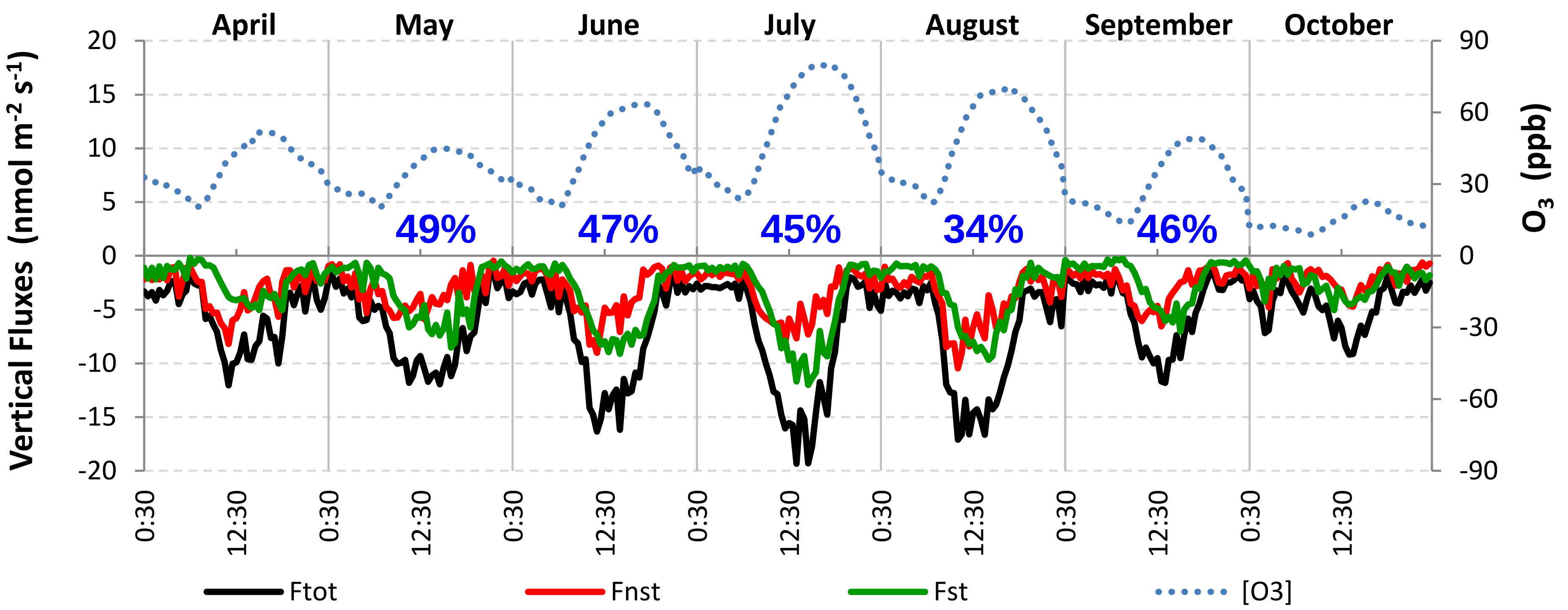
Nearly 50% of the total ozone flux



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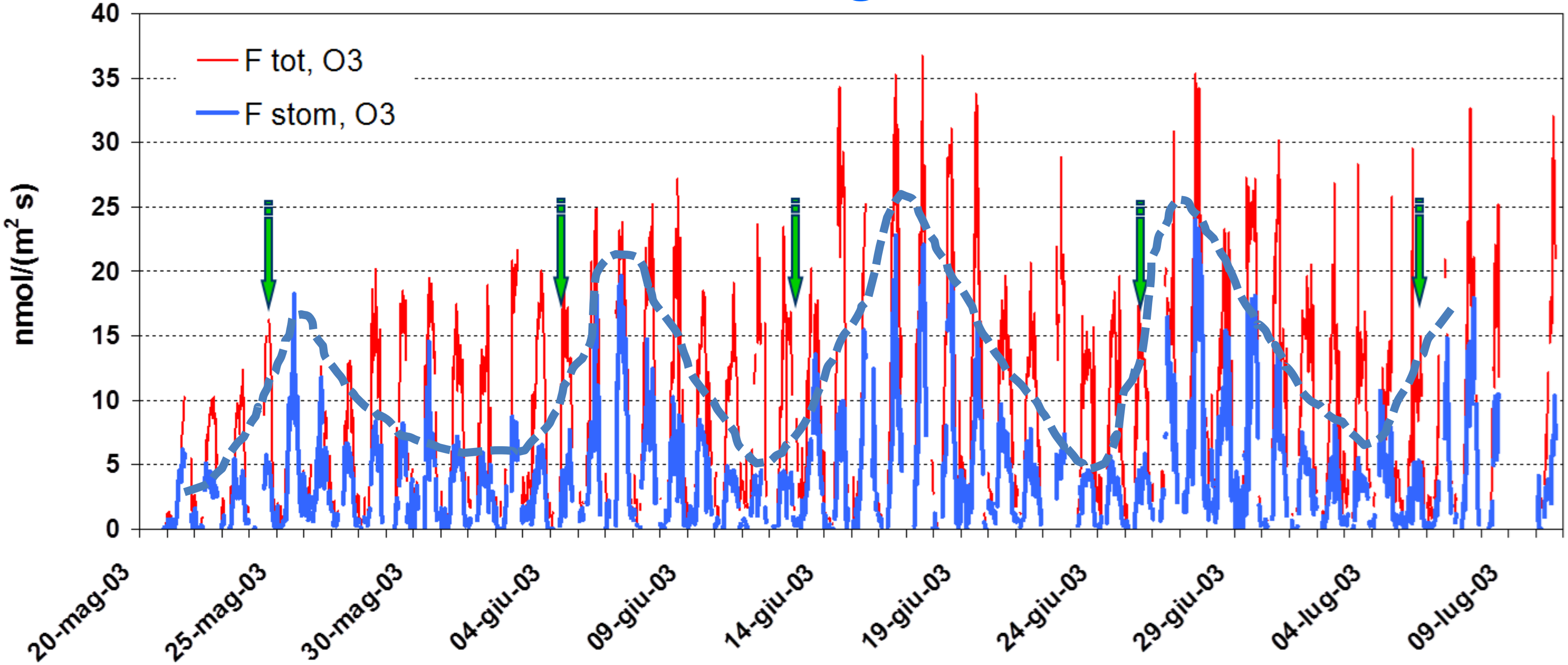
The stomatal *uptake* is driven by the water availability for plants

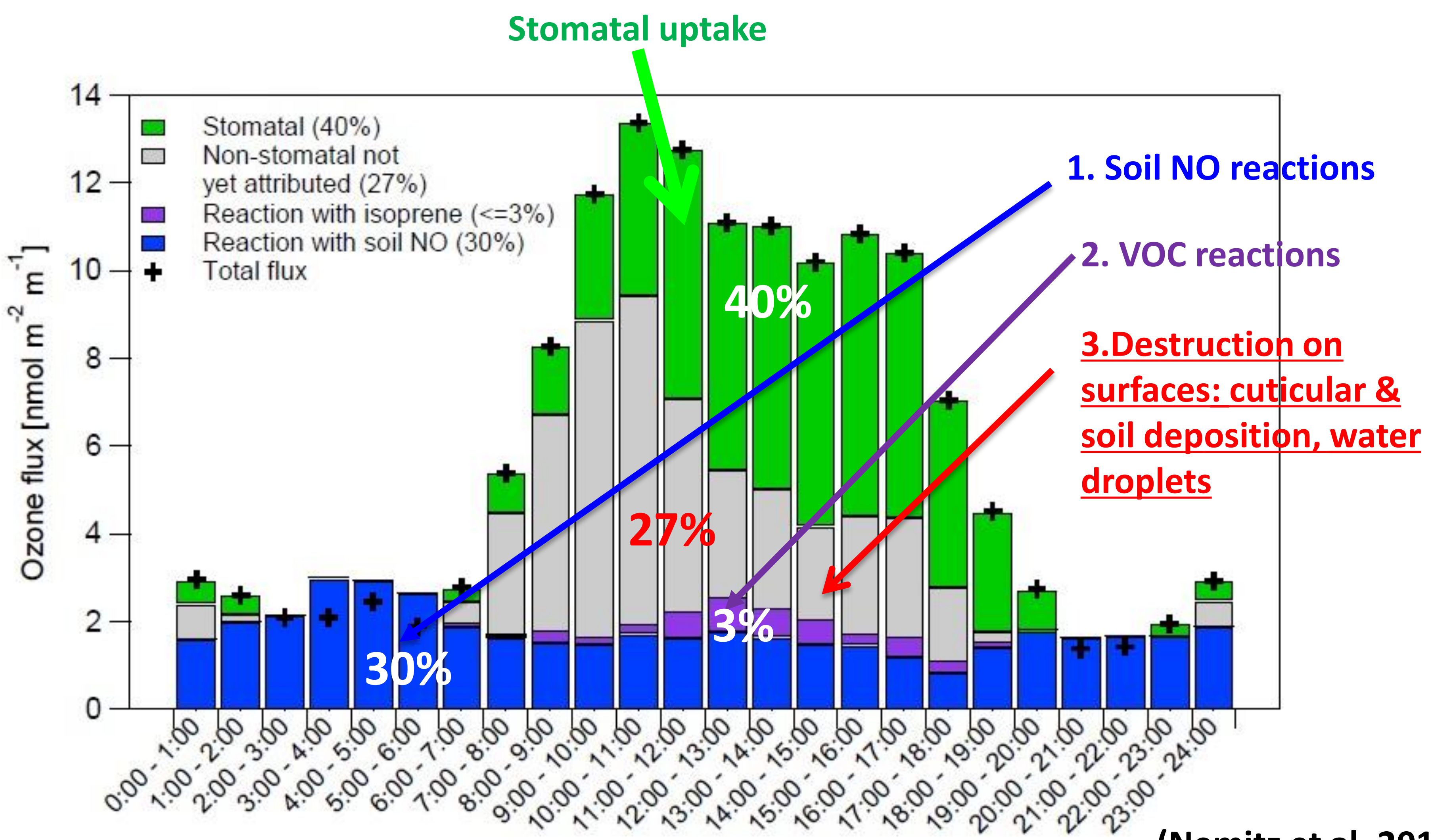
Onion field, Voghera (PV)

5 irrigations



Gerosa et al. 2007 Comparison of Different Algorithms for Stomatal Ozone Flux Determination from Micrometeorological Measurements. *Water Air Soil Pollution* 179:309–321

Relative importance of the other deposition processes



(Nemitz et al. 2013)

Quantify the ozone dose, the 1st determinant of the effects: EXPOSURE and the FLUX concepts

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Definitions

Exposure $= \int_{t_a}^{t_b} C_{air}(t)\, d$

Dose $= \int_{t_a}^{t_b} C(t)_{leaf} \cdot 1/R_{Stom}\, dt$ — G_{Stom}

Indicators

$$AOT40 = \sum_{\substack{\forall C(t) > 40\, ppb \\ \forall Glob.Rad \geq 50 W/m^2}} \left[C_{air}(t) - 40 \right] \Delta t$$

$$POD_Y = \int_{t_a}^{t_b} \left[C(t)_{leaf} \cdot G_{stom}(t) - Y \right] dt \qquad \forall F_{ST}(t) > Y$$

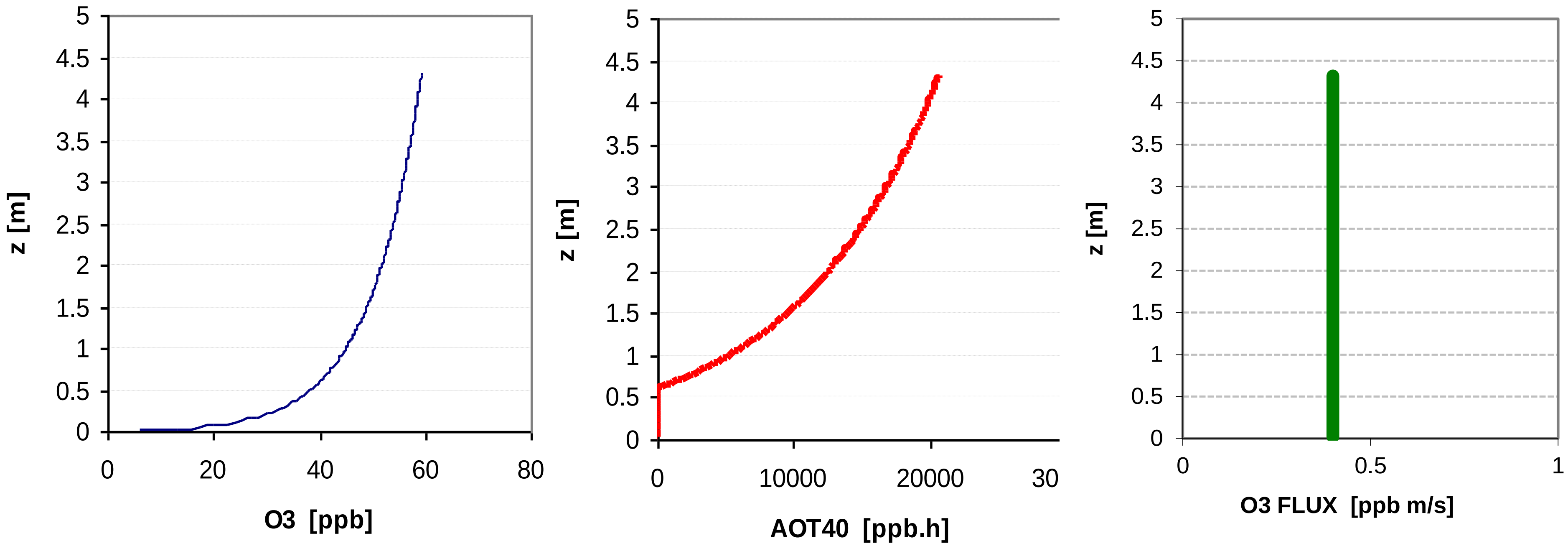
F_{Stom}

Apparently differences seem to be "only" on G_{stom} and O_3 meas. height…

Exposure	*vs*	**Flux**
• simple measurements		• sofisticated measurements
• easy to calculate		• difficult to calculate (requires G_{stom}, often modeled)
• it depends on the height of measurements		• It does not depends on the height of measures
• it does not dependent on the receptor physiology: it depends only on air chemistry		• it depends on the receptor physiology: **more biologically sound**!

AOT40 depends on the measurement height, while FLUX does not

AOT40 strongly depends on the measurement height (above the canopy)…

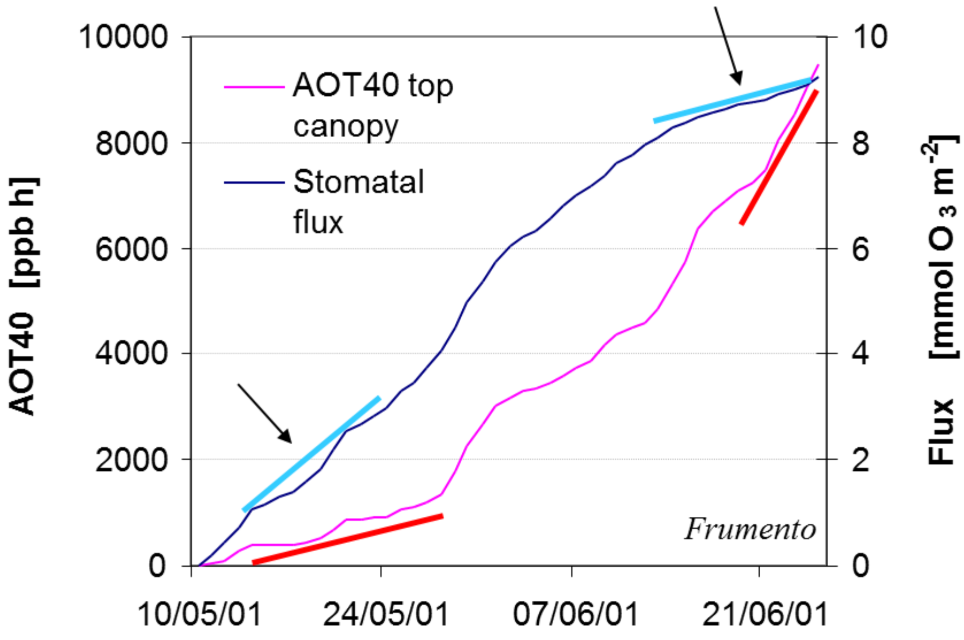


… while flux is independent of the measurement height (=Flux constant)

Exposure and stomatal flux behaves differently along the growing season

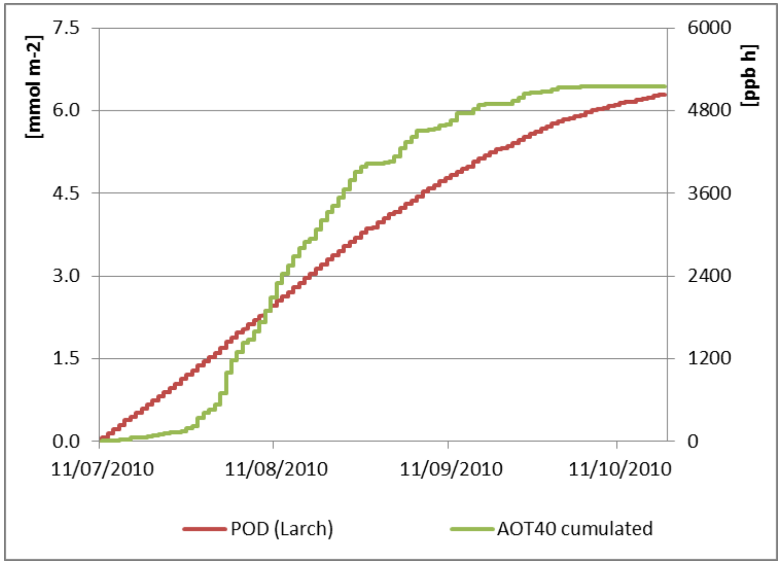
Wheat

Comun Nuovo (BG)



Larix forest

Valcamonica (BS)



Gerosa et al. 2003. Micrometeorological determination of time-integrated stomatal ozone fluxes over wheat: a case study in Northern Italy. *Atmospheric Environment*

Gerosa et al. 2013. Ozone Fluxes to a Larch Forest Ecosystem at the Timberline in the Italian Alps. Intech book, Management Strategies to Adapt Alpine Space Forests to Climate Change Risks

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The exposure index adoped in EU legislation (AOT40) does not allow to estimate the phytotoxical ozone dose

Esposures and Doses in comparison

			FLUX		AOT40	
			Stomatal		top canopy	At z=2m meas.height
Crop	*period*		*m mol m-2*	*Stomatal fraction*	*ppb h*	*ppb h*
Triticum aestivum	*anthesis-harvest*		9,237	*59.7%*	9482	*12152*
Hordeum vulgaris	*Anthesis-harvest*		8,701	*51.4%*	2566	*5755*
Glycine max	*Flowering-harvest*	*2001*	1,667	*24.1%*	2256	*6730*
Glycine max	*Flowering-harvest*	*2002*	7,439	*48.0%*	1334	*4092*

Exposure (AOT40) is not able to predict the toxicological ozone Dose (and the resulting effects…)

UE and UN/ECE critical level for crops: ***3000*** *ppb.h (AOT40)*

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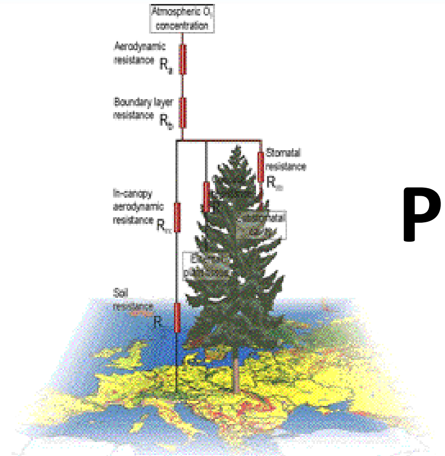
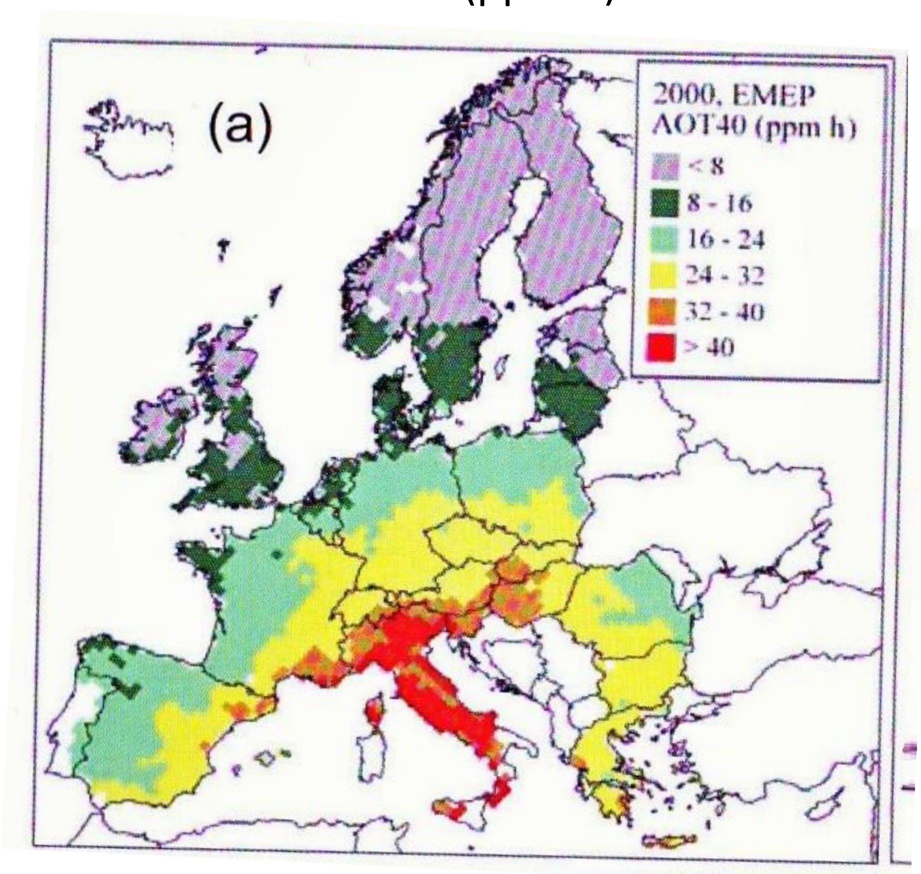
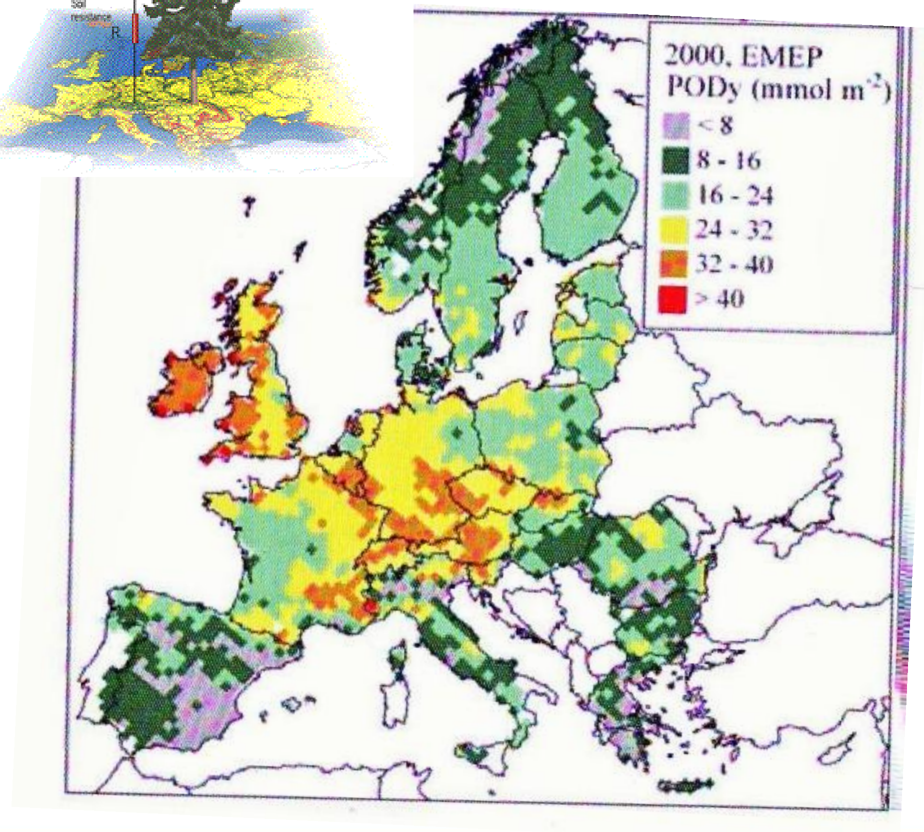
… and this penalises the Mediterranean countries, first of all Italy



AOT40 (ppm·h)



POD1 (mmol m^{-2})



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2. **Effects** on plants

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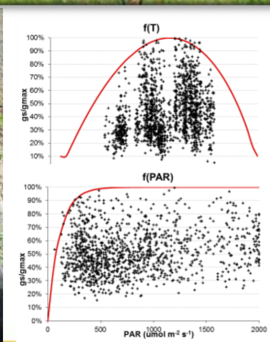
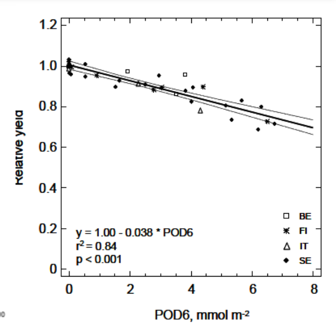
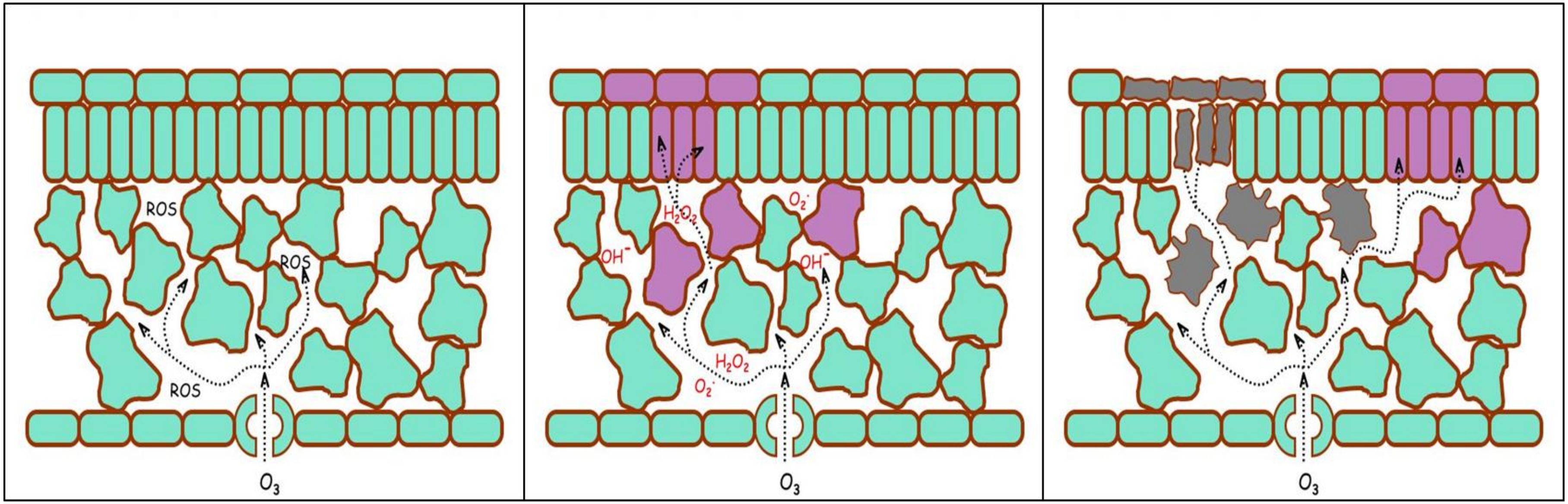
Sperimental facilities to study the effects of air pollutants on vegetation





Ozone penetration in leaves and ROS formation, the ultimate responsible of the plant injury



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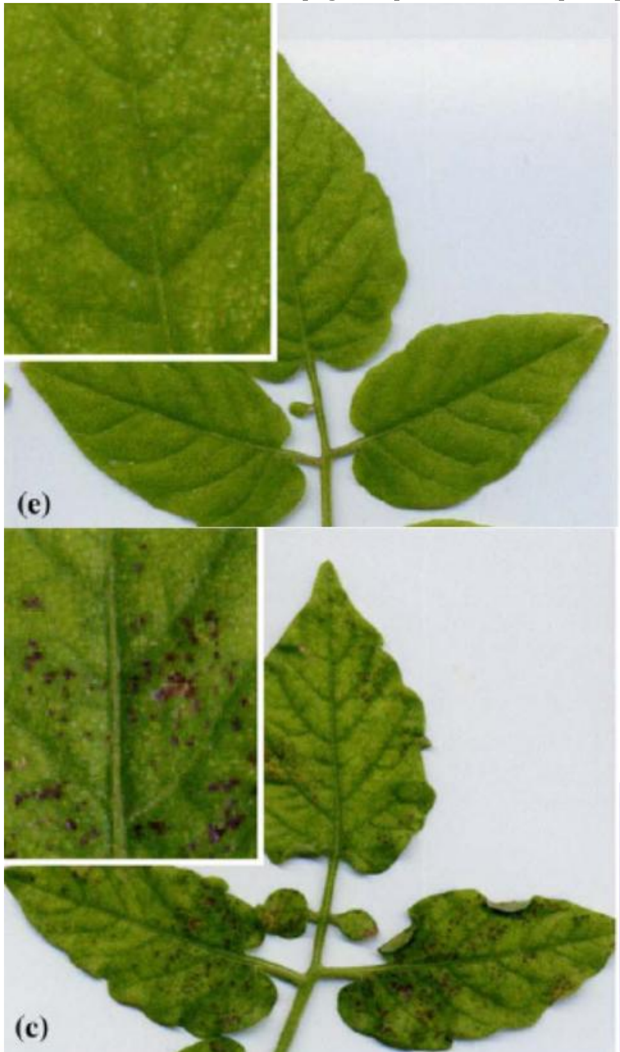
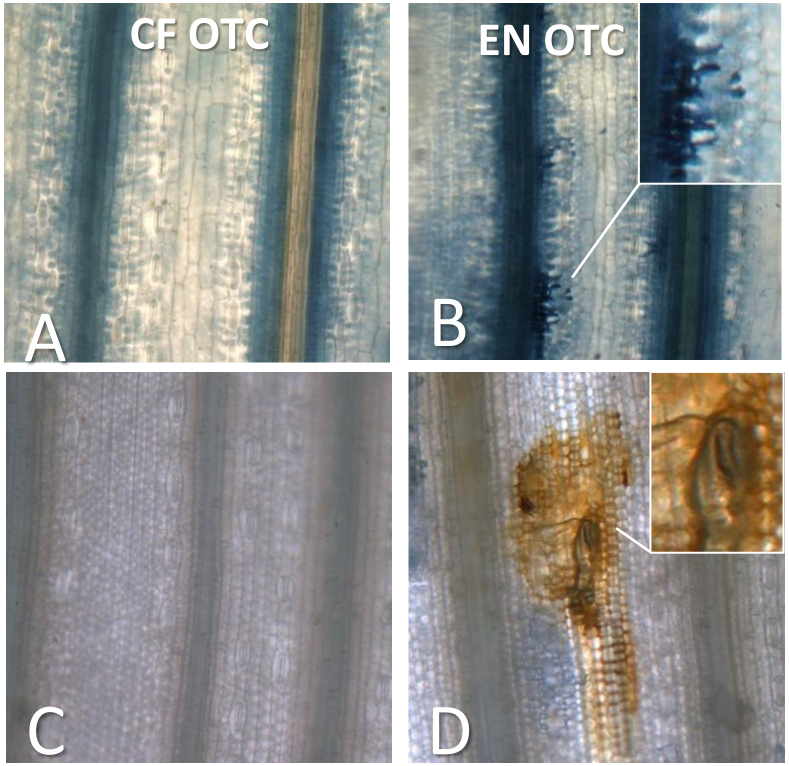
Leaf visible injuries

Tomato (***Lycopersicon pinpinellifolium***)





Durum wheat *cv. Colombo*

A, B – Evans' blue colouration for the detection of dead cells

C, D - DAB stain to reveal H_2O_2 deposits (brown patches)

The net result

At ***plant*** level this could result in

1. appearence of **visible sympoms**:
   - leaf injuries
   - increased crown trasparency, alterated ramification

2. **physiological** and **phenological imbalances**, eg:
   - alteration of CO_2 assimilation
   - reduction of the root traslocation of photosinthate
   - flowering alteration, anticipated leaf senescence

3. a generalised **decrease of net-productivity**:
   - decreased growth,
   - lower yield (grain or fruits),
   - alteration of the quality of the products

The net result

At ***community*** and ***ecosystem*** level this could result in

4. Alteration of **community structure**, e. g.:
   - decrease of abbundance of sensitive species
   - reduction of biodiversity

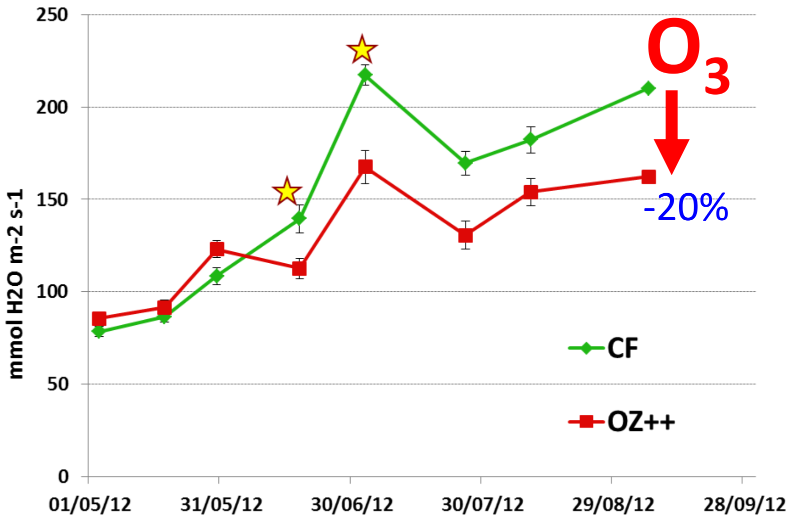
5. Alteration of **functionality**
   - imbalance of C cycle (increased respiration…)
   - Imbalance of N and nutrients cycles (e.g. effect on soil community)

6. Decrease of **resistance** and **resilience** to other stresses

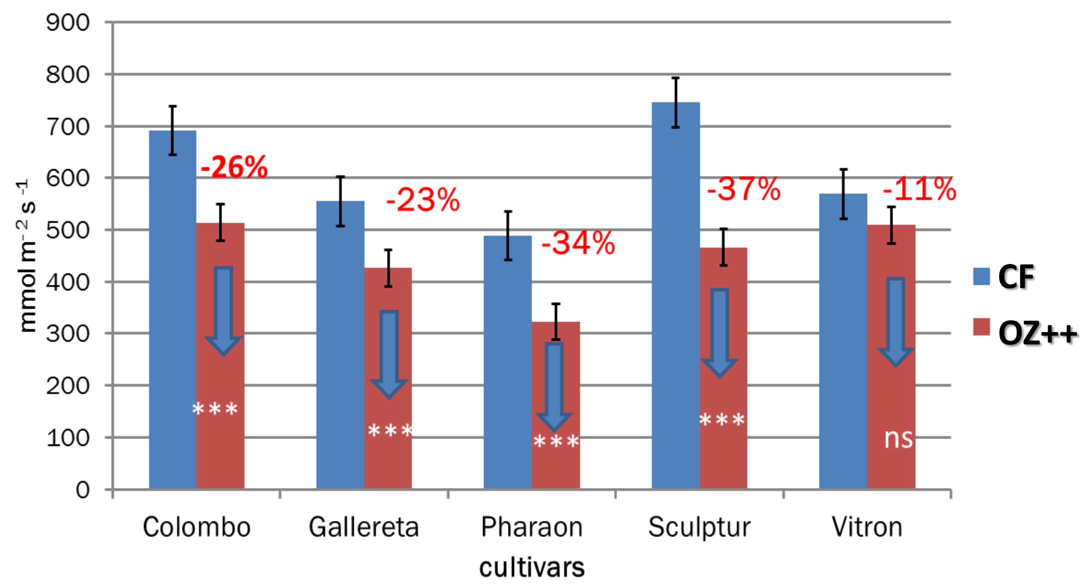
Negative effects at physiological level
Reduction of STOMATAL CONDUCTANCE

Stomatal conductance

Quercus robur



Triticum durum



Negative effects at physiological level
Reduction of PHOTOSYNTHESYS

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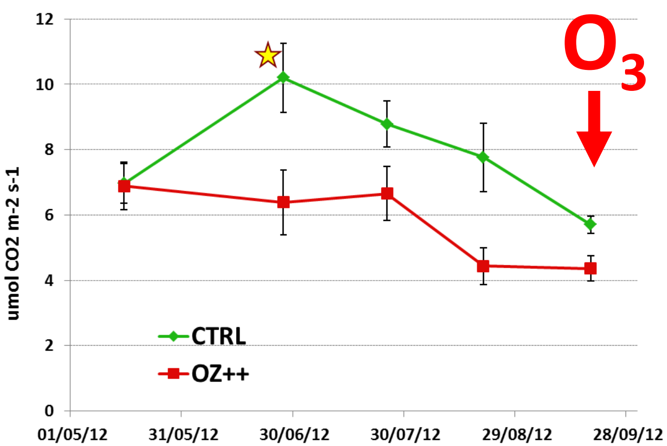
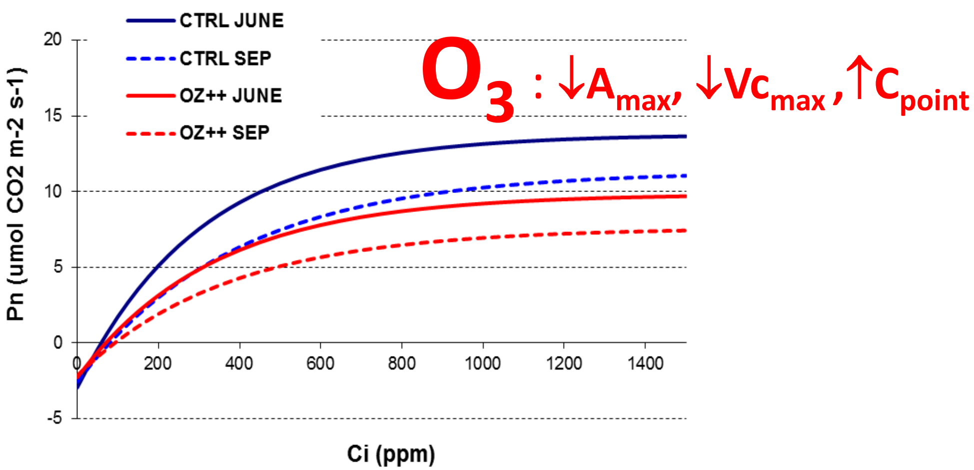
Quercus robur

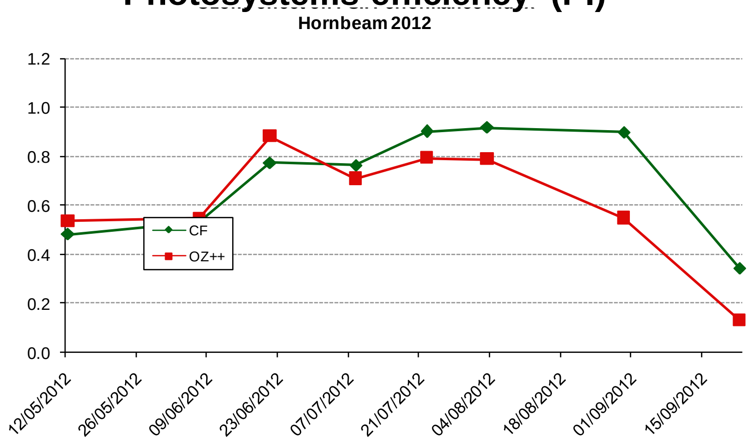
Net Photosynthesis



Carbon assimilation efficiency



Photosystems efficiency (PI)



Vcmax		-30%
Amax		-31%
Comp. Point		+17%
Dark respiration		-20%

Negative effects at productivity level
Reduction of PLANT BIOMASS

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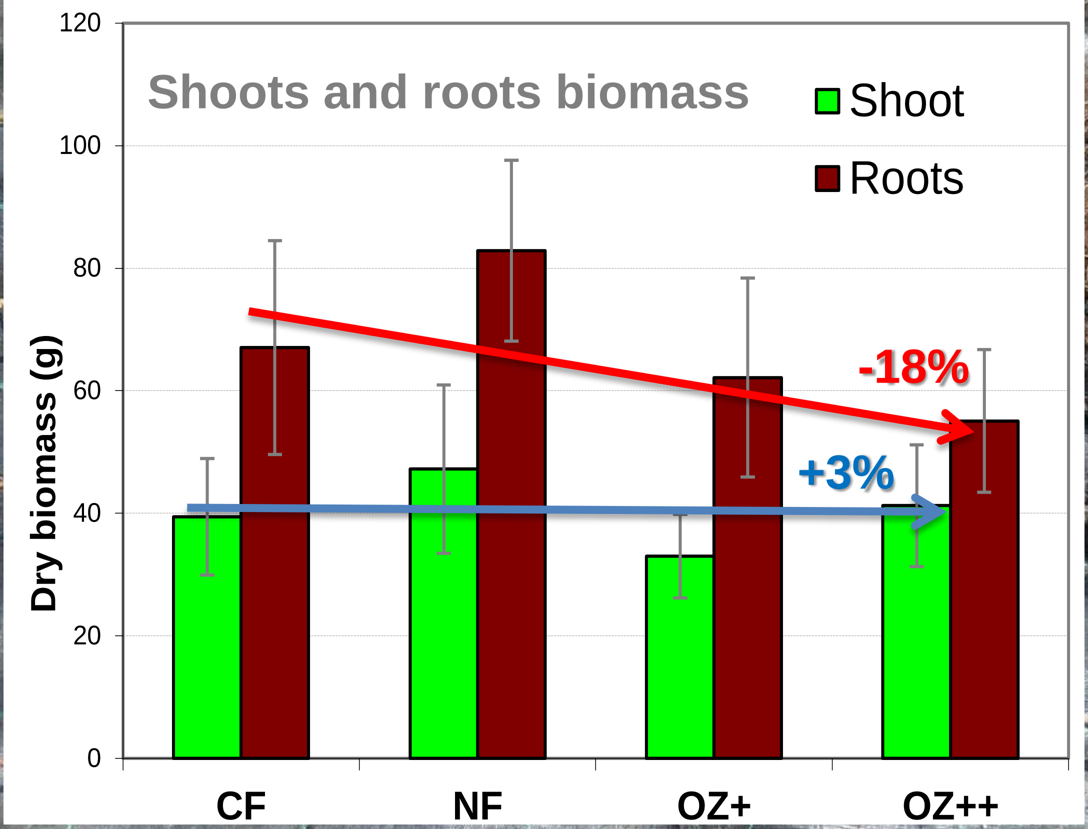
Quercus robur 2013



After two years of ozone treatments

Negative effects at productivity level
Reduction of YIELD

Tomato

	Ozone Treat.	AOT40 ppb.h	$AF_{ST}O_3$ $mmolm^{-2}s^{-1}$	Total yield: Fruits fresh weight (g)	Total yield: Fruits number	Marketable yield: Fruits fresh weight (g)	Marketable yield: Fruits mean fresh weight (g)	Marketable yield: Fruits number
Oxheart								
	CF	924	20.57	10333.0	90	8968.6	119.6	75
	NF	8162	36.63	6621.6	56	6199.6	119.2	52
Difference				**-35.90%***	**-37.77***	**-30.87%****	**-0.33%**	**-30.66%**

Gerosa et al., 2008. Ozone effects on fruit productivity and photosynthetic response of two tomato cultivars in relation to stomatal fluxes. ***Italian Journal of Agronomy***.

Bean

Total effect **Effects on beans filling**

Table 4
Crop yield popen-top chambers (OTC-F and OTC-NF, respectively)

Ozone exposure	Average seed weight/plant (g)	Average seed weight/pod (g)	100-Seed weight (g)
OTC-F	12.39 ± 5.13	1.82 ± 0.66	43.09 ± 2.432
OTC-NF	7.36 ± 3.99 **-40%**	1.63 ± 0.60 **-10%**	43.35 ± 2.073
OTC(*T*)	ns	ns	ns
T	***	***	ns

AOT40: CF-OTC = 600, NF-OTC = 5'000 ppb*h
AFst0: CF-OTC = 9, NF-OTC = 21 mmol O_3m^{-2}

Gerosa et al. 2009. A flux-based assessment of the effects of ozone on foliar injury, photosynthesis, and yield of bean (*Phaseolus vulgaris L. cv.* Borlotto Nano Lingua di Fuoco) in open-top chambers. ***Environmental Pollution.***

Negative effects at productivity level
PHENOLOGICAL imbalances

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Reduction of flowering

Less pods = less flowers

Table 4
Crop yield parameters of bean (*Phaseolus vulgaris L.*) plants grown in charcoal-filtered and non-filtered open-top chambers (OTC-F and OTC-NF, respectively)

Ozone exposure	No. of pods/ plant	No. of seeds/ plant	No. of seeds/ pod	Average pod weight/plant (g)	Average seed weight/plant (g)	Average seed weight/pod (g)	100-[illegible] w[illegible]
OTC-F	6.22 ± 2.03	27.07 ± 9.85	4.38 ± 1.22	3.77 ± 1.53	12.39 ± 5.13	1.82 ± 0.66	[illegible]32
OTC-NF +O_3	4.46 ± 1.90 -30%	18.06 ± 8.07	4.05 ± 1.09	2.31 ± 1.27	7.36 ± 3.99 -40%	1.63 ± 0.60 -10[illegible]	[illegible]2.073
OTC(*T*)	ns	ns	ns	ns	ns	ns	[illegible]
T	ns	***	***	***	***	***	[illegible]s

Each value represents the mean ± SD of 140 plants. The results of the GLMM analysis are presented at the bottom of the table. OTC(*T*): OTC nes[illegible] treatment factor; *T*: treatment (ns: $P > 0.05$; $^*P \leq 0.05$; $^{**}P \leq 0.01$; $^{***}P \leq 0.001$).

Togliere?

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The main determinant of plant response is genetics

There is a species variability in plants' response to tropospheric ozone

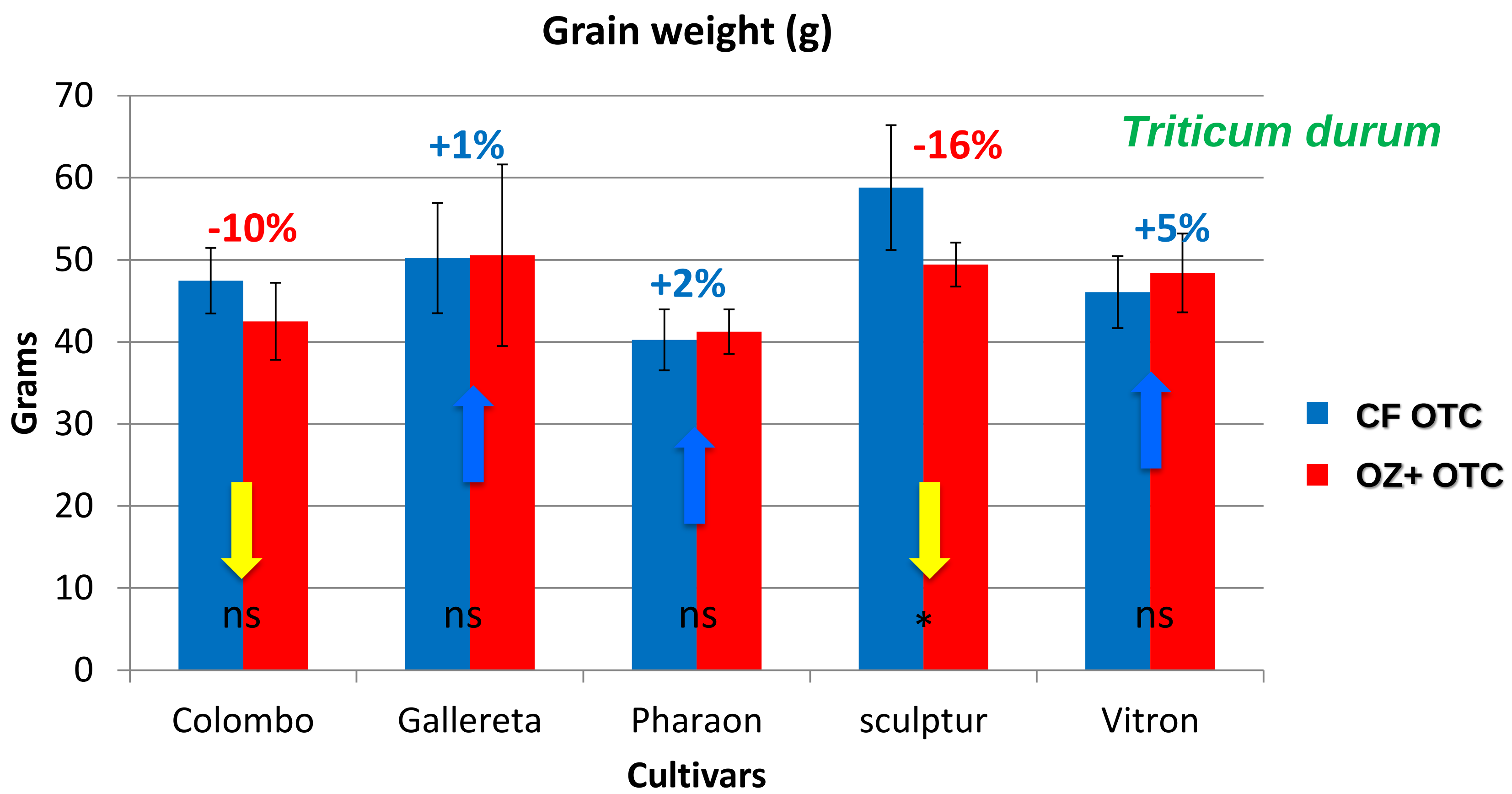
Sensitive species
Bean
Soybean
Alfalfa
Tomato
Lettuce
Winter wheat
Poplar
Ash

Intermediate sp.
Durum wheat
Scots pine
beech
Oak

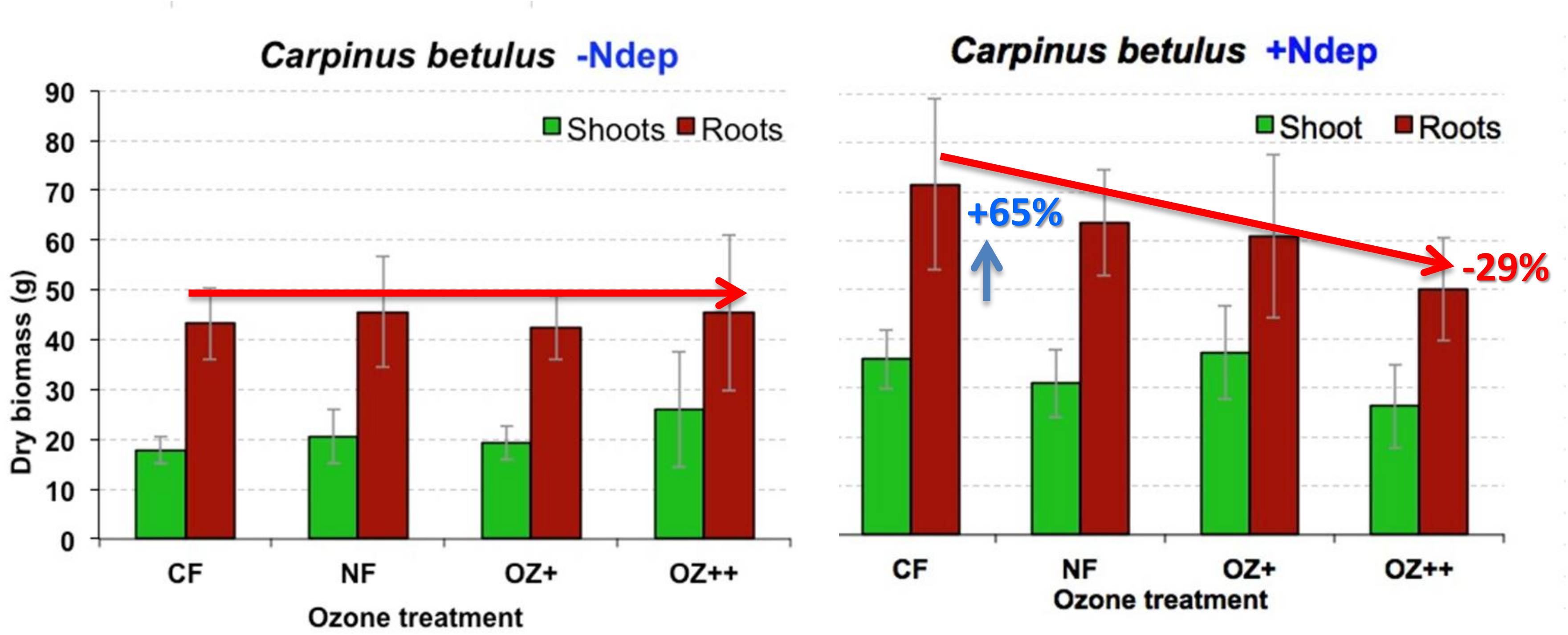
Tolerant species
Holmoak
Arbutus unedo
Hornbeam

The main determinant of plant response is genetics

But there is an intra-specific variability too …



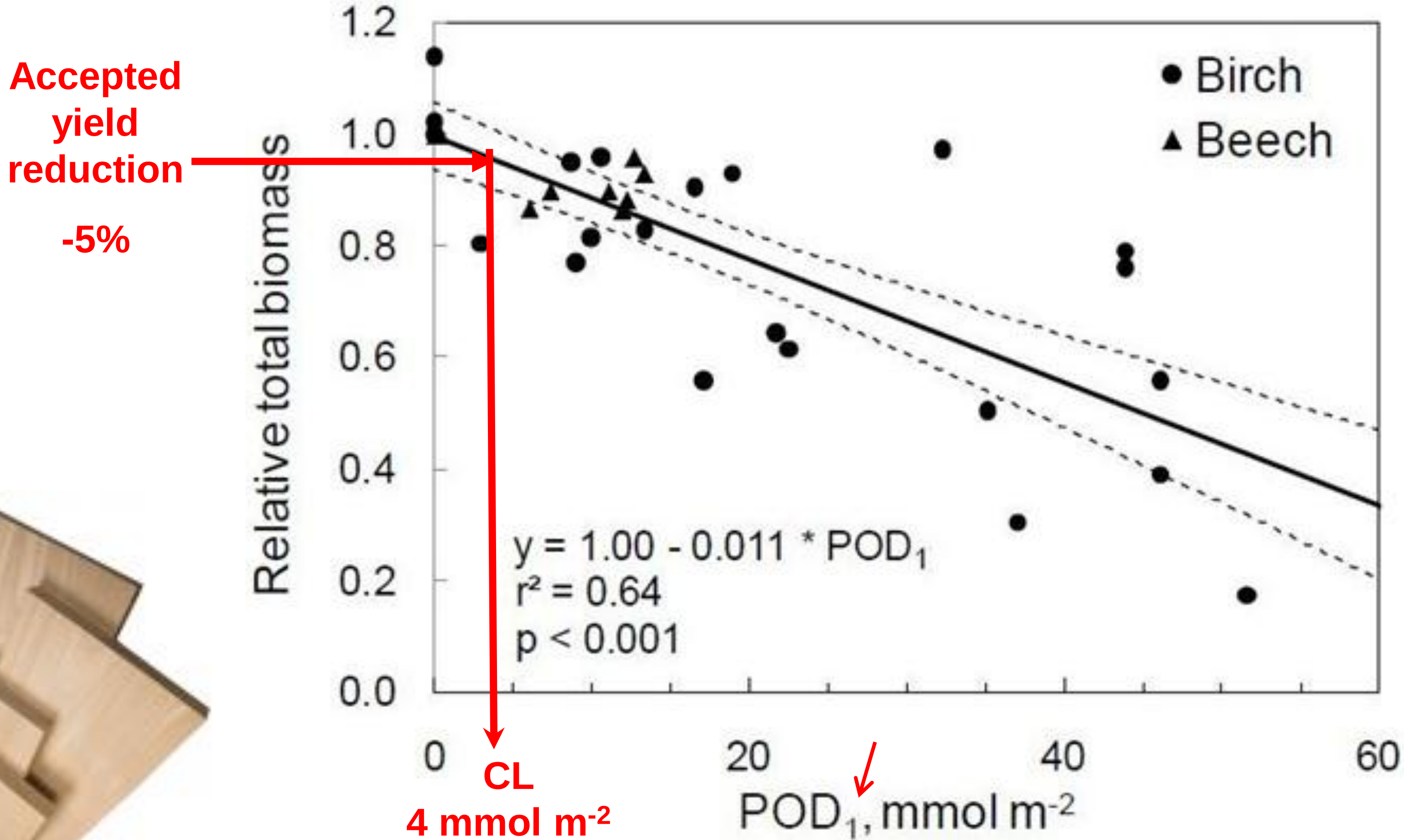
The interaction with other pollutants may alter plant response to a given pollutant. Importance of a multi-pollutant approach



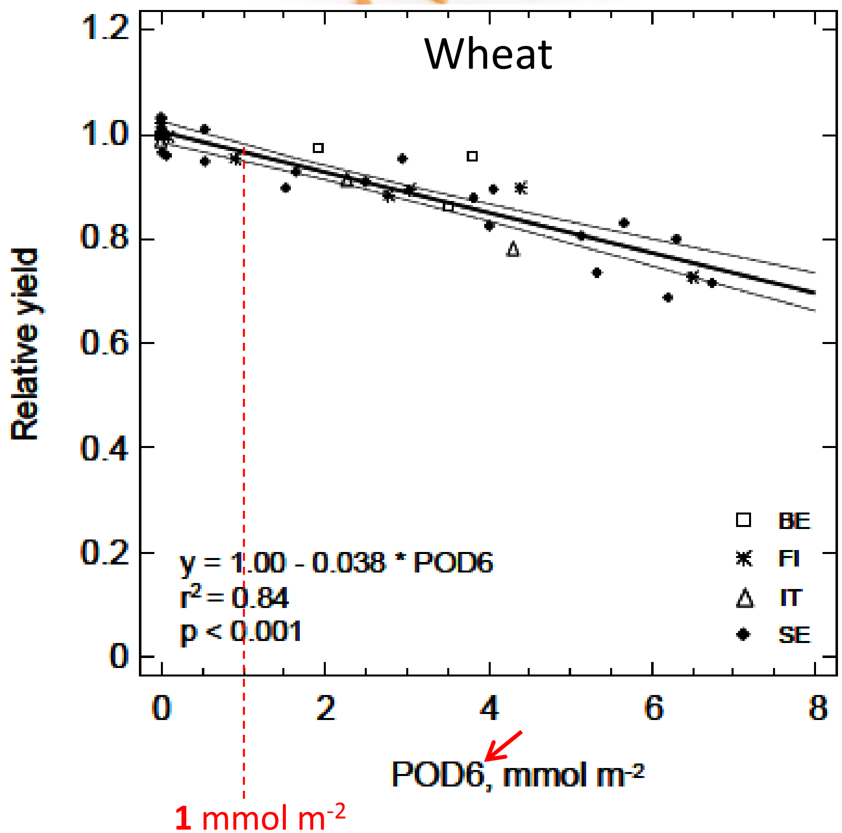
N-deposition increases Hornbeam sensitivity to ozone

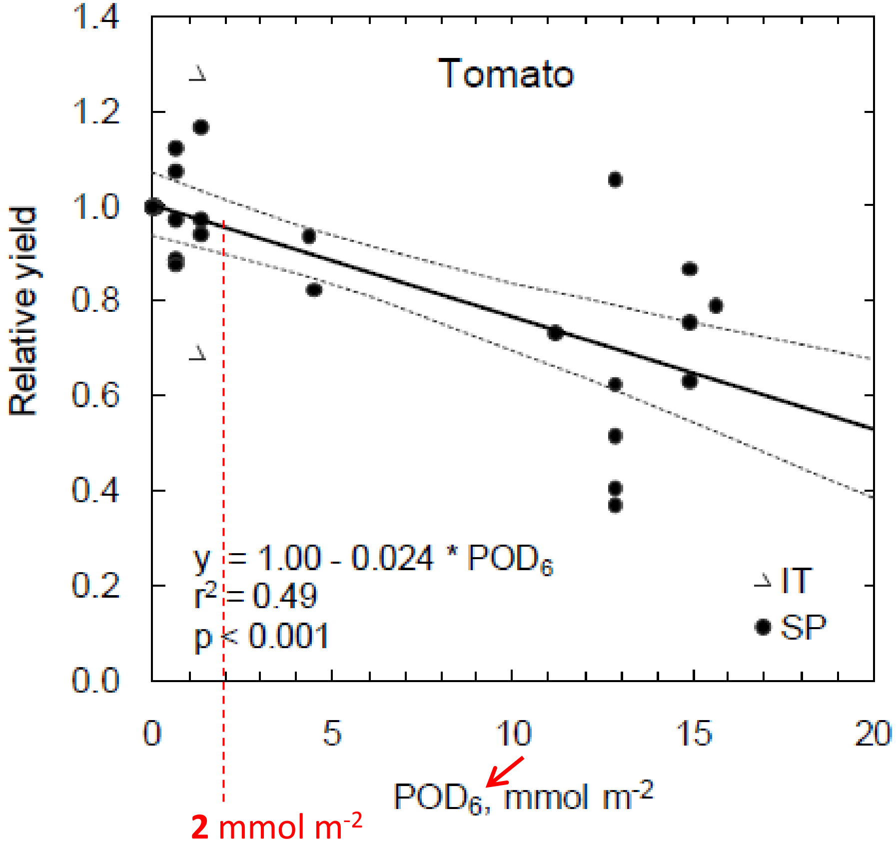
3.
Dose-response relationships and risk assessment

The dose metric and the risk assessment in the UN/ECE framework



Flux based dose-effect relationships for crop yield





Critical levels suggested for ozone risk assessment

UN/ECE Critical levels for STOMATAL DOSE

(Mapping Manual, 1994 rev. 2010, update 2011)

(a) Flux-based critical levels				
Receptor	**Effect (per cent reduction)**	**Parameter**	**Critical level (mmol m^{-2} PLA)**	**Scientific basis in Section**
Wheat	Grain yield (5%)	POD_6	1	3.5.2.1
Wheat	1000 grain weight (5%)	POD_6	2	3.5.2.1
Wheat	Protein yield (5%)	POD_6	2	3.5.2.1
Potato	Tuber yield (5%)	POD_6	5	3.5.2.1
Tomato	Fruit yield (5%)	POD_6	2	3.5.2.1
Norway spruce	Biomass (2%)	POD_1	8	3.6.2.1
Birch and beech	Biomass (4%)	POD_1	4	3.6.2.1
Productive grasslands (clover)	Biomass (10%)	POD_1	2	3.7.2.1
Conservation grasslands (clover)	Biomass (10%)	POD_1	2	3.7.2.1
Conservation grasslands (*Viola* spp), provisional	Biomass (15%)	POD_1	6	3.7.2.1

4.

Conclusion

One **future** challenge
and a provocation

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A challange

- Assess ozone effects on **adult plants** and mature ecosystems

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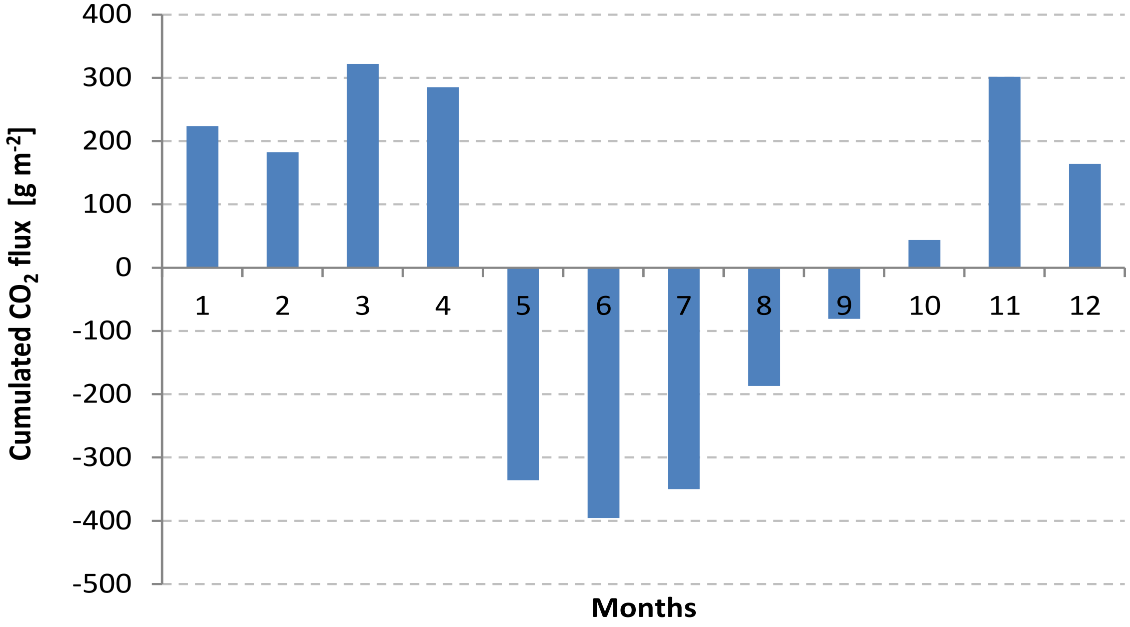
The lack of closure of the CO_2 budget may suggest that the ecosystem is under stress…



Carbon balance on 12 months = **+ 173 g/m2**

Our mature forest ecosystem resulted a carbon emitter instead of a carbon sink…

Conclusions

- Assess ozone effects on **adult plants** and mature ecosystems
- Importance of **long terms** surveys and **pluriannual-experiments**

Conclusions

- Assess ozone effects on **adult plants** and mature ecosystems
- Importance of **long terms** surveys and **pluriannual-experiments**
- Does EC really **want** to protect ecosystems from air pollution?
- Does anybody **really cares of** agriculture in EC?

*Practically there are **no funds** for experimental work….*

Thank you for your attention

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