UNECE Convention on Long-range Transboundary Air Pollution

ICP Vegetation

International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops

and

International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests

ICP Forests

Damage to Vegetation by Ozone Pollution

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

DEFRA
Department for Environment, Food & Rural Affairs

Federal Research Centre for Forestry and Forest Products
BFH

Ozone pollution

During the last two decades, damage to vegetation by ozone has become an issue of increasing concern in Europe and North America. Ground-level (tropospheric) ozone is formed when emissions of nitrogen oxides, mostly from transport and combustion processes, react with volatile organic compounds (VOCs) from road traffic and use of products containing organic solvents in the presence of sunlight. Highest ozone concentrations mostly occur in the early-mid afternoon during spring and summer (Fig. 1). Ozone episodes tend to last for a few days. Concentrations are highest in areas that are downwind of major cities, industrial areas and areas with high road traffic density. As the radiation of ultraviolet light is higher in the south, ozone concentrations are mostly higher there (Fig. 2). Ozone "plumes" can travel many tens and sometimes hundreds of kilometres from the source area.

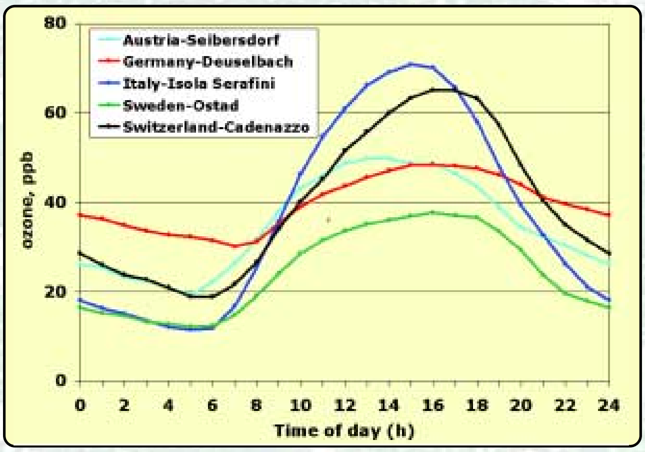


Figure 1: *Mean ozone profiles for the summer of 1999 at selected rural ICP Vegetation sites. The site at Germany-Deuselbach is 660m above sea level and illustrates a flatter ozone profile typically found at higher altitudes.*

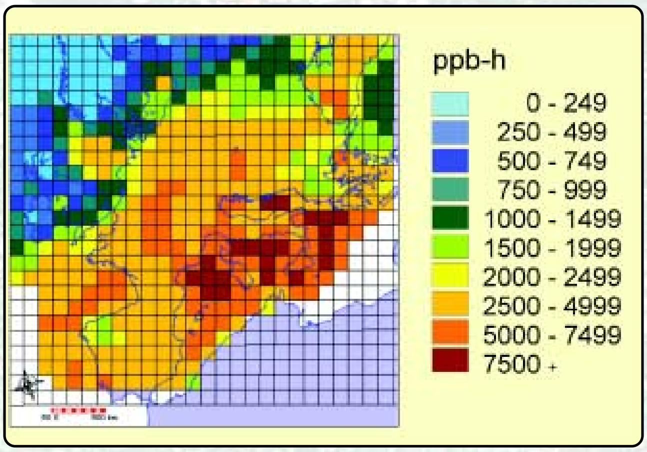


Figure 2: *Distribution of AOT40 values during June 1994, a month with high ozone concentrations (EMEP model; LE). AOT40 is a measure of ozone dose and is calculated as the accumulated hourly mean ozone over a threshold of 40 ppb during daylight hours.*

Ozone damage to vegetation

There is evidence that the ambient ozone concentrations found in Europe and North America can cause a range of effects on sensitive vegetation, including visible leaf injury, growth and yield reductions, and altered sensitivity to stress factors like frost and pests. Effects on health and materials are also a cause for international concern.

Ozone enters the leaves through the stomata, openings in the leaf surfaces through which gas exchange takes place. Within the leaf, ozone undergoes transformation, producing a variety of cell damaging compounds called free radicals. These destroy membranes, pigments and other biochemical compounds (Fig. 3). Ozone pollution leaves no elemental residue which can be detected by analytical techniques. Therefore, the visible injury on the leaves is the only easily detectable direct evidence in the field. Usually, the injury is present on the upper leaf surface as pale or bronze-coloured pinhead-sized spots, which, in severe cases, join to form large damaged areas over the leaf surface.

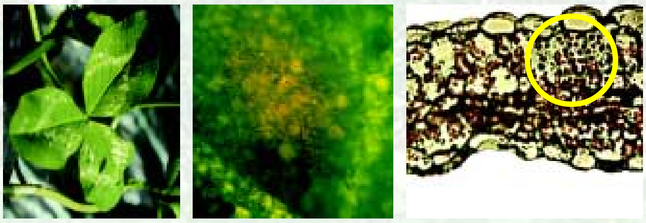


Figure 3: *Ozone damage of pinhead-sized pale-coloured spots on clover leaves. Under the microscope, these spots reveal areas of collapsed and damaged cells (WW).*

International efforts to reduce ozone pollution

Monitoring and quantifying the current effects of ozone on vegetation and predicting future effects, form an integral part of the international cooperative efforts under the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP).

Under the CLRTAP two international cooperative programmes (ICPs) are contributing to the monitoring and research:

The **ICP Vegetation** derives critical levels and fluxes of ozone by monitoring the effects of ambient ozone on crops and semi-natural vegetation in the ECE region, and by analysing data from the scientific literature.

The **ICP Forests** assesses ozone levels and visible injury on forest trees as part of its comprehensive survey of forest ecosystem condition in the ECE region.

Ozone effects on agricultural crops

Crops vary in their sensitivity to ozone. Wheat and soybean are amongst the most sensitive species, whereas barley and oat are insensitive to the concentrations found in ambient air in Europe. Current estimates suggest that the potential for wheat yield losses in Europe is highest in France, Germany, Belgium and the Netherlands. In these countries, ozone episodes occur at a time of year when the crop is actively growing and there is sufficient moisture in the soil to open plant stomata, which provide the route for ozone uptake. Lower yield losses are predicted in some southern European countries where wheat is often grown earlier in the year, before peak ozone concentrations are highest.

Potential yield losses occur in crops that respond to ozone episodes by developing visible injury on leaves, although some yield loss can occur even in the absence of visible symptoms.

Crop sensitivity to ozone

(derived from published results on effects on yield)

sensitive	moderately sensitive	moderately tolerant	tolerant
Wheat	Potato	Rice	Oat
Soybean	Tobacco	Maize	Barley
Bean	Sugar beet	Grape	
Cotton	Oilseed rape	Pasture	
	Lucerne		

Ozone injury on wheat (GM)

Ozone injury on tobacco (GL)

Ozone injury on clover (GM)

Ozone injury on bean (GM)

Ozone injury on maize (DV)

Ozone injury on grapevine (DV)

Ozone effects on horticultural crops

Many horticultural crops are sensitive to ozone. Damage can affect yield quality in leafy vegetables (e.g. lettuce, chicory, spinach, leek), reducing their value and, if injury is severe, making the crop unmarketable.

In hotter climates, ozone injury is more pronounced in irrigated crops, where an adequate water supply increases the uptake of ozone by increasing the aperture of the stomatal pores on leaf surfaces. Green bean, lettuce, and salad onion are amongst the most ozone-sensitive horticultural crops. Other, not depicted ozone sensitive species are chicory, leek, lettuce, watermelon, parsley, peach, pepper, red beetroot, spinach, tomato.

Musk melon (DV)

Courgette (JB)

lettuce (JB)

Radish (JB)

Salad onion (JB)

Ozone effects on grassland, field and forest margin vegetation

So far, about 100 species of "natural" vegetation have been reported as being sensitive to ozone at concentrations found in Europe. Effects, such as a reduction in seed production and viability, and a decreased tolerance to stresses such as drought and frost can cause an imbalance in the growth of plant communities. A shift in the species composition of plant communities might possibly occur, with a resultant loss of biodiversity. Such effects of ozone would be of particular relevance to southern Europe, where there are large numbers of endemic plant species. Not depicted examples of ozone-sensitive species are *Briza media, Chenopodium album, Chrysanthemem leucanthemum, Dianthus deltoides, Festuca rubra, Leontodon hispidus, Poa pratensis, Taraxicum officianalis, Tragopogon orientalis, Trifolium repens, Trifolium pratense, Sambucus ebulus, Ailanthus altissima, Rubus* sp.

Centaurea jacea (PB)

Eupatorium cannabinum (JF)

Ricinus communis (MS)

Cirsium arvense (EB, JB)

Ozone effects on forest trees and shrubs

There is evidence that ozone occurs at concentrations high enough to cause visible foliar injury to sensitive forest trees. Approximately 60 tree species have been reported as being sensitive to ozone at concentrations found in Europe. In addition to the described symptoms, sensitive tree species show a clear early senescence of leaves. Ozone effects on the tree health parameters of defoliation, discolouration and transparency have been reported for *Prunus serotina*, *Pinus halepensis*, *Betula pendula*, *Fraxinus excelsior*, *Fagus sylvatica*, *Robinia pseudoacacia* and *Ailanthus altissima*.

Fagus sylvatica (MSch)

Acer pseudoplatanus (MSch)

Salix alba (MSch)

Fraxinus excelsior (MS)

Alnus incana (MSch)

Betula pendula (MG)

Other ozone-sensitive species

Trees:

Acer campestre
Alnus glutinosa
Corylus avellana
Fraxinus ornus
Ulmus glabra
Ulmus minor

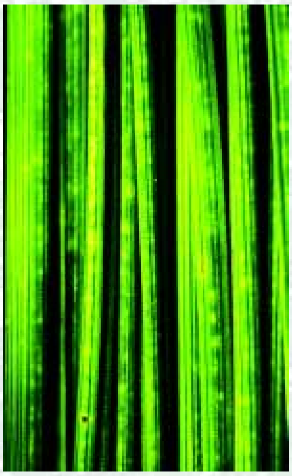
Shrubs:

Pistacia lentiscus
Viburnum lantana

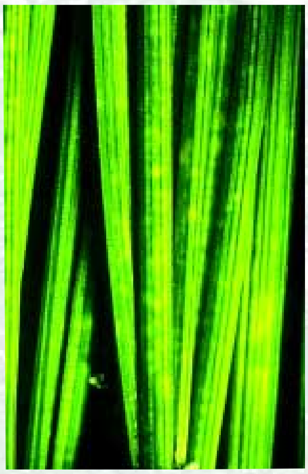
Robinia pseudoaccacia (MSch)

Tilia cordata (MSch)

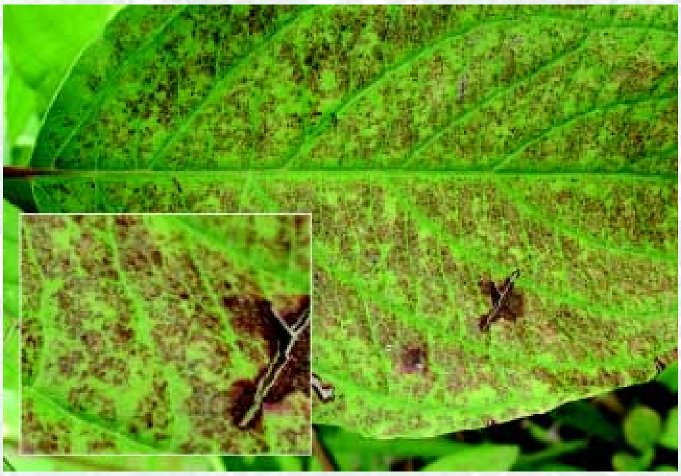
Populus nigra (MS)



Pinus halepensis (MS)



Pinus strobus (MS)



Cornus alba (MSch)

More pictures on forest trees and shrubs can be found at: **http://www.gva.es/ceam/ICP-forests**

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Coverphoto: Beech forest (RS); Exposure of wheat to ozone using open top chambers (JFu)
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