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Why do we still need to derive ozone critical levels for vegetation protection?

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Abstract

The tropospheric ozone levels (O3) are considered high enough over large regions of the globe to damage vegetation. To protect vegetation, current European standards use the O_3 exposure index AOT40, i.e. the cumulative exposure to O_3 hourly concentrations exceeding 40ppb over the daylight hours of the growing season. The biologically-sound stomatal flux-based standard (PODY) is under discussion as new European legislative standard although critical levels for vegetation protection still need to be validated. Epidemiological observation of O_3–induced injury and environmental variables, including O_3, can be used to derive consistent stomatal flux-based critical levels for different type of vegetation protection against O_3 under natural field conditions. The question about deriving significant critical level is still a challenge for the scientific community.

Keywords: Critical levels; Ozone; POD; Standard; Stomatal flux-based; Vegetation; Epidemiology

Introduction

Ground-level ozone (O_3) is a secondary photochemical air pollutant, strongly oxidant, and is still a major air quality issue over large regions of the globe [1-3] where current surface O_3 levels are considered high enough to damage vegetation by reducing growth and productivity [3-6] and by altering yield and quality [7-9].

To protect vegetation, current European standards use the O_3 exposure index AOT40, i.e. the cumulative exposure to O_3 hourly concentrations exceeding 40 ppb over the daylight hours of the growing season [10]. Critical levels are defined as the "*concentration, cumulative exposure or cumulative stomatal flux of atmospheric pollutants above which direct adverse effects on sensitive vegetation may occur according to present knowledge*" [10]. Ozone-exposure critical levels were proposed for the protection of vegetation under the framework of the Convention on Long-Range Transboundary Air Pollution (CLRTAP) of the United Nations Economic Commission for Europe (UNECE) and are the base of the Ambient Air Quality Directive 2008/50/EC of the European Union. In Europe, a target value of 9,000 ppb.h, averaged over 5-years, is recommended by the 2008/50/CE Directive for the protection of vegetation from 2010 [10]. Within the 2008/50/CE Directive, the critical level for agricultural crops (i.e. 3,000 ppb.h) is adopted as the long-term objective value for the protection of vegetation by 2020. For the protection of forests, a critical level of 5,000ppb.h is recommended by UNECE (2010). Recent studies showed that O_3 has a negative impact on vegetation even in countries where the AOT40 values for forests are usually low e.g. Lithuania [11] or Romania [12]. Reviews of O_3 effects on vegetation have been published for crops [13].

The O_3 effects on vegetation depend not only on the atmospheric concentrations, explicit in AOT40, but also result from the O_3 uptake through the stomata into the plants [14]. For taking into account this process a new metric has been proposed to protect vegetation, i.e. the Phytotoxic Ozone Dose, defined as the accumulated O_3 flux entering into the leaves via the stomata, over a detoxification threshold Y (PODY), integrating the effects of multiple climatic factors, vegetation characteristics and local and phenological inputs on O_3 uptake or flux [15]. For damage occurrence, the vegetation can be

a) genetically predisposed to be O_3 sensitive,

b) under optimal environmental conditions for O_3 uptake (temperature, relative humidity, solar radiation, soil water content) and

c) exposed to ambient O_3 levels exceeding the threshold required for injury occurrence [16-18].

The biologically-sound stomatal flux-based standard (PODY) is under discussion as new European legislative standard although critical levels for vegetation protection still need to be validated [19,20].

Many points are not yet clarified about derivation of critical levels for vegetation protection in terms of PODY. The uncertainties are due to some still unclear concern related to PODY concept and in particular: duration of the growing season [21], selection of the appropriated Y threshold [22], definition of the most appropriate target to express the damage of vegetation due to ozone (i.e. yield loss, growth, visible injuries occurrence, defoliation, others...) [5], modeling at different scales. These uncertainties make the development of the Critical Levels an exercise not yet solved by the ozone community.

The concepts of critical loads and critical levels were developed within the CLRTAP under the UNECE for assessing the risk of air pollution impacts to ecosystems and defining emission reductions. This tool is commonly used to anticipate negative effects of air pollution and, therefore, to protect ecosystems before the changes become irreversible. The critical levels approach is used for pollution control and was applied for emission reductions strategies under the 1999 Protocol to Abate Acidification, Eutrophication and Ground-level O_3 [10]. Ozone critical levels have also been proposed for the protection of natural vegetation at European level for two vegetation types, forests and semi-natural vegetation [10]. The new flux based O_3 critical levels allow species-specific physiological conditions and O_3 uptake mechanisms to be included. Since O_3 background concentrations are increasing [2,11,20], it is important to finely define appropriate and realistic critical levels, representative of actual field conditions, to

a) protect vegetation;

b) improve understanding and monitoring of the O_3 effects on ecosystems;

c) scientifically assess the effectiveness of air pollution control strategies and

d) undertake measures for abatement of O_3 precursors emissions [19,23-25]. The suggestion of new critical levels for the protection of vegetation against O_3 will serve as a decision-support tool for European authorities.

To date, most of derivation of critical levels for tree and crop species have been performed on seedlings under controlled conditions not representative of actual and future field conditions [14, 26-28] and for growth reduction, i.e. an aspecific O_3 parameter caused by multiple factors e.g. species specificity, local management, meteorology, site and soil characteristics, water limitation, so that the results may not help in developing realistic critical levels [23], in particular when the models were adapted to Mediterranean limiting conditions [29].

Conclusion

Epidemiological observation of O_3–induced injury and environmental variables, including O_3, can be used to derive consistent stomatal flux-based critical levels for different type of vegetation protection against O_3 under natural field conditions [5,23]. Following the revision of the National Emission Ceiling directive, the interest in epidemiologically based O_3 critical levels for forest protection is thus seriously rising in Europe [23,25,30,31].

There is an urgent need for further development, field-based validation of the O_3 flux-based method and establishment of robust flux-effect relationships to provide species-specific stomatal flux-based critical levels for vegetation protection against O_3 pollution in a changing climate. Future research challenges include additional epidemiological studies and model development to expand the sets of site-specific biological, climatic, soil and O_3 data to refine species-specific flux-based critical levels. Considering all the listed issues that are still open and need further investigation into the field conditions, at the moment the question about deriving significant critical level is still a challenge for the scientific community.

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