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A synthesis of AOT40-based response functions and critical levels of ozone for agricultural and horticultural crops

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Abstract

Crop-response data from over 700 published papers and conference proceedings have been analysed with the aim of establishing ozone dose-response functions for a wide range of European agricultural and horticultural crops. Data that met rigorous selection criteria (e.g. field-based, ozone concentrations within European range, full season exposure period) were used to derive AOT40-yield response functions for 19 crops by first converting the published ozone concentration data into AOT40 (AOT40 is the hourly mean ozone concentration accumulated over a threshold ozone concentration of 40 ppb during daylight hours, units ppm h). For any individual crop, there were no significant differences in the linear response functions derived for experiments conducted in the USA or Europe, or for individual cultivars. Three statistically independent groups were identified: ozone sensitive crops (wheat, water melon, pulses, cotton, turnip, tomato, onion, soybean and lettuce); moderately sensitive crops (sugar beet, potato, oilseed rape, tobacco, rice, maize, grape and broccoli) and ozone resistant (barley and fruit represented by plum and strawberry). Critical levels of a 3 month AOT40 of 3 ppm h and a 3.5 month AOT40 of 6 ppm h were derived from the functions for wheat and tomato, respectively.

Keywords: Ozone; Crops; Response functions; Critical levels; Yield; AOT40

1. Introduction

In recent decades, the current ozone pollution climate in Europe has been shown to have a detrimental effect on agricultural and horticultural crops. Typical effects include chlorotic and necrotic lesions on the leaf surface of sensitive species (Benton et al., 2000), physiological changes such as reduced photosynthesis (Sanders et al., 1992a), and reductions in both the quantity and quality of crop yield (Fuhrer et al., 1997; Piikki et al., 2003). Under the ICP Vegetation[1] of the UNECE

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[1]International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops.

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LRTAP[2] Convention, strong evidence has accumulated during the last 15 years that these effects on vegetation occur across most of Europe in most years, although the extent of damage varies between years and regions (Mills et al., 2000). During the same time period, contributors to the ICP Vegetation have been developing methods for mapping the impacts of ozone on vegetation with the aim of informing policy makers of the current and predicted future scale of the ozone problem. Two main approaches have been used to derive critical levels for ozone, above which adverse effects occur: concentration-based and stomatal flux-based methods. This paper reviews recent progress in deriving concentration-based critical levels for agricultural and horticultural crops, considers their potential application to ecological risk assessment and the uncertainties involved. Flux modelling and flux-effect relationships are described by Pleijel et al. (in press), and their use to derive flux-based critical levels is described in the most recent revision of the LRTAP Convention Mapping Manual (LRTAP Convention, 2004).

Four main sources of information exist in the literature on the responses of crops to ozone: the US National Crop Loss Assessment Network (NCLAN) studies conducted in the 1980s (see review by Heagle, 1989); the European Open Top Chamber Programme (EOTCP) conducted in the late 1980s and early 1990s (see review by Jäger et al., 1992) and more recent open-top chamber (OTC) experiments conducted mainly in Europe such as those on potato as part of the CHIP programme (Changing Climate and Potential Impact on Potato Yield and Quality, see De Temmerman et al., 2002). Several ozone parameters are quoted in the literature describing these experiments: seasonal 12, 7 h and daylight hour mean, cumulative exposure over a threshold such as 40 or 60 ppb, and cumulative exposure weighted by the highest values or phenological factors. Response relationships are usually indicated by fitting linear, quadratic, or Weibull functions. Krupa and colleagues have analysed the combined data sets from NCLAN and EOTCP in detail (Krupa et al., 1995, 1998) and have suggested that crops have the greatest response to cumulative exposures in the range 50–87 ppb in the USA and 35–60 ppb in Europe. Since the mid-1990s, the cumulative exposure parameter, AOT40 (defined later) has been favoured in Europe as the concentration-based descriptor of ozone effects on crops. The background to this choice is described in detail in Fuhrer et al. (1997) who showed a close linear relationship between AOT40 accumulated over 3 months during daylight hours and wheat yield for OTC experiments conducted with 10 cultivars in six countries over a period of 10 years ($r^2 = 0.88$).

The negotiations concerning ozone for the LRTAP Convention Gothenburg Protocol (1999) to abate acidification, eutrophication and ground level ozone were based on exceedance of critical levels of ozone for effects on crops, (semi-) natural vegetation and trees. For crops, a critical level of an AOT40 (defined in Section 2) of 3 ppm h accumulated over 3 months was set at the Kuopio Workshop in 1996 (Kärenlampi and Skärby, 1996) and was considered to be the lowest AOT40 at which significant yield loss due to ozone could be detected, according to current knowledge (LRTAP Convention, 1996). However, several important limitations and uncertainties have been recognised for using this concentration-based approach since AOT40-based critical levels only consider the ozone concentration at the top of the canopy. The Gerzensee Workshop in 1999 (Fuhrer and Achermann, 1999) first recognised the importance of developing an alternative critical level approach based on the flux of ozone through the stomatal pores to the sites of damage (Emberson et al., 2000). This approach has been refined in recent years, and flux-based critical levels for wheat, potato and provisionally for beech and birch were included in the 2004 revision of the Mapping Manual (LRTAP Convention, 2004). A third method, based on maximum permissible ozone concentration (MPOC) was also considered at the Gothenburg Workshop in 2002 and was incorporated into the Mapping Manual with the possibility of use to assess the risk to trees at the national level. The relative merits of all three methods for risk assessment were discussed in articles published in this journal over the last 2 years (Ashmore et al., 2004; Grennfelt, 2004; Krause et al., 2005).

Here, we describe the derivation of the recently revised AOT40-based critical levels of ozone for agricultural and horticultural crops represented by wheat and tomato, respectively, and their application to ecological risk assessment. AOT40-based yield response functions are also derived for a further 17 crops from a comprehensive review of data provided in over 700 papers published in the

[2]United Nations Economic Commission for Europe Convention on Long-range Transboundary Air Pollution.