Available online at www.sciencedirect.com
ScienceDirect
Environmental Pollution 146 (2007) 617–623
ENVIRONMENTAL POLLUTION
www.elsevier.com/locate/envpol

Simulation of stomatal conductance for Aleppo pine to estimate its ozone uptake

Susana Elvira, Rocío Alonso, Benjamín S. Gimeno*

Ecotoxicology of Air Pollution, CIEMAT, Avda. Complutense 22 (ed. 70), 28040 Madrid, Spain

Received 31 January 2006; received in revised form 20 June 2006; accepted 6 August 2006

Current EMEP stomatal uptake module needs to be re-parameterised for Mediterranean tree species.

Abstract

The data from a previous experiment carried out in open-top chambers to assess the effects of ozone (O_3) exposure on growth and physiology of Aleppo pine (*Pinus halepensis* Mill.) were re-assessed to test the performance of the EMEP O_3 stomatal conductance model used to estimate tree O_3 uptake at a European scale. Aleppo pine seedlings were exposed during three consecutive years to three different O_3 treatments: charcoal filtered air, non-filtered air and non-filtered air supplemented with 40 nl l^{-1}. The results of the model using the default parameterisation already published for Mediterranean conifers showed a poor performance when compared to measured data. Therefore, modifications of g_{max}, f_{min}, and new f_{VPD}, f_{temp} and f_{phen} functions were developed according to the observed data. This re-parameterisation resulted in a significant improvement of the performance of the model when compared to its original version.

Keywords: Ozone critical levels; Forest trees; Ozone flux; Aleppo pine; Stomatal conductance

1. Introduction

Ozone (O_3) adverse effects on terrestrial vegetation have been reported on a wide range of ecosystems. The background levels of this pollutant in the northern hemisphere have increased in the last century and therefore control policies have been developed in different countries to reduce the emissions of its precursors. In Europe, this process is based on the establishment of O_3 critical levels for different plant receptors enabling the analysis of different scenarios at regional and continental scales to define the more suitable control strategies for the reduction of O_3 risk for vegetation.

Ozone critical levels were previously defined by relating the recorded adverse effects on sensitive plants to their exposure to the pollutant. This approach led to the definition of critical levels based on the AOT40 exposure index (accumulated O_3 exposure above a cut-off of 40 nl l^{-1}) (see Fuhrer et al., 1997). Recently, it has been recognised that this index has a number of limitations since it does not consider environmental and plant characteristics influencing O_3 phytotoxicity. The effects of O_3 depend on the amount of pollutant entering through the stomatal pores and reaching the sites of damage within the leaves. Changes in environmental conditions such as light, temperature or humidity influence stomatal aperture and hence also the potential O_3 flux (Wieser et al., 2000). Therefore an alternative approach has been proposed to establish O_3 critical levels for the protection of vegetation based on the stomatal flux of O_3 (Ashmore et al., 2004).

The EMEP (Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air pollutants in Europe) ozone deposition module (DO_3SE, Deposition of Ozone and Stomatal Exchange) has incorporated a stomatal

* Corresponding author. Tel.: +34 91 346 6547; fax: +34 91 346 6121.
E-mail address: benjamin.gimeno@ciemat.es (B.S. Gimeno).

0269-7491/$ - see front matter © 2006 Published by Elsevier Ltd.
doi:10.1016/j.envpol.2006.08.008

conductance (g_s) model to calculate O_3 stomatal fluxes for different vegetation types, taking into account both plant phenology and environmental conditions (Emberson et al., 2000a; Tuovinen et al., 2004).

The EMEP g_s model has been adopted for establishing flux-based critical levels for agricultural crops allowing a quantitative assessment of impacts on wheat and potato (UNECE, 2004). However, too many uncertainties have been recognized for applying this approach to setting critical levels for forest trees (Karlsson et al., 2004;UNECE, 2004). These uncertainties can be found on both estimations of g_s at the leaf level and on the up-scaling from leaf to canopy stomatal conductance. In this study, the model used for estimating g_s at the leaf level was applied to a three-year experimental data set relating O_3 exposure and effects on Aleppo pine exposed in open-top chambers (OTC), aiming to test the performance of the model for Mediterranean conifers and suggest further improvements on the parameterisation for this kind of vegetation.

2. Material and methods

2.1. Experimental data set

A three-year experiment was carried out in OTC located at the Ebro Delta in north-eastern Spain (see Alonso et al., 2001, for further details). Two-year-old Aleppo pine seedlings were planted in 18-dm^3 pots containing 50% peat, 30% sand, 20% vermiculite and a slow-release fertilizer (Osmocote Plus, NPK 15:18:11 plus Mg and microelements; Sierra Chemical Co., CA, USA) to prevent nutrient limitations. Water was supplied using a drip irrigation system following plant requirements and preventing water from being a limiting factor. Seedlings were exposed to the following O_3 treatments: charcoal filtered air (CFA), non-filtered air (NFA) and non-filtered air supplemented with 40 nl l^{-1} O_3 from 08:00 to 18:00 h, 5 days a week (NFA + 40). Three OTCs per O_3 treatment were used and 24 seedlings per chamber were continuously exposed to the different O_3 treatments over 3 years (September 1993 to August 1996).

Ozone, nitrogen oxides (NO_x) and sulphur dioxide (SO_2) were continuously monitored using an automated time-share system described in Gimeno et al. (1999). Measurements of stomatal conductance to water vapour (g_s) were carried out under the prevailing environmental conditions using a LICOR-6200 infrared gas analysis system (Licor Inc., USA). Diurnal profiles of g_s of both previous and current-year needles were measured on a seasonal basis. Three replicated measurements for each needle age class were made on three trees per chamber, using 8–15 fascicles per measurement. Gas exchange rates were expressed on a projected needle surface area basis. Needle surface area was determined using a geometric model based on fascicle diameter and needle length enclosed in the chamber. Complementary measurements of net assimilation rates, photosynthetic pigments, antioxidant systems, growth and biomass have been presented elsewhere (Alonso et al., 2003).

2.2. Stomatal conductance model

Stomatal conductance was calculated using the multiplicative g_g simulation model included in the EMEP DO_3SE deposition module based on the methodology described by Jarvis (1976) and modified by Emberson et al. (2000a) and UNECE (2004). In this model, g_s is calculated as a function of species type, phenology and environmental conditions:

$$g_s = g_{max} * f_{light} * \max\{f_{min},\ (f_{phen} * f_{temp} * f_{VPD} * f_{SWP})\}$$

where g_{max} is the species-specific maximum g_s (mmol m^{-2} s^{-1}) expressed on a projected leaf area basis. The remaining parameters range 0–1 and are all expressed in relative terms as a proportion of g_{max} representing the different modifying factors: phenological changes (f_{phen}), photosynthetic active radiation (f_{light}), air temperature (f_{temp}), vapour pressure deficit (f_{VPD}), soil water potential (f_{SWP}) and f_{min} is the relative minimum g_s that occurs during daylight hours.

The model was applied to the same meteorological input data recorded during gas exchange measurements using the default parameterisation for Mediterranean conifers published by Emberson et al. (2000b). The resulted modelled data were compared to measured data of current and previous-year needles of the different O_3 treatments. Since the simulated data were poorly adjusted to measured values, the model was re-parameterised according to the observed data. A local parameterisation of the g_s response functions corresponding to f_{phen}, f_{VPD} and f_{temp} was carried out using the rationale provided in Emberson et al. (2000a, b). A total of 1600 g_s values were considered in the analysis including data of the different O_3 treatments and of current- and previous-year needles. Data of CFA, NFA and NFA + 40 treatments were considered together since no different adjustments to the functions could be detected depending on the O_3 treatment. Photosynthetic active radiation (PAR), air temperature and VPD data measured with the LICOR-6200 were used for function adjustments. The g_{max} and f_{min} values were modified corresponding to the 2% maxima g_s and 15% minima values recorded during daylight hours throughout the experiment considering all age needles and the three O_3 treatments. The f_{SWP} function was set to $f_{SWP} = 1$ for both default and re-parameterised model since the substrate humidity remained high during the experiment.

2.3. Statistical analyses

Differences among O_3 treatments were analysed with ANOVA using g_s values with PAR above 400 μmol m^{-2} s^{-1}. Post hoc comparisons were tested using the Fisher's least significance difference test (LSD) calculated at the 5% level. Simple regression analyses were used to study the relationships between measured and calculated data. All the analyses were performed using Statistica v5.1. (StatSoft Inc., USA).

3. Results

3.1. Ozone exposure and environmental conditions

The study area presents a mild Mediterranean climate typical of coastal areas with monthly average air temperatures ranging from 11 °C to 27 °C and RH ranging 67% to 99%. Ozone was the only air pollutant presenting potentially phytotoxic concentrations while SO_2 and NO_x levels were very low and in the range of the detections limits of the monitors used. Ambient O_3 concentrations showed diurnal and seasonal variations with the highest levels recorded at midday during spring and early summer reaching values up to 60 nl l^{-1} expressed as 10 h (07:00–17:00 h GMT) average (a more detailed description of O_3 levels can be found in Alonso et al., 2003). Every year during the study (1994–1996), ambient levels of O_3 exceeded the AOT40 value of 5 ppm h accumulated during the growing season, the current O_3 critical level for the protection of forest trees (values ranging 11.06 to 23.42 ppm h for the period April to September).

3.2. Ozone effects and seasonal changes of stomatal conductance

Both maximum daily values and diurnal pattern of g_s showed clear seasonal variations. Maximum daily g_s were the lowest during summer compared to the high values recorded in winter and spring (Table 1; for clarification only results of CFA and NFA + 40 are presented since NFA plants