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Integrated biomonitoring of air quality with plants and lichens: A case study on ambient ozone from central Italy

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Abstract

A biennial integrated survey, based on the use of vascular plants for the bioindication of the effects of tropospheric ozone together with the use of automatic analysers of ozone, as well as the mapping of lichen biodiversity was performed in the area of Castelfiorentino (Tuscany, central Italy). Photochemically produced ozone proved to be a fundamental presence during the warm season, with maximum hourly means reaching 114 ppb, exceeding the information threshold as fixed by EU: the use of supersensitive tobacco Bel-W3 confirmed the opportunity of carrying out detailed cost-effective monitoring surveys. The potential for didactical and educational implications of this methodology are appealing. Critical levels set up for the protection of vegetation have exceeded considerably. The comparison of biomass productivity in sensitive and resistant individuals (NC-S and NC-R white clover clones, in the framework of an European network) provided evidence that ambient ozone levels are associated with relevant reduction (up to 30%) in the performance of sensitive material; effects on flowering were also pronounced. The economic assessment of such an impact deserves attention. Mapping of epiphytic lichen biodiversity – which has been used to monitor air quality worldwide – was not related to ozone geographical distribution as depicted by tobacco response.

Keywords: Air pollution; Clover; Index lichen diversity; Tobacco

1. Introduction

Continuous measurement by physicochemical methods using stationary or mobile automatic gauges is the major source of information on atmospheric pollution. These measurements are essential to define the ambient concentrations of contaminants, but, conversely, are of minimal use to evaluate their biological impact. As an example, economic damage caused by a reduced performance of cultivated plants exposed to pollutants can hardly be predicted by any non-living item. Moreover, purchasing and maintenance of automatic gauges is quite expensive and environmental authorities can hardly monitor enough sites to warrant an adequate cover of the area of their competence, and normally only urban areas are monitored. Although about 80% of the European Union's population lives in urban areas (http://www.worldbank.org/data/), which are therefore the place where environmental problems most affect the quality of life of citizens, air pollution is not confined to urban areas.

Another crucial point is worthy of attention: sustainable development is currently an imperative task for all decision makers and opinion leaders: one of its key elements is the active participation of citizens in environmental issues, such as monitoring of air quality. Under this viewpoint, biological monitoring (biomonitoring) of air quality is a politically correct approach, which allows direct and active involvement of people in detecting the conditions of the environment. Particularly, the use of plants for environmental diagnosis should be regarded as a necessary complementary tool to be integrated with classical

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instrumental monitoring. In this context, many approaches may be followed and many techniques may be applied according to specific needs (Steubing and Jaeger, 1982).

The present paper reports the results of a biennial integrated multitask biomonitoring survey of air quality using plants carried out in a small community in Tuscany, Central Italy.

2. Materials and methods

Two coordinated surveys were carried out using vascular plants in the warm season of 2001 and 2002, namely the exposure of: (i) ozone-supersensitive tobacco germlings; (ii) ozone-resistant and ozone-sensitive clover clones. In addition, the diversity of epiphytic lichens was mapped in the same area.

2.1. Study area

The municipality of Castelfiorentino, in the Province of Florence, inner Tuscany (43°36′N, 10°57′E), 60 km far from the Tyrrhenian coast, was the region of this exercise. The area (66 km^2) is essentially flat, with gentle undulations in the range of 35–185 m a.s.l. Inhabitants are about 17000, with a fleet of 10000 vehicles. The economic structure is equally based on agriculture, industry (small and medium enterprises) and services. An important road (S.S. 429) and a railway line cross the study area from north to south. The general climate is sub-Mediterranean, with a mean annual temperature of 14.6 °C and a mean annual rainfall of 792 mm, which is concentrated in autumn and winter, while summer is fairly dry. Wind conditions are dominated by weak wet winds blowing from SW during the warm season, while the opposite holds for winter.

The monitoring network was based on a total of 11 sites, selected according to a systematic, stratified, non-linear design. The sites covered different land use types, from the densely populated town centre to remote areas. Meteorological data were compared with the historical series (since 1993).

2.2. Ozone measurements

During the study, automatic photometric ozone analyzers were operating in two sites (one urban and one industrial) in the nearby municipality of Montelupo Fiorentino (about 18 km NW of Castelfiorentino, 11000 inhabitants). These devices belong to the local environmental authorities (ARPAT) and were run routinely (1 scan min^{-1}, one daily calibration procedure). The operating efficiency was 98%. Ozone concentrations were expressed in ppb in volume (for O_3, 1 ppb is 1.96 $\mu g\ m^{-3}$, at standard temperature and pressure). The following cumulative indices of ozone exposure were calculated to evaluate the biological impact: AOT0, AOT10, AOT20, AOT30, AOT40, AOT60, AOT80, which represent the sum of the differences between the hourly O_3 concentrations (in ppb) and a threshold value, respectively of 0, 10, 20, 30, 40, 60 or 80 ppb, for each hour in the interval 08:00–20:00 h (*Directive 2002/3/EC, in Official Journal of European Communities, L. 67, March 9, 2002*). The latter parameter is imposed to evaluate the fraction of O_3 which is actually accessible to plants owing to stomatal opening.

2.3. Biomonitoring of ozone with tobacco

The miniaturized kit based on germlings of tobacco (*Nicotiana tabacum* L.) cultivars Bel-W3 (ozone supersensitive) and Bel-B (ozone-resistant) described by Lorenzini (1994) was used. In each monitoring site, three plates (69 plants) were positioned and typical exposure lasted 7 days; afterwards, the kits were transferred to an ozone-free (charcoal-filtered) controlled environment for 36 h to allow complete formation of lesions induced by exposure to ambient ozone. Visual assessment of lesions on cotyledons and on the first true leaves was performed by trained personnel (Lorenzini et al., 2000), with the help of a hand lens. Percentage of necrotic area was estimated by comparison with standard iconographic material and reported in terms of Leaf Injury Index (LII) and cotyledonar injury index (CII) on the basis of a 1-to-5 scale (Toncelli and Lorenzini, 1999). The survey was carried out from July 2 until September 30, 2001 and from July 22 until August 4, 2002.

2.4. Biomonitoring of ozone with clover clones

Rhizobia inoculated cuttings of white clover, *Trifolium repens* L. cv. Regal ozone-sensitive (NC-S) and ozone-resistant (NC-R), were processed as described by the ICP-Crops European network protocol (http://www.icp-vegetation.ceh.ac.uk), originally developed by Heagle et al. (1994). Every 28 days, above ground portions were cut and weighed (fresh weight), oven-dried at 105 °C and weighed again (dry weight). Leaf greeness was assessed on mature leaflets with a chlorophyll meter (Minolta SPAD 502) (Nali et al., 2004). The survey was carried out from July 2 to October 22, 2001 (four harvests) and from June 3 to October 21, 2002 (five harvests).

2.5. Diversity of epiphytic lichens

During winter 2001–2002, the epiphytic lichen vegetation was examined at all 11 monitoring sites. In each site, 3–5 free-standing lime (*Tilia* sp.) or oak (*Quercus cerris*, *Q. pubescens*) trees were sampled, and for each of them an index of lichen diversity (ILD) was calculated as the sum of frequencies of epiphytic lichens in a sampling grid consisting of four ladders of 50 × 10 cm, each divided into five quadrats of 10 × 10 cm, positioned on the trunk at the four cardinal sides, at 1 m from ground. The ILD value of each monitoring site was the arithmetic mean of the ILD values measured for each tree. In case of identification problems during field sampling, specimens were collected and identified later in the laboratory. To interpret the ILD values in terms of air pollution, a scale of environmen-