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Heavy element accumulation in *Evernia prunastri* lichen transplants around a municipal solid waste landfill in central Italy

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ABSTRACT

This paper presents the results of a biomonitoring study to evaluate the environmental impact of airborne emissions from a municipal solid waste landfill in central Italy. Concentrations of 11 heavy elements, as well as photosynthetic efficiency and cell membrane integrity were measured in *Evernia prunastri* lichens transplanted for 4 months in 17 monitoring sites around the waste landfill. Heavy element contents were also determined in surface soils. Analytical data indicated that emissions from the landfill affected Cd, Co, Cr, Cu, Ni, Pb, Sb and Zn concentrations in lichens transplanted within the landfill and along the fallout direction. In these sites moderate to severe accumulation of these heavy elements in lichens was coupled with an increase in cell membrane damage and decrease in photosynthetic efficiency. Nevertheless, results indicated that landfill emissions had no relevant impact on lichens, as heavy element accumulation and weak stress symptoms were detected only in lichen transplants from sites close to solid waste. The appropriate management of this landfill poses a low risk of environmental contamination by heavy elements.

1. Introduction

Landfilling is currently the main method of solid waste disposal worldwide, as it is the simplest, cheapest and most cost-effective practice to store municipal solid waste (Giusti, 2009). However, the disposal of municipal solid waste in landfills causes concern about possible adverse effects on the environment and human health, such as fires and explosions, unpleasant odours, damage to vegetation, as well as air, soil and groundwater contamination (Chrysikou et al., 2008; El-Fadel et al., 1997; Vrijheid, 2000). These adverse effects are mainly related to the release of inorganic and organic contaminants from the waste landfills via leachate and production of gases and particulate matter (Bogner and Matthews, 2003; Chalvatzaki et al., 2010; Koshy et al., 2009). Much attention has therefore been given to landfill emissions affecting air quality, and the EU has recently prescribed strict regulations on waste disposal in landfills (European Union, Directive 2008/98/EC).

Gas emissions from municipal solid waste landfills are a complex mixture of contaminants such as carbon dioxide, methane, hydrogen sulfide, nitrous compounds and hazardous volatile organic compounds (i.e., polycyclic aromatic hydrocarbons). The characteristics of landfill particulate matter reflect the nature and chemical composition of the disposed waste. Several contaminants such as toxic heavy elements (i.e., Pb, Cr, Cd and Zn) are associated with the airborne particles released from the landfill (Koshy et al., 2009). Municipal solid waste landfill is thus a reservoir and source of several inorganic and organic contaminants in the surface environment.

In the landfill, particulate matter is mainly generated by re-suspension and dispersal by wind of decomposed and altered waste materials. It is also generated by mechanical processes linked to landfill management such as: (i) the movement of dust-carts and vehicles over previously deposited waste; (ii) the tipping, sorting and compaction of waste by bulldozers; (iii) the stockpiling of soil and rubble required for daily waste coverage (Chalvatzaki et al., 2010; Fitz and Bumiller, 2000).

Gaseous and particulate emissions from municipal solid waste landfill may fall down close to the source and accumulate contaminants in soil (Iwegbue et al., 2010; Rizo et al., 2012; Waheed et al., 2010). The contaminants accumulated in soil may be released into watercourses and groundwater (Rajkumar et al., 2010) and be taken up by vegetables and animals, thus constituting a threat to living organisms, including humans (Acosta et al., 2011; Gupta et al., 2010; Krishna and Govil, 2007).

The levels and distribution of contaminants should be monitored in any study assessing the environmental impact of activities

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related to the management of municipal solid waste in landfill (Biswas et al., 2010; Paoli et al., 2012). In this context, lichens are valuable biomonitoring tools for evaluating air quality and controlling contamination in areas around waste landfills (Nimis et al., 2002; Pirintsos and Loppi, 2008).

Lichens are one of the most sensitive components of the ecosystem. These organisms are able to absorb and accumulate contaminants in their thallus, intercepting airborne materials and solutes of wet and dry precipitations, as well as atmospheric gases (Nash, 2008). Lichens are thus widely used as biomonitors and bioaccumulators of contaminants in air quality and environmental contamination surveys (i.e., Conti and Cecchetti, 2001; Loppi et al., 1997; Nimis et al., 2002; Wolterbeek, 2002).

Lichens are symbiotic, perennial and slow-growing organisms that maintain a fairly uniform morphology over time. They are highly dependent on the atmosphere for their macro and micronutrients. However, due to their large surface area, relatively low growth rate, and lack of waxy cuticle and stomata, lichens can also absorb and accumulate inorganic and organic contaminants such as heavy elements directly from the air. Moreover, several authors have shown that a direct relationship exists between heavy element concentrations in thalli and those in the environment (Bari et al., 2001; Ng et al., 2006; Rodrigo et al., 1999; Sloof, 1995).

Lichens are widely used in biomonitoring studies, which employ either native species, that is species naturally present in the study area (Augusto et al., 2007; Blasco et al., 2008), or transplanted species (Baptista et al., 2008; Bergamaschi et al., 2007; Frati et al., 2005; Sorbo et al., 2008). The latter technique involves the use of thalli removed from areas with little or no contamination and transplanted for a period in selected monitoring sites. Transplant techniques are frequently used when lichens are scarce or absent in the study area.

Changes in the physiology and chemical composition of lichen transplants provide information on the concentration of inorganic and organic contaminants in the air (Demiray et al., 2012; Guttova et al., 2011; Oztetik and Cicek, 2011). In urban and industrial settings, the accumulation of air contaminants such as heavy elements can damage the photosynthetic apparatus (Piccotto et al., 2011; Zambrano and Nash, 2000), decrease the integrity of cell membranes (Paoli et al., 2011) and induce oxidative stress (Carreras et al., 2009; Oztetik and Cicek, 2011) in transplanted lichens.

Lichens accumulate heavy elements through uptake of soluble species in wet depositions and trapping of airborne particles (Williamson et al., 2004). Trapped particles can remain within lichen thalli over long periods of time and may be leached out by acid precipitation or lichen organic compounds (Brown, 1987). As lichens lack a vascular system and roots, there is no interaction with the substratum. This feature eliminates any doubts as to the origin of contaminants, an issue when vascular plants are used to biomonitor air quality.

Besides being useful bioindicators, these characteristics make lichens very sensitive to changes in the chemical composition of air. Lichens can thus serve as "early-warning" indicators of environmental changes and are very helpful in monitoring spatial patterns and temporal trends in heavy element deposition and accumulation (Bennett and Wetmore, 1999, 2000).

The study determined some physiological parameters (photosynthetic efficiency and electrical conductivity) and concentrations of 11 heavy elements (As, Cd, Co, Cr, Cu, Ni, Pb, Sb, Tl, V and Zn) in transplants of *Evernia prunastri* (L.) Ach. lichen and in surface soils collected within and around a municipal solid waste landfill in central Italy. Variations in photosynthetic efficiency and cell membrane integrity, as well as the accumulation of heavy elements in transplanted lichens were used to assess the environmental impact of emissions from the municipal solid waste landfill and define the extent of heavy element distribution in air.

This lichen biomonitoring study contributes to understanding of how municipal solid waste landfills affect air quality. To our knowledge, few researches have focused on this topic (Paoli et al., 2012; Protano et al., 2014). The study also provides analytical data on toxic heavy elements in lichens such As, Sb and Tl, which are generally little investigated in such surveys.

2. Material and methods

2.1. Study area

The study area is centered on the Cà Mascio municipal solid waste landfill (MSWL), located about 1 km NNW of the urban center of Montecalvo in Foglia (Province of Pesaro and Urbino, Marche) in central Italy (Fig. 1). The landfill is located in a hilly zone with reliefs between 200 and 250 m a.s.l. The land is mostly used for agriculture (cereals), but there are also pastures and woodlands. The prevalent direction of winds is from SSW and SW (Fig. 1).

In the study area, pliocenic marine sediments belonging to the Argille azzurre formation crop out. This lithostratigraphic unit mainly consists of blue–gray clays and marly clays, with interbedded yellowish sandstones and silty clays.

According to the Italian law (Italian Legislative Decree n° 36/2003), the Cà Mascio landfill is classified as "landfill for municipal and not hazardous waste". This landfill consists of seven batches: the old batches, numbered from 1 to 6, were used from 1984 to 2000, and overall they contain about 600,000 m^3 of solid waste. These old batches were covered by a layer of soil and vegetation. The batch 7 was utilized since 2001 and is still in use when this research was carried out (2011).

2.2. Lichen sampling, transplant and laboratory treatment

The lichen transplantation is an effective technique widely used for the determination of heavy element accumulation and for assessing the variation of physiological characteristic (Ayrault et al., 2007; Conti et al., 2004; Godinho et al., 2008; Mikhailova, 2002; Pacheco et al., 2008; Sloof, 1995).

The use of lichen transplants in place of native lichens (lichens grown *in situ*) is mainly due to the following reasons: absence of native lichens in the study area, uniformity of the lichen species utilized in biomonitoring and of the exposure period, possibility to choose the monitoring sites and their number, knowledge of the concentration of chemical elements before exposure, possibility to evaluate the accumulation trend of chemical elements.

For these reasons, and especially because of the absence of native lichens, the transplant technique was employed to assess the influence of Cà Mascio landfill emissions on the air distribution of some heavy elements of environmental concern.

In February 2011 thalli of the fruticose *E. prunastri* (L.) Ach. lichen were randomly collected from tree twigs in a woody zone far from contamination sources, located about 25 km S of Siena (central Italy). The *E. prunastri* lichen was chosen because it is easily collected and transplanted. In addition, this species is one of the most used lichens in biomonitoring studies due to its bioaccumulation capacity and widespread distribution (Garty, 2001; Guttova et al., 2011; Loppi and Frati, 2006; Paoli et al., 2011).

The samples of native lichens were immediately transferred to laboratory in polyethylene bags, and left 48 h to acclimate in a climatic-chamber at 15 °C with relative humidity at 60 ± 5% and photoperiod of 12 h at 40 $\mu mol\ m^{-2}\ s^{-1}$ photons of