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Invited paper

Use and abuse of trace metal concentrations in plant tissue for biomonitoring and phytoextraction

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Plants that accumulate soil metals in their aboveground biomass are often incorrectly considered to be suitable for monitoring soil pollution or for phytoextraction purposes.

Abstract

Some plant species accumulate trace metals from the soil in their aboveground biomass. Therefore, some scientists have concluded that these species are suitable for biomonitoring trace metal concentrations in the soil or for removing excessive trace metals from the soil by means of phytoextraction. A significant correlation between the chemical composition of foliage and soil is not a sufficient condition for using the chemical composition of foliage as a biomonitor for the quality of the soil. The chemical composition of foliage can, however, provide additional information to the traditional soil samples. The phytoextraction potential of a plant species cannot solely be evaluated on the basis of the trace metal concentrations in the plant and soil tissue. Data on the depth of the rooting zone, the density of the soil and the harvestable biomass should also be taken into account. Although plant tissue analysis is a useful tool in a wide range of studies and applications, trace metal concentrations in plant tissue cannot be viewed in isolation. Instead it should be analysed and interpreted in relation to other information such as soil concentrations, rooted zone, biomass production, etc.

Keywords: Bioindicator; Phytoextraction; Trace metals; Foliar analysis; Soil analysis

1. Introduction

The uptake of soil metals by plants growing on polluted sites has been the subject of many research studies. Some plant species were reported to accumulate metals from the soil in their aboveground biomass. This observation has led some scientists to conclude that plants can be used to monitor soil pollution or to remediate polluted soils. However, we believe that these conclusions were often based on a superficial evaluation and interpretation of trace metal concentrations in plant tissues.

2. Bioindicators and biomonitors

An organism that provides qualitative information on the quality of its environment is called a bioindicator and one that provides quantitative information a biomonitor (Bargagli, 1998). Bioindicators and biomonitors can be passive or active. The terms bioindicator and biomonitor have been and still are mistakenly used as

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synonyms. However, the terminological confusion is not the main problem. More important are the logical flaws that have led to an excessive use of the terms bioindicator and biomonitor for what is often no more than a correlation between trace metal concentrations in tree foliage and trace metal concentrations in the soil. Many articles published in a variety of journals assume that as a result of this correlation, plant analysis can be used to monitor soil pollution.

We have selected the article of Madejón et al. (2004) recently published in this journal to illustrate some of the logical flaws which occur in scientific literature. Madejón et al. (2004) were interested in the environmental quality of the soil. Therefore soil samples were taken and the Cd and Zn concentrations determined. On the same site, foliar samples from white poplars (*Populus alba* L.) were also taken and analysed for Cd and Zn. The foliar Cd and Zn concentrations were reported to be positively correlated to the soil concentrations. The positive correlation persuaded Madejón et al. (2004) to suggest that the leaves of white poplar could be used for biomonitoring Cd and Zn in the soil. Given the definition of a bioindicator and a biomonitor this is a correct statement. However, we fail to see the advantage of using foliar samples to determine soil concentrations whenever it is possible to analyse the soil. Soil analyses are certainly the most straightforward method for assessing the soil quality, whereas using foliar analysis to monitor soil pollution has some practical constraints.

(i) Trace metal uptake is dependent on the species or even clonal species (Landberg and Greger, 1994). Therefore, monitoring is in practice restricted to areas where the specific species or clone is growing. Consequently the plant or clonal species has to be determined before analysis. In the case of clonal species, determination may be difficult and laborious.
(ii) At present, no plant species are known that respond to a wide range of elements. In the case of white poplars, biomonitoring is likely to reveal Cd, Zn and As pollution in the soil. However, the same biomonitoring strategy would fail to reveal soil pollution by, for example, Pb and Cu (Mertens et al., 2004). A soil sample which has been analysed for a wide range of elements would reveal the total concentration for those elements.
(iii) The trace metal concentration in tree foliage varies with the crown class, stand management, crown dimensions, infections, season, etc. (Luyssaert et al., 2002). Consequently, the variability in trace metal concentrations in tree foliage should be known and understood when designing a suitable leaf sampling procedure. For example, Cd, Zn, Cu and Pb concentrations in tree leaves are reported to vary during the growing season (Luyssaert et al., 2002). If the assessment of the soil quality is now based on the chemical composition of the foliage, the soil quality in terms of Cd, Zn, Cu and Pb concentrations will also vary during the growing season. Therefore, foliage sampling should be done in a predefined manner, which restricts the possibilities for determining the pollution on a site.
(iv) Due to the height of trees, collecting foliar samples is often impractical.

Even if the aforementioned difficulties could be overcome, would tree foliage analysis have advantages over soil analysis?

(i) It has been argued that bioindicators and biomonitors contain integrated information for a longer time period and over a larger space, whereas a soil sample provides information about the specific sampling time and location. Does this argument hold in the case of Madejón et al. (2004)? Tree roots cover a large soil volume. However, tree roots were reported to avoid zones contaminated with heavy metals. Avoidance was thought to be an efficient survival strategy of the plant (Dickinson et al., 1991; Breckle and Kahle, 1992). This means that the tree roots might avoid the hot spots, despite these spots having a considerable influence on the assessment of the soil's environmental quality (Hsiao et al., 2000). Tree roots stay in the soil year round and are therefore expected to contain time-integrated information. However, Madejón et al. (2004) analysed the leaves not the roots. Element concentrations in the roots are not simply reflected in the leaves. Foliar concentrations of trace metals are driven by accumulation, antagonism, accretion, resorption and excretion. Consequently, it is unlikely that the tree foliage contains the time-space-integrated information sought.
(ii) Environmental risk and damage occurs when the metals are available to the living organisms. Analysis of the total soil concentration provides no information about the availability. What does the availability for white poplar tell us about the availability for other living organisms at the site? Availability to poplars is not the same as availability to other species. Oak or ash, for example, did not accumulate Cd, Cu, Cr, Pb or Zn on sites where white poplars accumulated Cd and Zn (Mertens et al., 2004). This means that the availability is highly dependent on the species. Yet total soil analysis or sequential extractions are not a valid alternative for determining the availability of soil trace metals to living organisms. The availability of trace metals in an ecosystem can only be evaluated by simultaneously analysing soil and plant