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Review

An overview of indexes to evaluate terrestrial plants for phytoremediation purposes (Review)

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ABSTRACT

This paper reviews the various factors, coefficients and indexes developed to evaluate terrestrial plant performance in respect to phytoremediation.

A brief list of indexes includes the Accumulation factor, Bioabsorption coefficient, Bioaccumulation coefficient, Bioaccumulation factor, Bioconcentration, Bioconcentration coefficient, Bioconcentration factor, Biological absorption coefficient, Biological accumulation coefficient, Biological concentration factor, Biological transfer coefficient, Concentration factor, Enrichment coefficient, Enrichment factor, Extraction coefficient, Index of bioaccumulation, Mobility index, Shoot accumulation factor, Soil host transfer factor, Soil-plant transfer coefficient, Soil-plant transfer factor, Transfer factor and Translocation factor.

These indexes represent the result of a ratio calculation between element concentrations in plant parts to that of substrata. In other cases indexes arise from the ratio calculation of element concentrations in two distinct plant parts.

In the literature different terms have been attributed to the same ratio and this often represents an overlap in terminology. On the other hand the same term corresponds to several different ratios and this could create confusion and misinterpretation in data comparison.

Furthermore, the evaluation of hyperaccumulation, phytostabilization or phytoextraction of plant species is not always performed in the same way. Different plant parts are considered as well as different extraction procedures for both plant and substrata element assessment. As a consequence, a direct comparison between obtained data is not always reliable and possible.

In this paper the various available indexes are reviewed, highlighting both the similarity and differences between them with the aim of helping the community in choosing the appropriate term for both data evaluation and comparison. In this author's opinion there is no need of new terms to define indexes. I would stress the need for conformity to the original definitions and criteria.

1. Introduction

It is very difficult to go back in time and find out when studies on soil-plant relationship started. In the very beginning the curiosity and interest of researchers was probably devoted to herbs which were able to grow on toxic metalliferous substrata, restricting metals uptake or accumulating them in their tissues to varying degrees. In this respect, the study by Minguzzi and Vergnano (1948) on unusual Ni accumulation in *Alyssum bertolonii* is probably one of the first examples. Baker (1981) reported several experiments formerly conducted by other authors. Among these Nicolls et al. (1965) for example, studied plants-soil relationships for Zn, Pb and Cu in the plant ash of *Triodia pungens*, while Timperley et al. (1970) studied Ni and Cu plant/soil accumulation ratios in *Nothofagus fusca* and in *N. menziesii*. Ernst (1975) evaluated the concentrations of some metals in the leaf dry matter of a range of species growing on a naturally metalliferous soil in Germany, without defining any ratio among plant/soil concentrations. In 1982, Chumbley and Unwin performed a study in England, on a variety of vegetable crops in regards to Cd and Pb uptake, once again avoiding a definition of this ratio calculation.

From 1982–1994 there seems to be a gap in literature. Baker et al. (1994) studied several elements' accumulation and tolerance in British populations of *Thlapsi caerulescens* (now *Noccaea caerulescens* (J. Presl & C. Presl)). Using data for all paired plant/soil samples, they compared the ratio between plants and soil considering both total and extractable soil concentrations. They defined the Accumulation factor as the ratio of mean plant concentration/mean total soil concentration. The authors actually considered *T. caerulescens* rosette leaves and soil

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total metals concentrations obtained using a mixture of hydrofluoric acid (HF)/nitric acid (HNO_3) (1:1) as extractant. This experiment seems to represent the first attempt to define the ratio between plant (specifically leaves) and soil metal concentration.

Throughout the years a general increase in pollution and the necessity to find reliable methods for the restoration of contaminated sites has led to an increase in interest on these topics and a subsequent development of studies on plant use in restoration interventions (e.g. Chaney et al., 1997; Cunningham and Berti, 1993; Vangronsveld et al., 1996). New plant(part)/soil and plant part/plant part ratios have been created and, in parallel, new terms have been coined. The problem is that, sometimes, the original terms of the ratio calculation have been modified but, despite of this, the noun of the ratio has been preserved, thus creating confusion.

As an example, the Accumulation factor intended as the leaf/soil ratio (Baker et al., 1994) has been reported as the shoot/root ratio by Fitz and Wenzel (2002) and as the plant/soil ratio by Nirmal Kumar et al. (2009). As a consequence, a comparison between results is not possible, even if all three authors refer to the Accumulation factor. Similar considerations could be made in respect to the Bioaccumulation factor which is intended to be the plant/soil ratio (Khaokaew and Landrot, 2015a) or the shoot/soil ratio (Álvarez-Ayuso et al., 2016) or the leaf/soil ratio (De Nicola et al., 2015), or the root/soil ratio (Galal and Shehata, 2015; Rodríguez-Iruretagoiena et al., 2016).

Furthermore, especially in soil element determination, adopted analytical methodologies varied widely (e.g., total, pseudototal and extractable element concentrations), giving different results, thus nullifying any possible comparison among obtained results even in cases where the same ratio was applied.

As an example, Baker et al. (1994) considered total soil element concentration in the Accumulation factor calculation. Poschenrieder et al. (2012) performed the same ratio calculation but, in this case, considered soil ethylene diamine tetra-acetic acid (EDTA) extractable element concentration.

On the other hand, sometimes a particular ratio has been defined by several different terms and acronyms, thus creating uncertainty and confusion in the literature. As an example, the shoot/soil ratio has been labelled Bioabsorption coefficient (Varun et al., 2015), Bioaccumulation coefficient (Liang et al., 2017), Bioconcentration factor (Sidhu et al., 2017), Biological accumulation coefficient (Malik et al., 2010), Enrichment coefficient (Cui et al., 2007), Enrichment factor (Galal and Shehata, 2015), Extraction coefficient (Rodríguez-Iruretagoiena et al., 2016), Shoot accumulation factor (Bech et al., 2016), Transfer factor (Altansuvd et al., 2014). As a consequence of this overlapping terminology some confusion and difficulties arise when trying to search the literature in order to identify suitable indexes or experiments used to compare results.

Another relevant problem arises when trying to define plants as either hyperaccumulators or suitable for phytostabilization or phytoextraction interventions. In this respect, plants must have particular ratio values but there is a lack of clarity in respect to which ratio to consider, and the way soil elements' concentration is determined. As reported by Conesa et al. (2012) the high number of scientific terms for various processes, mechanisms, or techniques and the lack of uniformity among researchers may lead to confusion in the marketplace. Furthermore, as stated by van der Ent et al. (2013) in regards to plant element accumulation, unambiguous communication will require the international scientific community to adopt standard terminology and methods for confirming the reliability of analytical data in relation to metal and metalloid hyperaccumulators.

The aim of this review is to bring together and discuss the factors which can be applied in the evaluation of plants for phytoremediation interventions. To the best of this author's knowledge, nothing similar has been realized until now and hopefully it will serve to identify terms of comparison in future studies.

2. The ratio

One of the main objectives in phytoremediation studies is to evaluate the ability of plants to uptake elements from the substrata and also to verify whether or not elements are transferred and accumulated in the different aboveground plant parts. This evaluation is generally performed with a ratio calculation which involves plant and substrata element concentrations.

2.1. Plant/substrata ratio

To assess a plant's ability to uptake elements, a ratio calculation is performed between element concentrations in the plant(parts) and element concentrations in the substrata on which the plant grows. The concentration of elements in the plant(part) is considered the numerator in the ratio calculation.

After drying and milling the plant tissues, the resulting powder can be analyzed to give the metal concentration present in the whole plant. From the literature surveyed, in particular cases only specific plant parts were considered i.e., aboveground part, aerial plant part, shoot, top, leaf, stem, branch, bark, straw, shell, fruit, grain, root, rhizome, belowground tissues, thus separating the plant into its different components and analyzing them separately in order to detect specific element content. Some ratios which contemplate, for example, fruits or edible vegetables, are currently utilized to calculate the potentially harmful elements (PHEs) bioaccumulation factors. Soil-to plant transfer is one of the major pathways for pollutants to enter the food chain and is of importance when investigating the animal and human health risk associated with PHEs (Bini et al., 2013).

It has to be said that some terms like aboveground part, aerial part, shoot or top are probably to be considered synonymous as well as terms like belowground part, rhizome and root. Anyway, in this article the original terms have been maintained to give the exact picture of the current status with regards to the literature.

As it is possible to verify in the literature, herbs, shrubs and trees have been widely studied and almost all plant parts have been considered in former experiments (Badr et al., 2012; Bech et al., 2012b, 2016; Cui et al., 2007; Galal and Shehata, 2015; Gupta et al., 2008; Korzeniowska and Stanislawska-Glubiak, 2015; Lotfy and Mostafa, 2014; Mattina et al., 2003; Pérez-Sirvent et al., 2008; Uchida et al., 2006; Yoon et al., 2006).

However, it seems important to underline how metals concentrations vary largely in the different plant parts (Kabata-Pendias, 2011). In a ratio calculation with the substrata, the quotient might assume very different values with absolutely different significance when considering the whole plant or, otherwise, only a particular part of it.

2.2. Plant part/plant part ratio

Another branch of research evaluates the ability of plants to transfer elements from the roots to its aboveground parts. This is done for several reasons. On the one hand it is made for evaluating the possible transfer of elements into the food chain. On the other hand, it is performed for identifying useful plants for phytostabilization or phytoextraction interventions in polluted environments.

In this respect element content in plant parts is compared to that of the roots. Most of the experiments conducted concerned the shoot to root ratio (e.g.: Boechat et al., 2016; Elloumi et al., 2017; Hamzah et al., 2015; Ma et al., 2015; Marrugo-Negrete et al., 2015; Pandey et al., 2015; Sidhu et al., 2017; Sun et al., 2016; Varun et al., 2015). Nevertheless, other ratios were considered such as the aerial part/root (Abreu et al., 2012), aboveground/root (Korzeniowska and Stanislawska-Glubiak, 2015; Pachura et al., 2015; Wang et al., 2015; Xiao et al., 2015), leaf/root (Roccotiello et al., 2015; Souza et al., 2015; Yang et al., 2015), stem/root (Pandey, 2013), fruit/root (Gupta et al., 2008), branch/root (Yang et al., 2015), bark/root (Yang et al., 2015), wood/