Science of the Total Environment 468–469 (2014) 77–82

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Selenium content of Belgian cultivated soils and its uptake by field crops and vegetables

Ludwig De Temmerman [a], Nadia Waegeneers [a,*], Céline Thiry [a],
Gijs Du Laing [b], Filip Tack [b], Ann Ruttens [a]

[a] Veterinary and Agrochemical Research Centre (CODA-CERVA), Chemical Safety of the Food Chain, Leuvensesteenweg 17, B-3080 Tervuren, Belgium
[b] Ghent University, Laboratory of Analytical Chemistry and Applied Ecochemistry, Coupure Links 653, B-9000 Gent, Belgium

HIGHLIGHTS

- Selenium (Se) concentrations in Belgian soils are at the lower end of normal concentrations.
- The Belgian situation is representative for large parts of Europe.
- Wheat is an important source of Se in food but Se concentrations in wheat remain rather low.
- Among a high number of parameters that influence soil uptake of Se, soil Se and soil pH are most important.
- The Se concentrations in Belgian soils are far too low to generate a driving force on Se uptake.

ARTICLE INFO

Article history:
Received 14 April 2013
Received in revised form 27 June 2013
Accepted 7 August 2013
Available online xxxx

Editor: Charlotte Poschenrieder

Keywords:
Selenium
Soil uptake
Field crops
Vegetables
Soil–plant regressions

ABSTRACT

A series of 695 food crops were collected on 539 soils throughout Belgium. All samples were collected on commercial production fields, omitting private gardens. All crops were analyzed for their selenium (Se) concentration. The soils represent different soil types occurring in Belgium, with soil textures ranging from sand to silt loam, and including a few clay soils. They were analyzed for Se concentration, organic carbon content, cation exchange capacity and extractable sulphur (S) concentration. The Se concentrations in the soils were low (range 0.14–0.70 mg kg^{-1} dw), but increasing soil Se concentrations were observed with increasing clay content. Stepwise multiple regressions were applied to determine relations between Se concentrations in crops and soil characteristics.

Among field crops, wheat is the most important accumulator of selenium but the concentration remains rather low on the Belgian low Se–soils. Based on dry weight, leafy vegetables contain more Se than wheat. The soil is the most important source of Se and the element is transported with the water stream to the leaves, where it is accumulated. Vegetables rich in S, e.g. some *Brassica* and *Allium* species, have a higher capacity to accumulate Se as it can replace S in the proteins, although this accumulation is still limited at low soil Se concentrations.

In loamy soils, weak correlations were found between the soil Se concentration and its concentration in wheat and potato. The uptake of Se increased with increasing pH. The Se concentrations in Belgian soils are far too low to generate a driving force on Se uptake. General climatic conditions such as temperature, air humidity and soil moisture are also important for the transfer of Se within the plant, and plant linked factors such as cultivar, growth stage and edible part are important as well, although their influence remains limited at low soil Se concentrations.

1. Introduction

Selenium (Se) is an essential micronutrient for humans and animals. Besides its well-known protective action against oxidative stress in body tissues, Se also plays a role in the maintenance of defences against infection, modulation of growth and development, and there is a reduction in cancer risk at supranutritional levels (Combs, 2001). The main source of Se in the soil is the geological parent material. The crustal abundance of Se is low (<0.05 mg kg^{-1}) (Kabata-Pendias and Pendias, 1984). Selenium is found often manifold its crustal abundance in black organic-rich shales, coal, and to a lesser extent in petroleum. Seleniferous black shales are the parent material of the widespread seleniferous soils in the United States (Lakin, 1973), in Wales and in Ireland (Davies and Houghton, 2005). The geographical distribution of Se in soils is very uneven, ranging from almost zero to up to 1250 mg kg^{-1} in some seleniferous soils in Ireland (Oldfield, 2002). Selenium concentrations are particularly high in soils derived from cretaceous shales in semi-arid and arid regions (Rosenfeld and Beath, 1964 in Spadoni et al., 2007).

---

* Corresponding author. Tel.: +32 2 769 22 29; fax: +32 2 769 23 05.
E-mail address: nadia.waegeneers@coda-cerva.be (N. Waegeneers).

0048-9697/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.scitotenv.2013.08.016

Selenium is associated with volcanic sulphur and has been found in volcanic sulphur deposits leading to high Se concentrations in soils of volcanic regions (Lakin, 1973). The melting and boiling points of like forms of selenium and sulphur differ markedly and selenium is largely less volatile than sulphur. At ambient temperatures selenium dioxide is a solid and sulphur dioxide is a gas. This means that selenium dioxide is carried down by rain nearer to the source of emission than sulphur dioxide (Lakin, 1973), and the impact of volcanic emissions is mainly of local importance. Burning of coal and petroleum are more important as sources of atmospheric selenium than volcanic activities. The quantity of deposition is, however, far too low to generate Se accumulation in the top soil, and a resulting increase of Se in plants is unlikely. Atmospheric deposition of selenium species on crops is probably a direct source of selenium to crops. Indeed, there is a net input of airborne Se to herbage, even in remote areas but the inputs are generally low (Haygarth et al., 1991). Foliar application of selenite or selenate is able to enrich the Se status of plants (Kapolna et al., 2009). Soil applications of commercial fertilizers enriched with Se appear to be a safe method to increase the selenium uptake in low Se–soils (Hartikainen, 2005). As the selenium concentration in atmospheric deposition remains rather low, the soil Se concentration is apparently the most important source of selenium in crops. In Belgium the soil Se concentrations are moderately low with a reported concentration of only 0.11 mg kg^{-1} as an average value for the most representative agricultural soils (Robberecht et al., 1982). The concentration of Se in most soils lies within the range of 0.01 to 2 mg kg^{-1} (Kabata-Pendias and Pendias, 1984). In uncultivated soils on Quaternary parent material, De Temmerman et al. (1984), found total selenium concentrations ranging 0.2–0.5 mg kg^{-1} in sandy and sandy loam soils and 0.3–0.7 mg kg^{-1} in loam and polder clay soils. Excessive soil concentrations (>3 mg kg^{-1}) occur in areas of North America, China and Ireland,

The accumulation of selenium in plants is primarily depending on the availability of Se in soil. The availability of Se to plants is a function of the pH and the redox potential (Eh) of the soil as well as of the total Se content (Lakin, 1973). Selenium can be present in soils under various forms, but mostly selenate or selenite. Selenate is the major species in well aerated, neutral to alkaline soils (Kabata-Pendias and Pendias, 1984). As plants do not discriminate between sulphate and selenate, selenate is taken up and transported from the root to the shoot (Terry et al., 2000). Selenite is the major inorganic Se species in well-drained mineral soils with a pH from acidic to neutral (Li et al., 2008). It is still not sure whether there is an active or passive transport into the root and the root to shoot transport for selenite is both lower and slower than for selenate (Terry et al., 2000; Zhu et al., 2009). In soils, selenite is less bioavailable than selenate because it is strongly absorbed by iron oxides and/or hydroxides (Barrow and Whelan, 1989). In acid soils (pH 4.5–6.5) Se is usually bound as a basic ferric selenite of extremely low solubility and it is essentially unavailable to plants. In alkaline soils (pH 7.5–8.5) Se may be oxidized to selenate ions and become water soluble. This form is readily available to plants (Lakin, 1973). As such, bio–availability of soil borne Se is depending on the geochemical nature, pedoclimatic variables (temperature and rain intensity) and related to fluctuations of soil moisture and pH (Spadoni et al., 2007). Plant availability of Se decreases also at an increased content of organic matter, clay minerals and iron hydroxides (Gissel-Nielsen et al., 1984). In a pot experiment, Johnsson (1991) found that increasing the proportion of clay and peat in the soil substrate largely decreased selenium uptake for wheat and oilseed rape at pH 5 as well as at pH 7. The sulphur concentration in the soil also interacts with the Se uptake as wheat grain Se concentrations could be predicted from soil Se concentration and soil extractable sulphur (Stroud et al., 2010). Adams et al. (2002) did not find correlations between grain selenium and grain sulphur concentrations in a national survey in the UK, but in a field experiment they found that at an increasing rate of sulphur addition, grain selenium concentrations were significantly decreased. Phosphate also competes with Se for plant uptake, although to a lower extent (Hopper and Parker, 1999). In solution cultures, where the availability of sulphate and phosphate is larger than in soils, they found that sulphate–selenate antagonisms are stronger than phosphate–selenite antagonisms. Öborn et al. (1995) found a correlation between soil and plant selenium for potato, taking into account soil pH and organic matter, but not for wheat.

The aims of the present study were (a) to obtain insight into the Se concentrations in field crops and in vegetables grown on Belgian soils because of their contribution to the human Se intake, and (b) to determine whether there is a relation between Se concentrations in crops and Se concentrations in corresponding soils, taking into account other soil parameters such as pH, organic carbon and the extractable sulphur content. This study focussed on the actual situation in the main production areas for food crops in Belgium. This means that besides normal agricultural practices, no other practices were applied for experimental purposes. Fertilizers enriched with selenium are not yet a common practice in Belgium and there was no extra liming in order to alter the uptake of Se. The Se concentrations in Belgian soils are representative for large parts of Europe and topical in dealing with the intake of Se by human populations.

2. Materials and methods

2.1. Soil and plant sampling

Plant and corresponding soil samples were taken on commercial fields for crops and vegetable production. Samples were collected all over Belgium covering the main agricultural and horticultural regions. Soil and plant sampling took place in the period 2001–2012. Soil samples of the plough layer were taken with a gouge auger (Eijkelkamp) within the rooting zone of the sampled crops (25 cm). The soil samples were grouped in general soil texture classes according to a study of the Soil Service of Belgium (Vanongeval et al., 1992)

2.2. Sample preparation

The vegetable and crop samples were cleaned (removal of dirty, damaged and dead leaves) and separated from their non-edible parts following current kitchen practices. Wheat and other grains were threshed, dried and analyzed after grinding in a hammer mill (Culatti AG). Root, tuber and bulb crops were cleaned (removal of soil and roots), washed and peeled. The fresh edible part was cut, homogenized and dried. Leafy vegetables were washed (3 times in tap water), cut, homogenized and dried. All the samples were dried in an oven at 70 °C, ground with a hammer mill (Culatti, AG) and again homogenized. Dry products were stored in polyethylene pots at room temperature. The results were recalculated on a fresh weight basis by using the dry weight of an unwashed subsample.

The soil samples were air dried and sieved (2 mm) to remove stones and plant materials.

2.3. Chemical analysis

2.3.1. Plants

Selenium analyses in plant material were performed in duplicate. Each batch of samples was accompanied by an appropriate standard

Table 1
Summary of the parameters of the ICP-MS system used during selenium analysis.

ICP-MS instrument	VARIAN 820
Forward power	1.45 kW
Nebulizer gas flow	0.99 l min^{-1}
Cool gas (plasma gas)	17 l min^{-1}
Auxiliary gas	1.8 l min^{-1}
Sheath gas	0.20 l min^{-1}
Reaction gas	H2 90 l min^{-1}
Sample introduction	Micromist low flow nebulizer
Channel monitored	77 and 78