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Selenium uptake, transformation and inter-element interactions by selected wildlife plant species after foliar selenate application

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ABSTRACT

Plants are characterized by differing capabilities to accumulate selenium. A model small-scale field experiment was set up to investigate the selenium (Se) uptake by twelve different plant species growing at an uncultivated meadow, as well as the effect of Se foliar application on the uptake of essential elements for plants calcium (Ca), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), phosphorus (P), sulfur (S), and zinc (Zn). Foliar application of sodium selenate (Na_2SeO_4) was carried out in two rates (25 and 50 g Se/ha), and an untreated control variant was included and the element contents in the aboveground biomass were determined. The results showed that selenium levels actually increased due to application of selenium where confirmed the hypothesis, that foliar application of selenium will lead to an increase of this element content, depending on the plant species. The highest Se contents were determined in *Veronica chamaedrys* (1.052 ± 0.024 mg Se/kg), *Stellaria holostea* (0.775 ± 0.064 mg Se/kg), *Gallium aparine* (0.745 ± 0.027 mg Se/kg) and *Urtica dioica* (0.720 ± 0.011 mg Se/kg) biomass whereas *Cirsium arvense* and *Carex vesicaria* showed the lowest Se uptake. No symptoms of potential Se phytotoxicity were observed at these concentration levels. Among the selenium compounds, selenate and selenomethionine (SeMet) were the predominant ones regardless of the plant species documenting relative low ability of plants to transform the applied selenate to the organoselenium compounds. Regarding the minor organoselenium compounds such as selenocystine (SeCys2) and Se-methylselenocysteine (Se-MeSeCys) the results suggested differences in Se transformation between monocotyledoneous and dicotyledoneous plants where Se-MeSeCys exceeded SeCys2 in monocotyledoneous and opposite pattern was observed in dicotyledoneous plants. These findings as well as the ambiguous changes in other essential element contents in the plant biomass needs to be investigated in further research.

1. Introduction

Selenium belongs to the most important essential elements for animals and various beneficial effects were reported for plants, as well. For example, Hawrylak-Nowak et al. (2010) observed increasing tolerance of *Cucumis sativus* plants against the cold-induced stress after Se application. Similarly, selenium decreases the negative effect of high temperature on *Sorghum bicolor* (Djanaguiraman et al., 2010). Among other beneficial effects of Se improvement of *Solanum tuberosum* growth (Turakainen et al., 2004) or increasing number and weight of seeds of *Brasicca rapa* (Lyons et al., 2008). However, Landberg and Greger (1994) showed that selenium does not reduce the toxicity of cadmium and copper to plants. They observed that selenite increased cadmium contents in *Pisum sativum* roots up to 300% and selenate increased cadmium of *Triticum aestivum* shoots up to 50%. As obvious for most of the essential elements, the effect of Se on plants is dose-dependent. Hartikainen et al. (2000) documented induction of antioxidative effect and enhanced growth of *Lolium multiflorum* at low Se levels and enhanced oxidative stress at the high Se levels. The plants are able to take up selenite, selenate, and organic Se compounds such as selenocysteine (SeCys), and selenomethionine (SeMet) via their root system. On the contrary, selenides and elemental Se are not plant-available (Abrams et al., 1990; White and Broadley, 2009). Soilless cultivation of *Triticum turgidum* and *Brassica napus* showed better uptake of SeMet compared to the inorganic Se compounds (Kikkert and Berkelaar 2013). Opposite pattern was observed in soil-cultured *Festuca arundinacea* and *Brassica napus* plants where

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the soil was treated either with selenate or with seleniferous organic materials (Ajwa et al., 1998). In this case, more than 80% of the Se added as the Se-enriched organic matter remained in soils. Arvy (1993) documented at *Phaseolus vulgaris* plants that selenate is easily translocated from roots to the aboveground biomass whereas translocation of selenite was very limited. The enhancement of Se accumulation in *Zea mays* and *Medicago sativa* plants due to mycorrhizal accumulation was observed by Yu et al. (2011).

Plants vary substantially in their Se uptake and physiological response to selenium (Terry et al., 2000). Most of the common plants are not able to accumulate more than 25 mg Se/kg of dry matter in the aboveground biomass. These plant species belong to so-called non-accumulators usually intolerant to the elevated Se contents in the environment (White et al., 2007). Although *Portulaca oleracea* belongs to the plant species relatively tolerant to the elevated Se contents in soil, the increase in soil Se contents resulted in the decrease of plant growth (Prabha et al., 2015). Similarly, Hermosillo-Cereceres et al. (2013) reported reduced biomass yield of *P. vulgaris* grown in solution containing more than 20 μM solution of selenite. Selenium in plants is bound into various compounds where sulfur is replaced by selenium, such as SeCys and SeMet (Ng and Anderson, 1978; Ellis and Salt, 2003). As an example of the complexity of Se metabolism in plants following biochemical process can be presented: SeMet can be synthesized from SeCys *via* three-step reaction catalyzed by three enzymes. The first one is cystathionine-γ-synthase binding SeCys to *o*-phosphohomoserine resulting in Se-cystathionine. In the second step, Se-cystathionine is transformed to Se-homocysteine with help of cystathionine-b-lyase. In the end, Met-synthase is responsible for transformation of Se-homocysteine to SeMet (Pilon-Smits and Quinn, 2010). Other frequently occurring organic compound, Se-methylselenocysteine (Se-MeSeCys) is synthesized from SeCys in the presence of selenocysteine methyltransferase. This compound is typically present in Se-fortified selenium accumulating plants whereas in non-accumulating plants treated by selenate the predominant Se compound in plants is again selenate (de Souza et al., 1999; Freeman et al., 2007).

Selenium is characterized by narrow range between essential and toxic levels in animals. Therefore, the cases documenting either selenium deficit or overdose of animals are relatively frequent (Terry et al., 2000). The regular consumption or the diet containing more than 1 mg Se/kg of the dry matter can result in chronic poisoning of animals; the diet containing 1000 mg Se/kg of dry matter can be lethal (Rosenfeld and Beath, 1964; Wilber, 1980). The response of Se application on the contents of this element in plants was widely investigated in crops suitable for human consumption (Rahman et al., 2015; Golob et al., 2015; Hermosillo-Cereceres et al., 2013; Mechora et al., 2011; Mahmud et al., 2010) or animal feeding (Bañuelos and Mayland, 2000; Seppaenen et al., 2010). However, the information concerning the fate of Se in wildlife plants potentially available for wildlife herbivores are limited. According to Žáková (2014) the pasture for horses collected at different places of the Czech Republic was Se-deficient and the animals reached the physiological Se levels in blood only *due* to Se-fortified commercial feed additives. The information concerning interactions of selenium with other essential macro- and microelements in plants (except sulfur) are limited, as well. On the contrary to the essential elements, the interactions between Se and risk elements such as As, Cd, and Pb were more intensively investigated (Duan et al., 2013; Hu et al., 2014; Yathavakilla and Caruso, 2007). Therefore, the main objectives of this study were (i) to assess the response of selected grassland plant species on foliar application of Se as affected by Se dose and plant species; in this context, relatively wide range of Se contents in different plant species growing at one location were observed by Sasmaz et al. (2015) and the differences among the individual plant species were expected on our study, as well; (ii) to compare Se transformation ability of the individual plant species; (iii) to estimate potential effect of increasing Se uptake by plants on the uptake of other essential elements by these plant species.

2. Material and methods

2.1. Experimental design and sampling

At the Humpolec location, an uncultivated meadow was selected, where three subplots (25 m^2 each) were marked out between 49°33.42′N, 15°21.06′E, and 49°33.46′N, 15°21.02′E. The bedrock is based predominantly on paragleyis, the soil type is gleyic Cambisol, the texture is loam. The natural pseudototal (*Aqua regia* soluble) Se contents in the soil at this area were monitored in our previous study (Száková et al., 2015). Water solution of sodium selenate (Na_2SeO_4) of the analytical grade purity was applied to each subplot at the beginning of the stem elongation as follows: (i) C—untreated variant (control); (ii) Se 1—the Se amount corresponding to the rate 25 g Se/ha; (iii) Se 2—the Se amount corresponding to the rate 50 g Se/ha. Representative samples (≈25 g) of the aboveground biomass of the individual plant species occurring at all the tree subplots from each subplot were randomly harvested in the flowering stage (*i.e.* ≈four weeks after Se application). The harvested biomass of plants was gently washed with deionized water, freeze-dried and finely ground by using of the laboratory mortar (Retsch SM 100, Germany) and kept at the dry place until the laboratory analyses. The plant species sampled were: *Holcus lanatus* L. and *Alopecurus pratensis* L. (*Poaceae*), *Carex vesicaria* L. (*Cyperaceae*), *Galium mollugo* (L) Scop. and *Galium aparine* L. (*Rubiaceae*), *Juncus effusus* L. (*Juncaceae*), *Chaerophyllum temulum* L. (*Apiaceae*), *Cirsium arvense* (L) Scop. (*Asteraceae*), *Ranunculus repens* L. (*Ranunculaceae*), *Veronica chamaedrys* L. (*Veronicaceae*), *Stellaria holostea* L. (*Silenaceae*), *Urtica dioica* L. (*Urticaceae*).

The composite samples of soil (depth 0–25 cm) were collected at each subplot together with the plant samples. Soil samples were dried at 20 °C, ground in a mortar, and passed through a 2-mm plastic sieve. The pseudototal (*i.e. Aqua regia* soluble) contents of investigated elements in the soil are summarized in Table 1.

2.2. Analytical methods

2.2.1. Determination of total element contents in plants and soils

For determination of element contents in freeze-dried and homogenized aboveground biomass of plants, an aliquot (~500 mg of dry matter) of the plant sample was weighed in a digestion vessel. Concentrated nitric acid (8.0 mL) (Analytika Ltd., Czech Republic), and 30% H_2O_2 (2.0 mL) (Analytika Ltd., Czech Republic) were added. The mixture was heated in an Ethos 1 (MLS GmbH,

Table 1
The pseudototal contents of investigated elements in soil (mg/kg) according to the individual subplots determined after harvest of the plants; The averages marked by the same letter did not significantly differ at $p < 0.05$ within individual columns; data are presented as mean ± standard deviation, $n = 3$.

Treatment	Se	Ca	Cu	Fe	K
C	0.578^a	2178^a	19.8^b	22224^a	5978^a
Se 1	0.476^a	2138^a	17.3^a	22906^a	5592^a
Se 2	0.485^a	2104^a	17.0^a	23715^a	4719^a
	Mg	Mn	P	S	Zn
C	4458^a	233^a	418^a	453^b	58.5^a
Se 1	4335^a	248^a	380^b	321^a	55.2^a
Se 2	4319^a	316^b	409^a	337^a	57.1^a