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DYNAMICS OF CHANGES IN SELENIUM CONTENT IN SOIL AND WINTER WHEAT AFFECTED BY LONG-TERM ORGANIC FERTILIZATION

DYNAMIKA ZMIAN ZAWARTOŚCI SELENU W GLEBIE I ROŚLINACH PSZENICY OZIMEJ POD WPŁYWEM WIELOLETNIEGO NAWOŻENIA NAWOZEM NATURALNYM

Abstract: The objective of this study was to determine the selenium content in soil and its accumulation and distribution in winter wheat plants affected by organic fertilization. There was found a significant effect of FYM application on the total selenium in soil. A supplement of manure at the dose of 80 Mg · ha^{-1} resulted in the significantly highest increase of the total selenium content almost 50 % in soil, as compared with the soil from control plots. The total selenium content in soil was significantly correlated with organic carbon content. The highest selenium concentrations were observed in aboveground biomass of winter wheat gathered from plots treated with FYM with the doses of 20 and 40 Mg · ha^{-1}, which was about 70 % higher in comparison with the control plants. The application of manure in the dose of 80 Mg · ha^{-1} resulted in a decrease in the selenium content in aboveground wheat biomass. The bioaccumulation and translocation coefficients of selenium demonstrated that aboveground winter wheat biomass absorbed and transported selenium more easily from soil treated with FYM at the doses of 20 or 40 Mg · ha^{-1}. Both coefficients decreased considerably due to the highest doses of FYM.

Keywords: selenium, soil, winter wheat, organic fertilization

Selenium (Se) is considered as an essential trace element for humans, animals and plants. The concentration of this microelement in plants depends on the chemical form of it, its concentration and bioavailability in soils and on the accumulation capacity of the plant [1, 2]. Selenium is one of the trace elements strongly affected by microbiologically mediated redox processes affecting its solubility and, consequently, its mobility, bioavailability and uptake in the soil-plant system [3]. Although all the plants

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are able to take up and to metabolize selenium, the assumption about its necessity for plants has not been fully confirmed yet. Numerous studies have shown that at low concentrations Se exerts a beneficial effect promoting growth and increasing stress tolerance of plants by enhancing their antioxidative capacity, reducing lipid peroxidation and enhancing the accumulation of starch and sugars [4,5,6,7,8]. Higher plants vary in their capacity to accumulate and tolerate selenium and they are classified into non-accumulators, indicators and accumulators [9,10]. According to Whanger [11], the currently observed interest in selenium focuses on the health benefits of high-Se plants as a source of cancer-preventative Se compounds, for its unique role in recycling and delivering selenium from the soil to the food chain. In soils the natural total selenium content varies, ranging from 0.1 to 2 mg $\cdot$ kg^{-1}, however, in most agricultural areas, soils contain so little available selenium that crops usually do not absorb more than traces of this element. In many low-selenium countries the possibility of applying selenium fertilizer or foliar application of selenium to plants has been studied [5], however according to Stadlober et al [12], enhancing the selenium levels in crops is also possible by adding organic supplements of high level of selenium (sewage sludge, manure of selenium supplemented farm animals).

The objective of this study was to determine the selenium content in soil and its accumulation and distribution in winter wheat plants affected by organic fertilization.

Material and methods

Soil and plant samples were taken from a long-term static field experiment carried out since 1980 by the Department of Plant Nutrition of the Institute of Soil Science and Cultivation in Pulawy in the area of the Agricultural Experimental Station at Grabow on the Vistula River. Soil samples were collected in the 22nd year of the experiment, in May 2002, from the 0–20 cm layer in the winter wheat interrows (cv. Korweta). The experiment was designed in a split-plot with four replications on the 8 × 5 m (40 m^2) plots. The width of paths between the plots was 1 m. Crop rotation included: potato – winter wheat + intercrop – spring barley + undersown and red clover + grasses. The soil was treated with cattle *farmyard manure* (FYM) under potato in the doses of 0, 20, 40, 60 and 80 Mg $\cdot$ ha^{-1}. Soil samples were air-dried and sieved through a 2 mm screen. Plant material was sampled at the begging of the shooting stage into blade, rinsed in deionised water to remove soil particles, separated into aboveground biomass and roots, and dried. The total selenium content in soils and plants was determined using the method of Watkinson [13] with a Hitachi F-2000 spectrofluorometer. Samples were microwave digested with concentrated nitric (HNO_3) and perchloric ($HClO_4$) acids. Different forms of selenium in the samples were reduced by boiling with 10 % HCl. The selenium was complexed with 2,3-diaminonaphtalene (DAN) to give the fluorescent compound, which was extracted with cyclohexane and read on the spectrofluorometer at the excitation and emission wavelengths of λ = 376 and 519 nm, respectively. The analytical procedures provided satisfactory values for the standard reference material CRM024-050 Resource Technology Corporation (RTC), soil from the western part of the US of the loamy sand texture; Se 0.558 mg $\cdot$ kg^{-1} (certified value 0.540 mg $\cdot$ kg^{-1}).

The certified reference material was included in each batch of samples for quality control. The soil samples were analysed for granulometric composition according to Bouyoucos-Casagrande method, organic carbon – using wet oxidation with potassium dichromate, and pH in distilled water and 0.1M KCl – potentiometrically. All the analyses were performed in triplicate samples. The multireplication data from the analyses of soils and plants samples were evaluated using the statistical procedure. The analysis of variance for one-factore experiment in the split-plot design was made. The data were verified with the analysis of variance (ANOVA) and the Tukey test at $p < 0.05$. The analysis was facilitated with the use of Statistica for Windows software.

Results and discussion

The general properties of the soil under study are given in Table 1. The soil, according to the FAO classification, was classified as Haplic Luvisols and demonstrated the texture of loamy sand and sandy loam. The soil pH values were found in the slightly acidic range 5.7–6.2. The application of manure resulted in the highest amounts of organic carbon in soil, especially in soil from the plots fertilized with FYM with the doses of 60 and 80 $Mg \cdot ha^{-1}$.

Table 1

General properties and total selenium content in soil under study

Dose of manure [$Mg \cdot ha^{-1}$]	Soil particle size fraction [%]		pH in		C_{org} [$g \cdot kg^{-1}$]	Se_{tot} [$mg \cdot kg^{-1}$]
	< 0.02 [mm]	< 0.002 [mm]	H_2O	KCl		
0	18	7	6.2	5.8	8.6	0.099
20	16	7	6.2	5.8	9.9	0.171
40	17	6	6.0	5.7	10.3	0.179
60	18	6	6.2	5.8	10.6	0.184
80	15	5	6.2	5.8	11.1	0.191
						$LSD_{0.05}$ 0.010

The selenium content from the control plots ranged from 0.086 to 0.117 $mg \cdot kg^{-1}$ (average 0.101 $mg \cdot kg^{-1}$) (Table 1). Statistical analyses confirmed that the FYM application resulted in the highest amounts of total selenium content in soil (Table 1), which increased with increasing doses of manure. The soil fertilized with the highest dose of manure showed a two-fold higher rate of total selenium than the soil from the control plots, which could have been due to the amount of this microelement in farmyard manure since, as reported in literature, in various FYM the selenium content varies from 0.32 to 2.4 $mg \cdot kg^{-1}$ [14, 15]. According to Kabata-Pendias [7], the mean total selenium content in the soils worldwide is estimated as 0.44 $mg \cdot kg^{-1}$, while its background contents in various soil groups range from 0.05 to 1.5 $mg \cdot kg^{-1}$ being the lowest in Podzols and the highest in Histosols. Aro and Alfthang [16] and Hartikainen

[6] claim that soils containing less than 0.5 mgSe · kg^{-1} are likely to lead to crops and pastures with inadequate selenium concentrations (< 0.05 mg · kg^{-1} d.m.). The total selenium content in soil under study was significantly correlated with the organic carbon content, which coincides with our earlier findings [17] and those reported by other authors [7,14,18]. Navarro-Alarcon and Cabrera-Vique [19] report on selenium levels in soil generally being reflected in food and the Se levels in human populations. Se food content is influenced by the geographical location, seasonal changes, protein content and food processing. In the present study the average selenium content in upper parts of winter wheat from control plots reached 0.133 mg · kg^{-1} d.m. (Fig. 1). There were observed the highest selenium concentrations in aboveground parts of winter wheat from the plots treated with the doses of 20 and 40 Mg · ha^{-1}, the Se content increased on average above 70 % against the control. The application of manure in the doses of 60 or 80 Mg · ha^{-1} resulted in the decrease in selenium content in aboveground biomass of winter wheat. The selenium content in winter wheat roots from the control plots was on average above 30 % higher than from the FYM plots (Fig. 1).

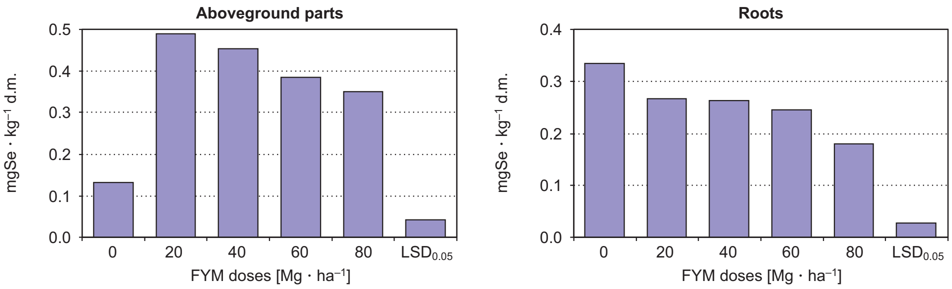

Fig. 1. Selenium content in winter wheat aboveground parts and roots

The value of bioaccumulation coefficient (BC) reflects plant capacity for the nutrients uptake from soil and informs about the amount and the rate of the nutrient translocation from soil solution to aboveground plant parts [20, 21]. The parameter is a ratio of the element concentration in plant aboveground parts or roots to its amount in soil. The bioaccumulation coefficients (BC) of selenium demonstrated that aboveground parts of winter wheat absorbed selenium more easily from soil of the control plots or from soil treated with FYM in the doses of 20 and 40 Mg · ha^{-1} (Fig. 2). The bioaccumulation coefficient (BC) decreased considerably as a result of the highest doses of manure. The highest selenium absorption in winter wheat roots was observed in the plants from plots without FYM (Fig. 2). The FYM application resulted in a 5-fold decrease in selenium bioaccumulation by winter wheat roots, as compared with the no-manure treatment. The distribution of selenium in various parts of the plant differs according to the species, its phase of development and its physiological conditions [9]. In Se-accumulators, Se is accumulated in young leaves during the early vegetative stage of growth, however at the reproductive stage, high levels of selenium were found in seeds, while the Se content in leaves is reduced [22]. The selenium concentration in grain and roots of cereal plants is often the same level, with lower amounts in the stems

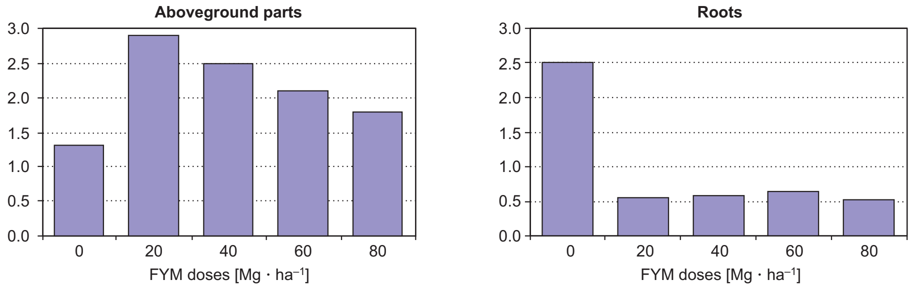

Fig. 2. Bioaccumulation of selenium in aboveground parts and roots of winter wheat in relation to its content in soil

and leaves. Zayed et al [23] report on the distribution of selenium in plants also depending on the form and the concentration of selenium supplies to the roots and on the nature and concentration of other ions, especially sulphates and on the degree of Se fixation in soils. Plants absorb Se easily from alkaline soils, where it often exists in water-soluble forms. Although acid soils may contain high selenium concentrations, plants assimilate only small amounts since Se is bound by insoluble iron compounds or by organic matter of soil [18]. According to Terry et al [20], since selenium and sulphur share similar properties, the Se compounds are absorbed and metabolized by mechanisms similar to those for S analogues. Soluble Se forms are likely to be taken up by plants – selenates and organic selenium are driven metabolically, however the uptake of selenites can be a result of passive mechanism. In general, organic Se is more readily absorbed by plants than inorganic forms. On the other hand, selenates are likely to be easily transported to aboveground parts than selenite or organic species (*eg* SeMet) [7].

The value of *translocation coefficient* (TC) informs about the amount and the rate of element translocation from roots to plant aboveground parts. The parameter is a ratio of the element concentration in aboveground plant parts to its amount in roots. Translocation coefficients (BC) demonstrated that selenium is more easily transported from roots to aboveground parts of plants on the plots with the rate of FYM application of 20 and 40 $Mg \cdot ha^{-1}$ (Fig. 3). The translocation of Se from root to shoot depends on the form of Se supplied, selenate being transported much more easily than selenite [9]. Munier-Lamy et al [21] observed the differences in transporting Se from roots to shoots between plant species, which could be related either to the root system, *ie* to soil exploration by roots and root exudation, or to the chemical conditions resulting of microbial activity in the rhizosphere. Indeed, some microorganisms may excrete organic compounds that increase bioavailability, and facilitate root absorption of essential metals, such as Fe as well as non-essential metals, such as Cd. Soil microorganisms can also affect metal solubility directly by changing their chemical forms. When Se is supplied as selenate to plants, Zayed et al [23] report on most of it being transported to the shoots unchanged with very little Se remaining in roots, which seems to suggest a reduction in selenate to selenium organic forms, which are less available in soil.

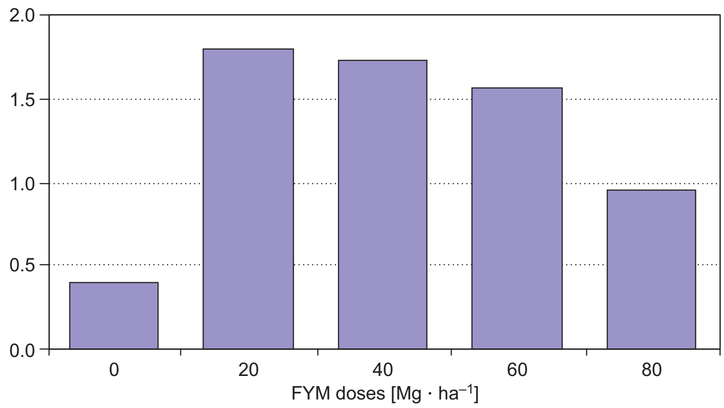

Fig. 3. Translocation of selenium from roots to aboveground parts of winter wheat

Conclusions

1. There was found a significant effect of FYM application on the total selenium content in the soil investigated. A supplement of manure at the dose of 80 Mg · ha^{-1} resulted in the significantly highest increase in total selenium content (almost 50 %) in soil, as compared with the control soil. The total selenium content in soil was significantly correlated with the organic carbon content.

2. There were observed the highest selenium concentrations in the upper parts of winter wheat from the plots treated with FYM with the doses of 20 and 40 Mg · ha^{-1}, namely about 70 % higher in comparison with the control plants. The FYM application in the dose of 80 Mg · ha^{-1} resulted in a decrease in the selenium content in aboveground parts of wheat.

3. The bioaccumulation and translocation coefficients of selenium demonstrated that aboveground biomass of winter wheat absorbed and transported selenium more easily from soil treated with FYM at the doses of 20 or 40 Mg · ha^{-1}. Both coefficients decreased considerably due to the highest doses of FYM.

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Abstrakt: Celem badań było określenie zmian zawartości selenu w glebie i roślinach pszenicy ozimej po wieloletniej aplikacji nawozu naturalnego. Wykazano istotny wpływ nawożenia obornikiem na zawartość selenu w glebie. Aplikacja obornika na poziomie 80 Mg · ha^{-1} istotnie zwiększyła zawartość tego mikroelementu o prawie 50 % w odniesieniu do jego zawartości w glebie z obiektu kontrolnego. Zawartość selenu ogółem w glebie była istotnie dodatnio skorelowana z zawartością węgla organicznego. Najwyższą zawartość selenu w nadziemnych częściach pszenicy ozimej wykazano na obiektach, na których obornik stosowano w dawce 20 i 40 Mg · ha^{-1}, w porównaniu z roślinami kontrolnymi. Po zastosowaniu obornika w tych dawkach zawartość selenu wzrosła o ponad 70 %. Aplikacja obornika w dawce 80 Mg · ha^{-1} spowodowała natomiast istotne obniżenie zawartości tego pierwiastka w częściach nadziemnych pszenicy.

Słowa kluczowe: selen, gleba, pszenica ozima, obornik