ECOLOGICAL CHEMISTRY AND ENGINEERING A

Vol. 18, No. 3 2011

Ewa STANISŁAWSKA-GLUBIAK[1]
and Jolanta KORZENIOWSKA[1]

TOLERANCE OF WHITE MUSTARD (*Sinapsis alba* L.) TO SOIL POLLUTION WITH SEVERAL HEAVY METALS

TOLERANCJA GORCZYCY BIAŁEJ NA SKAŻENIE GLEBY WYBRANYMI METALAMI CIĘŻKIMI

Abstrakt: A strict experiment on simulated copper, zinc and nickel soil contamination has been performed in concrete-framed microplots, 1 m^3 in capacity.

White mustard proved to be the most sensitive to nickel contamination of soil and most tolerant to excess copper in the substrate. The concentration of nickel in aerial parts of white mustard increased up to 30-fold, whereas the level of copper was twice as much as in the control. The translocation factors computed for the analysed metals in plants showed that copper was the least transferable from roots to shoots and, as its level rose, increasing quantities of this metal were retained in roots. At higher rates of nickel pollution in soil, white mustard transferred more of this metal to shoots. White mustard is only suitable for phytostabilisation of soils moderately contaminated with copper.

Keywords: soil pollution, Cu, Ni, Zn, phytoremediation, *Sinapsis alba* L.

Phytoremediation, ie recultivation treatments involving plants, is one of the measures taken to remediate soils polluted with heavy metals. One of the phytoremediation techniques is phytostabilisation, which relies on planting contaminated land with plants which are tolerant to high concentrations of toxic substances and can transport considerable amounts of pollutants to their aerial organs. The purpose of phytostabilisation is to lower bioavailability of contaminants occurring in soil, to protect the contaminated soil from further degradation and to reduce the risk of immediate contact of humans and animals with contaminants. Another phytoremediation technique, which attracts much attention and is an object of intensive worldwide research is phytoextraction, ie removal of heavy metals from polluted soils. In this process, plants take up heavy metals through their roots and transport them to shoots, where the pollutants are accumulated. Then the biomass is harvested and processed. For phytoextraction to

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[1] Institute of Soil Science and Plant Cultivation – National Research Institute in Pulawy Department of Weed Science and Tillage Systems in Wrocław, ul. Orzechowa 61, 50–540 Wrocław, Poland, phone: +48 71 71 363 87 07, email: e.glubiak@iung.wroclaw.pl

be effective, plants must be highly tolerant to high levels of heavy metals in soil and be able to absorb large amounts of such pollutants per surface area unit. High uptake of metals, in turn, depends primarily on an appropriately high green matter harvest or a very high concentration of a given element in the plant, that in on the level of the so-called hyperaccumulation. Much research is conducted with an aim of finding plant species that will fulfil these conditions, including studies on plants belonging to the family *Brassicaceae* [1–5], which are considered to be tolerant to excessive quantities of heavy metals in substratum, although their tolerance to particular metals varies [6]. This paper discusses tolerance to white mustard (*Sinaspis alba* L.), of the family *Brassicaeae*, to soil contamination with copper, nickel and zinc.

Material and methods

A strict microplot experiment, designed as completely randomised trials with 4 replications, has been conducted on three white mustard cultivars: Barka, Rota and Tango. Concrete-framed 1 × 1 × 1 m microplots, set below the ground level, were filled, in the top 0–30 cm horizon, with Haplic Luvoisols soil (pH_{KCl} = 5.5; fraction < 0.02 mm: 16 %; C_{org}: 0.8 %), containing 75 $mg \cdot kg^{-1}$ P i 160 $mg \cdot kg^{-1}$ K and 50 $mg \cdot kg^{-1}$ Mg.

Simulated soil contamination with copper, zinc and nickel was applied according to the following design: 1) control, 2) Cu_1 – 50 $mg \cdot kg^{-1}$, 3) Cu_2 – 100 $mg \cdot kg^{-1}$, 4) Cu_3 – 200 $mg \cdot kg^{-1}$, 5) Zn_1 – 200 $mg \cdot kg^{-1}$, 6) Zn_2 – 400 $mg \cdot kg^{-1}$, 7) Zn_3 – 800 $mg \cdot kg^{-1}$, 8) Ni_1 – 40 $mg \cdot kg^{-1}$, 9) Ni_2 – 80 $mg \cdot kg^{-1}$, 10) Ni_3 – 160 $mg \cdot kg^{-1}$. The metals in the form of sulphates were dissolved in water and applied to plots using a watering can. The metals were first introduced to the 15–30 cm layer and mixed with soil. Next, they were added to the 0–15 cm layer and also thoroughly mixed. White mustard was sown after 3 weeks and grown until the early flowering stage.

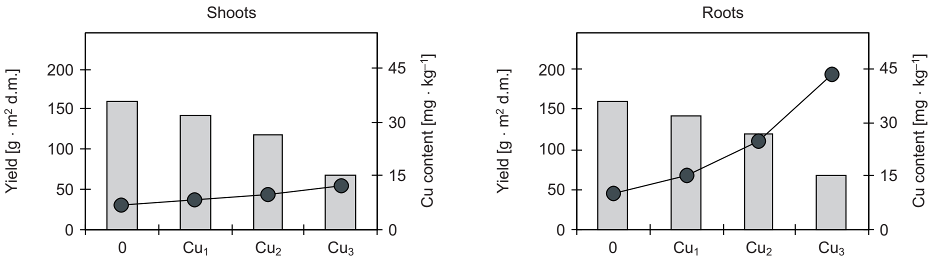
After harvesting the plants, average plot samples of shoots and roots of plants from each cultivar were taken to analyse the concentration of Cu, Zn and Ni, using the AAS technique after dry mineralisation of the samples in a muffle furnace and dilution in hydrochloric acid.

The results of the chemical analyses are given as means from 3 cultivars.

The data on yields of white mustard are means for the three cultivars, too. However, in the statistical computations, each experimental object is represented by 12 replications (4 replications for each cultivar × 3 cultivars).

Results and discussion

White mustard responded to soil pollution by depressing the dry matter yields, with the actual decrease depending on the metal causing pollution. For soil contaminated with Cu (Fig. 1), statistically significant decrease occurred at the level of 100 and 200 $mg \cdot kg^{-1}$ (Cu_2 and Cu_3), reaching 25 % and 60 %, respectively, relative to the control yield. As the yield was on the decrease, the concentration of Cu in shoots increased from 6.8 to 12.2 $mg \cdot kg^{-1}$ d.m., that is two-fold higher at the most compared with the uncontaminated object. Plants accumulated more Cu in roots than in shoots (Fig. 1). Other authors have also found out that crop roots accumulate more copper than shoots [7, 8]. Studies on phytotoxicity of copper towards crops typically indicate lack of relationship between yield loss caused by excessive copper in soil and copper concentration in crop shoots, which is frequently within the optimum range [9–13]. McBride [14] demonstrated that the content of copper in maize shoots increased as the rates of copper went up, but only to a certain level, after which increasing soil contamination with copper corresponded to small increments of copper levels in shoots.

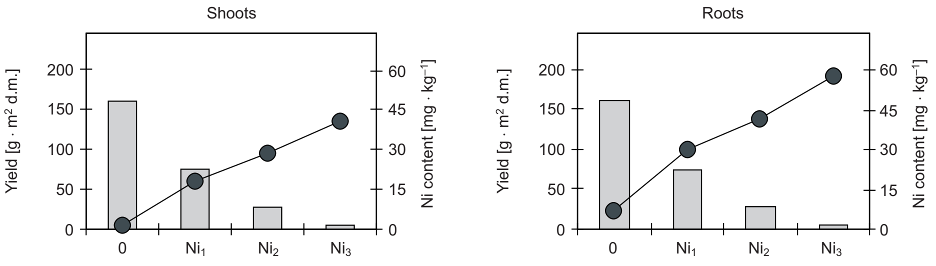


	0	Cu_1	Cu_2	Cu_3
—●—	a	a	ab	b
■	b	b	ba	a

	0	Cu_1	Cu_2	Cu_3
—●—	a	ab	b	c
■	b	b	ba	a

Fig. 1. Content of copper in the dry matter of shoots and roots (line) against the background of the biomass (bars). Identical letters in the table denote lack of differences tested with Tukey's test ($p < 0.05$)

The negative effect of nickel on white mustard consisted of a 50 and 80 % loss of plant yields at 40 and 80 mg · kg^{-1} of nickel added to soil (Ni_1 and Ni_2). At the highest rate of nickel, the plants nearly completely died out (Fig. 2). The concentration of this element in shoots increased, depending on the dose of nickel, by about 10-, 20- and 30-fold relative to the control, reaching 41 mg · kg^{-1} d.m. for the Ni_3 polluted object. Increasing soil pollution with nickel also caused an increasing accumulation of this metal in roots, which was about 1.5-fold higher than in shoots (Fig. 2). Spiak [15] demonstrated that at a rate of Ni equal 80 mg · kg^{-1} and a loss of green mass produced by field pea and horse bean reaching over 80 %, the concentration of nickel in field pea increased 48-fold and in horse bean – 75-fold versus the control. In contrast, millet, which contained 27-fold more nickel in green matter, did not lower yields in response to soil contamination with this metal. Ciecko and Wyszkowski [16] found a 5 % loss of oats and maize yield when 30 mg · kg^{-1} of nickel was introduced to soil, with the amount of nickel in green matter increasing 15-fold in oats and 20-fold in maize. According to Kabata-Pendias and Pendias [6], nickel is a very mobile element and can readily transfer to aerial parts of plants, especially to seeds or grains. Poulik [17] determined a 5–11 % increase in the concentration of nickel in oats grain on soil contaminated with this element. The above studies suggest that, irrespective of the toxicity of nickel to a given crop species, the metal is easily transported to the parts of plants above the ground.

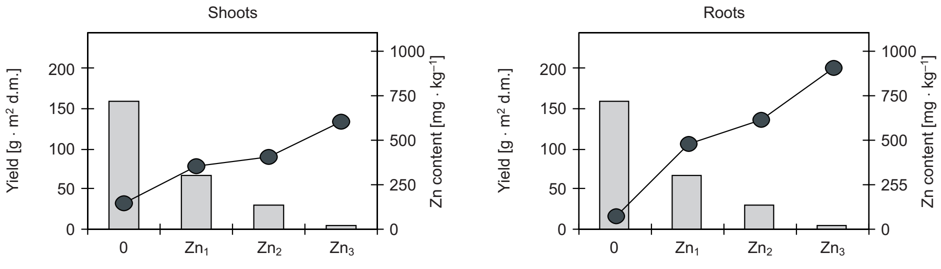


	0	Ni_1	Ni_2	Ni_3
—●—	a	b	bc	c
■	c	b	ba	a

	0	Ni_1	Ni_2	Ni_3
—●—	a	b	c	d
■	c	b	ba	a

Fig. 2. Content of nickel in the dry matter of shoots and roots (line) against the background of the biomass (bars). Identical letters in the table denote lack of differences tested with Tukey's test ($p < 0.05$)

Contamination of soil with zinc added at 200 and 400 mg · kg^{-1} (Zn_1 and Zn_2) resulted in a 60 and 80 % decrease of biomass yields, respectively, as well as nearly complete loss of plants when the highest rate of Zn_3 (800 mg · kg^{-1}) was applied (Fig. 3). White mustard growing on the zinc contaminated objects accumulated the metal in shoots at levels 2- to 4-fold higher than on the control objects. The roots, in turn, were found to contain 6- to 12-fold more zinc than roots of control plants (Fig. 3). When the soil contamination with zinc reached 200 mg · kg^{-1}, the concentration of zinc in shoots rose from 148 to 360 mg · kg^{-1} d.m. the pot experiments performed by Spiak et al [18] evidenced that the amount of 120 mg Ni · kg^{-1} of light soil is harmful to mustard. The concentration of Zn observed under such conditions was 100–300 mg · kg^{-1} d.m. In the pot trials conducted by Wrobel and Nowak [19], high yield loss of mustard growing on light soil was observed as a response to the concentration of zinc in the substratum equal 150 mg · kg^{-1}. The concentration of Zn in shoots was about 2000 mg · kg^{-1} d.m.



	0	Zn_1	Zn_2	Zn_3
—●—	a	b	bc	c
■	c	b	ba	a

	0	Zn_1	Zn_2	Zn_3
—●—	a	b	c	d
■	c	b	ba	a

Fig. 3. Fig. 3. Content of zinc in the dry matter of shoots and roots (line) against the background of the biomass (bars). Identical letters in the table denote lack of differences tested with Tukey's test ($p < 0.05$)

In this study, similarly to the work presented by Marchiol et al [3], the so-called translocation factor (TF = $(C_{aerial}/C_{root}) \cdot 100$) was used to determine the ability of white mustard to transfer metals from roots to aerial parts (Table 1).

Table 1

Translocation factor of metals [TF = $(C_{aerial}/C_{root}) \cdot 100$]
calculated for plants of *Sinapsis alba* L.

Contamination level	Metal		
	Cu	Ni	Zn
0	68.7	22.7	197.3
1	54.7	59.7	74.7
2	40.8	68.5	75.8
3	28.2	70.7	66.6
Mean	48.1	55.4	103.6

Most translocation factors have suggested that, out of the three heavy metals examined, copper was most unreadily transferred from roots to shoots. At the same time, as the level of soil pollution with copper increased, more of this metal was kept in roots. In contrast, when the soil contamination of nickel increased, white mustard was able to transfer more of this metal to shoots. By analogy, in the pot trials completed by Gupta et al [20], plants of *Brassica juncea* (L.) accumulated heavy metals in aerial part in the following order: Ni > Zn > Cu.

Plants are generally tolerant to high levels of copper in soil. Kabata-Pendias and Pendias [6] claim that *Brasssicaceae* are tolerant to excessive amounts of nickel in soil. In the present study, it was excess nickel that proved to be the most harmful to white mustard of the three metals. The yield gathered at 160 mg Ni $\cdot$ kg^{-1} was barely 4 % of the control yield, whereas at the level of contamination with copper or zinc equal 200 mg $\cdot$ kg^{-1} slightly over 40 % of the dry matter yield was harvested compared with the uncontaminated objects. White mustard, therefore, was comparably tolerant to excess zinc and copper in soil, although it could more easily transport zinc than copper to shoots.

Nonetheless, when confronted with the threshold value, which define the degree of soil contamination with trace metals [21], white mustard was weakly tolerant event to the lowest degree of soil pollution with nickel and zinc (to so-called raised content), or to the moderate contamination with copper.

Conclusions

1. White mustard (*Sinapsis alba* L.), of the family *Brassicaceae*, growing in soil polluted with copper, nickel and zinc proved to be more tolerant to excess copper and the most sensitive to raised quantities of nickel in the substratum.

2. Using white mustard for remediation of soil contaminated with copper is feasible at the most under a moderate level of soil contamination with this metal.

3. Due to insufficiently low white mustard biomass, it is impossible to use this crop for phytoextraction. However, white mustard can be considered for phytostabilisation of soil contaminated with copper, owing to its ability to retain this element in the roots.

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TOLERANCJA GORCZYCY BIAŁEJ NA SKAŻENIE GLEBY WYBRANYMI METALAMI CIĘŻKIMI

Instytut Uprawy Nawożenia i Gleboznawstwa – Państwowy Instytut Badawczy w Puławach,
Zakład Herbologii i Technik Uprawy Roli we Wrocławiu

Abstrakt: Przeprowadzono doświadczenie ścisłe w obetonowanych mikropoletkach, o pojemności 1 m^3, z symulowanym zanieczyszczeniem gleby miedzią, cynkiem oraz niklem.

Gorczyca biała okazała się najbardziej wrażliwa na zanieczyszczenie gleby niklem, a najbardziej tolerancyjna na nadmiar miedzi w podłożu. Zawartość niklu w częściach nadziemnych wzrastała nawet trzydziestokrotnie, podczas gdy zawartość miedzi zaledwie dwukrotnie w stosunku do kontroli. Na podstawie obliczonych współczynników translokacji badanych metali w roślinie stwierdzono, że miedź najtrudniej przemieszczała się z korzeni do pędów i wraz ze wzrostem poziomu zanieczyszczenia gleby była zatrzymywana w korzeniach w coraz większym stopniu. W przypadku wzrastającego poziomu zanieczyszczenia gleby niklem gorczyca przemieszczała ten pierwiastek w coraz większym stopniu do pędów. Gorczyca biała nadaje się do wykorzystania jedynie w procesie fitostabilizacji gleb średnio zanieczyszczonych miedzią.

Słowa kluczowe: zanieczyszczenie gleby, Cu, Ni, Zn, fitoremediacja, gorczyca biała