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Monika TABAK[1*] and Olga GORCZYCA[1]

CONTENT OF NICKEL IN MAIZE AND SOIL FERTILIZED WITH ORGANIC MATERIALS DERIVED FROM WASTE

ZAWARTOŚĆ NIKLU W KUKURYDZY I GLEBIE NAWOŻONEJ MATERIAŁAMI ORGANICZNYMI POCHODZENIA ODPADOWEGO

Abstract: The research was conducted to determine the influence of fertilization with waste organic materials on the content and uptake of nickel by maize as well as on the total nickel content in soil. The three-year field experiment comprised 7 treatments: a non-fertilized soil (control treatment) and a soil fertilized with mineral fertilizers, cattle manure, green waste compost, sewage sludge, compost from sewage sludge and straw as well as with a mixture of sewage sludge and hard coal ash. The content of nickel in the above-ground parts of plants and in the soil was determined using ICP-AES method.

During the research no nickel pollution of the plants and soil was found. A significant increase in the element content in maize as a result of fertilization was found only in the 2nd year of the research, after fertilization with mineral fertilizers. In the 1st year, the plants fertilized with the compost from sludge and straw, and in the 3rd year all the fertilized plants contained significantly less nickel than the control plants. Maize fertilized with the mixture of sludge and ash had the highest mean weighted nickel content. The total nickel uptake from the fertilized soil was higher than the uptake from the control soil. The soil fertilized with the green waste compost and the soil fertilized with the mixture of sludge and ash contained significantly more nickel than the non-fertilized soil.

Keywords: waste organic materials, sewage sludge, compost, nickel, trace elements

Physiological role of nickel is connected with, among other things, its occurrence in hydrogenases and in urease [1, 2]. Since nickel is indispensable for proper functioning of urease (an enzyme which breaks down urea to ammonia and carbon dioxide), an adequate supply of nickel is important during soil fertilization with urea. Follmer [3] draws attention also to the participation of urease in the processes of defense against phytopathogens. Moreover, nickel also plays a role in the processes of iron uptake and

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[1] Department of Agricultural and Environmental Chemistry, University of Agriculture in Krakow, al. A. Mickiewicza 21, 31–120 Kraków, Poland, phone: +48 12 662 4348, +48 12 662 4341, fax: +48 12 662 43 41, email: Monika.Tabak@ur.krakow.pl,o.gorczyca@ur.krakow.pl

* Corresponding author: Monika.Tabak@ur.krakow.pl

atmospheric nitrogen fixation [2]. Growth inhibition and leaf necrosis are symptoms of nickel deficiency [1, 2]. In animals and humans, nickel deficiency results in a decrease in the level of hemoglobin in blood, disorders in functions of the epidermis and in pigmentation, impairment of liver functions [4].

In the case of living organisms, not only deficiency of trace elements is harmful, but also their excess. Excess of nickel leads to chlorosis (caused by disordered iron uptake), it also causes disturbance in the course of the processes of atmospheric nitrogen fixation, photosynthesis, transpiration [4]. In animals and humans, exposure to nickel can be a cause of allergy; mutagenic and carcinogenic effects of nickel have also been found. The danger of environmental pollution with trace elements occurs, among other things, during fertilization with organic materials derived from waste.

The research was conducted to determine the influence of fertilization with waste organic materials on the content and uptake of nickel by maize as well as on the total nickel content in soil.

Material and methods

The 3-year field experiment was set up in 2008 at an experimental station of the University of Agriculture in Krakow and was continued in the next two years. The experiment was conducted on brown soil, with graining of light soil. It was an acid soil (pH_{KCl} = 5.40), which had a very high content of available phosphorus and potassium (94.9 mgP and 219.2 mgK $\cdot$ kg^{-1} d.m.). The soil contained 9.88 $gC_{organic} \cdot kg^{-1}$ d.m., 1.07 $gN_{total} \cdot kg^{-1}$ d.m., and 5.00 $mgNi_{total} \cdot kg^{-1}$ d.m. The content of trace elements in the soil did not exceed the limit values established for agricultural use of sewage sludge, neither did the pH_{H2O} value of the soil make fertilization with sewage sludge impossible – this applies to the values which were in effect during the field experiment [5, 6] and the values which are in effect now [7].

The experiment comprised 7 treatments: a non-fertilized soil (control) as well as a soil fertilized with mineral fertilizers, cattle manure, green waste compost, municipal sewage sludge, compost from sewage sludge and straw as well as with a mixture of sewage sludge and ash. Each treatment was carried out in 4 replications. Pioneer maize PR 39F58 was the test plant in all years of the research and it was grown for silage. In the first year, 160 kgN, 168 kgP_2O_5 and 140 $kgK_2O \cdot ha^{-1}$ were introduced to the soil of fertilized treatments (except the control). To the soil fertilized with manure and organic materials, the whole nitrogen dose was introduced in the mentioned fertilizer and materials. Mineral fertilizers (ammonium nitrate 34 % N, enriched superphosphate 40 % P_2O_5 and potassium chloride 60 % K_2O) were used in order to introduce nutrients to the soil fertilized with mineral fertilizers as well as to even up the doses of phosphorus and potassium in the soil of the remaining fertilized treatments. These fertilizers were also used to conduct fertilization in the second and third years of the experiment, introducing 100 kgN, 30 kgP_2O_5 and 110 $kgK_2O \cdot ha^{-1}$ to the soil each year. Detailed data regarding conditions of conducting the experiment are included in the papers of Tabak and Filipek-Mazur [8, 9].

The content of trace elements in the organic materials used for fertilization did not exceed the limit values established for agricultural use of sewage sludge [5–7]. Table 1 shows nickel content in the manure and in the organic materials used for fertilization as well as doses of nickel introduced to the soil with manure and these materials.

Table 1

Nickel content in manure and in organic materials as well as doses of nickel introduced to soil with manure and materials

Material	Content [mgNi · kg^{-1} d.m.]	Dose [gNi · ha^{-1}]
Manure	4.49	25
Green waste compost	8.59	95
Sewage sludge	13.17	104
Compost from sewage sludge and straw	11.64	76
Mixture of sewage sludge and ash	15.43	170

The sewage sludge and the materials containing it had more of that element than the manure and the green waste compost. The highest nickel content was found in the mixture of sewage sludge and ash (15.43 mgNi · kg^{-1} d.m.), and with that mixture the biggest dose of the element (170 gNi · ha^{-1}) was introduced to the soil.

After harvest, the plant material was dried at a temperature of 70 ^{o}C in a hot air dryer and milled. Then it was mineralized in a muffle furnace (8 h, 450 ^{o}C), evaporated with hydrochloric acid solution, and the remains were diluted in nitric(V) acid solution [10]. The total nickel content in the air-dry soil sieved through a 1 mm mesh sieve was determined after incineration in a furnace (8 h, 450 ^{o}C), evaporation with a mixture of concentrated nitric(V) and chloric(VII) acids, and dilution of the remains in hydrochloric acid [10]. The nickel content in the above-ground parts of maize and in the soil was determined with inductively coupled plasma atomic emission spectrometry (ICP-AES) on JY 238 Ultrace apparatus (Jobin Yvon).

Statistica software, version 10 (StatSoft, Inc.), was used for statistical elaboration of the results. A univariate analysis of variation was carried out, and the significance of differences between the mean values was estimated using the Duncan test ($\alpha \le 0.05$).

Results and discussion

During the research, no nickel pollution of the above-ground parts of maize was found. Between 0.47 and 1.15 mgNi · kg^{-1} d.m. was determined in the plant material (Table 2), whereas the permissible content for plants intended for feed was established by Kabata-Pendias et al [11] to be 50 mgNi · kg^{-1} d.m.

The danger of considerable accumulation of nickel in the above-ground parts of maize is low as this plant stores collected trace element mainly in roots [12, 13].

A significant increase in the nickel content in maize as a result of fertilization was found only in the 2nd year of the research – maize fertilized with mineral fertilizers

Table 2

Nickel content in above-ground parts of maize [mgNi · kg^{-1} d.m. ± SD]

Treatment	1st year	2nd year	3rd year	Weighted mean content
No fertilization	$0.80^{bc*} \pm 0.12$	$1.02^{a} \pm 0.06$	$0.69^{d} \pm 0.03$	0.83
Mineral fertilizers	$0.74^{b} \pm 0.12$	$1.15^{b} \pm 0.04$	$0.51^{ab} \pm 0.03$	0.82
Manure	$0.72^{ab} \pm 0.06$	$1.11^{ab} \pm 0.08$	$0.54^{abc} \pm 0.03$	0.81
Green waste compost	$0.71^{ab} \pm 0.09$	$1.10^{ab} \pm 0.13$	$0.55^{bc} \pm 0.06$	0.80
Sewage sludge	$0.70^{ab} \pm 0.08$	$1.05^{ab} \pm 0.08$	$0.47^{a} \pm 0.06$	0.77
Compost from sewage sludge and straw	$0.58^{a} \pm 0.06$	$1.05^{ab} \pm 0.09$	$0.48^{ab} \pm 0.07$	0.71
Mixture of sewage sludge and ash	$0.93^{c} \pm 0.09$	$1.12^{ab} \pm \leq 0.00$	$0.59^{c} \pm 0.04$	0.90

* Mean values in columns marked with the same letters do not differ statistically significantly at $\alpha \leq 0.05$, according to the Duncan test; SD – standard deviation.

contained 13 % more nickel than the non-fertilized plants. In the 1st year, the plants fertilized with the compost from sludge and straw, and in the 3rd year all the fertilized plants contained significantly less nickel than the plants gathered from the control. It should be explain by accumulation of the element in the low yield of maize harvested from the control (a negative effect of the lack of fertilization on the amount of maize yield was found particularly in the second and third years of the research [9]). Maize fertilized with the mixture of sludge and ash was characterized by the highest mean weighted nickel content (by 8 % higher than the one found in maize gathered from the control treatment), whereas only plants fertilized with that mixture had a higher mean nickel content than the content determined in the non-fertilized plants.

Bibliographic data indicate a possibility to increase nickel content in plants fertilized with organic materials derived from waste. Such a relation was shown by, among others, Bhattacharyya et al [14] who grew rice on soil treated with municipal solid waste compost. Differently than in own research, Akdeniz et al [15] found an increase in nickel content in sorghum leaves as a result of fertilization with sewage sludge (however, content of the element in grains did not change after fertilization).

The amount of an element taken up with plant yield is a product of the content of that element in the yield and the size of that yield. In own research, dry matter yield from the above-ground parts of the fertilized plants was always higher than the yield harvested from the control treatment – depending on year and object of the research, the increase in yield as a result of fertilization reached between 9 and 88 % [9]. In consequence, despite a relatively high content of the component in the control plants, nickel uptake from the fertilized soil was generally higher than from the soil of the control treatment (particularly in the 1st and 2nd years of the research) (Fig. 1).

During three years of the research, the non-fertilized plants took up 38.0 g Ni · ha^{-1}. Total nickel uptake from the fertilized soil was higher by 13–47 % than the uptake from the control soil (the highest from the soil fertilized with mineral fertilizers, manure, green waste compost, and the mixture of sludge and ash).

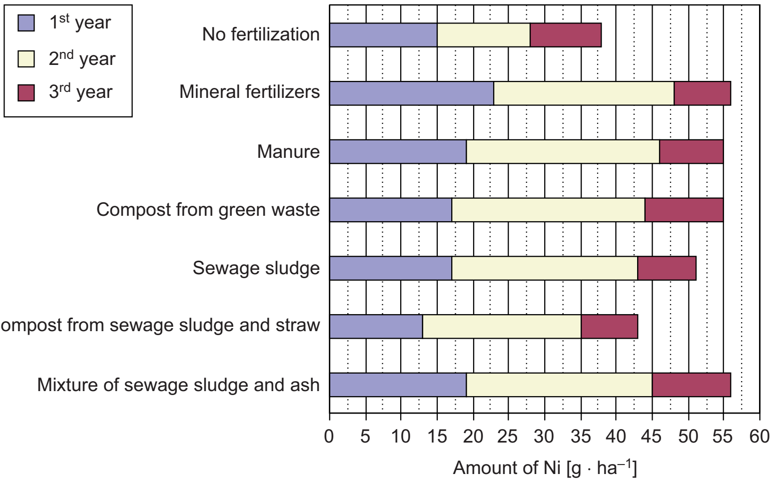

Fig. 1. Amount of nickel taken up by maize

Soil from the experimental field contained between 4.0 and 5.71 mg Ni · kg^{-1} d.m. (Table 3).

Table 3

Content of total forms of nickel in soil [mg Ni · kg^{-1} d.m. ± SD]

Treatment	1st year	2nd year	3rd year
No fertilization	4.36^{a}* ± 0.48	4.15^{ab} ± 0.06	4.26^{ab} ± 0.36
Mineral fertilizers	4.04^{ab} ± 0.74	4.03^{a} ± 0.52	4.10^{a} ± 0.58
Manure	5.08^{abc} ± 0.87	5.16^{d} ± 0.24	5.04^{bc} ± 0.22
Green waste compost	5.36^{bc} ± 0.76	5.33^{d} ± 0.46	5.21^{c} ± 0.59
Sewage sludge	5.00^{abc} ± 0.65	5.00^{cd} ± 0.29	4.84^{abc} ± 0.66
Compost from sewage sludge and straw	4.68^{abc} ± 0.53	4.53^{bc} ± 0.68	4.66^{abc} ± 0.68
Mixture of sewage sludge and ash	5.71^{c} ± 0.05	5.41^{d} ± 0.05	5.37^{c} ± 0.22

* See Table 2; SD – standard deviation.

No soil pollution with nickel was detected in any year of the research, because, as specified by Kabata-Pendias et al [16], natural nickel content in medium soil (which was examined in the own experiment) is up to 25–50 mg · kg^{-1} d.m., depending on soil pH values. Neither did the nickel content in the soil from the experimental field exceed the permissible level for soils of agricultural lands, established in the regulation on soil and earth quality standards [17] and amounting to 100 mgNi · kg^{-1} d.m. In addition, the nickel content was several times lower than the permissible content in soil, established for fertilization use of sewage sludge and amounting to 35 mgNi · kg^{-1} d.m. [7].

In all years of the research, the soil fertilized with the green waste compost as well as with the mixture of sludge and ash contained significantly more nickel than the non-fertilized soil. Depending on treatment and year of the research, that content was higher by 22–31 %.

When studying the effect of fertilization with composts from municipal sewage on nickel content in soil, Weber et al [18] generally did not show a statistically significant effect of the applied fertilization on the content of the element. Only application of a large dose of compost from municipal sewage from a strongly industrialized area led to an increase in nickel content in soil, although this effect occurred only in the year when the compost was used. Different results were obtained in own research where the green waste compost was used for fertilization. Wolejko et al [19], who used sewage sludge on city soils, found an increase in nickel content in the humus level (when comparing with the geochemical background value), although not to a content that would indicate soil pollution, according to Polish law. Antonkiewicz et al [20], who used a mixture of sewage sludge and fly ash for fertilization, did not find any changes in nickel content in soil. Own observations do not confirm these results.

When summarizing the presented results of own research, it should be emphasized that only soil fertilization with the mixture of sewage sludge and hard coal ash led to an increase in the nickel content in maize and soil. However, this effect was noticeable only in some years of the research, and fertilization with the mixture never led to pollution of plants and soil. From the materials used for fertilization, the mixture of sludge and ash had the highest nickel content. It resulted from a high nickel content in ash that was used for preparing the mixture; ash used in own research contained 24.9 mgNi $\cdot$ kg^{-1} d.m.

As highlighted above, fertilization use of materials derived from waste with high content of trace elements results in an increase in the content of these elements in soil, and sometimes also in plants. Content of elements in a plant is, however, a derivative not only of their total content in soil, but also of the form of their occurrence (availability). In own research, a tendency for a higher nickel content in the plants fertilized with mineral fertilizers was observed. The content of the element taken up from soil of this treatment was also high (Table 2, Fig. 1). It was probably a result of higher acidification of the soil fertilized with mineral fertilizers and of lower organic matter content in that soil in comparison to the soil of the other treatments. This is because, along with a decrease in soil pH value and a decrease in organic matter content in soil, the availability of trace elements for plants increases [21, 22].

Conclusions

1. During the research no nickel pollution of the plants and soil was found.
2. A significant increase in the element content in maize as a result of fertilization was found only in the 2nd year of the research (maize fertilized with mineral fertilizers contained more nickel than the non-fertilized plants). In the 1st year, the plants fertilized with the compost from sludge and straw, and in the 3rd year all the fertilized plants contained significantly less nickel than the non-fertilized plants.
3. Only plants fertilized with the mixture of sewage sludge and ash had a higher mean nickel content than the content determined in the non-fertilized plants.

4. Total nickel uptake from the fertilized soil was higher than the uptake from the control soil (the highest from the soil fertilized with mineral fertilizers, manure, green waste compost, and the mixture of sludge and ash).

5. Fertilization with the green waste compost as well as with the mixture of sewage sludge and ash resulted in a statistically significant increase in the nickel content in the soil.

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ZAWARTOŚĆ NIKLU W KUKURYDZY I GLEBIE NAWOŻONEJ MATERIAŁAMI ORGANICZNYMI POCHODZENIA ODPADOWEGO

Katedra Chemii Rolnej i Środowiskowej
Uniwersytet Rolniczy im. H. Kołłątaja w Krakowie

Abstrakt: Badania przeprowadzono w celu określenia wpływu nawożenia odpadowymi materiałami organicznymi na zawartość i pobranie niklu przez kukurydzę oraz na ogólną zawartość niklu w glebie. Trzyletnie doświadczenie polowe obejmowało 7 obiektów: glebę nienawożoną (kontrola) oraz glebę nawożoną nawozami mineralnymi, obornikiem bydlęcym, kompostem z odpadów zielonych, osadem ściekowym, kompostem z osadu ściekowego i słomy oraz mieszaniną osadu ściekowego i popiołu z węgla kamiennego. Zawartość niklu w częściach nadziemnych roślin i glebie oznaczono metodą ICP-AES.

W trakcie prowadzenia badań nie stwierdzono zanieczyszczenia roślin i gleby niklem. Istotne zwiększenie zawartości pierwiastka w kukurydzy w wyniku nawożenia stwierdzono tylko w II roku badań, po nawożeniu nawozami mineralnymi. W I roku rośliny nawożone kompostem z osadu i słomy, a w III roku wszystkie nawożone rośliny zawierały istotnie mniej niklu od roślin zebranych z obiektu kontrolnego. Największą średnią ważoną zawartością pierwiastka cechowała się kukurydza nawożona mieszaniną osadu i popiołu. Sumaryczne pobranie niklu z gleby nawożonej było większe od pobrania z gleby kontrolnej. Gleba nawożona kompostem z odpadów zielonych oraz mieszaniną osadu i popiołu zawierała istotnie więcej niklu od gleby nienawożonej.

Słowa kluczowe: odpadowe materiały organiczne, osad ściekowy, kompost, nikiel, pierwiastki śladowe