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CONTENT OF HEAVY METALS IN THE TOP LAYER OF SOILS WITH TRITICALE GROWING THEREON IN ONE-CROP SYSTEMS

ZAWARTOŚĆ METALI CIĘŻKICH W WIERZCHNIEJ WARSTWIE GLEBY W UPRAWIE PSZENŻYTA W MONOKULTURACH ZBOŻOWYCH

Abstract: The research was carried out in the period from 2002 to 2008 on the basis of a strict field experiment located at the Experimental Station of the Department of Soil and Plant Cultivation, University of Agriculture in Krakow, in the locality of Mydlniki near Krakow. A two-factor experiment was set up using a method of random sub-blocks, in 4 repetitions, on a typical, good wheat complex soil of a slightly acid reaction (pH_{Cl} = 5.7). Two triticale species were grown: Woltario winter triticale and Matejko spring triticale, using three crop sequences: Norfolk crop rotation, two species, one-crop system with the addition of oats, and one species, one-crop system with the addition of triticale. The objective of the research was to assess the heavy metal contamination level (Cr, Zn, Pb, Cu, Cd, Ni, and Mn) of the top soil layer (0–20 cm) when triticale was grown thereon using a one-crop system method in comparison with the cultivation of triticale using crop rotation. In the soil material, the following was determined: pH, organic matter, and total content of heavy metals. The research experiments showed that the analyzed soil on which triticale was grown during a period of 6 years using a one-crop system was characterized by an averagely higher content of Cr, Zn, Pb, Cu, Ni, and Mn compared with the crop rotation system, and by a higher content of Cd. In the objects, where a two species, one-crop system was applied with oats as a forecrop for triticale, it was reported that the content of Cr, Zn, Pb, Fe, and Ni tended to decrease whereas the Cu content to increase. Except for Cu, the highest increase in the content of heavy metals in the soil was reported for the one species, one-crop system used to grow this cereal.

Keywords: heavy metals, triticale, arable layer, and one-crop system

The content of heavy metals is a very important factor for soils meant for plant production. Agricultural soils are particularly exposed to the contamination by heavy metals. For the majority of soils in Poland, it is characteristic that heavy metals constitute their naturally occurring components [1–3]. The increased content of heavy metals in the soils in Poland is the effect of using crop protection chemicals and mineral & natural fertilizers, which contain heavy metals [4]. Two agricultural measures:

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introducing new plant varieties into field production and increasing their amounts in the disposition of crops can play a part in exhausting reserves of phytoavailable forms of microorganisms in soils. Acidification of soils and reduction of organic manuring [5] are two of a number of factors impacting the negative balance among microorganisms in soils. Thus, the research into soil microorganisms appears very important and is gaining in importance in modern agriculture & farming.

The objective of the present research was to assess and compare the contamination degree of the top layer of soils (arable layer of soils) by Cr, Zn, Pb, Cu, Cd, Ni, Fe, and Mn when growing triticale using a six-year, one-crop system and a crop rotation system.

Material and methods

The research was carried out in a period from 2002 to 2008 on the basis of a strict field experiment, in a field located at the Experimental Station of the Department of Soil and Plant Cultivation, University of Agriculture in Krakow, in the locality of Mydlniki near Krakow. A two-factor experiment was set up using the method of random sub-blocks, in 4 repetitions, on a typical, good wheat complex brown soil. The soil in the experimental field showed a slightly acid reaction (pH_{KCl} = 5.7) and its content of organic matter was 1.40 % (Table 2).

The granulometric composition of the field soil under experiment was: sand – 34 %; dust – 42 %; silt and clay fraction – 25 %; therefore, this soil was texturally classified as a medium soil. Two triticale speciess: Woltario winter triticale and Matejko spring triticale were grown using three crop sequences: Norfolk crop rotation, two-species, one-cropsystem with the addition of oats, and one-species, one-crop system with the addition of triticale.

A general soil sample was taken from the soil layer, its thickness being 0–20 cm, using a soil auger; this general soil sample consisted of six (6) primary samples in four (4) repetitions from the object. The samples collected were dried and screened through a 2 mm- mesh screen. Next, pH of the soil was determined in 1 mol · dm^{-3} KCl using the potentiometric method, and the content of organic carbon (C_{org}) using the Tiurin method. The per cent content [%] of organic matter was calculated by multiplying the content of C_{org} by 1.72. The total content of heavy metals: Cr, Zn, Pb, Cd, Cu, Fe, Ni, and Mn was determined using the ICP-AES method (ie *Inductively Coupled Plasma – Atomic Emission Spectroscopy*) with JY 238 ULTRACE apparatus manufactured by Jobin Von Emission. The assessment of the content level of those metals was based on the standards indicating their limit values. The occurrence stability of the microelements examined was measured by applying a Coefficient of Variation (CV [%]). In the statistical calculations, the method of variance analysis was applied, and the statistical hypothesis was verified using the multiple Tukey's test at the statistical significance level of $\alpha = 0.05$.

Results and discussion

The content of heavy metals studied was expressed in mg · kg^{-1}. In the three experimental objects, the average content of those heavy metals was as follows: Cr –

1.06; Zn – 27.90; Pb – 20.90; Cu – 4.27; Cd – 0.59; Ni – 1.20; Fe – 1139.40; and Mn – 134.90 (Table 1). According to the relevant standard [6] ref. to medium soils, the average content value of Cd and Zn should be, respectively: for Cd – 0.31 mg · kg^{-1}, and as Zn – 33.2 mg · kg^{-1}. The results of the analysis performed by the authors of this paper showed that the average content of Cd varied between 0.55 and 0.67 mg · kg^{-1}, and the content of Zn between 25.93 and 30.98 mg · kg^{-1}. Therefore, the average content of Zn in the soils analyzed was below the standard level. However, according to Straczynski [7], the standard content of Zn in medium soils should be 10.44 mg · kg^{-1}; thus, the content of this metal in the soils under experiment was three (3) times as high as recommended by Straczynski. It is generally assumed that 10 % of soils located in the Krakow region (ie where the experiment took place) are characterized by a low content of Zn, 62 % – by a medium content of Zn, and 28 % – by a high content of Zn. According to the authors' own studies, the content of Cd ranged from 0.55 to 0.66 mg · kg^{-1} and exceeded the value as indicated in the relevant standard. The highest concentrations of Cd are found in the western part of the former province of Krakow [8]. The soils in the Krakow region show a high ability to accumulate cadmium because they are relatively heavy [9]. Soils which strongly accumulate cadmium predominate in the NW part of the province in question. The variations quoted for the concentrations of Cd and Zn in soils are connected with different parent rocks from which they derive and with chemical properties of soils, and the availability of heavy metals to plants increases with the rising level of soil acidification [10].

The following was found during the experiment: compared with the soil where a crop rotation system was applied to grow triticale, the soil used to grow triticale in a 6-year, the one crop system was on average characterized by a higher content of Cr, Zn, Pb, Cu, Ni, and Mn, as well as by a higher amount of Cd. In the objects, where two species were grown using the one-crop system, and oats was used as a forecrop for triticale, it was found that the contents of Cr, Zn, Pb, Fe, and Ni tended to drop, and the content of Cu – to rise. When triticale was cultivated in the one-species system, the highest increase in the content of heavy metals in the soil was reported, except for Cu. Furthermore, a significantly higher content of Cr, Zn, Pb, Cd, and Mn (Table 1) was reported in the object with the triticale grown using the one-species, one-crop system compared with the object with a crop rotation system. In the case of Ni, Cu, and Fe, their content values were insignificant, but the results obtained show that the content values of those heavy metals tend to grow in the soil used to grow triticale in the one-species system. The content of Ni varies widely in the soils in the Krakow region and ranges from 0.60 to 47.8 mg · kg^{-1}, with the average content in the soils in Poland being 12.12 mg · kg^{-1}. Organic matter strongly binds nickel, and its solubility increases along with the increase in the acidity of soil [11]. The majority of arable soils in this region (58 %) show a high ability to accumulate Ni, and only 35 % of the soils are characterized by a low ability to bind this metal [8]. During the authors' own research, they did not find any significant variations in the pH values of soils in the experimental objects. Yet, they found the organic matter content to tend to rise when the one-species, one-crop system of growing triticale was applied (Table 2). The content of Ni was higher in the objects where the triticale was cultivated using the one-species, one-crop system.

Table 1

Contents of heavy metals and their variance (CV [%]) in soils on which triticale is grown using crop rotation and one-crop systems (Mydlniki 2008)

Objects	Forecrop	Form	Cr	Zn	Pb	Cu	Cd	Ni	Fe	Mn
			[mg · kg^{-1}]							
Crop rotation	*Horse-bean*	*Winter triticale*	0.92	25.98	18.18	4.13	0.56	1.18	1043.80	102.93
	Sugar beet^{++}	*Spring triticale*	0.94	27.10	18.30	4.12	0.55	1.21	1046.80	110.93
Two-species one-crop system	*Winter triticale*	*Spring triticale*	1.08	26.88	19.63	4.16	0.59	1.18	1112.00	125.20
	Oat	*Winter triticale*	0.98	25.93	19.20	4.33	0.56	1.19	1046.30	125.00
One-species one-crop system	*Spring triticale*	*Winter triticale*	1.21	30.98	20.35	4.42	0.67	1.22	1287.50	168.75
	Winter triticale	*Spring triticale*	1.21	30.55	20.90	4.46	0.66	1.25	1300.00	176.50
Average Value			1.06	27.90	19.40	4.27	0.59	1.20	1139.40	134.90
$LSD_{\alpha = 0.05}$ for the objects			0.19	3.67	1.68	n.s.**	0.06	n.s.	n.s.	34.2
CV [%]*			14.0	10.9	3.4	11.5	23.7	1.7	55.5	27.4

* CV [%] – variation coefficient; ** n.s. – non-significant differences; ++ manure rate.

Table 2

Contents of organic matter (expressed in %) and pH of the soils in three objects of the experiment (Mydlniki 2008)

Objects	Forecrop	Form	pH_{KCl}	Organic matter [%]
Crop rotation	*Horse-bean*	*Winter triticale*	5.7	1.45
	Sugar beet $^{++}$	*Spring triticale*	5.8	1.38
One-crop, two-species system	*Winter triticale*	*Spring triticale*	5.7	1.38
	Oat	*Winter triticale*	5.7	1.38
One-crop, one-species system	*Spring triticale*	*Winter triticale*	5.8	1.36
	Winter triticale	*Spring triticale*	5.7	1.43
Average Value			5.7	1.40
CV [%]			0.8	3.9

In the soils in Poland, the content of Pb is, on average, 13.8 mg · kg^{-1}. With regard to the content of this element in the entire Krakow region, the soils in the western part of this region are the most Pb-contaminated. The authors' own studies revealed that the standard value of Pb content was exceeded as this content ranged from 18.18 to 20.9 mg · kg^{-1}. No Cu-contamination of the soils was found; the content of Cu in the soil in three experimental objects varied between 4.12 and 4.46 mg · kg^{-1}. The average content of Cu in the soils in Poland is from 0.2 to 293 mg · kg^{-1}. During the experiment, the authors found that the content of Cu was higher in the soils in the object where oats and the one-species, one-crop system of triticale were grown. Similarly, it was reported that the content of Fe and Mn tended to increase in these objects.

In some other regions of Poland, top layers of soils used for agricultural purposes are contaminated by heavy metals: zinc, lead, copper, and cadmium [12]. The contamination degree of those soils varies. In the Krakow region, the majority of soils belong to medium and heavy classes of soils. Brown soils predominate (47.7 %). Zn and Pb are main elements to contaminate soils in the Krakow region [8].

The results presented in this paper correspond with the results of research obtained by other authors [8, 9, 11] in the Krakow region. In the region where this experiment was carried out, the elements Zn, Cd, and Pb contaminate the soils to a high degree and their contents exceed the recommended standard levels. The results obtained by the authors of this paper proved the crop sequence of cereals grown on arable soils had an effect on the content of heavy metals in the soils. It was found that the soil contamination by heavy metals in the objects with the triticale grown under one-species system was higher compared with the soils in the objects with crop rotation. Compared with the soils with triticale grown using the crop rotation system, soils with the one-species system showed a significant increase in the content of Cr, Zn, Pb, Cd, and Mn. Additionally, compared with soils with crop rotation, the content of Cr significantly increased in the soils where the one-species, one-crop system of growing triticale was used. The content of Cr and Zn tended to decrease in the soils where the two-species, one crop-system with oat was applied to grow cereals; the content of those two elements was close to their content in soils where crop rotation was applied (Table 1). Thus,

a presumption can be made that the content of oats in the two-species, one-crop system can moderate negative effects of this specific crop sequence. And, in this case, the soil contamination by heavy metals was reported to be lower than in the soils where the one-species, one-crop system was used; also, this contamination level was reported to be comparable with the contamination degree in soils where the crop rotation system was applied. Furthermore, a higher variation (V [%]) in the contents of cadmium, manganese, and iron in soils was reported. Nickel and lead showed the lowest variation in their contents in the soils.

Conclusions

1. Under the conditions of the experiment described, the levels of soil contamination by heavy metals in the objects used in the experiment mostly did not exceed the ranges of the standards adopted. Those ranges were exceeded only in the case of cadmium, zinc, and lead.

2. The crop sequence impacted the variations in the heavy metal contents in the soils analyzed. It was found that the contents of heavy metals increased in the soils used to grow triticale with the multiyear, one-species & one-crop system applied.

3. When triticale was grown using a two-species, one-crop system with oats, the negative effects of this sequence could be moderated and it was possible to keep the content values of heavy metals at a level close to that reported for the soils used to grow triticale under the crop rotation system.

4. It was found that the variance (V%) in the content of cadmium, manganese, and iron in the soils analyzed was higher than in the content of the remaining heavy metals. The lowest variation in the content level was reported for nickel and lead.

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Abstrakt: Badania realizowano w latach 2002–2008 na bazie ścisłego doświadczenia polowego, zlokalizowanego w Stacji Doświadczalnej Katedry Ogólnej Uprawy Roli i Roślin Uniwersytetu Rolniczego w Mydlikach koło Krakowa. Dwuczynnikowe doświadczenie założono metodą losowych podbloków, w 4 powtórzeniach, na glebie brunatnej właściwej, kompleksu pszennego dobrego o odczynie lekko kwaśnym (pH_{KCl} = 5,7). Uprawiano dwie odmiany pszenżyta – ozimą Woltario i jarą – Matejko w trzech wariantach następstwa roślin: płodozmian Norfolk, monokultura zbożowa 2-gatunkowa z udziałem owsa i monokultura 1-gatunkowa z udziałem pszenżyta. Celem badań była ocena stopnia zanieczyszczenia wierzchniej warstwy gleby (0–20 cm) Cr, Zn, Pb, Cd, Cu, Fe, Ni i Mn w uprawie pszenżyta w monokulturach zbożowych w porównaniu z uprawą tego zboża w płodozmianie. W materiale glebowym oznaczono: pH, materię organiczną oraz całkowitą zawartość metali ciężkich. Wyniki badań wykazały, że gleba spod uprawy w 6-letniej monokulturze zbożowej pszenżyta charakteryzowała się średnio wyższą w porównaniu z płodozmianem zawartością Cr, Zn, Pb, Cu, Ni i Mn oraz podwyższoną zawartością Cd. W monokulturze 2-gatunkowej w obiektach, gdzie przedplonem dla pszenżyta był owies, obserwowano tendencję do spadku zawartości Cr, Zn, Pb, Fe, Ni i wzrostu zawartości Cu. Natomiast w 1-gatunkowej monokulturze tego zboża zanotowano największy wzrost zawartości metali ciężkich w glebie – z wyjątkiem Cu.

Słowa kluczowe: metale ciężkie, pszenżyto, warstwa orna, monokultura