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THE INFLUENCE OF ORGANIC MATTER ON YIELD AND QUALITY OF WINTER WHEAT *Triticum aestivum ssp. vulgare* (L.) CULTIVATED ON SOILS CONTAMINATED WITH HEAVY METALS

WPŁYW MATERII ORGANICZNEJ NA PLON I JAKOŚĆ PSZENICY OZIMEJ *Triticum aestivum ssp. vulgare* (L.) NA GLEBACH ZANIECZYSZCZONYCH METALAMI CIĘŻKIMI

Abstract: The aim of this study was to determine the influence of organic matter from different sources on the yield of winter wheat and macroelements content in it. The experiment was carried out in stoneware pots sank into the ground filled up with 56.4 kg of soil: Haplic Luvisols formed from loamy sand. The soil was slightly acidic. The soil was mixed up with liquid form of salts: $Cd(NO_3)_2$, $Pb(CH_3COO)_2$ and $ZnSO_4$. To the soil a brown coal preparation, so called "Rekulter", brown coal, peat and farmyard manure were applied in the amount of 180, 140, 390 and 630 g per pot, which is equivalent to 5 Mg of organic carbon per ha. Winter wheat *Triticum aestivum ssp. vulgare* (L.) for grain was cultivated. The manurial value of organic substance originated from different sources expressed as the plants' crop was the highest for Rekulter and the lowest for peat. The addition of organic substance to soil contaminated with heavy metals causes the higher content of potassium, magnesium and nitrogen in winter wheat's grain. The content of calcium and sodium in winter wheat grain's did not depend from addition of organic matter to soil. Organic matter added into contaminated soil increased the uptake of main macroelements by winter wheat straw. Organic matter fertilization broadened the K: (Ca + Mg) ratio in grain and straw.

Keywords: soil contaminated with heavy metals, winter wheat, yield, macroelements

Wheat is the species of cereals which, owing to its extremely varied uses and large area of cultivation, constitutes the basic food all over the world. Suitable supply of all nutrients throughout the whole growing season is a necessary condition for producing high and good quality wheat grain yields. Not only nitrogen fertilization but also phosphorus, potassium or magnesium nutrition is important [1, 2]. Health authorities in many parts of the world are becoming increasingly concerned about the effects of heavy metals on environmental and

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human health and their potential implications to international trade. For example, Cd accumulation in the offal of grazing animals not only makes it unsuitable for human consumption but also imperials the access of offal products to overseas markets. Similarly, bioaccumulation of Cd in potato, wheat and rice crops has serious implications to local and international commodity marketing [3-5].

In Poland, soils species (predominantly sandy soils) and inadequate land management have led to a reduction in the organic matter content of soils. Among the various reactive soil constituents, soil organic matter has a large sorption capacity towards metal ions [6-8]. Organic matter has been considered to preserve a record amount of heavy metals. The protective role of organic matter towards plants lies in forming simple and chelate complex compounds with ions of heavy metals. Maintenance of adequate organic matter levels in the soils is also very necessary to maintain soil fertility and sustainable crop production [9]. Therefore, new sources of organic matter have been tapped, such as municipal solid waste compost, low energetic value brown coal and sewage sludge [10-12]. Moreover, the produced low-cost brown coal preparation could be used as amendment in agriculture, meanwhile recycling its valuable components: organic matter, N, P and other plant nutrients [13, 14].

The aim of this study was to determine the influence of organic matter from different sources (brown coal preparation, so called "Rekulter", brown coal, peat and farmyard manure) on the yield of winter wheat *Triticum aestivum ssp. vulgare* (L.) and content of macroelements: K, Mg, Ca, Na, P, N, cultivated on heavy metals contaminated soils.

Materials and methods

The experiment was carried out in stoneware pots of a diameter of 40 cm and a height of 120 cm sank into the ground filled up with 56.4 kg of soil: Haplic Luvisols originated from loamy sand, situated in an open area. To the slightly acidic soil a brown coal preparation, so called "Rekulter", brown coal, peat, and farmyard manure were applied in the amount of 180, 140, 390 and 630 g per pot, which is equivalent to 5 Mg of organic carbon per ha. The "Rekulter" contained 85% brown coal, 10% peat, 4% brown coal ash, and 1% mineral fertilizers. The soil was mixed up with liquid form of salts: cadmium as $Cd(NO_3)_2$, lead as $Pb(CH_3COO)_2$ and zinc as $ZnSO_4$, which after blending led to the following concentrations of heavy metals (in $mg \cdot kg^{-1}$ of soil): 90.0 (Zn), 60.4 (Pb) and 0.80 (Cd).

Soil samples were taken at the depth of 20 cm, in the second year after the application of amendments. In the soil samples the following data were determined: pH_{H_2O} and pH_{KCl}, total organic carbon (TOC) content by Tiurin's method, total nitrogen (Nt) content by Kjeldahl's method.

Winter wheat *Triticum aestivum ssp. vulgare* (L.) was harvested at the full maturity stage. Plants were collected and washed, weighted, and dries at 60°C to constant weight. Content of macroelements: K, Mg, Ca, Na, P in plant samples were determined by atomic absorption. Nitrogen after mineralization in concentrated H_2SO_4 by Kjeldahl's method.

Results and discussion

From the experiment it follows that introduction into the soil of organic matter coming from various sources changes physicochemical properties of the soil (Table 1). The highest increase in pH (pH_{H_2O} = 5.38; pH_{KCl} = 4.98) was found in the stonepots (soil without heavy metals) where the Rekulter was used, and the smallest increase occurred in objects (soil without heavy metals) with manure (pH_{H_2O} = 4.93; pH_{KCl} = 4.54).

In objects with brown coal (soil contaminated or not contaminated with heavy metals), the total organic carbon (TOC) amounted to about 12 $g \cdot kg^{-1}$; in the stonepots with the Rekulter to about 15 $g \cdot kg^{-1}$, while in the objects with peat or farmyard manure it was about 8 $g \cdot kg^{-1}$. The highest growth in the total nitrogen content (0.655 $g \cdot kg^{-1}$) occurred with the Rekulter, and the lowest (0.508 $g \cdot kg^{-1}$) in the object with peat. The widest range of TOC to Nt ratio came about with the Rekulter, which was due to the highest TOC content in this object. Other authors experimenting with Rekulter and brown coal obtained similar results [15, 16].

Table 1

The basis properties of soil samples

Objects	pH in		TOC	Nt	TOC:Nt
	H_2O	KCl	$[g \cdot kg^{-1}]$		
Control	4.92	4.33	7.30	0.460	15.9
Control + heavy metals	4.93	4.39	7.90	0.476	16.6
Rekulter	5.38	4.98	15.05	0.629	24.6
Rekulter + heavy metals	5.32	4.96	15.49	0.655	23.6
Peat	5.22	4.62	8.01	0.509	15.7
Peat + heavy metals	5.06	4.79	8.19	0.508	16.1
Farmyard manure	4.93	4.54	8.27	0.533	15.5
Farmyard manure + heavy metals	4.99	4.53	8.56	0.538	15.9
Brown coal	5.25	4.96	12.35	0.596	20.7
Brown coal + heavy metals	5.12	4.97	12.65	0.594	21.3
LSD $\alpha = 0.05$	0.021	0.024	0.17	0.025	0.47

Notation: LSD - least significant different, TOC - total organic carbon, Nt - total nitrogen

Soil contamination with cadmium tends to have an adverse influence on the yield of plants. Ghani [17] proved that cadmium decreased general yield of mungbean. Ciećko et al [18] showed that cadmium soil pollution caused a much greater decline of green matter yield in maize than in oats. Organic amendments *eg* farmyard manure, peat contain plant nutrients and organic matter, which are beneficial to soils with respect to their productivity as well as for reclamation purposes.

It comes out from the experiment, that introduction of organic matter from different sources, into heavy metals' contaminated soil influenced, on yield and plant quality (Tables 2-5). The manurial value of organic substance originated from different sources expressed as the plants' crop was the highest for Rekulter and the lowest for peat. In the present trial contamination of soil with cadmium, lead and zinc caused a high decline in the yield of winter wheat of fresh and dry mass reaching, respectively, 88% and 78% compared with objects without heavy metals (Table 2). By adding the Rekulter, brown coal, peat and farmyard manure, the negative influence of heavy metals on yield of winter wheat was neutralized. The highest yield of winter wheat of fresh and dry mass was in case were Rekulter was applied. It acts by creating better soil conditions for plants' vegetation using Rekulter. Similar results were reported by Ciećko et al [19], they found out that addition of brown coal into contaminated soil caused a considerable increase in the yield of above-ground part of triticale.

Table 2

The yield of above - ground part of winter wheat of fresh and dry mass [g·pot^{-1}]

Objects	Yield	
	Fresh mass	**Dry mass**
Control Control + heavy metals	145.0 127.5	100.0 78.5
Rekulter Rekulter + heavy metals	446.5 217.8	289.5 143.5
Peat Peat + heavy metals	372.2 192.5	240.0 123.3
Farmyard manure Farmyard manure + heavy metals	421.2 245.0	267.5 146.3
Brown coal Brown coal + heavy metals	432.8 240.0	280.0 138.7
LSD $\alpha = 0.05$	38.18	31.72

Notation: see Table 1

Tables 3, 4 and 5 show the changes in plant composition, due to the heavy metals and different sources of organic matter treatment, in terms of the ratio of the concentration of Ca, Mg, K, Na, N or P in plants grown.

Potassium is one of the cations which are absorbed by plants in advance to their biomass growth. Accumulation of potassium in wheat goes on until the flowering stage, after which it fell by half compared with the maximum uptake [20]. Whitehead [21] reported potassium concentration of 25 g·kg^{-1} as typical of grass, with different species in the range of 15-35 g·kg^{-1} (ryegrass and white clover). Winter wheat from this experiment had potassium concentrations range from 4 to 10 g·kg^{-1} (Table 3). Contents of potassium in grain of winter wheat, significantly increased, influenced by addition of organic matter in comparison with control object. However, contamination of soil with heavy metals, significantly decrease potassium uptake by grain of winter wheat. The accumulation of potassium in straw was bigger than in grain of winter wheat.

Calcium concentrations were higher in winter wheat in objects with addition of organic substance into soil (Table 3). The increase of content of calcium in straw of winter wheat was higher in objects without heavy metals. High concentrations of heavy metals, especially Zn^{2+} ions may cause limited sorption of calcium ions, what directly diminishes the cementing of cell walls by calcium pectinates that leads to the maceration of root tissue [22]. In straw of winter wheat contents of calcium was the highest on object with farmyard manure.

Good magnesium supply favours higher content of nitrogen and proteins. Contents of magnesium in winter wheat increased, after addition of organic matter from different sources in comparison with control object (Table 3). In all examined parts of winter wheat contents of magnesium was the highest on object with “Rekulter”. Just as in case of calcium, there was in grain smaller contents of magnesium, which was apparently translocated from roots to above ground part of winter wheat. Straw magnesium concentrations in this study ranged from 0.53 to 3.55 $g \cdot kg^{-1}$ compared with 2.40-3.12 $g \cdot kg^{-1}$ in a companion field study [23].

Table 3

Potassium, calcium and magnesium content in winter wheat dry mass [$g \cdot kg^{-1}$ d.m.]

Objects	Grain			Straw		
	K	**Ca**	**Mg**	**K**	**Ca**	**Mg**
Control	4.18	0.28	1.08	4.08	2.05	0.53
Control + heavy metals	4.03	0.30	1.12	5.61	2.44	0.47
Rekulter	4.97	0.29	1.94	6.87	3.55	0.58
Rekulter + heavy metals	4.68	0.38	1.15	9.84	3.13	0.62
Peat	4.55	0.34	1.86	6.85	3.00	0.58
Peat + heavy metals	4.46	0.35	1.17	8.43	2.77	0.61
Farmyard manure	4.92	0.36	1.84	7.17	2.95	0.58
Farmyard manure + heavy metals	4.66	0.35	1.23	9.19	2.85	0.61
Brown coal	4.94	0.38	1.94	6.27	3.33	0.55
Brown coal + heavy metals	4.75	0.40	1.25	10.4	3.06	0.73
LSD α = 0.05	0.09	0.08	0.05	1.24	0.35	0.11

Notation: see Table 1

Content of sodium in grain of winter wheat was the smallest in variant with farmyard manure whereas the highest in variant with brown coal on both contaminated soil and without heavy metals (Table 4). Content of sodium was the biggest in straw in object with brown coal. Organic matter from different sources did not significantly effect on content of sodium in grain and straw of winter wheat in objects with contaminated soil compared with objects without heavy metals.

Table 4

Sodium, phosphorus and nitrogen content in winter wheat dry mass [$g \cdot kg^{-1}$ d.m.]

Objects	Grain			Straw		
	Na	**P**	**N**	**Na**	**P**	**N**
Control	0.030	3.29	17.4	0.03	3.64	48.3
Control + heavy metals	0.028	3.57	18.4	0.04	3.59	57.2
Rekulter	0.032	3.70	27.8	0.08	4.57	33.6
Rekulter + heavy metals	0.031	3.45	30.9	0.15	4.37	77.4
Peat	0.030	3.51	27.7	0.04	4.65	36.2
Peat + heavy metals	0.032	3.54	30.9	0.08	4.42	68.9
Farmyard manure	0.027	3.63	25.1	0.05	4.57	45.6
Farmyard manure + heavy metals	0.028	3.46	27.3	0.14	4.12	77.9
Brown coal	0.033	3.68	26.4	0.07	4.69	49.9
Brown coal + heavy metals	0.032	3.45	28.7	0.16	4.29	90.2
LSD α = 0.05	0.003	0.84	2.50	0.09	0.65	7.01

Notation: see Table 1

Addition of organic matter from different sources into soil has not caused growth of content of phosphorus in grain of winter wheat (Table 4). Content of phosphorus in straw of winter wheat has grown influenced by added organic matter on soil contaminated with heavy metals. It was also observed that higher content of this macronutrient was in straw than in grain, in all objects. Contents of phosphorus in grain and straw of winter wheat did not differ significantly depending on source of organic matter added into soil relatively to control. The results confirm researches of other authors [24] where addition of brown coals' ash caused decrease of contents of phosphorus in plants.

It was observed the smallest content of nitrogen in grain of winter wheat on control from uncontaminated soil whereas, the highest in objects with the Rekulter and peat (Table 4). Content of nitrogen in biomass of winter wheat was significantly higher on soil contaminated in comparison with soil without heavy metals. Added into soil organic matter significantly influence on growth of content of nitrogen in grain of winter wheat. It catches on generally, that mineral fertilization supported by organic fertilization it plays decisive effect on in forming of harvest of plant and their chemical compositions [13, 24]. The results obtained from this research confirmed them.

The ratio of potassium to sum of calcium and magnesium could be used to express the relationships between K content and Ca plus Mg contents, respectively [25, 26]. The ratio of potassium to sum of calcium and magnesium decide about usefulness of plant. It catches on, that this ratio should not be widest in plants than 2.5 : 1, so, danger gets in case of grain of all objects on soil contaminated with heavy metals (Table 5). Under influence of organic matter from the “Rekulter” the contents of calcium and magnesium in grain of winter wheat increased and reduced the ratio K: (Ca + Mg) in plants which influenced on theirs quality.

Table 5

Ratio K: (Ca + Mg) in winter wheat

Objects	Grain	Straw
Control	3.07	1.58
Control + heavy metals	2.84	1.93
Rekulter	3.23	1.66
Rekulter + heavy metals	3.06	2.62
Peat	2.07	1.91
Peat + heavy metals	2.93	2.49
Farmyard manure	2.24	2.03
Farmyard manure + heavy metals	2.95	2.66
Brown coal	2.13	1.62
Brown coal + heavy metals	2.88	2.74

Conclusions

Organic matter originated from different sources application into soil increased soil pH, content of total organic carbon (TOC) and total nitrogen. In object with the Rekulter, this led to significant increases of yield and its quality compared with farmyard manure, peat and brown coal treatments. The content of sodium in grain of winter wheat did not depend from addition of organic matter into soil. The addition of organic substance into soil contaminated with heavy metals (Cd, Zn, Pb) causes the smaller content of phosphorus in grain and straw of winter wheat. Winter wheat cultivated on contaminated soil contained more nitrogen in comparison with objects without heavy metals.

Basing on the final results it can be stated that the “Rekulter” had the biggest, positive influence on analysed factors compared with farmyard manure, peat and brown coal. Under the influence of the “Rekulter” the contents of calcium and magnesium in winter wheat increased and reduced the ratio K: (Ca + Mg) in plants which influenced on their quality.

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WPŁYW MATERII ORGANICZNEJ NA PLON I JAKOŚĆ PSZENICY OZIMEJ *Triticum aestivum ssp. vulgare* (L.) NA GLEBACH ZANIECZYSZCZONYCH METALAMI CIĘŻKIMI

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Abstrakt: Celem pracy była ocena wpływu materii organicznej z różnych źródeł na wielkość plonu i zawartość makroelementów w pszenicy ozimej. Badania prowadzono w wazonach kamionkowych umieszczonych w gruncie, które wypełniono glebą płową właściwą (wg WRB, Haplic Luvisols), wytworzoną z piasku gliniastego lekkiego na glinie lekkiej. Gleba charakteryzowała się lekko kwaśnym odczynem. Do gleby wprowadzono metale ciężkie w formie soli: $ZnSO_4$, $Pb(NO_3)_2$ i $Cd(NO_3)$. Jednocześnie do gleby dodano jednorazowo: nawóz organiczno-mineralny z węgla brunatnego "Rekulter", węgiel brunatny, torf lub obornik w dawkach odpowiednio 180, 140, 390 lub 630 g na wazon, co odpowiadało 5 tonom C-org na ha. W doświadczeniu uprawiano pszenicę ozimą *Triticum aestivum ssp. vulgare* (L) odmiany Alba. W próbach roślinnych oznaczono ogólną zawartość wapnia, magnezu, sodu, potasu, fosforu i azotu. Wartość nawozowa substancji organicznej z różnych źródeł wyrażona plonem roślin była najwyższa dla „Rekultera”, a najniższa dla torfu. Dodatek substancji organicznej do gleby powoduje wzrost zawartości K, Mg, P i N w ziarnie i słomie pszenicy. Zawartość sodu i wapnia w ziarnie pszenicy nie zależała od zanieczyszczenia gleby metalami ciężkimi i dodatku materii organicznej. Zawartość azotu w ziarnie i słomie pszenicy na glebie zanieczyszczonej była większa w porównaniu do roślin z gleby bez metali ciężkich. Dodatek materii organicznej do gleby spowodował rozszerzenie stosunku K : (Ca + Mg) w ziarnie i słomie pszenicy.

Słowa kluczowe: gleba zanieczyszczona metalami ciężkimi, pszenica ozima, plon, makroelementy