Middle-East Journal of Scientific Research 22 (6): 859-863, 2014
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2014.22.06.21957

Features of Nutrient Uptake by Spring Barley Grain at the Contamination of Chernozem with Zinc and Lead

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Abstract: The contents of heavy metals, nitrogen, phosphorus and potassium in the grain of spring barley grown on an chernozem contaminated with Zn and Pb have been studied. The contamination of chernozem with heavy metals resulted in their accumulation in plants. A decrease in the content of nitrogen in the grain has been revealed at the application of Pb to the soil. The use of ameliorants - capbonate, glauconite and manure added together or separetly in the treatments with Pb has increased the content of nitrogen in the barley grain.

Key words: Barley · Grain · Chernozem · Heavy Metals · Contamination · Nitrogen · Phosphorus · Potassium

INTRODUCTION

The increase of grain production is the key problem of Russian agriculture. In the Rostov oblastduring the period from 1961 to 1990, the barley area was about a million and a half ha on the average, which made up more than 40% of the total cereal crop area. The increase of barley production involves not only the increase of barley grain yield, but also the significant improvement of its quality depending on the destination.

The study of nutrient status in plants grown with an excess in the environment of heavy metal (HMs) compounds, has theoretical and practical importance. This identification of ions antagonists of heavy metals which may reduce the flow of pollutants in plants and thus reduce their toxic effects. It should also be noted that the chemical composition of the plant determines the quality of products.

The effect of HMs on the quality and yield of spring barley is a poorly studied problem. It is known that the contamination of soils with HMs negatively affects the cultivated crops: it decreases the amount and deteriorates the quality of crops, with is the main criterion of their use [1]. Differences in the content of Zn and Pb in organs of barley explained by their physiological role *in vivo*. Zn is an essential trace element, while Pb, although present in all plants in natural conditions until the present time to identify any particular its role in the metabolism failed.

The contents of nutrients (nitrogen, phosphorus and potassium) are quality parameters of agricultural crops [2, 3]. The balanced chemical composition of plants is the main condition of their normal growth and development. The high concentrations of Zn and Pb result in the imbalance of nutrient components in plants. The direct effect of excess metals is accompanied by their indirect effect: the conversion of nutrients to a form unavailable to plants.

Little data are available about the effect of HMs on the content of nutrients in cultivated plants and they are relatively contradictory. The contents of nitrogen and phosphorus in the grain of spring wheat appreciably decreased with the increasing content of Zn (50–150 ppm) in the soil. At the same time, the application of Zn to the soil had no distinct effect on the content of potassium in grain or straw. The input of essential nutrients (N, P and K) into barley decreased at the contamination of soddy-podzolic soil with HMs. The effect of the high rates of Zn alone on the contents of nitrogen and phosphorus in spring wheat grain was noted by other authors [4].

Different methods of detoxification are used for farming on contaminated soils. The use of different sorbents, including organic matter, zeolites and chalk, is one of the most common and efficient methods [5].

The contents of the essential macronutrients (nitrogen, phosphorus and potassium) in the grain of

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barley grown on the soil contaminated with zinc and lead were determined in model field experiments. The effect of different ameliorants on the qualitative composition of barley was also studied.

MATERIALS AND METHODS

A long-term small-plot experiment was established in the Rostov oblast (the South of Russia) in 2010 year. The test plot area was 1 m^2.The soil was a deep low-humus heavy loamy ordinary chernozem with the following properties: C_{org}, 2.2%; $CaCO_3$, 0.2%; pH $_{H2O}$, 7.5; particles <0.01 mm, 58.0%; particles <0.001 mm, 32.5%; exchangeable cations (mmeq/100 g): Ca^{2+}, 30.0; Mg^{2+}, 4.5.

The supply is estimated as high for available phosphorus and increased for exchangeable potassium according to the corresponding soil classification [6].

Lead and zinc were studied as the pollutants most common in the Rostov oblast, the contents of which exceed their maximum permissible concentrations (MPCs). The metals were introduced into the plow (0-20 cm) horizon in the form of dry soluble acetates at rates of 600 mg/m^2 for Zn and 200 mg/m^2 for Pb, which corresponded to 3 MPC for these elements. Chalk, glauconite and semi-decomposed cattle manure were used to remove the effect of soil contamination [7, 8]. The ameliorants were applied three months after the contamination of soil.

Experimental Design: (1) control; (2) metal (background); (3) background + 2.5 kg/m^2 $CaCO_3$; (4) background + 2.5 kg/m^2 $CaCO_3$ + 5 kg/m^2 manure; (5) background + 5 kg/m^2 $CaCO_3$; (6) background + 5 kg/m^2 $CaCO_3$ + 5 kg/m^2 manure; (7) background + 2 kg/m^2 glauconite; (8) background + 2 kg/m^2 glauconite + 5 kg/m^2 manure; (9) background + 5 kg/m^2 manure. Zinc was used in one series of experiments and lead was used in the other series of experiments. The experiments were performed in triplicate.

The Odesskii-100 cultivar of spring barley (*Hordeum sativum distichum)* was used. The zonal crop management practice was used. Trial establishment, observations, calculations and sampling were performed in accordance with the recommended procedures of field experiments. Plant samples were taken at the stage of full ripeness.

In the barley grain, nitrogen was determined by photocolorimetry using the indophenol green method; phosphor was determined by the vanadate–molybdate method with photocolorimetric detection; potassium was determined by the flame photometric method. Heavy metals in plants were determined by wet combustion in an HNO_3 + HCl mixture [6] with AAS detection.

RESULTS AND DISCUSSION

It was found that the content of Zn in barley grain on the control plot was 21.6–24.8 ppm. The content of Pb in grain was significantly lower than in the other plant organs: 0.2 to 0.4 ppm (Table 1).

The contamination of ordinary chernozem with HMs resulted in their accumulation in plants. The contents of Zn and Pb in grain exceeded their MPCs (50 ppm for Zn and 0.5 ppm for Pb [6] by 1.3 and 5 times, respectively.

In aftereffect Zn concentration in the grain of barley decreased by 10.2% at the same time exceeds the MPC.

Adding ameliorants led to decrease Zn and Pb in the barley grain. The greatest meliorative effect had a combination of a double dose of carbonates and manure, as in effect, as well as an aftereffect. Separate application of glauconite and manure least effective. In the aftereffect at applying ameliorants HM concentration decreases much faster and does not exceed the MPC.

According to literature data, the mean content of nitrogen in barley grain is 2.1%. Under the experimental conditions, the content of nitrogen in grain varied during three years from 1.66 to 1.82% depending on weather conditions (Table 2).

Table 1: The content of Zn and Pb in barley grain, ppm

Variants		Zn		Pb	
		Effect	Aftereffect	Effect	Aftereffect
1.	Control	22.6	23.6	0.35	0.21
2.	Metal (background)	65.3	58.7	2.42	1.37
3.	Background + 2.5 kg/m^2 $CaCO_3$	45.0	26.5	1.41	0.36
4.	Background + 2.5 kg/m^2 $CaCO_3$ + 5 kg/m^2 manure	48.7	29.7	0.86	0.25
5.	Background + 5 kg/m^2 $CaCO_3$	44.6	25.6	1.38	0.20
6.	Background + 5 kg/m^2 $CaCO_3$ + 5 kg/m^2 manure	42.3	21.2	0.50	0.19
7.	Background + 2 kg/m^2glauconite	51.3	30.4	1.83	0.41
8.	Background + 2 kg/m^2glauconite + 5 kg/m^2 manure	49.8	29.6	1.75	0.47
9.	Background + 5 kg/m^2 manure	53.2	32.7	1.70	0.40

Table 2: Effect of Zn and Pb on the contents of nutrient in barley grain, % of total weight

	Nitrogen				Phosphorus				Potassium			
	Zn		Pb		Zn		Pb		Zn		Pb	
Vari ants	Effect	Aftereffect	Effect	Aftereffect	Effect	Aftereffect	Effect	Aftereffect	Effect	Aftereffect	Effect	Aftereffect
1.	1.78	1.82	1.78	1.82	0.39	0.44	0.39	0.44	0.61	0.69	0.61	0.69
2.	1.70	1.85	1.54	1.72	0.37	0.45	0.42	0.43	0.60	0.69	0.58	0.69
3.	1.56	1.78	1.65	1.86	0.41	0.46	0.39	0.44	0.61	0.66	0.61	0.69
4.	1.67	1.83	1.60	1.77	0.38	0.44	0.38	0.45	0.62	0.70	0.59	0.71
5.	1.65	1.73	1.68	1.72	0.41	0.44	0.39	0.43	0.61	0.69	0.59	0.69
6.	1.60	1.72	1.67	1.87	0.40	0.45	0.37	0.43	0.61	0.68	0.60	0.70
7.	1.72	1.71	1.71	1.85	0.39	0.42	0.40	0.44	0.60	0.67	0.60	0.70
8.	1.64	1.84	1.63	1.73	0.38	0.46	0.38	0.42	0.60	0.71	0.60	0.69
9.	1.70	1.76	1.65	1.80	0.39	0.45	0.38	0.43	0.60	0.70	0.61	0.69

At the contamination of plants with the studied HMs, a decrease of the nitrogen content in grain was observed, by 3.4% at the application of Zn and statistically reliably by 10.9% at the application of Pb. The lowest effect of HMs on the studied parameter was observed in 2009: the toxic effect of the HM was probably reduced by the favorable weather conditions.

The positive effect of the studied ameliorants was manifested on the soils contaminated with Pb. The impact of ameliorants results in an increase of nitrogen concentration in barley grain. In the treatments with Zn, on the contrary, a tendency toward a decrease of nitrogen content was observed (Table 2).

For the aftereffect variation of the nitrogen content under study within the experimental error was observed.

On the control plot, the contents of phosphorus and potassium in grain were within 0.4 and 0.66%, which corresponded to the mean contents of these elements in barley grain.

At the contamination of ordinary chernozem with Zn and Pb, no significant changes in the contents of phosphorus and potassium in barley grain were revealed in all three years of the studies. The ameliorants also little affected the contents of these elements in grain (Table 2). Variations within the experimental error were observed.

Mechanisms for delivering HMs in plants are determined by many factors: soil and climatic conditions, plant species, their age and vary greatly in different organs.

Our results correspond to the average content of Zn and Pb in barley grain in the Rostov region, which contains 12-26 ppm for Zn and 0.2 – 0.6 ppm for Pb in cereals [9, 10 and 11].

Root systems often contain more Zn, than the aerial parts, especially if the plant is grown in soil rich in Zn. When the optimal content of Zn in the soil, this element can be moved from the roots and accumulating in the upper parts of the plants [9].

There are protective barriers in plants at the border stem-grain, which prevent the accumulation of Pb in the generative organs. The main barrier function to reduce the income of toxicants in plants carries out roots. With the penetration of heavy metals in the roots of plants is their chelation and, as a consequence, reduced mobility.

It is known that the studied soil (Ordinary chernozem) is a highly buffer self-cleaning system [12, 13]. However, self-defense mechanisms are triggered efficiently enough. This situation has resulted in the need to find ways to remediate contaminated soil by applying ameliorants.

The greatest meliorative effect, resulting from the introduction of 5 kg/m^2 $CaCO_3$ and 5 kg/m^2 manure together because of $CaCO_3$ and organic matter are among the main factors HM sorption by soils. Moreover, it was at a dose of 5 kg/m^2 $CaCO_3$ characteristic maximum reduction of metal mobility in plants. This suggests that calcium ions (Ca^{2+}) came from carbonates in the soil solution, compete with cations of lead (Pb^{2+}) for uptake by plants.

By comparing the effect ameliorants in their separate application, it may be noted that glauconite and manure changed the concentration of Pb in plants weaker than carbonates.

In the aftereffect at the ameliorants application the HM concentration decreases much faster and does not exceed the MPC. Plants are accumulated Bless than in the action that is associated with the formation firmly bound compounds and decrease the element mobility in the soil [5].

Nutrition plants and their chemical composition depend on both the internal (genetic) factors and the external conditions (the reaction medium, the concentration of nutrients and their ratio in the soil solution, etc.). Low dependence of the contents of nutrition elements in barley grain from heavy metal contamination is confirmed by many researchers [14, 15].

The most difficult to discuss the element is nitrogen. In plants it comes in the form of nitrates, ammonium salts or organic compounds, is cleaved during the ammonia biochemical transformations [16]. The high mobility in plants of low molecular weight nitrogen compounds, its ability to reutilization creates additional difficulties in the interpretation of results.

In Knop nutrient mixture nitrogen represented NO_3^-. Consequently, the phenomenon of antagonism with metal cations is hardly possible. Sparingly soluble heavy-metal compounds are also not formed because all nitrates are highly soluble salts thereof. Practically no information on the effect of metals on nitrogen metabolism in plants. There are only fragmentary research. For example, according to, an antagonistic relationship observed between nitrogen and zinc, wherein the concentration of the latter in the soil was only 20 ppm. Other authors on the subject have expressed the opposite view.

Hms application to the soil had no significant impact on the nutrients content in barley grain, presumably because of the small doses of metals. All changes in nutrient content were within experimental error and determined their natural variability in different variants of experience years.

CONCLUSION

Thus, no significant effect on the chemical composition (phosphorus and potassium) of barley grain was revealed at the contamination of ordinary chernozem with Zn and Pb.

Soil contamination with Pb has reduced to decrease nitrogen content in barley grain.It is proposed a definition of the nitrogen amount in the grain, as a diagnostic indicator under the soil contamination with Pb.

The main indicator of the quality of plant products requiring control by pollution is the content of toxic elements.

The after effect at the ameliorants application of barley grain the HM concentration in decreases much faster and does not polluted. The greatest meliorative effect, resulting from the introduction of 5 kg/m^2 $CaCO_3$ and 5 kg/m^2 manure together because of $CaCO_3$ and organic matter are among the main factors HM sorption by soils.

ACKNOWLEDGEMENTS

This work was supported by the Ministry of Science of the Russian Federation (project no. 5.885.2014/Ê). Analytical work was carried out on the equipment of Centers for collective use of Southern Federal University "High Technology", grant RFMEFI59414X0002.

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