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Features of environmentally-friendly product obtaining from sugar and fodder beets in conditions of zinc contamination of sod-podzolic sandy loam soils

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ABSTRACT

This article presents the results of a field experiment on obtaining environmentally friendly products from sugar and fodder beets in conditions of zinc contamination. It was found that various intensification factors during the cultivation of sugar and fodder beets significantly change the agrochemical and agroecological properties of sod-medium podzolic sandy loam soil. The zinc content in sugar and fodder beets was almost two times lower within the treatments with the simultaneous introduction of lime as $N_{60}P_{60}K_{60}$ + Zn + lime and $N_{60}P_{60}K_{60}$ + Zn + lime + manure. Liming significantly increased the yield of products. In general, using a fairly minimal set of intensification factors on sod-podzolic soils without a combination with supporting liming caused the suppression of sugar and fodder beets on sod-podzolic soils under conditions of zinc contamination. Agroecological regimes were changed quite pronouncedly on soddy-podzolic soils of light granulometric composition, susceptible to zinc pollution, when lime fertilizers were applied, which makes it possible to reduce the mobility of zinc in the soil environment. The introduction of dolomite flour in the treatments $N_{60}P_{60}K_{60}$ + Zn + lime and $N_{60}P_{60}K_{60}$ + Zn + lime + manure reduced the translocation of zinc in the soil-plant system within concentrations above the established norms. However, in the production of fodder beets, this effect was established only in the treatment $N_{60}P_{60}K_{60}$ + Zn + lime + manure. Thus, obviously the application of mineral fertilizers in combination with liming and manure as $N_{60}P_{60}K_{60}$ + Zn + lime and $N_{60}P_{60}K_{60}$ + Zn + lime + manure on sod-podzolic soils of light granulometric composition in conditions of zinc pollution make it possible to obtain environmentally-friendly products of sugar and fodder beets due to the negative impact reduction.

Keywords: Zinc, Heavy metals, Environmentally friendly products, Beets, Food.
Article type: Research Article.

INTRODUCTION

Soil contamination with zinc compounds is primarily conditioned by the involvement of mineral fertilizers in agricultural circulation, the supply of dusty substances from technogenic production and an increasing number of working vehicles (KirupaSree 2021). A sharp elevated maximum permissible concentration (MPC) of zinc in the soil environment causes a slowdown of agronomic crop growth, the yield decrease and, ultimately, the complete death of the plant (Biziuk & Marek 2001). Zinc is a necessary element that regulates the normal vital activity of a plant; however, this property is manifested within the framework of the established MPCs. Zinc is actively absorbed by the root system of the beetroot plant and retains its toxicological properties for a long time, has a fairly stable and long-term negative effect in terms of exposure. Zinc, as a heavy metal, has a pronounced

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heterogeneous toxic effect in terrestrial ecosystems - it is accumulated in the surface soil layers and is absorbed by the root system even in the absence of biological and physical-chemical effects (Rathoure & Ashok 2020). From this point of view, the improvement of the system aimed at population provision with ecologically safe food products of plant and animal origin is a paramount task faced by the modern ecological and agronomic part of the fundamental natural science cycles. With an increasing intensity of agricultural and industrial production, there is an increasing impact on the natural environment under the conditions of irrational use of natural resources, which subsequently affects the change in global and biogeochemical cycles (biogeocenotic cycles) of zinc and affects the rate and speed of migration, direction and displacement of ecologically significant zones of its removal and its accumulation in soil (Ragimov 2021). In this regard, on the territories subject to agricultural and urbanized impacts, where anthropogenic and man-made factors are an active force, there is a significant violation of the ecological balance, and the task of environmentally friendly product obtaining becomes almost impossible. However, under conditions of a positive change in ecosystem properties, the soil and vegetation cover exhibits a rather pronounced ecological response in time and space to the reclamation impacts carried out under the conditions of technogenic load, which makes it possible to reduce the risks for safe product obtaining (Zhou & Xun 2018). Healthy, high-quality and environmentally friendly food is an essential component for the normal functioning of the population (Bagnyuk 2020). Beet, as a plant product, is a socially significant crop of agricultural production, which is included in the food basket and is used year-round to ensure that the needs of the population are met (Sood & Sonia 2017). Sugar beet is an industrial crop, the main value of which is the high content of sucrose. It is used to obtain granulated sugar, which is an essential social element of the population food basket (Nirmal & Nilesh 2021).
Thus, a fairly large demand for sugar consumption by the population is formed and an increasing production volume determines high requirements for its quality, which depends on the quality of the raw materials sought (Prasoona & Jogipet 2021). On the contrary, fodder beet is one of the products for feeding farm animals. Thus, the receipt of environmentally-friendly products through the soil-plant-human cycles also does not lose its relevance and importance (Vural & Aydal 2020; Vladimirovna Demina *et al.* 2020; Abolpour *et al.* 2021). In this regard, the processes of agricultural production intensification under the conditions of soil cover contamination by zinc make it possible to develop theoretical and practical foundations for the reproduction of soil fertility, increasing the yield of cultivated plants and improving its quality (Li & Yan 2018). Therefore, the need to study the translocation mechanism to obtain ecologically clean products of sugar and fodder beets at the primary stage is a priority task of ecological agriculture. Work purpose was to study the influence of various intensification factors in terms of sod-medium podzolic sandy loam soil contamination with zinc on the production of ecologically safe products of sugar and fodder beets. Research objectives include: 1) To study the effect of intensification systems on the change in agrochemical parameters of sod-medium podzolic sandy loam soil contaminated with zinc in the areas with sugar and fodder beet cultivation; 2) To reveal the peculiarities of the subsurface migration flows of zinc when using various intensification factors in the areas with the cultivation of sugar and fodder beets; and 3) To establish the peculiarities of sugar and fodder beet yield development in the conditions of various treatments of intensification and contamination with zinc.

MATERIALS AND METHODS

The experience was laid on a plot occupied for arable land. The soil cover of the land plot is represented by sod-medium podzolic sandy loam soil on moraine loam. To study the agrochemical and agroecological state, the following methods were used: determination of soil acidity level by the potentiometric method in a salt extract KCL (GOST 26483-85, 1985), determination of mobile forms of phosphorus and potassium by the Kirsanov method (GOST R 54650-2011, 2013), the content of organic substances according to the Tyurin method in the modification of TsINAO (GOST 26213-91. 1992), the value of hydrolytic acidity according to the Kappen method (GOST 26212-91. 1992), the content of calcium and magnesium by the complexometric method (GOST 26428-85.1992). The determination of zinc was carried out by the atomic absorption method in an acid extract (Methodical 1973). The primary agrochemical characterization of the soil before laying the experiment is characterized by the following indicators:
On the plot for sugar beet cultivation: pH_{kcl} 4.2 (strongly acidic); P_2O_5: 54.7 mg kg^{-1} of soil (low content); K_2O 112.7 mg kg^{-1} of soil (average content); organic matter content 1.29%, absorbed bases: calcium 2.34, magnesium

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1.10 mg-eq/100 g of soil; the sum of absorbed bases is 3.44 meq/100 g of soil.

On the site for fodder beet cultivation: pH_{kcl} 4.1 (strongly acidic); P_2O_5 62.8 mg kg^{-1} soil (low content); K_2O 120.1 mg kg^{-1} soil (average content); organic matter content 1.33%, absorbed bases: calcium 2.27, magnesium 0.94 mg-eq/100 g of soil; the sum of absorbed bases is 3.21 meq/100 g of soil. Due to the uniformity of the soil cover and the proximity of the experimental plots, significant differences in agrochemical properties were not revealed. The gross content of Zn (in acid extract): in the area for sugar beet cultivation 23.3 mg kg^{-1} and 24.5 mg kg^{-1} in the area for fodder beet cultivation. Mobile forms of Zn (in a buffer solution): in the area for the cultivation of sugar beets - 1.21 mg kg^{-1} and 1.42 mg kg^{-1} in the area for the cultivation of fodder beets. The general replication is fourfold and the experience scheme of intensification factors for potatoes are as follows:

1. Control
2. $N_{120}P_{40}K_{60}$
3. $N_{60}P_{60}K_{60}$ + Zn
4. $N_{60}P_{60}K_{60}$ + Zn + lime
5. $N_{60}P_{60}K_{60}$ + Zn + manure
6. $N_{60}P_{60}K_{60}$ + Zn + manure + lime
7. $N_{120}P_{120}K_{120}$ + Zn

As a source of zinc contamination, zinc sulfate was introduced at the dose of 1318 mg kg^{-1} of soil. Mineral fertilizers (NPK) were used in a dose of $N_{60}P_{60}K_{60}$ and in a double dose of $N_{120}P_{120}K_{120}$ in the form of ammonium nitrate (34.6%), double superphosphate (43%) and potassium chloride (59%). Organic fertilizers were applied in the form of manure at a calculated dose of 60 t/g. In the treatment of $N_{120}P_{120}K_{120}$, mineral fertilizers were applied in a double dose (NPK). Mineral fertilizers were applied during spring time: phosphorus and potash fertilizers when digging the soil, and nitrogen fertilizers just before planting. Lime fertilizers were used in the form of dolomite flour, the dose was set at the rate of 10 ton ha^{-1}. Planting care was carried out during the summer of 2020: regular loosening, hilling, watering and weeding from the weed component.

RESULTS

The study made it possible to establish that various intensification factors significantly change the agrochemical properties during the cultivation of sugar and fodder beets on sod-medium podzolic sandy loam soil. The results of changes in agrochemical indicators of soddy-medium podzolic soil are presented in Tables 1 and 2.

Table 1. Influence of intensification factors on agrochemical indicators at zinc contamination in sugar beet crops.

Experience option	pH	C	P_2O_5	K_2O	Hr	Ca	Mg	∑Ca+Mg
1. Control	4.2	1.29	54.7	112.7	3.7	2.34	1.10	3.44
2. $N_{60}P_{60}K_{60}$ - background	4.1	1.31	91.6	142.5	4.2	2.18	0.92	3.10
3. $N_{60}P_{60}K_{60}$+ Zn	4.1	1.44	101.2	178.3	4.7	2.12	0.74	2.86
4. $N_{60}P_{60}K_{60}$+ Zn + lime	6.0	1.32	97.3	140.4	1.2	3.98	2.10	6.08
5. $N_{60}P_{60}K_{60}$+ Zn + manure	4.1	1.45	121.8	178.6	4.3	2.42	0.88	3.30
6. $N_{60}P_{60}K_{60}$+ Zn + manure + lime	5.9	1.41	119.4	140.3	1.1	3.91	2.19	6.10
7. $N_{120}P_{12}0K_{120}$ + Zn	4.0	1.34	162.1	216.4	4.6	2.11	0.71	2.82

Table 2. Influence of intensification factors on agrochemical parameters at zinc contamination in fodder beet crops.

Experience option	pH	C	P_2O_5	K_2O	Hr	Ca	Mg	∑Ca+Mg
1. Control	4.1	1.33	62.8	120.1	3.8	2.27	0.94	3.21
2. $N_{60}P_{60}K_{60}$ - background	4.1	1.37	92.9	153.1	4.3	2.15	0.79	2.94
3. $N_{60}P_{60}K_{60}$+ Zn	4.2	1.39	97.6	165.6	3.5	2.72	1.18	3.9
4. $N_{60}P_{60}K_{60}$+ Zn + lime	5.7	1.36	102.9	154.4	2.2	3.42	1.70	5.12
5. $N_{60}P_{60}K_{60}$+ Zn + manure	4.8	1.45	118.7	168.3	3.2	2.89	1.30	4.19
6. $N_{60}P_{60}K_{60}$+ Zn + manure + lime	5.3	1.40	131.2	165.0	2.3	3.29	1.68	4.97
7. $N_{120}P_{12}0K_{120}$ + Zn	4.0	1.35	159.7	214.5	4.6	2.10	0.70	2.80

So, there is a significant acidification of the soil environment in the areas where organic and mineral fertilizers were applied, while the introduction of calculated doses of fertilizers in combination with the recommended dose of lime fertilizer in the experiment. On the contrary, equalizes the acidity value to optimal values both in sugar and fodder beet crops. The average shift level of the pH value in sugar beet crops were 0.5 and 0.58 units of pH in the areas with fodder beets.

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In the areas where liming was not carried out, the shifts were 0.13 and 0.18 units of pH for sugar beet and fodder beet crops, respectively. In the treatments of the experiment, where lime fertilizer was applied in combination with a dose of mineral and organic fertilizers, the pH value approached neutral values. Quite naturally, the content of mobile forms of phosphorus and potassium increased in the treatments where mineral and organic fertilizers were applied. The average shear levels of the mobile forms of P_2O_5 were 60.8 and 54.4 mg kg^{-1} in sugar beet crops and fodder beet crops respectively. The shifts of mobile potassium contents in sugar and fodder beet crops were 53.4 mg kg^{-1} and 50.1 mg kg^{-1}, respectively. The additions of lime caused hydrolytic acidity decreased by 2.6 meq/100 g and 1.6 meq/100 g of soil in sugar and fodder beet crops on average respectively. In turn, the average shifts in hydrolytic acidity were 0.35 meq/100 g and 0.45 meq/100 g of soil for sugar and fodder beet crops, respectively. The average shifts of organic matter contents were 0.09% and 0.06% of soil in sugar and fodder beet crops, respectively. By the application of lime fertilizer, the contents of Ca^{2+}, Mg^{2+} and the amount of absorbed bases also increased markedly. So, in the crops of sugar beet, the average level of shifts were as follows: Ca^{2+} = 0.45 mEq/100 g, Mg^{2+} = 0.16 mEq/100 g and $\sum Ca^{2+} + Mg^{2+}$ = 0.60 mEq/100 g. In the case of fodder beet, the average levels of shift were as follows: Ca^{2+} = 0.49 mEq/100 g, Mg^{2+} = 0.29 mEq/100 g and $\sum Ca^{2+} + Mg^{2+}$ 0.78 mEq/100 g. The analyses of all treatments on the intensification of sugar and fodder beet cultivations to obtain environmentally-friendly products allow us to conclude that the introduction of lime fertilizers has a positive effect on the fixation of zinc in soil and significantly reduces its mobility. Thus, they established a tendency towards zinc concentration decrease in the treatment of $N_{60}P_{60}K_{60}$ + Zn + manure lime. The results are shown in Table 3.

Table 3. Influence of intensification factors on the zinc content in soddy-podzolic soil, depending on various intensification factors in sugar and fodder beet crops.

Experience Option	Sugar beet			Fodder beet		
	Gross form	**Mobile form**	**Mobility coefficient**	**Gross form**	**Mobile form**	**Mobility coefficient**
1. Control	23.3	1.21	0.05	24.51	1.42	0.06
2. $N_{60}P_{60}K_{60}$ - background	22.8	1.19	0.05	23.91	1.41	0.06
3. $N_{60}P_{60}K_{60}$+ Zn	131.65	89.05	0.68	132.9	89.22	0.67
4. $N_{60}P_{60}K_{60}$+ Zn + lime	258.95	73	0.28	260.16	73.47	0.28
5. $N_{60}P_{60}K_{60}$+ Zn + manure	139.8	85.6	0.61	141.01	85.97	0.61
6. $N_{60}P_{60}K_{60}$+ Zn + manure + lime	189.5	72.75	0.38	190.71	73.16	0.38
7. $N_{120}P_{12}0K_{120}$ + Zn	115.75	80.4	0.69	116.96	84.1	0.72

Since sugar and fodder beets were used in the experiment in the form of pre-grown seedlings, the growing season was 140 days after its planting on the plot intended for the experiment. The survival rate of the planted seedlings turned out to be different, depending on the intensification factors used. So, in the treatments with zinc pollution, oppression and death of crops occurred. However, under conditions of zinc pollution and the combined use of manure and lime, the development of both sugar and fodder beets took place under normal conditions. As shown in Table 4, zinc pollution sharply reduces the yield of both fodder and sugar beets. However, the yield increases in combination with manure and lime fertilizer. The values of sugar and fodder beet yield for all treatments of the experiment and the intensification level are presented in Table 4.

Table 4. Intensification factor influence on the yield of sugar and fodder beets in sod-podzolic soil, depending on various intensification factors and zinc contamination.

Experience Option	Yield g/flask	
	Sugar beet	**Fodder beet**
1. Control	97.6	92.4
2. $N_{60}P_{60}K_{60}$ – background	251.4	257.2
3. $N_{60}P_{60}K_{60}$+ Zn	204.5	202.3
4. $N_{60}P_{60}K_{60}$+ Zn + lime	294.8	289.8
5. $N_{60}P_{60}K_{60}$+ Zn + manure	248.1	249.6
6. $N_{60}P_{60}K_{60}$+ Zn + manure + lime	397.2	394.4
7. $N_{120}P_{12}0K_{120}$ + Zn	234.8	232.3

According to the developed methodological guidelines, the maximum permissible concentration of zinc in fresh and frozen vegetables is 10 mg kg^{-1}. The results of zinc accumulation in sugar and fodder beets are presented in

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Table 5. It was found that in terms of lime fertilization, the concentrations of zinc in the fruits of sugar and fodder beets significantly decrease. However, noteworthy, in terms of mineral fertilizers, manure and lime use in the fruits of sugar beet, there is zinc content decrease below the MPC. With regard to fodder beets, zinc concentration decrease below the MPC takes place only in the treatment $N_{60}P_{60}K_{60}$ + Zn + manure + lime.

Table 5. Influence of intensification factors at zinc contamination of sod-podzolic soil on zinc content in sugar and fodder beets.

Experience Option	Sugar beet	Fodder beet
1. Control	**5.2**	**5.9**
2. $N_{60}P_{60}K_{60}$ – background	6.9	7.1
3. $N_{60}P_{60}K_{60}$+ Zn	12.8	17.9
4. $N_{60}P_{60}K_{60}$+ Zn + lime	8.3	11.1
5. $N_{60}P_{60}K_{60}$+ Zn + manure	8.6	11.3
6. $N_{60}P_{60}K_{60}$+ Zn + manure + lime	6.8	7.9
7. $N_{120}P_{12}0K_{120}$ + Zn	14.7	18.4

DISCUSSION

Obtaining environmentally-friendly products of sugar and fodder beets fully depends on all properties of the soil environment. By the involvement of various intensification factors in agricultural production, it is fully possible to regulate not only the elemental composition of the soil, but also agroecological properties, which have a clearly differentiated effect on the yield of ecologically-safe products of sugar and fodder beets in sod-podzolic soils. Based on the results of the field experiment, it was found that the application of lime fertilizers in the options $N_{60}P_{60}K_{60}$ + Zn + lime and $N_{60}P_{60}K_{60}$ + Zn + lime + manure under the conditions of sod-podzolic soil contamination with zinc objectively allowed to reduce the acidity of the soil environment in the crops of sugar and fodder beets by 1.75 and 1.89 units of pH respectively.

The liming in conditions of zinc contamination made it possible to increase the content of organic matter in the sugar and fodder beet crops by 0.07% and 0.05% respectively. The content of mobile forms of phosphorus and potassium increased on average by 53.65 mg kg^{-1} of P_2O_5 and 27.6 mg kg^{-1} of K_2O in sugar beet crops, while by 61.2 mg kg^{-1} of P_2O_5 and 30.1 mg kg^{-1} of K_2O in fodder beet crops. Liming sharply reduced the hydrolytic acidity by 2.55 and 2.43 meq per 100 g of soil in sugar and fodder beet crops respectively. The saturation of Ca^{2+} and Mg^{2+} and the value of the sum of absorbed bases on Ca^{2+} increased by 1.6, Mg^{2+} by 1.1 and $\sum Ca^{2+} + Mg^{2+}$ by 2.65 mg-eq per 100 g of soil in sugar; while Ca^{2+} by 1.57, Mg^{2+} by 1.23 and $\sum Ca^{2+} + Mg^{2+}$ by 2.81 in fodder beet crops, respectively. Sufficiently clear changes in agrochemical parameters were not revealed in other treatments of the experiment. This fact indicates that liming makes it possible to adapt sugar and fodder beets to the conditions of zinc pollution and to reduce the toxicological load.

The variation of zinc gross form content in the field experiment of sugar and fodder beet ranged from 22.8 to 258.9 and 23.9 to 260.1 mg kg^{-1} of soil respectively. So that, the highest zinc concentration was established in the treatments using lime fertilizer $N_{60}P_{60}K_{60}$ + Zn + lime and $N_{60}P_{60}K_{60}$ + Zn + lime + manure, while in other treatments the zinc concentration was much lower. Against this background, the tendency of zinc mobile form concentration decrease was clearly observed in terms of the bulk composition concentration increase. The use of mineral and organic fertilizers in combination with liming makes it possible to obtain a high yield of sugar and fodder beets with a low zinc content in comparison with other treatments of the experiment, which amounted to $N_{60}P_{60}K_{60}$ + Zn + lime 294.8 g (8.3 mg kg^{-1}); $N_{60}P_{60}K_{60}$ + Zn + lime manure 397.2 g (6.8 mg kg^{-1}); $N_{60}P_{60}K_{60}$ + Zn + lime 289.8 g (11.1 mg kg^{-1}); and $N_{60}P_{60}K_{60}$ + Zn + lime + manure 394.4 g (7.9 mg kg^{-1}). Moreover, in the treatments with fodder beets, the lowest zinc content was found only in the treatment of $N_{60}P_{60}K_{60}$ + Zn + lime + manure.

CONCLUSION

After the conducted field experiment, it was found that the use of various intensification factors makes it possible to regulate the yield of ecologically clean products of sugar and fodder beets on sod-podzolic soils of light granulometric composition. The results obtained indicate that in conditions of soil cover zinc contamination in soddy-podzolic soil of light particle composition, in order to obtain safe products, it is necessary to carry out detoxification measures aimed at soil environment change. Periodic liming is among the most necessary measures, the effect of which is fully revealed in combination with the introduction of organic and mineral fertilizers. Thus,

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the greatest effect was set from carrying out detoxification measures and obtaining environmentally-friendly products of sugar and fodder beets within the established maximum permissible concentrations in the options of $N_{60}P_{60}K_{60}$ + Zn + lime and $N_{60}P_{60}K_{60}$ + Zn + lime + manure. Carrying out liming contributes to a significant shift in soil environment reaction, which allows zinc to be fixed in the arable horizon (0-20 cm) and prevents its further migration to the underlying soil layers.

The liming process of soddy-podzolic sandy loam soil in the treatments $N_{60}P_{60}K_{60}$ + Zn + lime and $N_{60}P_{60}K_{60}$ + Zn + lime + manure significantly reduces the phytotoxic effect of zinc pollution. This indicates that, subject to the regulations for the joint use of lime with mineral and organic fertilizers, it is possible to obtain ecologically safe products of sugar and fodder environment on sod-podzolic sandy loam soil.

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