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Research article

Yield and quality of potato tubers depending on a complex of chemicals applied under radioactive contamination

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Abstract. The influence of chemicals on productivity and quality of potato tubers cv. Kurazh cultivated on sod-podzolic sandy soils under radioactive contamination was studied in the south-west of the central Non-Black Soil Zone of the Russian Federation. Organo-mineral system (manure, 40 t/ha + $N_{75}P_{30}K_{90}$) applied in complex with chemicals and biological agent Gumistim turned to be the most effective fertilizer system providing the maximum potato yields during the experiment. Moreover, complex application of the chemicals increased protein level and decreased starch content in tubers, it also improved amino acid composition; concentration of heavy metals and specific activity of cesium-137 did not exceed sanitary and hygienic standards (SanPiN 2.3.3 1078—01).

Key words: potato, yield, marketability, starch, nitrates, heavy metals, amino acids, cesium-137

Introduction

Potato is one of the leading agricultural crops ensuring the country's food security to a large extent. In terms of acreage, potato is second after cereals and is the most popular in the consumer basket of the population used for the production of a variety of food products. Moreover, it is the most important forage and technical crop [1—3]. The high competitiveness of potatoes and their intended use is largely determined by a number of quality indicators, the most important of which is the bio-chemical composition of tubers [4].

One of the factors affecting the productivity, quality indicators of potato tubers and biochemical composition, is cultivation conditions including soil, climate and optimal mineral fertilizing throughout the growing season [5].

In order to increase potato productivity, it is necessary to use science-based agricultural practices allowing to optimize fertilizer doses, ratio of nutrients, pesticides, humic fertilizers [6], which are natural biochemical active substances stimulating growth, improving plant nutrition, taking part in redox reactions at the cellular level, reducing radionuclide and heavy metal intake, increasing plant resistance and activating anti-stress mechanism in plants [7—9].

Vast territories in the south-west of the Non-Black Soil Zone of the Russian Federation are radioactive contaminated, where cesium-137 is the main dose-generating radionuclide. Therefore, the main task of agricultural producers is to introduce scientifically-based agrochemical methods into plant cultivation processes that contribute to reducing transition of ^{137}Cs to marketable products and where potassium fertilizers play a major role [10–12].

The purpose of the research was to study the complex application of fertilizers, chemicals and biological agent Gumistim during cultivation of early potato cultivars grown in sod-podzolic radioactively contaminated sandy soil.

Materials and methods

The field experiments were carried out on the experimental field of Novozybkov branch of Bryansk State Agrarian University on sod-podzolic, loose-sandy radioactively contaminated soil in 2013–2017. Arable layer of the soil had the following agrochemical parameters: pHkcl 6.7—6.9, Ng — 0.51—0.56 mmol-EQ/100 g of soil; absorbed alkali — 12.2—16.4 mmol-EQ/100 g of soil; mobile phosphorus and exchangeable potassium (according to Kirsanov) — 370—390 and 76—86 mg/kg of soil, respectively. Organic matter content was 1.9 to 2.2 (according to Tyurin). The density of ^{137}Cs soil contamination in the experimental plot was 526—666 kBq/m^2. Early potato cv. Kurazh was studied in the four-factor experiment, total area of the experimental plot was 90 m^2, and the accounting one was 70 m^2. The experiment scheme included the following variants: control (without fertilizers); manure 80 t/ha; manure 40 t/ha + $N_{75}P_{30}K_{90}$; $N_{75}P_{30}K_{90}$; $N_{150}P_{60}K_{180}$; $N_{225}P_{90}K_{270}$; manure 40 t/ha + $N_{75}P_{30}K_{90}$ + pesticides; $N_{75}P_{30}K_{90}$ + pesticides; $N_{150}P_{60}K_{180}$ + pesticides; $N_{225}P_{90}K_{270}$ + pesticides; manure 40 t/ha + $N_{75}P_{30}K_{90}$ + pesticides + Gumistim; $N_{75}P_{30}K_{90}$ + pesticides + Gumistim; $N_{150}P_{60}K_{180}$ + pesticides + Gumistim; $N_{225}P_{90}K_{270}$ + pesticides + Gumistim.

Such fertilizers as cattle manure, double granulated superphosphate, potassium chloride were used in the experiments. All the fertilizers were applied in spring during plowing of the fall tillage. Bioagent Gumistim contains biohumus in the dissolved form: humins, vitamins, natural phytohormones, succinic acid, micro-and macronutrients in organic form, and spores of soil microorganisms. The biological agent (6 l/ha) was used in two terms: the first was combined with chemical pesticides in the budding stage, and the second — at the end of flowering. Weeds, pests and diseases on potato plants were controled by the following chemicals: Zencor 50% a.i. — 0.7 kg/ha; Titus — 0.050 kg/ha; Ridomil Gold — 2.5 kg/ha; Sektim Phenomen — 1.25 kg/ha, Aktara — 0.06 kg/ha. Depending on weather conditions, no less than 3 treatments were carried out during the vegetation period. The farming practice of potato cultivation was generally accepted for the region. Potato planting was carried out in the third decade of April, harvesting — in the first decade of August, tuber harvest was weighted. Field and laboratory-analytical researches were performed according to the generally accepted methods in agrochemical service in the center for collective use of scientific equipment and devices of the Bryansk State Agrarian University [13, 14]. The weather conditions of vegetation periods in the years of field experiments differed in moisture and temperature. 2014 and 2016 were the most favorable for these indicators, less moisture was in 2013, 2015 and 2017, characterized by low soil productive moisture in the arable soil horizon, insufficient rainfall and uneven precipitation. These circumstances resulted in fluctuations in potato tuber yields over the research years.

Rezults and dicussion

Potato yield was the lowest in the control variant and averaged 9.3 t/ha for 5 research years (Table 1).

Table 1

Yield and quality of potato tubers depending on the chemicals applied (average for 2013—AL2017)

Variant	Yield, t/ha	Increase compared to control, t/ha	Starch content, %	Protein content, %	Protein yield, t/ha
Control without fertilizers	9.3	—	13.0	2.06	0.202
Manure 80 t/ha	20.5	11.2	12.6	2.16	0.469
Manure 40 t/ha + $N_{75}P_{30}K_{90}$	25.9	16.6	12.4	2.26	0.640
$N_{75}P_{30}K_{90}$	22.0	12.7	12.3	2.15	0.520
$N_{150}P_{60}K_{180}$	23.8	14.5	11.8	2.24	0.589
$N_{225}P_{90}K_{270}$	23.0	13.7	11.6	2.34	0.583
Manure 40 t/ha + $N_{75}P_{30}K_{90}$ + pesticides	30.7	21.4	12.2	2.41	0.786
$N_{75}P_{30}K_{90}$ + pesticides	23.5	14.2	12.3	2.16	0.553
$N_{150}P_{60}K_{180}$ + pesticides	27.8	18.5	12.0	2.25	0.648
$N_{225}P_{90}K_{270}$ + pesticides	26.2	16.9	11.7	2.37	0.633
Manure 40 t/ha + $N_{75}P_{30}K_{90}$ + pesticides + Gumistim	35.1	25.8	12.4	2.51	0.876
$N_{75}P_{30}K_{90}$ + pesticides + Gumistim	25.2	15.9	12.4	2.28	0.620
$N_{150}P_{60}K_{180}$ + pesticides + Gumistim	31.1	21.8	12.5	2.39	0.786
$N_{225}P_{90}K_{270}$ + pesticides + Gumistim	27.2	17.9	12.5	2.46	0.726
HCP05, t/ha	2.7	—	0.64	0.16	—

Organic fertilizer (litter manure 80 t/ha) increased yields of potato tubers by 11.9 t/ha compared to the control, amounting to 21.7 t/ha. The use of mineral fertilizers in the dose of $N_{150}P_{60}K_{180}$ (according to the number of nutrients, a manure dose of 80 t/ha) resulted in 23.8 t/ha potato yields, which was 14.5 t/ha higher compared with the control, and 3.3 t/ha higher compared to variant with 80 t/ha of manure. The results indicate a higher availability of nutrients contained in mineral fertilizers and a higher coefficient of their use in the first year after application of relatively organic fertilizer. Applying organic fertilizer (manure 40 t/ha + $N_{75}P_{30}K_{90}$) increased potato yield by 16.6 t/ha compared to the control, and by 5.4 t/ha compared to organic system (manure 80 t/ha). The use of higher doses of NPK ($N_{225}P_{90}K_{270}$), especially under deficit soil moisture and high air temperatures, did not contributed to the adequate increase in potato tubers, the yields of tubers was at the level of the average NPK dose ($N_{150}P_{60}K_{180}$). Cultivating potato plants with pesticide application contributed to a further potato yield increase which averaged 1.5—4.8 t/ha. The higher yields of potato tubers were observed while appliing fertilizers, chemical plant protection means and biological agent Gumistim in complex. On average, over the research years, the increase in potato yield reached the level of 15.9—25.8 t/ha under complex use of chemicals in comparison with the control. The highest potato yield — 35.1 t/ha — in was obtained in the variant with organic-mineral system of fertilizing in combination with pesticides and biological agent Gumistim (manure 40 t/ha + + $N_{75}P_{30}K_{90}$ + pesticides + Gumistim).

On average over the research years, starch content decreased by 0.5—1.9% under the influence of the studied means of chemicalization. The applied systems of fertilizer both at separate, and at complex application promoted an increase in the protein content of potato tubers from 2.06 up to 2.51%. The protein content of potato tubers increased on average by 0.13—0.25% under complex use of chemicals. The maximum protein yield (0.876 t/ha) resulted from organic mineral fertilizing combined with plant protection means and Gumistim.

Quantitative changes in the amino acid composition of potato tubers depended on the studied fertilizer systems (Table 2) on average over 5 years. In quantitative terms aspartic acid and leucine were allocated.

The tubers of potatoes contain the least of histidinum and methionine referring to irreplaceable amino acids. The largest number of essential amino acids (% of the total amount of all amino acids), 38.0 and 39.0 %, was obtained in the organic mineral fertilizer system (manure 40 t/ha + $N_{75}P_{30}K_{90}$), mineral ($N_{150}P_{60}K_{180}$) in complex with plant protection means and biological agent Gumistim.

Table 2

The effect of fertilizers, chemicals and Gumistim bioagent on amino acid composition of potato tubers, tons per 1 kg of dry mass (average for 2013—2017)

Amino Acids	Variants				
	Control	Manure 40 t/ha +			$N_{75}P_{30}K_{90}$ + pesticides + Gumistim
		+ $N_{75}P_{30}K_{90}$	+ $N_{75}P_{30}K_{90}$ + pesticides	+ $N_{75}P_{30}K_{90}$ + pesticides + Gumistim	
Alanine	5.82	5.76	5.48	6.88	5.86
Arginine	4.46	4.53	4.62	4.66	4.68
Asparagine	18.42	18.56	18.86	18.88	18.76
Valine*	5.82	5.58	5.64	5.91	5.86
Histidine*	1.29	1.42	1.46	1.53	1.52
Glycine	3.71	3.84	3.88	3.93	3.92
Glutamine	5.09	5.13	5.18	5.22	5.26
Isoleucine*	3.32	3.48	3.53	4.12	3.86
Leucine *	6.92	7.29	7.38	7.42	8.54
Lysine*	4.58	4.66	4.85	5.13	5.26
Methionine*	1.66	1.68	1.72	1.74	1.76
Promin	6.32	6.46	6.56	7.54	6.73
Serine	4.36	4.41	4.46	4.63	4.52
Tyrosine	4.06	4.43	4.48	5.18	4.52
Threonine	3.66	3.84	3.88	3.92	3.90
Tryptophan*	4.36	4.43	4.52	5.21	4.58
Phenylalanine*	3.88	4.26	4.35	5.13	5.09
Amount	87.73	89.73	90.85	95.43	94.62
Essential amino acids, % of total amino acids	37.0	37.0	37.0	38.0	39.0

Note: *essential amino acids.

It was established that concentration of heavy metals under the influence of the applied means of chemicalization changed (Table 2). Thus, concentration of copper in potato tubers varied on average from 1.35 to 1.46 mg/kg dry mass in the variants of the experiment.

Table 3

The content of heavy metals and cesium-137 in potato tubers depending on the chemicals used (2013—2015)

Variant	Content, mg/kg					Specific Activity ^{137}Cs, BK/kg	Reduction ratio, times
	Cu	Pb	Zn	Mn	Cd		
Control without fertilizers	1.35	0.11	3.86	11.21	0.01	80	—
Manure 80 t/ha	1.37	0.16	2.53	10.87	0.015	30	2.67
Manure 40 t/ha + $N_{75}P_{30}K_{90}$	1.22	0.12	0.36	12.04	0.015	26	3.08
$N_{75}P_{30}K_{90}$	1.32	0.08	3.18	9.16	0.015	21	3.81
$N_{150}P_{60}K_{180}$	1.43	0.06	3.52	11.18	0.02	20	4.00
$N_{225}P_{90}K_{270}$	1.46	0.22	3.75	11.56	0.025	17	4.71
Manure 40 t/ha + $N_{75}P_{30}K_{90}$ + + pesticides	1.12	0.11	2.30	9.97	0.015	19	4.21
$N_{75}P_{30}K_{90}$ + pesticides	0.86	0.06	2.12	10.26	0.015	23	3.48
$N_{150}P_{60}K_{180}$ + pesticides	0.68	0.06	2.42	11.18	0.018	18	3.44
$N_{225}P_{90}K_{270}$ + pesticides	1.32	0.13	2.48	12.45	0.025	16	5.00
Manure 40 t/ha + $N_{75}P_{30}K_{90}$ + + pesticides + Gumistim	1.06	0.10	2.09	11.16	0.01	17	4.71
$N_{75}P_{30}K_{90}$+ pesticides + Gumistim	0.74	0.06	2.18	10.17	0.012	17	4.41
$N_{150}P_{60}K_{180}$+ pesticides + Gumistim	1.18	0.05	2.22	10.13	0.015	14	5.71
$N_{225}P_{90}K_{270}$ + pesticides + Gumistim	1.26	0.10	2.34	9.60	0.02	10	8.0
MAC, мg/kg	5.0	0.5	10.0	—	0.03		

The introduction of consistently increasing doses of mineral fertilizers resulted in increase in concentration of copper in potato tubers compared to the control, but its concentration in tubers did not exceed the marginal acceptable concentration (MAC).

The concentration of lead varied in the range of 0.05—0.22 mg/kg in variants on average over the research years. Complex application of chemicals (var. 7—14) contributed to decrease in concentration of lead in potato tubers in comparison with the control.

Content of manganese in potato tubers varied from 9.16 to 12.45 mg/kg according to the variants of the experiment, with its concentration in tubers of 11.21 mg/kg.

The potassium content in potato tubers did not exceed the threshold value (0.03 mg/kg) on average over the research years, and it was within the marginal acceptable concentration (MAC).

During five-year research specific activity of cesium-137 in the control variant was 80 Bq/kg (standard 120 Bq/kg). The applied chemicals contributed to the reduction of specific activity of ^{137}Cs in potato tubers. The application of organic fertilizer system (manure 80 t/ha) resulted in 2.67-fold reducing the specific activity of ^{137}Cs in potato tubers in comparison with the control. Organic-mineral system of fertilizer caused 3-fold decrease in specific activity of cesium-137 in potato tubers compared to the control. The use of the mineral fertilizer system with consistently increasing doses of NPK reduced the specific activity of ^{137}Cs in potato tubers by 3.81—4.71 times. The use of plant protection chemicals has also contributed to the reduction in the specific activity of ^{137}Cs in potato tubers through biological dilution while increasing the yields of potato tubers in these variants.

Complex application of chemicals contributed to the reduction of specific activity of cesium-137 in potato tubers compared to the control variant. The greatest decrease in the specific activity of ^{137}Cs (8.0 times) was obtained in the variant $N_{225}R_{90}K_{270}$ in combination with pesticides and bio-agent Gumistim (var. 14).

Conclusions

Thus, while cultivating potatoes in sod-podzolic sandy radioactively contaminated soil the maximum yields of potato tubers of 31.1 t/ha was achieved by using the organic-mineral system of fertilizers (manure 40 t/ha + $N_{75}P_{30}K_{90}$) in complex with plant protection agents and Gumistim. The applied fertilizer systems, both in separate application and in combination with the pesticides and Gumistim reduced the starch content in tubers by 1.5—1.9%, and increased the protein content in tubers on average by 0.13—0.25%. The maximum protein yield of 0.876 t/ha was ensured the variant with organic mineral system (manure 40 t/ha + $N_{75}P_{30}K_{90}$) in combination with pesticides and bioagent Gumistim. The greatest level of essential amino acids in potato tubers was provided by the organic-mineral (manure 40 t/ha + $N_{75}P_{30}K_{90}$) and mineral ($N_{150}P_{60}K_{180}$) systems in combination with plant protection means and Gumistim. The concentration of heavy metals in potato tubers in all studied fertilizer systems did not exceed MAC. Specific activity of ^{137}Cs in potato tubers was reduced from 2.67—8.0 times both in separate and complex application under the influence of the studied fertilizer systems.

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Научная статья

Продуктивность и качество клубней картофеля в зависимости от комплекса применяемых средств химизации в условиях радиоактивного загрязнения агроценозов

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Аннотация. В условиях радиоактивного загрязнения сельскохозяйственных угодий юго-запада Центрального Нечерноземья Российской Федерации изучали влияние комплексного применения средств химизации на продуктивность и качество клубней картофеля сорта Кураж, возделываемого в плодосменном севообороте на дерново-подзолистой песчаной почве. Показано, что в условиях проводимого эксперимента оптимальной системой удобрения, обеспечивающей максимальную урожайность клубней, оказалась органоминеральная система (навоз 40 т/га + $N_{75}P_{30}K_{90}$), применяемая в комплексе с химическими средствами защиты растений от вредных организмов и биопрепаратом Гумистим. Отмечено, что под влиянием комплексного применения изучаемых средств химизации повышалась белковость и снижалась крахмалистость, улучшался аминокислотный состав, концентрация тяжелых металлов и удельная активность цезия-137 не превышала санитарно-гигиенических нормативов (СанПиН 2.3.3 1078—01).

Ключевые слова: картофель, урожайность, товарность, крахмал, нитраты, тяжелые металлы, аминокислоты, цезий-137

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