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Developing of modern cultivation technology of organic potatoes

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Abstract. Medium term field experiment demonstrates the effectiveness of biological ways to increase potatoes yield on the sod-podzolic, light loamy soil.
The effects of the following two groups of factors were studied:
1. The level of mineral nutrition provided by compost;
2. Microbiological pant protection product (bio preparations): Flavobacterin which has N fixer attribute and Vitaplan and Kartofen, which have bio fungicide features.
Potatoes varieties 'Nevsky' and 'Udacha' were cultivated. The compost was applied in the dose range from 0 to 160 kg N ha^{-1}. Treatment with bio-preparations was carried out by potato tubers during planting and leaves during the growing season. Weeds were removed mechanically. Weather conditions had a significant impact on the formation of the crop. The average yield of standard potato tubers for 2017–2018 ranged from 14.1 to 29.3 t ha^{-1}. The use of both microbiological preparations and compost gave approximately the same effect and increased yields by 35–37% compared to the control. The use of compost together with bio-preparations provided an output of 27.6–29.3 t ha^{-1} of potatoes. In 2019, the joint use of compost and bio-preparations allowed to reach a yield of 40 tons ha^{-1} of marketable potatoes. On the basis of the obtained data, the mathematical dependences of the yield of potatoes on the dose of compost, the type of biological preparation and the complex indicator of the year conditions were determined.

Key words: crop rotation, potatoes, organic fertilizers, microbiological drugs, field experiment.

INTRODUCTION

The modern agricultural food system is quite productive, but it creates many environmental problems, such as reduced biodiversity, soil degradation, eutrophication of water bodies, the release of large amounts of greenhouse gases, and a number of others (Foley et al., 2005; Ponisio et al., 2015). One of the most widely practiced and studied alternative to intensive farming is organic farming. Organic production is actively developing around the world. According to the last annual IFOAM report (2018), in 2017 the number of countries where organic production is carried out was 181, and where there is government regulation - 93. The value of the global organic market in the same year reached 90 billion euros. Although there is an opinion about the low productivity of agricultural systems that do not use synthetic fertilizers and pesticides, they are more profitable and environmentally friendly and provide the same or more nutritious products that don't contain pesticide residues compared to conventional agriculture. A review by Reganold et al. (2016) and meta-analysis by Ponisio et al. (2015) demonstrated that when using crop rotation in organic farming, including fields with perennial legumes, the yield gap is only 8–9%. Feiziene et al. (2016) experimentally confirmed that in organic crop rotations, including red clover, it is an active storage of carbon and nitrogen in the soil humus compounds and a significant reduction in greenhouse gas emissions compared with intensive agriculture. Similar results are presented by Müller-Lindenlauf (2009), who emphasizes that the increase in soil carbon and nitrogen reserves in organic production provides greater sustainability of crop productivity compared to conventional agriculture. Obviously, it is the use of composts, presence of legumes in the crop rotation and the softer mechanical soil treatment that contributes to the preservation of organic matter in the soil (Huhta & Minin, 2014).

However, Ponisio et al. (2015) emphasize that the time has come to invest in analytically accurate, agroecological and socio-economic studies aimed at bridging yield gaps between sustainable and conventional agriculture (when they arise), identifying barriers to the introduction of sustainable methods and improving the living conditions of the rural poor. At the same time, one must be guided by taking into account the various interests of farmers, including social ones, which intend to engage in organic farming (Raudsepp-Hearne C et al., 2010; Escobar et al., 2019).

In Russia, Federal Law N 280 dated 03.08.2018 '*On organic products and on amendments to certain legislative acts of the Russian Federation*' was adopted in August 2019 and entered into force on January 1, 2020. There are also four federal regulatory documents that determine the requirements for the production and delivery of organic products to consumers. It should be noted that these requirements generally comply with similar requirements adopted by IFOAM and the European Union.

The scientific basis is an adaptive, landscape approach aimed at a more complete use of natural processes and cycles, as far as possible closing biogeochemical cycles and so cutting the cost of non-renewable resources, preserving biodiversity and, at the same time providing high-quality food (Zhuchenko, 2008). Organic farming is well-suited to small-scale producers who will be able to enter the market with high-quality local products produced with minimal negative impact on the environment which are attractive to local consumers. This requires the use of modern, alternative agricultural technologies based on a synthesis of the latest achievements of biological and engineering science and adapted to local conditions (Seufert et al., 2012; Popov et al., 2018). However, according to the Union of Organic Agriculture, most Russian agricultural producers are not familiar with effective methods of organic farming.

Potato is the third most important food crop, after rice and wheat, with a total production of more than 300 million metric tons, as established by the International Potato Center (2017) in Lima, Peru. The Russian Federation ranks third in the world in the production of potatoes, which is cultivated in all major regions of the country. Potato is a very flexible crop that is why it is widely distributed. Potatoes were cultivated in the North-Western zone of the Russian Federation in the first half of the eighteenth century. However, intensive potato cultivation technologies began to be developed and used by agricultural producers in the seventies of the twentieth century.

To date, a number of instructions and recommendations have been issued on the cultivation of potatoes for the main zones of the country (Loginov et al., 2009; Starovoitov et al., 2013). The natural conditions of the North-Western region of the Russian Federation are characterized mainly by low fertility soils, increased rainfall in the second half of the growing season, and the appearance of potato late blight in some years. In accordance with this, the instructions recommend the introduction of increased doses of artificial fertilizers for potatoes, possibly together with organic ones, and regular treatment with pesticides, which contradicts the requirements for the production of organic potatoes. In this regard, the goal of our work is to formulate the technology for competitive production of organic potatoes in this area using the achievements of agricultural sciences and information technology.

MATERIALS AND METHODS

An experimental field crop rotation with elements of organic farming started in the Experimental Field of the Institute in 2016. The experiments were conducted on Humose, Coarse Loamy, Gleyic Sod-Podzolic soil, developed on calcareous moraine, with a weakly acidic reaction and medium to high levels of available P and K. The crop rotation consists of following crops: potatoes; red beat; barley with subseeding of clover and timothy; 2 years of perennial grasses; on the 3rd year grasses will be moved and rye will be sowing. Rye will be mowed in the spring and plowed into the soil, as green fertilizer. Plot size was 5.6×11 m = 61.6 m^2, with four replications in a complete randomized design.

This article presents data obtained in the plots with potato crops.

Three factors studied in the experiment were following:

1. Organic fertilizers (composts) to improve the mineral nutrition of potatoes;
2. Culture of microorganisms - nitrogen fixers (Flavobacterin preparation), which can contribute to the production of additional biological nitrogen by potatoes;
3. The effect of bio fungicides: Extrasol (2016), Vitaplan SP (2017–2018) and Kartofen SP (2019).

The studies were carried out with two types of compost based on chicken manure and prepared industrially:

- Compost produced in the IAEP bio convector (BIOGUM);
- Compost produced in the bio convector of Biozem LLC (KMN).

They are characterized by a high dry matter content (about 50%) and a high content of nitrogen and phosphorus (Table 1). BIOGUM was used in the experiment of 2017–2019, and KMN - in 2016 and 2017.

Table 1. Composts composition in field experiments

	Type of compost	Dry matter, %	N mg kg^{-1}	P mg kg^{-1}
1	BIOGUM	48.5	2.20	0.81
2	KMN	54.2	1.74	1.33

The compost doses used in the experiments were calculated on nitrogen (0; 40; 80; 160 kg N ha^{-1}) and corresponded to different levels of the planned potato productivity. Organic fertilizers were applied before ridging, followed by embedding the fertilizer by disking.

Two potatoes varieties were cultivated: variety 'Nevsky' in 2016 and variety 'Udacha' in 2017–2019. Potato variety 'Nevsky' is a traditional variety, medium early, relatively resistant to many diseases. The 'Udacha' potato variety is a new variety, relatively resistant to late blight, perfectly adapts to various soils and weather conditions, it characterized by good taste and smoothness of the tuber surface (Shabanov, 2016). Potatoes for cultivation were obtained from the seed farm (super elite and elite classes).

Biological fungicides based on *Bacillus subtilis* named as Vitaplan SP (strain VCM-B-2604D) and Kartofen SP (strain VCM-B-2605D) developed by Russian Research Institute of Plant Protection) were used in the experiment to protect potatoes from diseases. Potatoes were treated with bio-preparations at the time of planting and by foliar spray during the growing season. For this purpose, a specially designed sprayer was installed on the planter and on the cultivator. Inter-row cultivation was carried out regularly, starting from the second week after planting, using an experimental specimen of a row-crop cultivator of an original design that provides deep loosing of inter rows. Weed vegetation was removed mechanically using small rotary harrow BRU-0.7 harrows mounted on the cultivator.

For operational work with experimental data, a specialized process management information system was created, into which all the information obtained in the experiments was entered. Observations of the growth rate of biomass (by the phases of plant development), phytosanitary conditions and soil properties were carried out regularly. Soil samples were taken from the arable horizon (0–25 cm) four times per season. Following characteristics were determined: soil moisture, pH, nitrate and ammonium content.

Analytical studies were performed at the IAEP Chemical Analytical Laboratory in accordance with the relevant GOSTs. Determination of nitrates and ammonium in soil was carried out using the ion metric method, GOST 26951-86.

Statistical processing of research results was carried out using the Statistic program.

Theory and modelling

The main way to organize competitive production of organic products is to ensure high productivity in optimal agro-technical terms with high accuracy and minimal material and energy resources. The solution to this problem is possible by creating and using an Information Management System (IMS). The IMS will collect operational information about weather conditions and the state of the soil environment and vegetation cover. On this basis and with the use of it knowledge base on plant development, depending on the prevailing conditions and methods of technological impact on this development, the IMS will recommend the choice of operations and the time of its implementation to farmer. In the future, the IMS will send commands directly to robotic agricultural equipment. Field studies are carried out to provide the future IMS with information on the dependence of the formation of potato biomass and its chemical composition on the prevailing weather and soil conditions and agrotechnical effects (Table 2). Obviously, this kind of research is also carried out by other scientists (Timoshina 2017), therefore, all available information will be used to form the information base of the future IMS.

Table 2. Scheme of the main technological processes of potatoes cultivation and of factors affecting them

No.	Technological process	Factors determining the choice of operations	Time interval selection
1	Autumn soil cultivation	1.1. Type of previous crop and the time of it harvest; 1.2. Soil moisture.	Before soil freezes
2	Spring soil cultivation	2.1. Type of autumn soil cultivation; 2.2. Soil moisture and temperature; 2.3. Soil density.	
3	Fertilization and incorporation	3.1. According analysis of soil and fertilizer; 3.2. Soil moisture and soil physics status.	As close to sowing time as possible
4	Ridging and potatoes sowing	4.1. Characteristic of variety; 4.2. Soil moisture and temperature.	In steady warm weather
5	Crop protection against diseases and pests,	5.1. Phytosanitary condition of agroecosystem.	At potatoes sowing; During potatoes vegetation
6	Potato planting care	6.1. Weather conditions; 6.2. Soil physical condition; 6.3. Weeds.	During potatoes vegetation
7	Harvesting	7.1. Weather conditions; 7.2. Soil physical condition.	When the potatoes are ripe

RESULTS AND DISCUSSION

The weather conditions in 2016–2019 are presented in Table 3. They significantly differed among themselves during critical periods of development of potato plants. Potato planting took place in the last week of May during all years and the first seedlings appeared, usually after two weeks. Weather conditions in May were characterized by high variability of both temperature and precipitation, which created various temperature and humidity conditions in the soil at the beginning of the development of potatoes. 2017 was characterized by cold weather, both in May and in June, in May rainfall was also limited. In 2018, the weather was very warm in both May and June, with very limited rainfall during these months, which caused some drying of the soil surface. The years 2016 and 2019, in turn, were distinguished by fairly warm weather in May - June and a sufficiently large amount of precipitation. The second critical period was indicated in August, when the active formation of tubers was completed and their ripening was in progress. The maximum rainfall fell in 2016, exceeding more than twice the annual average. Heavy rains began on July 20, which caused the growth of weeds, but the agricultural machinery could not work, due to waterlogged soil. Weed removal was carried out manually. At the end of July, there was a massive development of late blight on all variants of the experiment, which led to large losses in the crop. A lot of precipitation fell in 2017, also. According to the results of the first year of research, we changed the type of bio fungicide, the variety of potatoes and the soil cultivation system (we began to deepen the row spacing).

Table 3. Weather conditions on experimental field I 2016–2019

Month	Weather indicators	Year				Coefficient of variation	Annual average
		2016	2017	2018	2019		
May	Temperature, C°	14.8	9.4	15.1	12.1	20.60	11.3
	Precipitation, mm	30	13	14	79.3	91.39	46
	HTK	0.67	0.45	0.64	2.11	79.37	0.97
June	Temperature, C°	16.4	13.6	16.2	18.7	12.85	15.7
	Precipitation, mm	99	69	35.2	79.3	37.80	71
	HTK	2.09	1.69	1.02	1.42	28.97	1.56
July	Temperature, C°	19	16.5	20.8	16.5	11.52	18.8
	Precipitation, mm	151	123	152	179.8	15.31	79
	HTK	2.56	2.48	2.85	3.52	16.57	2.85
August	Temperature, C°	17.2	17.4	15.7	17.0	4.56	16.9
	Precipitation, mm	190	148	60.1	94.6	46.58	83
	HTK	3.31	2.83	2.02	1.80	28.26	2.49

Note: HTK – Selyaninov hydrothermal coefficient.

The data on influence of weather conditions and doses of compost on the content of mineral forms of nitrogen in early summer soils are presented in Table 4. The low temperature in 2017 and the reduced precipitation in 2017 and 2018 led to the weak development of the mineralization processes of both soil organic matter and compost. In this regard, very low amount of mineral forms of nitrogen (nitrates and ammonium) was present in the soil, which, in turn, restrained the development of potatoes. In 2016 and 2019, there is an active development of mineralization processes due to favorable weather conditions, in connection with which the content of mineral forms of nitrogen in the soil has increased significantly, especially in the case of composting. However, in the studies of Skudra & Ruza (2019), no dependence of the content of mineral forms of nitrogen in the soil on the conditions of the year was noted.

Table 4. Influence of weather conditions and compost doses on the content of mineral nitrogen forms in soils (mg kg^{-1}) in first decade of June

Compost doze	Yeas			
	2016	2017	2018	2019
Control	40	17	13	35
40 kg N ha^{-1}	91	17	-	-
80 kg N ha^{-1}	140	21	14	48
160 kg N ha^{-1}	-	19	15	55
Equation	R			
A = -58.10+3.28B+55.86C	0.607			

Note: A – the content of mineral N forms in the soil in the first decade of June; B – doze of compost, in N ha-$^{-1}$; C – HTK.

Responsiveness of potato variety Udacha for cultivation operations was largely determined by the prevailing weather conditions. As showed above, the content of mineral forms of nitrogen in the soil, at the beginning of the formation of potato plants, was ensured by the intensity of the mineralization process. The optimal conditions for this microbiological process are determined by temperature and humidity. Apparently, the development of potato plants correlates with the intensity of the mineralization process in the soil as well as with the prevailing weather conditions.

In the period 2017–2019, the productivity of potatoes varied from year to year, however, in all years, both composting and biological preparations significantly increased the potato yield. Interesting data was obtained in 2018–2019, when we began to leave separate plots without plant protection products. The biological fungicides, in both years, gave the same increase in potatoes productivity as compost. The combined effects of biologics and composts were summarized. The maximum productivity of potatoes, which largely corresponded to the potential of the variety, was achieved in 2019. While in control 24.6 t ha^{-1} of standard potatoes tubes were obtained, the use of bio fungicides alone ensured a yield increase to 29.1–24.5 t ha^{-1} (Table 5). Compost significantly increased the yield of standard tubers. Without bio fungicides, compost provided an increase in the yield of standard tubers up to 5.9 t ha^{-1}, that is, each kilogram of compost nitrogen provided an increase of 73.7 kg ha^{-1} of standard tubers. Combination of bio fungicide and compost provided a further increase in potato yields. So, yield of 41.6 t ha^{-1}of standard tubes was achieved on the plots with combination of Flavobacterin + compost application. It should be noted that Flavobacterin provided a smaller proportion of small tubers in the total biomass (less than 1%) on all treated plots. The action of Kartofen, together with compost, also allowed a reliable increase. With a compost dose of 160 kg N ha^{-1}, the yield of standards tubes amounted to 40.4 t ha^{-1}.

Table 5. The influence of compost, biological plant protection products and weather conditions on the potato yield in the experiment during 2016–2019

Compost doze	Type of biological plant protection products	Yield, t ha^{-1}				
		Year	2016	2017	2018	2019
		Variety	Nevsky	Udacha	Udacha	Udacha
0	0		9.9	-	17.8	24.6
0	Extrasol		12.5			
0	Vitaplan / Kartofen		-	14.1	25.3	29.1
0	Vitaplan +Flavobacterin		-	16.6	24.0	29.5
40N kg ha^{-1}	Extrasol		8.2			
80 N kg ha^{-1}	0		-	-	24.5	30.5
80 N kg ha^{-1}	Extrasol		11.5			
80 N kg ha^{-1}	Vitaplan / Kartofen		-	18.7	29.2	32.7
80 N kg ha^{-1}	Vitaplan +Flavobacterin		-	18.4	27.6	41.6
120 N kg ha^{-1}	Extrasol		6.4			
160 N kg ha^{-1}	Vitaplan / Kartofen		-	16.4	29.3	40.4
LSD $_{0.95}$			1.9	1.64	1.8	4.0

Mathematical dependencies calculated according to the results obtained in the experiment are presented in Table 6. They confirm that the content of mineral forms of nitrogen in June predicts a possible future yield. However, in any case, it is weather conditions that have a decisive influence on productivity.

The question arises about the need to regulate the moisture content in the soil in June by agro technical methods. A rational combination of agrotechnical methods of soil cultivation contributes to the optimal moisture content in the soil during the period of active development of potatoes (June - July):

• Softening of the soil during its fall ploughing, providing moisture accumulation in the autumn and winter periods;

• Minimization of pre-planting tillage eliminating turning of furrow slice and active loosening of the arable layer (rotary tillage), ensuring minimal loss of accumulated moisture;

• Deep loosening of row-spacing in the technological process of planting potatoes, providing unhindered movement of moisture between soil horizons.

Table 6. Mathematical Regression of potato productivity against, the content of mineral N forms in the soil in June, compost doses and HTK values

Equation	R	Indicators
У2 = 73,806+6.57 A - 6.9 C – 11AC +2.24 A^2 + 8.58 C^2	0.9235	У2 – yield of potatoes, (t ha^{-1}) with compost dose 80 kg N ha^{-1}; C – HTK A – the content of mineral N forms in the soil in the first decade of June;
У = 13.02 – 0.533 A +0.504B + 0.231C	0.6382	Y – yield of potatoes, t ha^{-1} (all compost doses); B – doze of compost, in N ha^{-1}

But the most cardinal way is to organize irrigation during critical periods. This is the method used in New Zealand, which allows farmers to harvest 70–80 tons of potatoes per hectare. However, in preparing recommendations to farmers, it will be necessary to consider a wider range of factors, including social (Kubule et al., 2019).

CONCLUSIONS

1. In the results of the studies, mathematical dependences of potato productivity on the dose of compost and weather conditions were established. These dependencies allow us to proceed to the formation of models of production processes and the general model of agroecosystem crop rotation of a row crop.
2. The use of biological fungicides made it possible to activate the soil environment and potato plants, which ensured the same increase in yield as compost.
3. When using complex of variety, special tillage, compost and bio fungicides, the combination of their action a further significant increase in potato yield were ensured.
4. The conditions for preparing the soil for planting potatoes and its contents during potato growing season are formulated.

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