WASTEWATER TREATMENT AND DISPOSAL OF INDIVIDUAL RESIDENTIAL BUILDINGS IN AGRICULTURE

Andrey Novikov[1, 2], Anton Poddubsky[3], Evgenii Dugin[4], Olga Poddubskaya[5], Maksim Filimonov[1, 2], Regina Gurina[3]

[1]Volgograd State Technical University, Russia; [2]Federal State Budget Scientific Institution the All-Russian research institute of irrigated agriculture, Russia; [3]Peoples' Friendship University of Russia, Russia; [4]Volgograd State Agricultural University, Russia; [5]State University of Humanities and Technology, Russia

poddubskiy-aa@rudn.ru

Abstract. In the conditions of limited possibilities of traditional regulation of production processes in bioagrocenoses it is necessary to find ways to increase their potential yield due to excessive man-made resources such as sludge from recycled wastewater. Ecological technologies of waste-free production, including the sludge sediment utilization as bio-fertilizer on agricultural fields, are a very promising direction of stabilizing the degradation processes of reducing soil fertility as well as increasing the moisture capacity, which is especially important for arid regions of the world. With the growth of suburban settlements the problem of high-quality wastewater treatment of individual buildings and, accordingly, the ecological well-being of these areas has become so urgent that it requires the development and creation of modern compact bio-cleaning modules, which should provide deep destruction of biogenic elements and possibility of secondary use of man-made resources without restructuring existing septic tanks and periodically exporting wastewater. In particular, it is a possibility to use purified water for irrigation of household plots or other technical needs, and to use sludge as a bio-fertilizer enriched with macro- and microelements. Ecological technologies of waste-free production, including the utilization of sludge from biological stations on agricultural fields as a bio-fertilizer, are very promising ways of stabilizing the degradation processes of reducing soil fertility in addition to increasing their water-holding capacity. Studies on the impact of various doses of the bio-fertilizer on the water-physical properties and the degree of soil contamination, as well as on the quality and yield of potato tubers cultivated for seed in the arid climate of the Lower Volga region confirmed its high efficiency and environmental friendliness.

Keywords: biological wastewater treatment, modular bio-station, sludge sediment, bio-fertilizer, drip irrigation, potatoes, seeds, water-physical properties of the soil, heavy metals, pollutants, environmental technology.

Introduction

In the conditions of limited possibilities of traditional regulation of production processes in bioagrocenoses it is necessary to find ways to increase their potential yield due to excessive man-made resources such as sludge from recycled wastewater [1-4]. Ecological technologies of waste-free production, including the utilization of sludge sediment on agricultural fields as bio-fertilizer, is a very promising direction of stabilizing degradation processes of reducing soil fertility, as well as increasing its water-holding capacity, which is especially important for arid regions of the world [5-8].

The most effective of the known methods is the use of biological processes in wastewater treatment, since it provides not only their purification but also the removal of the biogenic elements nitrogen and phosphorus by freely floating biocenosis of activated sludge. However, the effective operation of biostations is achieved only with strict adherence to the technological process. The main difficulty in simultaneously removing nitrogen and phosphorus compounds from effluent is that their removal requires different conditions – nitrification and denitrification. Varying species and quantitative composition of microorganisms from the optimal value, for example, because of fluctuations in the initial concentrations of pollutants due to instantaneous emissions, a decrease in the concentration of dissolved oxygen, nutrients or an abrupt change in the pH of the medium can cause a change in the sedimentation characteristics of the activated sludge and a disruption of production – destruction processes in biocenosis [9-13].

At modern biostations wastewater treatment is carried out in several stages. As a result of passing the effluent through the full cycle of bioremediation, the output is conditionally purified water with the possibility of its secondary use, for example, for watering home gardens and other technical needs [14;15]. The problem of quality wastewater treatment of country houses and villages arose not so long ago, and as a result, local sewage systems became widespread, which are often "handicraft" and far from perfect because of their overall size, the need to restructure existing septic tanks and periodic removal

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effluents, the impossibility of rational organization of biochemical processes of deep destruction of effluents and the secondary use of resources, including water [16;17].

In this regard, the aim of the work was to develop a module for biological treatment of household wastewater for individual residential buildings and to study the utilization of sludge sediment as a bio-fertilizer in potato cultivation in irrigated conditions of the Lower Volga region.

Materials and methods

To solve the aim a module was developed for biological wastewater treatment, which was mounted into an existing sealed septic tank. The module is a compact container with a sealed bottom, which is equipped with technological means. When the module is installed in a septic tank, a biostation is formed with two technological zones: the aeration tank and the secondary settling tank. The walls of the existing septic tank serve as a module casing, Fig. 1 [18;19].

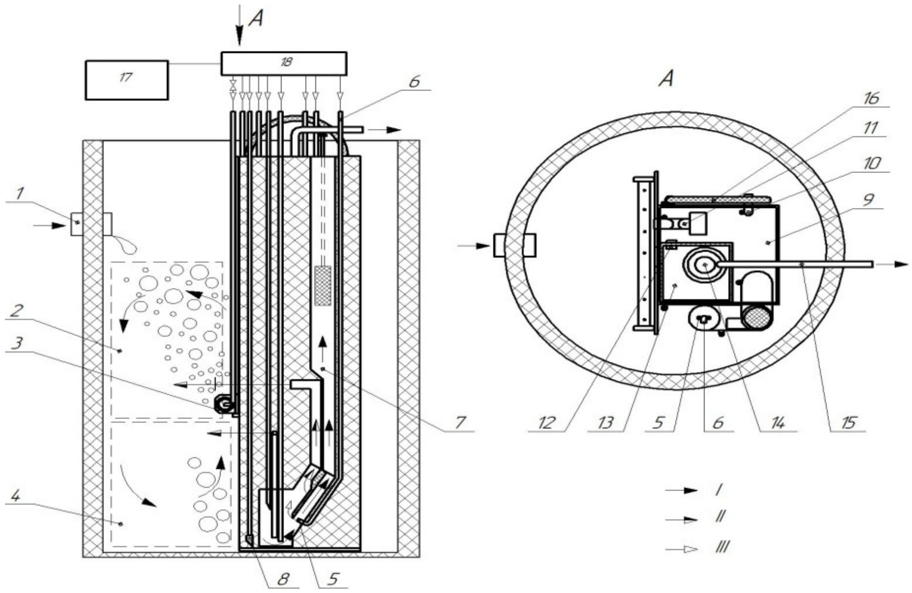

Fig. 1. **Modular biostation for wastewater treatment:** I – sludge mixture; II – air-sludge mixture; III – air ; 1 – inlet nozzle 2 – aerobic zone; 3, 8 – aerators; 4 – anaerobic zone; 5 – blowing; 6, 11, 16 – airlifts; 7 – desilter; 9 – module housing; 10 – recirculation line; 12 – overflow pipe; 13 – clean water capacity; 14 – submersible pump; 15 – pressure pipeline; 17 – compressor; 18 – air distribution tank

The removal of excess activated sludge was made by airlift from the bottom part of the module anaerobic zone. Analytical studies of sludge after its pre-drying included the laboratory definition of toxicological, agrochemical, and sanitary-hygienic indicators for compliance with regulatory and technical documents [20;21].

Silt was disposed as a bio-fertilizer in the irrigated fields of the Lower Volga region in cultivation of potatoes for seed. To assess the effectiveness and environmental friendliness of the bio-fertilizer one-factor plotting experience was established for studying doses (at a rate of 20, 40 and 60 $t \cdot ha^{-1}$) of bio-fertilizer for quantitative and qualitative indicators of potato tubers. Bio-fertilizers were applied to the field surface after the main tillage. In the control variant, instead of bio-fertilizers, complex mineral nutrition was applied with a dose of N_{150} P_{60} K_{135} , with phosphate and potash fertilizers applied under the main tillage, and nitrogen fertilizers were applied together with planting potatoes [22].

In the experiments we used the zoned variety “Arosa”, planting was carried out by the ridge method with a width of aisle of 0.7 m in the III decade of June at a rate of 70 thousand tubers per hectare, and harvesting potatoes was in the II – III decades of October [23;24].

Field experience in irrigation conditions was laid in accordance with existing methods [25;26], variants were placed systematically in fourfold, and data processing was performed by the method of dispersion analysis. The landing plot area was 280 m ^{2} (2.8 × 100), and the registered one was 70 m ^{2} (2.8 × 25).

According to the phases of growth and development of potatoes depending on the weather conditions, diseases and pests, planting debris, traditional plant care activities were carried out.

Weather conditions were assessed by the Selyaninov hydrothermal coefficient (1) [27], which shows the moisture supply of the region by precipitation:

$$HTC = \left(10\sum P\right)\cdot \sum t^{-1} \tag{1}$$

where P – precipitation for the period with the average daily temperature above 10 ºC, mm;
t – temperature over the same period, ºC ;
1.6 ≤ SCC ≤ 1.3 – zone of sufficient moisture;
1.3 ≤ SCC ≤ 1.0 – weakly arid zone;
1.0 ≤ SCC ≤ 0.7 – arid zone;
0.7 ≤ SCC ≤ 0.4 – extremely dry zone;
SCC < 0.4 – zone with a dry climate.

Irrigation land reclamation is the limiting factor in the production of agricultural products in the arid conditions of the Lower Volga region, and drip irrigation is the most rational and resource-saving way to maintain the given humidity in the wetted soil layer. The pre-irrigation threshold of soil moisture was maintained at a level not lower than 80 % HB during the flowering phase in a layer of 0.4 m and 70 % HB in the remaining phases in a layer of 0.6 m [28-31].

The effectiveness of the bio-fertilizer was evaluated by the yield of potato tubers per seed, the ecological compatibility of the bio-fertilizer was evaluated by soil contamination Z (2) [32] and the quality of potato tubers for compliance with the standards [33]:

$$Z = \sum_{i=1}^{n}\left(C_i / C_{fi}\right) - (n-1), \tag{2}$$

where n – number of components;
C_i – actual content of the i-th component in the soil, mg·kg^{-1} ;
C_{fi} – background content of the i-th component in the soil, mg·kg^{-1}.

The determination of the qualitative indicators of potato tubers (heavy metals, starch, dry matter and nitrates) and heavy metals in the soil was carried out in an analytical laboratory. The content of organic matter was determined according to Tyurin [34-35], mobile forms of phosphorus and exchangeable potassium were determined according to Machigin [36], and easily hydrolyzed nitrogen – according to Tyurin and Kononova [35].

Water-physical properties of the soil were studied by standard methods: the density of addition was determined by the drilling method, the density of the solid phase by the pycnometric method, the natural humidity by the thermostatist – weight method, the lowest (field) moisture capacity by the method of flooded areas with sampling of soil samples for humidity after 48 hours. Soil samples were collected by a soil drill in fourfold repetitive ten-centimeter layers from the surface to a depth of one meter [37;38].

The soil is classified as chestnut by type, the subtype is light chestnut, and by its particle size distribution it is heavy loamy. The surface of the experimental area is without slopes, groundwater occurs at a depth of more than 5 m. The water-holding capacity of the soil is high, the meter layer can hold up to 2850 m^3·ha^{-1}.

The developed scheme of field experience allows us to give a comprehensive assessment of the effectiveness and environmental friendliness of the bio-fertilizer.

Results and discussion

Taking into account the experience of designing industrial biostations, a compact module, Fig. 1, has been developed for bioremediation of wastewater from individual residential buildings [18;19]. The aeration element 3, installed at a medium height outside the settler, divides the working volume of the module into the upper (aerobic) 2 and lower (anaerobic) 4 zones, functionally creating a vertical-zonal aeration.

Conditions for nitrification and regeneration are created in the upper zone, and a denitrification zone is formed in the lower part. Large bubble aerators 8 are installed at the bottom part of the anaerobic zone for blending the sludge mixture.

Module housing 9 (functionally performing the work of the secondary clarifier) is made of polypropylene sheets and is a vertical container with a sealed bottom. Airlifts are installed to remove settled activated sludge and biofilm formed on the surface inside the settler. The anaerobic zone of the aerotank is connected to the secondary settling tank by the desilter 7. All the elements of the module are made of polymeric materials. The module is equipped with a mini-compressor 17 for the aeration system and air-lift operation. Air is supplied by the module elements through PVC hoses connected to the nozzles of technological elements in continuous mode through the air distribution tank 18. Stop valves are installed on the supply pipe to regulate the performance of the fine bubble aerator 3.

When the modular biostation is operating the effluent through the inlet nozzle 1 enters the oxidation zone 2 of the receiving chamber of the aerotank, where a high level of dissolved oxygen is maintained due to the vertically-stepped aeration. Under the action of the fine bubble aerator 3 in the receiving chamber not only the oxidation and decomposition of organic matter takes place, but also the regeneration of the sludge mixture coming from the secondary clarifier. Further the wastewater enters the anaerobic zone 4. Due to the lack of oxygen the biocenosis in the anaerobic zone begins to absorb oxygen from nitrites and nitrates formed in the oxidation zone.

The sludge mixture under the action of flow enters the desilter 7 through the air tube formed by the blowing 5 of the circulation airlift 6. Most of the sludge is retained and mixed with the help of a large bubble aerator 8 in the anaerobic zone.

The sludge mixture in the desilter passes through three successively installed chambers: a flow divider, a floating bio-load and a channel flow quencher. Under the action of air bubbles a swirling upward movement is formed in the flow divider. The partition is also installed here which allows to separate the vortex flow from the total flow, thereby carrying with it suspended substances into the recirculation channel directed into the aerobic zone. After passing through the flow divider the effluent passes through bio-loading along an upward trajectory which allows immobilizing activated sludge, keeping the slowly growing forms of microorganisms on itself. The resulting biofilm consisting of aerobic and anaerobic microorganisms creates an additional circuit after purification of residual contaminants.

Air is supplied to the upper part of the flow damper, the bubbles of which form a reverse countercurrent to the flow of water and partially repulse the sludge suspension from the damper returning them to bioloading. The three-stage sludge separator system allows to intensify the process of sludge separation and to increase the efficiency of wastewater treatment.

The accumulated sediment in the secondary settling tank is forcibly transferred via the recirculation line 10 to the aerobic zone, where in the pauses between the flow of effluent the activated sludge is regenerated. When applying wastewater, activated sludge is mixed with them providing a high oxidation rate of pollutants.

As a result of sedimentation a biofilm is formed on the surface of the secondary clarifier which is removed by a U – shaped airlift 11. Next the treated effluent enters the accumulative capacity of clean water 13 through the overflow pipe 12. A submersible pump 14 is installed in the accumulator, which automatically pumps water through the pressure pipeline 15 outside the modular biostation.

Excessive activated sludge (sludge sediment) is removed from the bottom part of the anaerobic zone by an airlift 16. It is absolutely harmless, it represents a complex organic-mineral bio-fertilizer saturated with macro- and microelements (Table 1), which is caused by its biological purification technology, ensuring the removal of nitrites and nitrates, as well as its deep mineralization.

To assess the soil of the experimental plot studies were conducted, the results of which showed that the total porosity and density of soil composition in the arable layer is 55.3 % and 1.25-1.29 $kg \cdot m^{-3}$, respectively. Down the profile the porosity decreases to 37.0 % and the density increases sharply to 1.40-1.44 $kg \cdot m^{-3}$. The moisture content of the steady wilting of plants in the topsoil is about 9.6 %, with a decrease down the profile to 7.6 %. The reaction of the soil solution is slightly alkaline, pH of the aqueous extract varies from 7.2 to 7.6 units.

The density of the solid phase from the surface to the depth of one meter increases down the soil profile from 2.46 to 2.61 $t \cdot m^{-3}$, indicating the increase of solid particles in the soil, including mineral and organic components.

Table 1

Physical and chemical indicators of sludge after bioremediation of household waste

Monitored indicators	Values according to NTD	Actual value
pH salt, units	5.5-8.5	6.7
Moisture, %	< 70.0	35.0
Organic matter, %	> 20.0	15.0
Total nitrogen, %	> 0.6	2.54
Total phosphorus, %	> 1.5	4.2
Total potassium, %	> 0.1	1.25
Sulfur mobile, $mg \cdot kg^{-1}$	not normalized	1950.0
Mobile copper, $mg \cdot kg^{-1}$	not normalized	8.2
Mobile zinc, $mg \cdot kg^{-1}$	not normalized	35.0
Cobalt mobile, $mg \cdot kg^{-1}$	not normalized	0.18
Mobile manganese, $mg \cdot kg^{-1}$	not normalized	56.5
Pathogenic microflora	not allowed	missing
Heavy metals, $mg \cdot kg^{-1}$		
Lead	500.0	60.6
Cadmium	30.0	24.4
Mercury	15.0	0.20
Zinc	3500.0	553.9
Arsenic	20.0	3.0
Fluorine	10.0	2.56

The content of humus decreases down the profile from 2.20 % in horizon A to 0.88 % in horizon C. The composition of humus contains approximately equal amounts of humic and fulvic acids. The mobile forms of phosphorus are medium – 15 $mg \cdot kg^{-1}$, exchangeable potassium is high – more than 340 $mg \cdot kg^{-1}$, low-hydrolysable nitrogen is low – 43 $mg \cdot kg^{-1}$.

The content of easily soluble salts is insignificant and safe for cultivation of potatoes, their amount from the surface to the depth of one meter increases, respectively chlorides – from 0.067 to 0.103 %, sulfates – from 0.0028 to 0.007 %.

Thus, the data obtained correlate with the previous studies [39, 40], the soil of the experimental plot is typical for the zone of the Lower Volga region and is suitable for growing potatoes for seed.

The formation of reserves of productive moisture and the choice of the irrigation regime of potatoes were influenced by the precipitation and temperature conditions, the graphical interpretation of which is shown in Fig. 2. The observation period (from June to September) in terms of heat availability was close to the average long-term values, planting potatoes were provided with heat until full maturity.

The distribution of precipitation was uneven. From May to September the precipitation fell was about 183 mm and taking into account the sum of temperatures for May 471 ° C the hydrothermal coefficient was only 0.59, which characterizes the study area as extremely dry. Moreover, precipitation due to rain showers with high intensity did not provide soaking of deep layers and for the most part was spent on runoff and evaporation by the soil itself.

In conditions of insufficient natural moisture the share of irrigation water in the total water consumption of potatoes was 50.5 % or 2200 $m^{3} \cdot ha^{-1}$. The share of precipitation in the structure of total water consumption of potatoes was 42.1 % or 1830 $m^{3} \cdot ha^{-1}$ and the use of soil moisture reserves – 7.4 % or 320 $m^{3} \cdot ha^{-1}$. In general there were 12 vegetative irrigations with the norm from 110 to 290 $m^{3} \cdot ha^{-1}$, and the total water consumption of potatoes was 4350 $m^{3} \cdot ha^{-1}$.

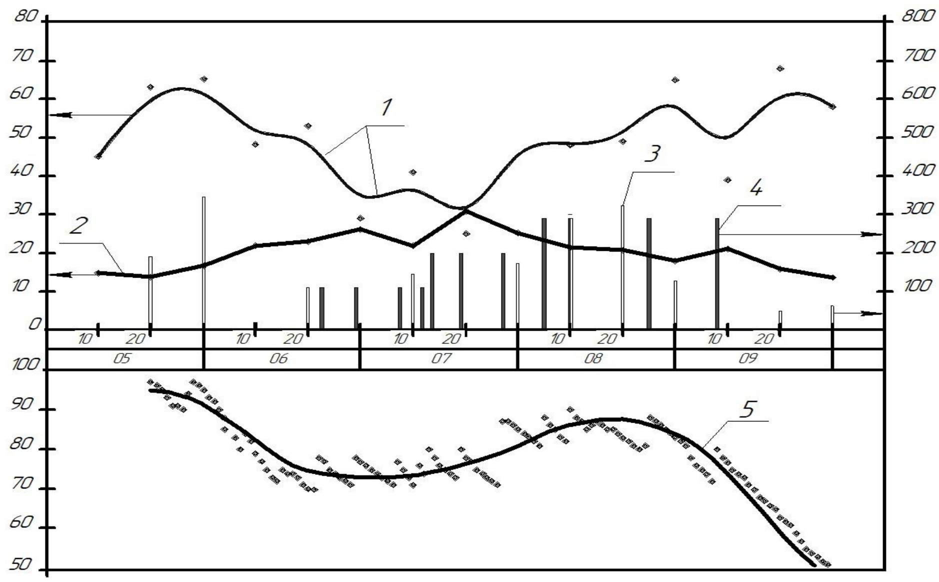

Fig. 2. **Drip irrigation regime, climatic conditions and soil moisture in control potato plantations:** 1 – relative air humidity, %; 2 – air temperature, ºC; 3 – total precipitation per decade $m^3 \cdot ha^{-1}$; 4 – irrigation rates, $m^3 \cdot ha^{-1}$; 5 – moisture distribution in soil, % HB

The results of observations of humidity *W* (%) and density of soil composition ρ ($t \cdot m^{-3}$) according to the experimental options in a layer of 0.0-0.3 m before planting (in the numerator) and before harvesting (denominator) of potatoes are presented in Table 2.

Table 2

Average values of water-physical properties of the soil

Layer Soil, m	Options for doses of fertilizers, $t \cdot ha^{-1}$							
	Control		20		40		60	
	W	*ρ*	*W*	*ρ*	*W*	*ρ*	*W*	*ρ*
0.0-0.1	16.2 / 12.8	1.24 / 1.27	16.5 / 13.0	1.23 / 1.27	17.4 / 13.0	1.22 / 1.26	18.8 / 13.5	1.21 / 1.25
0.0-0.2	16.3 / 12.8	1.24 / 1.28	16.5 / 13.0	1.23 / 1.27	17.4 / 13.0	1.22 / 1.26	18.8 / 13.5	1.21 / 1.25
0.0-0.3	16.3 / 12.3	1.26 / 1.30	16.6 / 12.7	1.25 / 1.30	17.2 / 12.8	1.23 / 1.28	18.7 / 13.2	1.22 / 1.27

Studies of the moisture content and density of soil composition by layers, Table 2, show their change depending on the doses of bio-fertilizer applied. The lowest soil moisture is noted at the control, where before planting potatoes in a layer of 0.0-0.3 m the indicator changes from 16.2 to 16.3 %, and before harvesting it varies from 12.8 to 12.3 %, in variants with bio-fertilizer the soil moisture rises with increasing the dose. So, before planting it increases from 16.5-16.6 % at 20 $t \cdot ha^{-1}$ to 18.8-18.7 % at 60 $t \cdot ha^{-1}$ and before harvesting at the same doses it increases from 13.0-12.8 % to 13.5-13.2 %. This proves the presence of sludge sorption properties in relation to moisture due to the structure of sludge, which is an accumulation of microorganisms with a total surface of about 100 m^2 per gram of dry matter [5-8].

The results of statistical processing of the data array of the dependence of W on the doses of biofertilizer application by layers for the accepted 5 % level of significance show that all differences are significant, however, there are both significant (before planting potatoes) and insignificant differences (after harvesting potatoes) between the options. This trend after harvesting potatoes is mainly due to the soil drying because of the cessation of irrigation and slight precipitation in September – it is about 11 mm at a sum of temperatures of 507 ºC, Fig. 2, and leveling the humidity in layers. So, before planting a crop with a dosing rate of 20 $t \cdot ha^{-1}$ the soil moisture in the layers 0.0-0.1, 0.1-0.2, 0.2-0.3 m exceeds the control respectively by 0.3 % (NDS_{05} = 0.15-0.22 %). With increasing dose the difference between the options becomes more significant: with a dose of 40 $t \cdot ha^{-1}$ – 0.9-1.2 %, with a dose of 60 $t \cdot ha^{-1}$ – 2.4-2.6 %.

A radically opposite pattern is observed with the density of the soil. Its greatest value is fixed at the control, where before planting potatoes in a layer of 0.0-0.3 m the indicator changes from 1.24 to 1.26 $t \cdot m^{-1}$, and before harvesting – from 1.27 to 1.30 $t \cdot m^{-1}$. With the introduction of bio-fertilizer, ρ somewhat decreases: before planting potatoes in layers 0.0-0.1 and 0.1-0.2 m from 1.23 to 1.21 $t \cdot m^{-1}$, in layer 0.2-0.3 m from 1.25 to 1.22 $t \cdot m^{-1}$; before harvesting potatoes – in layers of 0.0-0.1 and 0.1-0.2 m from 1.27 to 1.25 $t \cdot m^{-1}$, in a layer of 0.2-0.3 m from 1.30 to 1.27 $t \cdot m^{-1}$, respectively with an increase in the dose from 20 $t \cdot ha^{-1}$ up to 60 $t \cdot m^{-1}$. This trend for a short observation period indicates an increase in the soil content of agronomically valuable and water-resistant fractions of more than 0.25 mm in size when sludge is introduced, which allows to characterize it not only as a bio-fertilizer saturated with macro and microelements, but also ameliorating soil structure.

The results of statistical processing of the data array of the dependence of ρ on the doses of bio-fertilizer applied by layers for the accepted 5 % level of significance are heterogeneous, there are both significant and insignificant differences between the options. Significant differences in the density of soil composition are observed in the variants with doses of 40 and 60 $t \cdot ha^{-1}$ for layers 0.1-0.2 and 0.2-0.3 m.

So, before planting potatoes, ρ in layers of 0.1-0.2 and 0.2-0.3 m in variants with a dose of 40 and 60 $t \cdot ha^{-1}$ bio-fertilizer is lower than in control, respectively, by 0.02-0.03 $t \cdot m^{-3}$ and 0.03-0.04 $t \cdot m^{-3}$ (HCP05 = 0.017; 0.014 $t \cdot m^{-3}$). Before harvesting significant results are observed only in the variant with a dose of applying bio-fertilizer 60 $t \cdot ha^{-1}$ in the layer of 0.0-0.3 m the density of soil composition is 0.02-0.03 $t \cdot m^{-3}$ lower than in the control (HCP05 = 0.014-0.023 $t \cdot m^{-3}$).

The content of gross forms of heavy metals is a factor of capacity reflecting the potential danger of contamination of plant products, infiltration and surface water, but does not reflect the degree of availability of elements for plants. According to the degree of danger of pollutants exposure on the soil class 1 includes chemicals Cd, Pb, Zn, As, Hg, Se, F and $C_{20}H_{12}$ [32]. Taking into account the chemical composition of the sludge deposit (Table 1), observations were made of the dynamics of the entry of heavy metals — cadmium, lead, zinc, and copper (element 2 of hazard class) into the soil, Table 3, and potato tubers, Table 4.

Table 3

Characteristics of gross forms of heavy metals in the topsoil

Heavy metals	Permissible concentration, $mg \cdot kg^{-1}$		Concentrations in the variants according to the doses of fertilizers, $mg \cdot kg^{-1}$			
	MPC	JDC	Control	20 $t \cdot ha^{-1}$	40 $t \cdot ha^{-1}$	60 $t \cdot ha^{-1}$
Cd	1.0	2.0	0.16	0.39	0.40	0.59
Pb	65.0	130.0	16.0	16.21	17.5	17.7
Zn	110.0	220.0	44.0	44.4	45.43	46.32
Cu	65.0	132.0	16.0	16.27	17.37	17.98

Table 4

Qualitative and quantitative indicators of potato tubers

Options for doses of fertilizers	Heavy metals, $mg \cdot kg^{-1}$				*Y*, $t \cdot ha^{-1}$	Starch, %	Nitrates, $mg \cdot kg^{-1}$ (250)	Dry matter, %
	Cd (0.03)	Pb (0.5)	Zn (10.0)	Cu (5.0)				
Control	0.015	0 . 81	7.97	5.65	20.6	12.64	35.7	20.32
20 $t \cdot ha^{-1}$	0.016	0.82	8.86	6.07	21.9	12.96	36.0	20.45
40 $t \cdot ha^{-1}$	0.020	0.84	10.47	6.54	23.7	13.32	137.0	21.46
60 $t \cdot ha^{-1}$	0.024	0.87	11.14	7.07	26.4	14.24	227.0	22.54

The degree of soil contamination of the experimental site with heavy metals was determined by comparing it with the maximum permissible concentration (MPC) and the approximate permissible concentration (APC) of the corresponding pollutant or its background content, as well as the pollution index Z [32]. Analysis of the data in Table 3 shows that all the observed elements in the topsoil do not exceed the MPC and APC. Soil pollution index varies from 2.5 units at a dose of biofertilizer 20 $t \cdot ha^{-1}$

to 4.0 units, respectively, at a dose of 60 t·ha^{-1}. When $Z < 16$ the soil belongs to the category with acceptable contamination.

The chemical composition of plants reflects the elemental composition of the soil. Therefore, the excessive accumulation of heavy metals by potato tubers is due to their concentration in soils, as well as by non-root absorption from air currents. The quality of potato tubers depends on the content of starch, dry matter and nitrates. Products are considered to be of high quality, when the starch content is from 10 to 24 %, dry matter from 20 to 30 % and nitrates not more than 250 mg·kg^{-1} . Relatively to heavy metals, products are considered "clean", when they are below the MPC, "conditionally suitable" – above the MPC, but not more than 2 MPC, unfit – more than 2 MPC [33].

According to the data obtained, potato tubers in terms of starchiness, nitrates and dry matter (Table 4) are related to quality products, and relatively to heavy metals, to "pure" and "conditionally suitable" products. At the same time, taking into account the seed orientation of potato tuber production, the presence of pollutants in the range from MPC to 2 MPC is further leveled when growing commercial potatoes.

The effectiveness of bio-fertilizers was evaluated by the yield of potato tubers Y (Table 4). According to the results of statistical data processing it is obtained that all differences are significant. The yield of potato tubers in options with doses of bio-fertilizer 20, 40 and 60 t·ha^{-1} exceeds the control variant, respectively, by 1.35, 3.15 and 5.85 t·ha^{-1} (HCP05 = 0.74 t·ha^{-1}) or by 6.3, 15.0 and 28.2 %.

Conclusions

The use of modern compact modules for biological treatment of domestic wastewaters of individual residentials unable to connect to centralized sewage systems allows not only to improve the ecological well-being of suburban settlements, but also to reuse water for irrigation of household plots or other technical needs, and also to use sludge as a source of macro-and micronutrient nutrition of agricultural crops. The bio-fertilizer based on deeply mineralized sludge has sorption properties, increases the number of agronomically valuable and water-resistant aggregates, and is environmentally safe for soil and plants. The use of the bio-fertilizer is especially important in conditions of hydrothermal climatic tension, since the moisture sorbed and retained by sludge stimulates the germination and vegetation of crops.

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