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MOISTENING FERTILIZER IRRIGATION SYSTEM USING TREATED STOCK-BREEDING SEWAGE

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Abstract

This study aims to improve the process flow design of the moistening fertilizer irrigation system using treated stock-breeding wastewater. To irrigate perennial grass, it is necessary to make three applications of stock-breeding wastewater at a rate of 60 m^3/ha and natural water at a rate of 1 640 m^3/ha in which case the supply of nitrogen, phosphorus, and potassium will be 970, 180, and 944 kg/ha, respectively. The irrigation of corn for ensilage requires making four applications of treated stock-breeding wastewater at a rate of 46 m^3/ha and natural water at a rate of 654 m^3/ha, whereas the amount of nutrient enrichment shall be $N_{776}P_{187}K_{566}$. The combined process flow design of moistening and fertilizing with treated stock-breeding wastewater allows ensuring the input of a preset irrigation rate to the drop irrigation system simultaneously with the input of organic mineral fertilizer to the subterranean irrigation system. According to the agroecological assessment of the soil cover, the new system makes the soil more fertile. It is noted herein that the humus, phosphorus, potassium, and nitrate nitrogen content rose by 0.03 to 0.09 %, 30, 10, and 110 %, respectively. The increase in the metabolic calcium content from 64 to 75 % on average in the 0 to 60 cm layer and the reduction in the metabolic sodium content by 2.3 % of the total SAC decreased the intensity of salt accumulation in the soil.

Keywords: Treated stock-breeding wastewater; irrigation system; irrigation mode; drop irrigation; subterranean irrigation.

I. Introduction

Agricultural industry is a major consumer of developed water resources and makes about 70 % of water supply intakes from lakes, rivers, and waterbeds. Consequently, farmers should aim to find more productive and efficient ways of using water in agriculture. Treated wastewater is the most available source of water suitable for repeated use and partially cuts the deficiency of water in agriculture [XVI, V, XXV].

One cubic meter of polluted effluents and stock- and poultry-breeding wastewater make unfit for further use 10 to 50 and, respectively, 200 to 1 000 m^3 of water from surface sources [XIII].

Talking about protecting water sources against pollution and eliminating the deficiency of water resources and depletion of fresh water reserves, it is necessary to note that the repeated use of treated stock-breeding wastewater for irrigating crops allows sharply reducing the intake of natural water. This is why, the creation and upgrade of systems with highly productive utilization of irrigation water and, in particular, stock-breeding wastewater, including moistening fertilizer systems based on drop and subterranean irrigation, are one of the major problems in modern agricultural science [XXII, XXVII, XXIV].

This study aims to improve the process flow design of the moistening fertilizer irrigative system using treated stock-breeding wastewater.

The scientific novelty of the study consists in making more efficient the soil moistening by drop irrigation used jointly with the application of fertilizers in the subterranean irrigation system with the aid of treated stock-breeding wastewater.

The main objectives of the study were to

-upgrade of the moistening fertilizer irrigation system using treated stock-breeding wastewater;

-determine the mode of irrigating crops by means of the moistening fertilizer irrigation system using treated stock-breeding wastewater in the period of vegetation;

-make the agroecological assessment of the influence of the irrigation with treated stock-breeding wastewater on the condition of the soil cover.

The irrigation of crops with stock-breeding wastewater is a well-known practice followed in many countries. In the United States, United Kingdom, and Germany two billion, 130 million, and 200 to 300 million tons of liquid manure, respectively, are used for irrigation every year. According to German researchers [VI], the irrigation with treated stock-breeding wastewater is especially efficient for cereals and clover-cereal mixes. The amount of stock-breeding wastewater supplied depends on the features of irrigated crops, irrigation dates, and climate conditions.

In India [XXVI, XXIX] the amount of wastewater used to irrigate sugarcane, tobacco, cotton plant, corn, and fodder grass, reaches 18,6 mlnm^3/day; however, only mechanically treated wastewater is used for the purpose. As a result of studying irrigation with wastewater, the micronutrient content in the soil increased and the productivity of cotton plant and corn rose by 11.2 and 10.19 %, respectively.

In Rumania [X] stock-breeding wastewater is applied after a site is equipped for joint irrigation with wastewater and natural water. One and the same site is irrigated with wastewater at an interval of at least two years, which allows reaching high wastewater rates of up to 850 m^3/ha per year.

According to authors from Slovakia [I], the repeated utilization of wastewater in agriculture may reduce water deficiency. As shown by several studies aimed at analyzing the influence of crude and treated sewage on the sprouting and growth of medick, oats, and ambercane plantlings, the loss of oats after irrigation with crude sewage was 18 %, the seed sprouting speed went down by 37.5 %, and the blade and root length of medickplantlings went down by 80 %.

The studies conducted in Iran [VIII, XX] were aimed at determining the peculiarities of using treated wastewater for various kinds of irrigation, including subterranean irrigation, drop irrigation, and furrow irrigation, especially in dry regions. The heaviest yield of corn was gathered upon subterranean irrigation with wastewater and amounted to $12.11 x 10^3$ kg/ha; the lightest crop was gathered upon furrow irrigation and amounted to $9.75 x 10^3$ kg/ha. The amount of water spent on furrow, subterranean, and drop irrigation was 6 822, 6 591, and 5 907 m^3/ha, respectively.

The application of wastewater for subterranean irrigation of corn, cotton, wheat, and beans has been studied in Israel [XV, III]. It is observed that not only does subterranean irrigation increase the productivity of corn but it also allows saving about 30 % of water resources.

It has been recognized in the United States that drop irrigation systems are more efficient at delivering wastewater and chemicals to the plant root zone than most of the other forms of irrigation [XVIII]. According to N. C. James and C. Rufus [XXIII], the annual estimated amount of waste on stock- and poultry-breeding farms in the United States is 1.2 to five billion tons and the irrigated area at an applied nitrogen rate of 100 kg/ha reaches 60 million ha. In case of repetitive irrigation with stock-breeding wastewater all the nutrients contained in the fertilizer timely reach the plants, which ensures an even output of herbage on pastures in mowing cycles.

The high efficiency of using stock-breeding wastewater for irrigating fodder crops has been proven by the long-term experience of Russian researchers. The yield of crops on these soils increases at least two to threefold as compared with bogharic lands. In the Martynov district of the Rostov oblast' a site of 34 ha in area was chosen and prepared for mole-subterranean irrigation with stock-breeding wastewater. The parsley yield from that site and from the bogharic site was 4.5 and 2.31 t/ha, respectively, whereas the corn yield for green feed was 96 t/ha. It was noted that the cultivated crop had a high quality and an increased content of protein upon the application of nitrogen at rates of 160 to 200 kg/ha [II, IX].

The soil processing with purified stock-breeding wastewater treated with sugarbeet production waste (defecate) changed the water physical and physical chemical properties of the soil and main nutrients. Eight vegetation irrigations at a rate of 650 m^3/ha were performed. As noted by the authors, in the 0 to 40 cm layer the humus content rose by 0.5 %, the nitrogen content rose by 0.12 % or by 1 250 kg/ha, and the total phosphorus content rose in the 0 to 20 cm layer (the increase with and without irrigation was by 108 and 54 mg per 100 g of soil, respectively). Treated wastewater from stock-breeding farms was recommended for use following several studies of radish seed sprouting [XII, XIV].

It is indicated by Russian and foreign researchers that irrigation with wastewater can be either fertilizing or moistening, which depends on the content of biogenic matter in wastewater. Regular irrigation with wastewater shall not have any negative influence on the growth and development of crops. Numerous works by foreign researchers are dedicated to using wastewater in drop and subterranean irrigation, and also in furrow irrigation of crops. It still remains an understudied issue how to use treated stock-breeding wastewater in moistening fertilizer irrigation regimes, which helps cope with the risk of polluting the air, water sources, and groundwater, makes the soil more fertile, and increases the productivity of certain crops.

II. Methods

The test production site of the moistening fertilizer irrigation system using treated wastewater is located on irrigated lands in OAOAksayskayaNiva in the Aksayskiy district of the Rostov oblast'.

The soil cover is homogeneous and consists of common black earth. The profile has a medium humic horizon of up to 80 to 110 cm. In terms of grain-size distribution the surveyed soils are clayey and heavy loams with loessoid (28.8 %) and silt (42.2 %) as the main components. The site has a low humus content of 3.6 to 4.2 %, low nitrogen supplies, and medium mobile phosphorus and metabolic potassium supplies (Table 1).

Table 1: Agrochemical properties of common black earth on the test production site

Soil layer, cm	Humus, %	Nitrate nitrogen, mg/kg	Mobile phosphorus, mg/kg	Metabolic potassium, mg/kg
0-20	5.35	18.2	27.6	378
20-40	4.74	15.1	15.4	285
40-60	3.81	21.9	8.0	209
60-80	2.66	17.0	5.9	214
80-100	1.72	6.9	4.4	202
0-100	3.65	15.8	12.3	258

The test site soil in the 0 to 100 cm layer has the following water physical properties: the bulk density is 1.3 g/cm^3, the total pore space is 47.4 %, the minimal moisture retention capacity is 26.5 % (Table 2).

Table 2: Water physical properties of common black earth in the test production site

Horizon, cm	Consistence density,g/cm^3	Specific density,g/cm^3	Total pore space, %	Maximum hygroscopity, %	Field moisture capacity, %
0-10	1.15	2.52	52.7	11.26	30.2
10-20	1.18	2.49	52.2	11.24	29.8
20-30	1.17	2.51	50.7	10.75	28.6
30-40	1.24	2.49	46.8	10.17	28.4
40-50	1.26	2.50	46.3	10.05	26.5
50-60	1.27	2.51	45.8	10.06	25.7
60-70	1.29	2.52	47.2	10.16	24.8
70-80	1.33	2.50	44.7	10.17	24.1
80-90	1.30	2.51	44.1	9.87	23.5
90-100	1.36	2.52	43.5	9.61	23.0
0-100	1.30	2.51	47.4	10.4	26.5

Perennial grass and corn for ensilage were irrigated on a test production site of 7 ha. The stock-breeding wastewater was applied as in [XIX] and characterized by faintly alkaline reactions, high content of nutrients (phosphorus as organic compounds, soluble potassium, easily soluble ammonia nitrogen), minor and major elements necessary for plant nutrition and development (Table 3).

Table 3: Chemical composition of treated stock-breeding wastewater used for irrigation

Indicator	Value	Indicator	Value
Moisturecontent, %	99.6	Dryresidue, mg/dm^3	1458
Pн	7.3	Mineral residue, mg/dm^3	1346

Ammonia-N (NH_4^+), mg/dm^3	187	HCO_3^- , mg/dm^3	838
Nitrate-N (NO_3^-), mg/dm^3	20	Cl^- , mg/dm^3	245
Nitrite-N (NO_2^-), мг/дм^3	52	SO_4^{2-} , mg/dm^3	76
Total N, mg/dm^3	285	Ca^{2+} , mg/dm^3	208
Phosphorus (P_2O_5), mg/dm^3	364	Mg^{2+} , mg/dm^3	84
Potassium (K_2O), mg/dm^3	387	Na^+ , mg/dm^3	192

The principles at the core of the studies were the process design standards of irrigation systems using stock-breeding wastewater [IV]. The soil cover was exposed to agroecological assessment pursuant to conventional procedures [XXVIII, XVII, XI].

III. Results

The studies helped RosNIIPM upgrade the moistening fertilizer irrigation system using treated stock-breeding wastewater. The system includes a set of treatment facilities according to [XIX]: in these facilities the liquid fraction (water) is distributed by drop irrigation (I) and the solid fraction (organic mineral fertilizer) is distributed by subterranean irrigation (II) (Fig. 1).

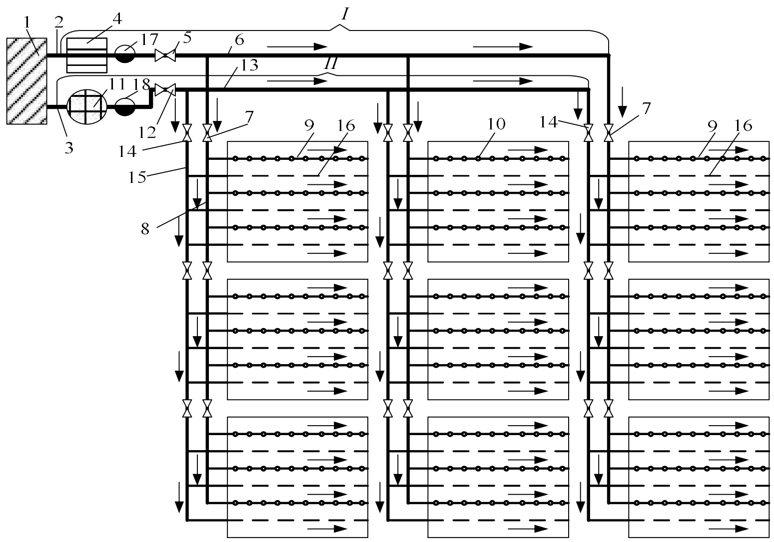


Fig. 1: Moistening fertilizer irrigation system using treated stock-breeding wastewater delivered in a forced flow, including drop irrigation section I and subterranean irrigation section II.

I is the drop irrigation section; II is the subterranean irrigation section; 1 is the set of facilities for treating stock-breeding wastewater; 2, 3 are the parallel head conduits; 4 is the storage pool; 5, 7, 12, 14 are the shutoff and control valves, 6 is the main pipeline, 8, 15 are the perpendicular distribution conduits, 9 are the dripper lines with drippers 10; 11 is the storage tank; 13 is the main pipeline, 16 are the irrigation mole drains; 17, 18 are the pump stations.

Wastewater from stock-breeding farms is supplied to set of treatment facilities 1, where they are separated into the liquid and the solid phase. The liquid phase (water) flows in the drop irrigation system. The water is supplied to storage pool 4 along head conduit 2. Shutoff and control valves 5 help the water flow by gravity along main pipeline 6. Then the water is directed with the help of shutoff and control valves 7 along perpendicular distribution conduits 8 to dripper lines 9 with drippers 10.

The solid phase (organic mineral fertilizer) travels in the subterranean irrigation system. The water runs to storage tank 11 along head conduit 3. Shutoff and control valves 12 help the water flow by gravity along main pipeline 13. Then the organic mineral fertilizer is directed along perpendicular distribution conduits 15 with the help of shutoff and control valves 14 to irrigation mole drains 16. The organic mineral fertilizer is supplied directly through the irrigation mole drains under capillary forces to the crop roots to the subsurface soil to a depth of 40 to 60 cm.

The application rates of treated stock-breeding wastewater were found individually for nitrogen, phosphorus, and potassium and amounted to 970, 180, and 944 m^3/ha, respectively, for perennial grass, and 776, 187, and 566 m^3/ha for corn for ensilage (Table 4).

Table 4: Results of calculating application rates of mineral fertilizers for irrigation with treated stock-breeding wastewater

Crop	Planned , hwt/ha	Removal per hwt. of product, kg			Wastewater application rates, m^3/ha			Calculated wastewater application rates, m^3/ha
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	
Perennial grass	300	0,4	0,1	0,5	970	180	944	180
Corn for ensilage	800	0,32	0,1	0,3	776	187	566	187

The moistening and the fertilizer rate of treated stock-breeding wastewater were established while developing the regime of crop irrigation. Moistening irrigation was set proceeding from the water consumption by the crops. The fertilizer application rate of treated wastewater was determined, considering the plants' biological features and the soils' fertility. The amount of nitrogen and potassium lacking in the soil for reaching the planned crop productivity was refilled with mineral fertilizers at 216 kg/ha of nitrogen for perennial grass, 250 kg/ha of potassium, 161 kg/ha of nitrogen for ensilage corn, and 123 kg/ha of potassium (Table 5).

Table 5: Results of calculating the regime of irrigation with treated stock-breeding wastewater

Crop	Calculated rates of mineral fertilizers, kg/ha			Annual irrigation rate against water balance deficiency (at 95 %), m^3/ha	Number of applications	Rate of irrigation with natural water, m^3/ha	Rate of irrigation with wastewater, m^3/ha
	N	P_2O_5	K_2O				
Perennial grass	216	–	250	5100	3	1640	60
Corn for ensilage	161	–	123	2800	4	654	46

With the supply against water balance deficiency (95 %) for the Rostov oblast', it is necessary to irrigate perennial grass three times at a rate of 1 700 m^3/ha. Corn for ensilage shall be irrigated four times at 700 m^3/ha: the first, second, third, and fourth application shall be made when 7 to 8 leaves are formed, ten days prior to the ear formation phase, in the grain formation phase, and at the beginning of the milky phase, respectively. Thus the annual irrigation rate set against water deficiency (5 100 and 2 800 m^3/ha) exceeds the calculated rate of wastewater application (180 and 187 m^3/ha), which is why the irrigation with treated stock-breeding wastewater and with natural water shall be conducted synchronously. For perennial grass and corn for ensilage the respective inputs of stock-breeding wastewater per one application to the soil will be 60 and 46 m^3/ha and the inputs per one application of natural water will be 1 640 and 654 m^3/ha.

IV. Discussion

The analysis of the moistening fertilizer irrigation with treated stock-breeding wastewater allowed establishing its influence on the agrochemical properties of soil cover. The soil supply with mobile nutrients increased with from average to enhanced: the average supply of phosphorus to the 0 to 60 cm layer was 20.2 and 22 mg/kg for perennial grass and corn for ensilage (17 mg/kg without irrigation), respectively; the average supply of potassium was 322 and 328.3 mg/kg (290.6 mg/kg without irrigation) for perennial grass and corn for ensilage, respectively. It was noticed that the nitrate nitrogen content in the 0 to 60 cm layer for perennial grass and corn for ensilage increased by 110 and 130 %, respectively, as compared with the variant without irrigation. The humus content for perennial grass and corn for ensilage increased by 0.03 and 0.09 %, respectively (Fig. 2).

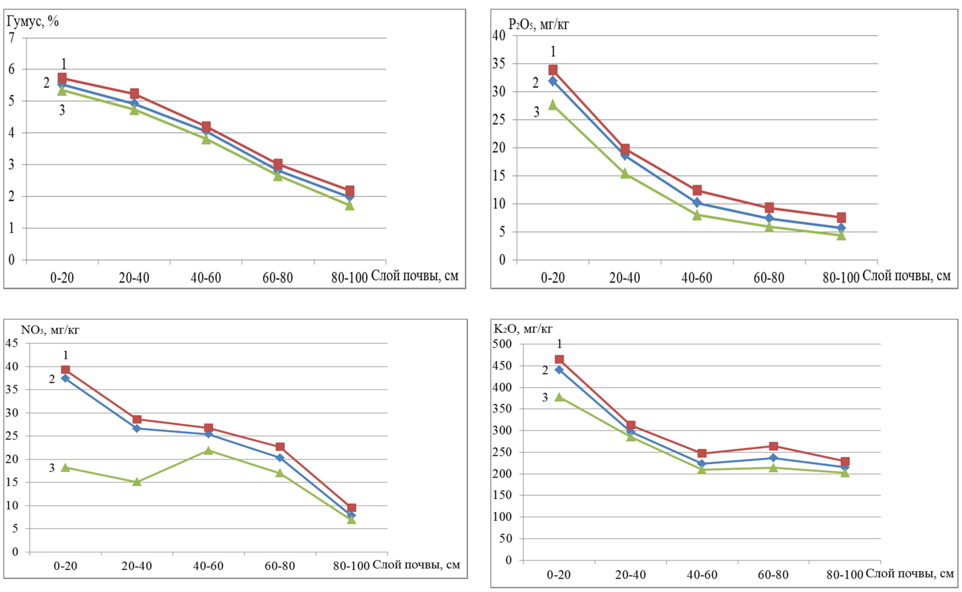
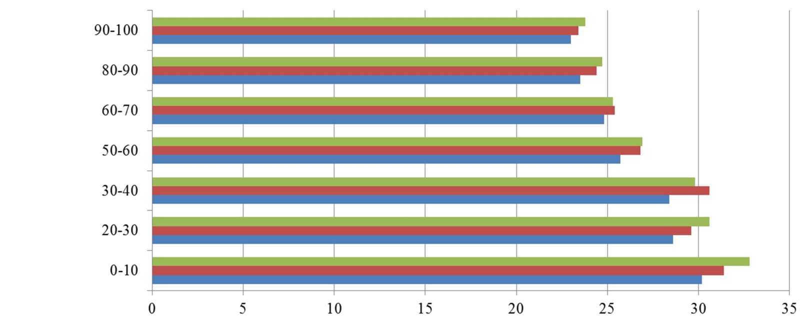


Fig. 2: Content of main fertilizer elements in the soil before and after irrigation with treated stock-breeding wastewater

1 is the corn for ensilage; 2 is the perennial grass; 3 is the control site without irrigation

A considerable increment in the content of main fertilizer elements in the soil is conditioned by the fertilizing and moistening properties of treated stock-breeding wastewater, which is of primary importance to the surveyed area with a lack of moistening.

The accumulation of organic substances in the arable layer improves the soil's water physical properties as well. The total porosity in the 0 to 40 cm layer was one to two percent higher than in the control area, which was why the moistening network increased the soil's porosity and aeration. The soil's water capacity increased across the entire soil profile in relation to the control area, and the peak value for perennial grass registered in the upper layer of 0 to 10 cm and in the 30 to 40 cm layer was 31.4 % (30.2 % without irrigation) and 30.6 % (28.4 % without irrigation), respectively (Fig. 3).



	0-10	20-30	30-40	50-60	60-70	80-90	90-100
Кукуруза на силос	32,8	30,6	29,8	26,9	25,3	24,7	23,8
Многолетние травы	31,4	29,6	30,6	26,8	25,4	24,4	23,4
Контроль	30,2	28,6	28,4	25,7	24,8	23,5	23

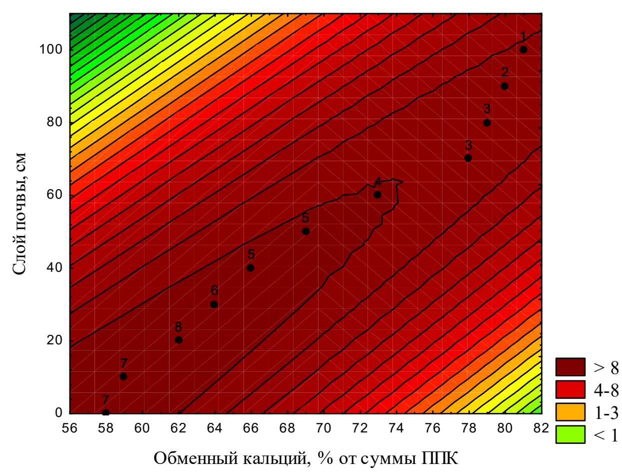
Кукуруза на силос ■ Многолетние травы ■ Контроль

Fig. 3: Changes in water capacity across soil profile after irrigation with treated stock-breeding wastewater

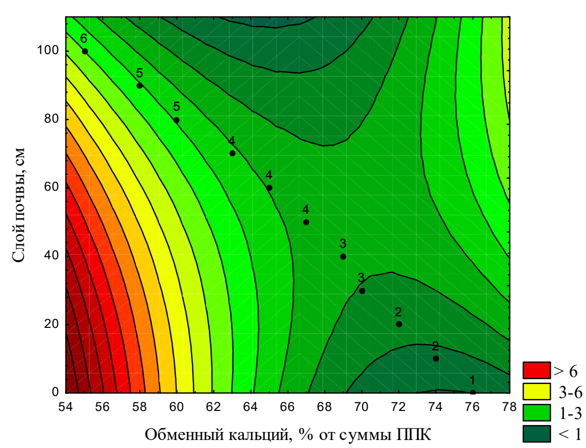
To make the soil more fertile by moistening fertilizer irrigation, it is important to exercise the land capability control over the salt and water regime of irrigated lands.

The test site has a solonetzic soil cover. The excessive metabolic sodium content in the 0 to 60 cm layer (6 % of the aggregate soil adsorption complex) of the original soil provokes negative changes in the SAC by making the soil less fertile, aggravating the mineral nutrition conditions for plants, and suppressing their growth and development. The irrigation of perennial grass with treated stock-breeding wastewater in the 0 to 60 cm layer increased the metabolic calcium content in the soil to 76 %, which was due to the outwashing of sodium from the SAC, with a decrease to 1-3 %, which led to the aggregation of the soil, made it more permeable to water, and, consequently, less solonetzic. The irrigation of corn for ensilage reduced the metabolic sodium content to 2 to 4 % (Fig. 4).

Control site without irrigation



Perennial grass upon irrigation



Corn for ensilage upon irrigation

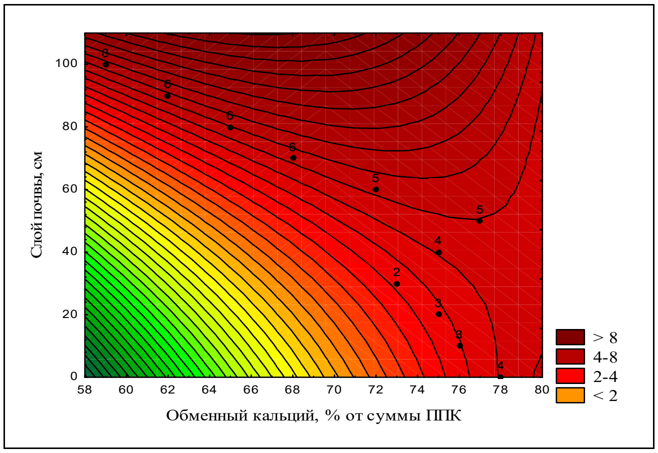


Fig. 4: The level line of the relation of the metabolic sodium content to the metabolic calcium content across the soil profile in the test area irrigated with treated stock-breeding wastewater

Слой почвы, см	Soil layer, cm
Обменный кальций, % от суммы ППК	Metabolic calcium, % of aggregate SAC

A considerable reduction in the metabolic calcium content was observed in the 0 to 10 cm layer down along the soil profile, where treated stock-breeding wastewater produced the greatest effect. Calcium as a good coagulant encourages the formation of soil colloids and a water-stable structure in the soil's surface layer.

The agroecological assessment of the soil cover on the test site allows recommending for application the moistening fertilizer irrigation with treated stock-breeding wastewater.

V. Conclusion

1.The upgraded moistening fertilizer irrigation system using treated stock-breeding wastewater allows utilizing water resources in a rational manner, efficiently delivering moisture and main fertilizer elements to the plant root system, which is attained with the motion of the liquid phase in the dropirrigation system and the motion of the solid phase in the subterranean irrigation system.

2.The irrigation of perennial grass requires making three applications of treated stock-breeding wastewater at a rate of 60 m^3/ha in which case the supplied amount of fertilizer elements shall be$N_{970}P_{180}K_{944}$. The irrigation of corn for ensilage requires making four applications of treated stock-breeding wastewater at a rate of 46 m^3/ha in which case the supplied amount of fertilizer elements shall be$N_{776}P_{187}K_{566}$.

3.The moistening fertilizer irrigation system using treated wastewater facilitates uninterrupted supply of irrigation water and fertilizers to the soil surface layer and to the root-inhabited layer, respectively, allows mechanizing and automatizing the distribution of treated wastewater across the field, and leads to more ecofriendly crop cultivation and wastewater disposal.

4.The irrigation with treated stock-breeding wastewater sustains and improves the soil fertility and, namely, increases for perennial grass and corn for ensilage the respective average humus content for the 0 to 60 cm layer by 0.03 and 0.09 %, phosphorus content by 20 and 30 %, and potassium content by 10 %. The 0 to 60 cm layer appears to contain by 110 % more nitrogen than the control site. The soil's water physical properties improve as well, including the general porosity in the 0 to 40 cm layer, the soil's porosity and aeration, and, consequently, the soil's water capacity, which leads to a better distribution of moisture across the soil profile. The change in the physical chemical indicators normalizes the salt and water regime of irrigated lands: the average metabolic calcium content in the 0 to 60 cm layer increases from 64 to 75 %, whereas the metabolic sodium content decreases by 2.3 % of the aggregate SAC.

5.Moistening fertilizer irrigation considerably affects the soil-water-plant environmental system, which shows in an improved agroecological state of the soil cover.

6.The study results can be recommended to producers of agricultural goods for saving water resources and mineral fertilizers and irrigating crops with the help of the moistening fertilizer system using treated stock-breeding wastewater.

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