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COMPLEX ORGANO-MINERAL FERTILIZERS BASED ON SEWAGE SLUDGE WITH MINERAL ADDITIVES AND THEIR EFFECTIVENESS IN GROWING CORN FOR SILAGE IN THE FODDER CROP ROTATION CHAIN IN THE NORTHERN FOREST-STEPPE OF UKRAINE

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Abstract

It was determined that the sewage sludges of the sewage treatment facilities of a million-plus city and the industrial center in the north of Ukraine, after the final aging on sludge sites, according to agroecological indicators, are suitable for their use as a local organic raw material to produce innovative types of complex organo-mineral fertilizers. The composition of complex organo-mineral fertilizers based on sewage sludge with mineral additives of various origins was developed and new types of organo-mineral fertilizers of prolonged action for multi-purpose use were obtained. When studying the effectiveness of new types of organo-mineral fertilizers in a field experiment, it was established that on gray forest soil under the conditions of the northern Forest-Steppe of Ukraine, fertilizers of the first type were not inferior to traditional and non-traditional organic fertilizers in terms of effectiveness in the year of direct action when the main application was made in optimal doses under corn for silage and complete mineral fertilizer in equivalent doses. New organo-mineral fertilizers of the second type were not inferior to organic fertilizers in terms of direct-action efficiency.

Key words: *effectiveness, organic-mineral, mineral additives, sewage sludge; Ukraine.*

INTRODUCTION

At the present time, a serious problem in megacities, large cities and industrial centers is the rational disposal of sewage sludge (hereinafter - SWS) of municipal sewage treatment plants.

Among the organic wastes, SWS of sewage treatment facilities (hereinafter - SWTF) of these cities, belongs to a special category, it is contaminated with toxic substances and harmful microorganisms and therefore is mostly not suitable for direct use as non-traditional organic fertilizers in agriculture.

The main volumes of such SWS after technological treatment at the SWTF as a waste of IY–Y hazard classes (low-toxic substances) are placed at waste storage facilities (GOST 12.1.007-76).

Storage of SWS in sludge storage facilities is a dangerous method of its disposal and causes significant economic and ecological losses for society due to environmental degradation, violation of the natural state of large areas, loss of useful substances, negative impact on the health of the population (Dregulo et al., 2012; Ospanov et al., 2014; Nasirov et al., 2015).

At the current rates of urbanization and agglomeration and the lack of innovative methods of final disposal of SWS, there is a threat of significant accumulation of these multi-tonnage organic wastes and catastrophic environmental pollution.

Some scientists believe (Merzla, 2006) that it is possible to stabilize the situation with the final disposal of SWS only by implementing new technologies for wastewater treatment, sediment treatment and processing them into complex organic-mineral fertilizers of the new generation (hereinafter - OMF), which will ensure a decrease in energy consumption and a sharp reduction of land areas for the arrangement of storage facilities for the disposal of SWS.

At the same time, in connection with the low efficiency and danger of the assortment of mineral tuks, the urgency of creating a new generation of OMF with increased agroecological value and efficiency is increasing.

The work (Melnikov, 2007) proposed a concept that substantiates the need to revise the existing fertilizer policy in favor of the production and use of ecologically safe organic, organo-mineral fertilizers using for this purpose mineral-raw resources, waste, and substances of humus nature. Agricultural scientists predict (Bambalov et al., 2020) that in the XXI century, there will inevitably be a gradual replacement of fast-dissolving forms of mineral fertilizers by fertilizers with a prolonged effect, including OMF, and in the second half of the century, fertilizers with a programmed release of nutrients will become the dominant forms.

In the literature (Doroshkevich et al., 2002; Stepanova et al., 2003; Pyndak et al., 2010) there are data on the creation of new complex OMF based on the SWS of large cities and industrial centers of the Russian Federation (Volgograd, Ulan-Ude, Orla) with mineral additives (mineral tuks, natural sorbents - zeolites, glauconites, etc.).

In Ukraine, technology and a technological line for the production of organo-mineral mixtures (hereinafter - OMM) have been developed on the basis of SWS of large cities (Zaporizhia, Dnipropetrovsk) with industrial waste-lignin and phosphogypsum (Shevchuk et al., 2001). New complex OMF were created on the basis of the SWS of the megacityand municipal solid waste (Malyuga et al., 2005), as well as on the basis of the SWS of the megacity with mineral additives (mineral tuks, natural sorbents - agroperlite, expanded vermiculite) (Patents, 2017; Dyshlyuk, 2022) and others. New types of OMF have higher agronomic, ecological, energy and economic efficiency indicators than standard complex mineral fertilizers, which indicates the prospects of using man-made organic raw materials for the production of new generation of fertilizers.

In Ukraine, the problem of the final disposal of accumulated SWS in cities with a population of more than 1 million inhabitants, primarily in the capital, industrial centers, etc., has not been solved. bridge. For more than 30 years, there has been an acute problem of disposing of the accumulated SWS of the million-plus city in the north of Ukraine (hereafter - the megalopolis), which threatens the country's largest city with an ecological disaster, as well as all the settlements adjacent to the Dnipro. Every day, 3,000 tons of liquid SWS are produced at the city's SWTF, which are placed on sludge sites (area 272 hectares). Their capacity has already exceeded three times - instead of the 3.5 million tons provided, they hold 10 million tons of SWS (dry matter - hereinafter DM).In 2013, there was a breach of the dam, but then it was possible to prevent an environmental disaster that could have occurred due to the spill of liquid sewage into the Dnipro (Bortnytsky Aeration Station Problem..., 2018). The problem of utilization of the accumulated SWS of the megacity is one of the important environmental tasks that requires an immediate solution.

The goal of the work:

- to study the quality indicators of the SWS of a megacity in the north of Ukraine and to find out the feasibility of using them as a local organic raw material for the production of a new generation of OMF;
- to create new OMF for use in agriculture on the basis of the SWS of the megacity;
- to evaluate the effectiveness of new OMF based on the specified SWS in the year of their direct action on soils of the eluvial type of soil formation.

MATERIALS AND METHODS

The object of the study: megacity SWS of the long-term storage, formed under the conditions of technogenesis in the pre-crisis period.

The study of the effectiveness of non-traditional organic fertilizers (SWS) and their processing products (new OMF) was carried out in a temporary field experiment located at the experimental site of the State Institution "Central Scientific Research Laboratory of Water and Soil Quality" of the Institute of Water Problems and Land Reclamation of the National Academy of Sciences, in the conditions of the northern Forest-steppe of Ukraine.

The experiment studied the effectiveness of the direct action of non-traditional organic fertilizers in the form of SWS at different rates of their application per unit area of arable land (in a dose of N_{total}, equivalent to 220 and 300 kg/ha), of the above-mentioned fertilizers in combination with mineral fertilizers (respectively in a dose of N_{total}, equivalent to

150 kg/ha + $P_{90}K_{90}$) to balance the ratio of the main nutrients in the soil, processing products of SWS - 4 types of experimental fertilizer composites (OMM), in particular, mixtures of the first type, which are based on the organic matter of anthropogenic origin (SWS) and mineral fats and natural sorbents (OMM 1 and 2 in a dose, equivalent to $N_{150}P_{90}K_{9}$) and, accordingly, the second type, which is based on SWS and only mineral additives (natural sorbents) (OMM 3 and 4 in a dose of N_{total}, equivalent to 150 kg/ha).

The rates of application of the studied substrates into the soil were established based on the content of total nitrogen in them. The following plots of the experiment were accepted as control options: without fertilizer (control 1), with the application of traditional organic fertilizer (cattle manure) (in a dose of N_{total}, equivalent to 150 kg/ha) (control 2) and complete mineral fertilizer (in a dose N_{150} P_{90} K_{90}) (control 3).

Experiment scheme:

1 - without fertilizers (control 1);
2 - SWS in a dose of N_{total} 300 kg/ha;
3 - SWS in a dose of N_{total} 220 kg/ha;
4 - SWS in a dose of N_{total} 150 kg/ha + $P_{90}K_{90}$;
5 - Cattle manure in a dose of N_{total} 150 kg/ha (control 2);
6 - Complete mineral fertilizer in a doseN_{150} P_{90} K_{90} (control 3);
7 - OMM 1 based on the dose $N_{150}P_{90}K_{90}$;
8 - OMM 2 based on the dose $N_{150}P_{90}K_{90}$;
9 - OMM 3 based on the dose on $N_{tot.}$ 150 kg/ha;
10 - OMM 4 based on the dose on $N_{tot.}$ 150 kg/ha.

The following fertilizers were used in the experiment: semi-rotted cattle litter manure, SWS of long-term storage (8-10 years), mineral fertilizers: nitrogen (ammonium nitrate), phosphoric (simple superphosphate) and potash (potassium-magnesium), 4 types of new fertilizer mixtures: OMM 1 (SWS + mineral tuks (nitrogen, phosphorus, potassium) + natural sorbent (agro perlite), OMM 2 (SWS + mineral tuks (nitrogen, phosphorus, potassium) + natural sorbent (vermiculite), OMM 3 (SWS + natural sorbent (agro perlite), OMM 4 (SWS + natural sorbent (vermiculite).

The experimental group of OMM was obtained by mixing the specified components in certain ratios and the subsequent physical and physicochemical interaction of activated organic matter and the elemental composition of SWS with mineral components. Protection documents from Ukraine were obtained for the method of production of OMM based on SWS with mineral additives (Patents, 2017).

The study of the effectiveness of fertilizers and the rates of their application was carried out in the chain of fodder crop rotation: corn for silage - winter wheat - annual grasses. The area of the sown plot is 10.8 square meters (3.6 m x 3.0 m). The location of options is single-tiered, and the repetition of options is four times with randomized placement of plots.

Agrotechnics of growing crops is zonal, with the exception of the studied factors. Fertilizers were applied to the soil in one application in a continuous way (scattered) under the main tillage for the first crop of the crop rotation chain - maize for silage (hybrid Kolektivny 205). The soil of the research area is gray forest light loam. When establishing the experiment and conducting research, generally accepted methods were used. Soil samples for research were taken from the 0-20 cm layer in the spring and at the end of the growing season. Agrochemical, physicochemical, and ecological-toxicological parameters were determined in the samples of cattle manure, SWS, and OMM 1-4 according to regulatory documents.

The assessment of the degree of contamination of SWS and OMV 1-4 with toxicants was carried out according to DSTU (2013), the level of provision of soil with microelements according to the Methodological Guidelines (1976), the level of soil contamination with toxicants and the suitability of plant products for feeding farm animals on the content of heavy metals according to Departmental Regulatory Documents (1999).

This report presents the results of research on establishing the effectiveness of OMM 1-4 in a year of a direct action of fertilizers in a field of corn on silage.

RESULTS AND DISCUSSIONS

It has been established that SWS of long-term storage is characterized by sufficiently high fertilizing properties. Their composition contains a high content of total nitrogen and phosphorus, but the content of potassium is insignificant.

Among the mobile nutrient forms, P_2O_5 (0.35% per DM) prevails in SWS, the content of mineral forms of nitrogen ($N\text{-}NH_4$+ $N\text{-}NO_3$) is 0.21% per DM, K_2O is contained in an insignificant amount (0.02% per DM). The agrochemical indicators of SWS meet the requirements of the regulatory document (DSTU, 2013) (Table 1).

Table 1. Agrochemical composition of SWS (average data)

Indicators	Content[1]	Norm[2]
Mass fraction of dry matter	50.94	-
Mass fraction of organic matter	39.30	not>40
Mass fraction of total carbon, C total	19.12	-
Mass fraction of total nitrogen, N	2.84	not>1.5
Mass fraction of total phosphorus, P_2O_5	4.90	not>0.7
Mass fraction of total potassium, K_2O	0.29	-
pH_{H2O}	6.5	6.5-7.5
Correlation C: N	8.2	-

1 - in % per DM
2 - norms of agrochemical indicators of SWS according to DSTU 7369.

SWS is characterized by a high content of total carbon (19% per year). The SWS has a narrower C:N ratio (8 units vs. 12 in cattle manure) and a higher total nitrogen content (2.84% vs. 2.16% in cattle manure), which indicates a higher fertilizing effect of SWS than cattle manure.

SWSis characterized by high remedial indicators. Thus, the content of water-soluble calcium in SWS varies between 17.00 and 25.44 meq/100 g of substrate (compared to 1.02 meq/100 g in cattle manure), the Ca:Na ratio in the salt composition of SWS is 75-77 units, (in cattle manure - 0.5 units). SWS contains a significant amount of organic matter (39% per DM).

The carbon content of humic acids in the composition of organic matter of SWS prevails over the carbon content of fulvic acids (respectively, 1.58% versus 0.93% per DM). The type of humus formation in SWS is fulvate-humate. In the granulometric composition of the SWS, the content of physical clay is in the range of 38-48%, including silt (coarse and fine) and colloids - 23-29%. The number of fractions with a particle size > 0.05 mm (fine, medium, and coarse sand) varies between 14 and 30%. The number of fractions participating in soil structuring as passive material (coarse, medium and fine dust) is 46-57%. According to the classification of soils according to the granulometric composition of SWS with a physical clay content of 38-48%, it can be conditionally equated to a soil characterized by medium, and heavy loam granulometric composition.

As a result of the assessment of the quality indicators of the SWS and its properties, we came to the conclusion that these wastes can be characterized as organic raw materials with a complex of agronomically valuable features. The substrate has high fertilizing and ameliorative properties (high soluble calcium content, high calcium activity), which is important for soil improvement, reducing the acidic reaction (pH of the soil - 5.3-5.6) and enriching the soil-absorbing complex with calcium. SWS can be used as a material, capable of performing the functions of a geochemical barrier in the path of toxicants. However, SWS has an unbalanced ratio of the main nutrients (N:P:K = 1:1.70:0.10), and increased concentrations of certain heavy metals (hereafter HM), which according to their systematic agriculture application may cause soil contamination by HM.

It should be noted that at the present time, newly formed SWS contains permissible values of HM in connection with the decrease in the share of industrial wastewater in the city-wide runoff, which conditions the prospects of their agricultural application (Delalio et al., 2003). Therefore, due to the indicated disadvantages of long-term storage, from an ecological point of view, it is more appropriate to use it as a local organic raw material for the production of new OMF.

New OMM 1-4 are characterized by high fertilizing properties (especially OMM 1-2), high cation exchange capacity, and prolonged action, as well as the ability to transfer mobile forms of HM into a fixed state.

OMM 1-2 differ from the original SWS by a more optimal ratio of the main nutrients (OMM 1, ratio N:P:K = 1:1.20:0.90; OMM 2, ratio N:P:K = 1:1.10:0.70), a higher content of mobile nutrients and their longevity, a wide range of macro- and microelements, better physicochemical properties. Agrochemical indicators of OMM 1-2 generally meet the requirements of the normative document (DSTU, 2013) (Table 2).

Table 2. Agrochemical composition of OMM 1 and 2 (average data)

Indicators	OMM 1	OMM 2
	Content[1]	
Mass fraction of dry matter	75.14	71.93
Mass fraction of organic matter	34.00	34.50
Mass fraction of total nitrogen, N	4.74	4.64
Mass fraction of total phosphorus, P_2O_5	5.58	5.12
Mass fraction of total potassium, K_2O	4.18	3.14
pH_{H2O}	5.60	5.70
Correlation C: N	3.6	4.6

1 - in % per dry matter

The new OMM 3-4 differ from the original SWS by a more balanced ratio of the main nutrients (OMM 3, ratio N:P:K = 1:1.30:0.40; OMS 4, ratio N:P:K = 1:1.50:0.50), a higher content of mobile nutrient elements and their prolongation, the presence of a wide range of macro-and trace elements and better physicochemical properties, but they are inferior to OMM 1-2 in terms of the content of general and mobile forms of NPK. Agrochemical indicators of OMM 3-4 generally meet the requirements of the normative document (DSTU, 2013) (Table 3).

Table 3. Agrochemical composition of OMM 3 and 4 (average data)

Indicators	OMM 3	OMM 4
	Content[1]	
Mass fraction of dry matter	87.31	82.02
Mass fraction of organic matter	35.61	36.90
Mass fraction of total nitrogen, N	2.23	2.29
Mass fraction of total phosphorus, P_2O_5	2.88	3.44
Mass fraction of total potassium, K_2O	0.87	1.23
pH_{H2O}	6.0	6.1
Correlation C: N	8.1	7.2

1 - in % per DM

Samples of new fertilizers (OMM 1-4) have low moisture content (25-28%), which is important for saving costs for their transportation, and reduces technological costs for application to the soil and storage.

In a field experiment, we established that the main application of OMM 1-2 under corn in the fodder crop rotation chain provided an increase in plant production of standard quality in the range of 27.1-29.5 t/ha (silage mass) in the year of direct action of fertilizers compared to the control without fertilizers (yield on control - 28.5 t/ha) and in terms of efficiency were not inferior to organic fertilizers (traditional, non-traditional) and full mineral fertilizer in equivalent doses.

OMM 3-4 were inferior to OMM 1-2 in terms of efficiency, but also provided an increase in plant production within the range of 15.5-16.5 t/ha of silage mass and were not inferior to organic fertilizers in terms of efficiency.

CONCLUSIONS

New OMM 1-4 based on SWS with mineral additives are characterized by increased agrochemical and agroecological value compared to sewage sludge.

The use of 1-4 natural sorbents in the composition of OMM, thanks to their high exchange and sorption capacity, makes it possible to consider them as an effective means for optimizing the fertilizing and reclamation properties of fertilizers, reducing non-productive losses of nutrients (nitrogen) of plants, preventing toxicant contamination of plant products and environmental components.

New OMM 1-2 on the basis of SWS with mineral additives for the main application under corn for silage in the year of their direct effect was not inferior in effectiveness to complete mineral fertilizer, organic fertilizers (traditional, non-traditional) in equivalent doses.

With a science-based approach, the SWS of urbanized areas can become a constantly renewable source of local raw materials for the production of qualitatively new, highly efficient OMF.

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