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EFFICIENCY OF NEW FERTILIZERS BASED ON SEWAGE SLUDGE OF URBAN TREATMENT FACILITIES IN THE FODDER CROP ROTATION IN THE WESTERN FOREST-STEPPE OF UKRAINE

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Abstract

Sewage sludge (50-52% moisture) of a large regional city in the western part of Ukraine is characterized by a complex of agronomically valuable traits, but their direct incorporation into the soil as a non-traditional organic fertilizer is ecologically impractical due to a number of unfavorable factors, therefore, they should be processed into quality fertilizers of the new generation. The composition of complex organo-mineral fertilizers based on sewage sludge with mineral additives of different origin is developed and new three- and two-component organo-mineral fertilizers of prolonged action for multi-purpose use are obtained. In a field experiment (2017-2019) with a comparative study of the effectiveness of different types of fertilizers in the fodder crop rotation, it was found that new organo-mineral fertilizers with the main application in optimal doses on light gray forest soil in the Western Forest-Steppe of Ukraine had the same effect in the year of action and aftereffects as traditional and non-traditional organic fertilizers, as well as complete mineral fertilizers (in equivalent doses), and allow with a single application of the first crop rotation crop to grow the second and third crops without fertilizers 110% and 45% according to the control without fertilizers.

Key words: *efficiency, new organo-mineral fertilizers, fodder crop rotation, Western Forest-Steppe, Ukraine.*

INTRODUCTION

Currently, the problem of waste disposal is one of the most urgent problems of our time. Waste is a source of environmental pollution, as a result of their accumulation, the sanitary-hygienic and epidemiological indicators and aesthetic qualities of nature significantly are deteriorating. At the same time, wastes of certain industries have properties that determine the possibility of their reuse, which defines interest in them as a secondary material resource. These include sewage sludge (hereinafter - SS) from municipal wastewater treatment plants (hereinafter - WWTP), which are stored on the sludge sites of municipal wastewater treatment plants and dumps at risk to the environment and the population, creating technological problems in the process of wastewater treatment. Improper storage conditions lead to environmental pollution in urban and suburban areas, worsen water quality in water bodies, as in most cases WWTPs with sludge sites and landfills are located on river banks to discharge wastewater. According to scientists (Kireeva, 1996; Sevalnev, 2000; Nasirov et al., 2015) storage of production and consumption waste on sludge sites of WWTPs causes significant economic and environmental losses to society due to environmental pollution and degradation, lack of quality drinking water, disturbances of natural state of territories, loss of health of the population. Thus, SS is a source of environmental pollution and its disposal in storage and sludge sites, as a temporary way to solve this problem has long been exhausted. On the other hand, properly treated solid waste from municipal sewage treatment plants is a reserve of non-traditional organic fertilizers and ameliorants of local origin (according to requirements) and/or resource-intensive raw materials for their production that can be used in agriculture. Therefore, the development of innovative ways to safe SS disposal is one of the urgent tasks of mankind. Without solving the problem of safe utilization of organic waste, there is a risk of significant accumulation and catastrophic environmental pollution (Merzla, 2006; Dregulo et al., 2012; Dregulo et al., 2016; Manenko et al., 2020).

In Ukraine, the situation in the field of SS in large cities and industrial centers due to the formation of their large volumes and the lack of long-term adequate response to the danger they pose to the environment and human, is assessed as a crisis. According to estimates (Drozd et al., 2001; Melnichuk et al., 2003), 50-55 million tons of SS (in dry matter) have been accumulated in recent years; according to other data (Bagno et al., 2011), up to 1 billion tons of SS of long-term storage have been accumulated in the country. Every year, more than 25-30 million tons of liquid SS are formed, or 0.7-1.0 million tons in dry matter (Degodyuk et al., 2006; Bagno et al., 2011). In general, almost all volumes of SS in large cities and industrial centers are subject to disposal (Drozd et al., 2001; Melnychuk et al., 2003; Drozd et al., 2013), although the law provides for their recycling and disposal (Law, 1998). The total storage area of SS is more than 10 thousand hectares, waste is placed on sludge sites, storage facilities, quarries, temporary storage sites that do not meet environmental requirements. Due to the lack of safe practices for the management of SS in the places of its accumulation, it pollutes the environment and has a detrimental effect on public health (Kireeva, 1996; Sevalnev, 2000).

It was determined (Dyshlyuk et al., 2020) that SS of most large cities (22 cities with a population of over 200 thousand inhabitants and developed industrial potential in 20 oblasts, including 20 oblast cities), which was formed under the conditions of technogenesis in the pre-crisis period, after the final holding on sludge sites, mainly meet the requirements for ecological and sanitary indicators for use in agricultural production as a non-traditional organic fertilizer. There is a group of cities where SS is biologically contaminated and requires more effective decontamination, a sufficient level of which can be achieved by adhering to technological processes in the treatment cycle at sewage treatment plants, longer holding time on sludge sites, or by biothermal processing into quality biofertilizers.

As a result of assessing the degree of contamination with SS toxicants in large cities and industrial centers, formed under the conditions of technogenesis in the pre-crisis period, it was found that most of them exceed the permissible concentrations for fertilizing field crops. Therefore, depending on the actual content of toxicants in SS, 6 groups of cities are classified, according to which the technology of waste use for fertilizers is determined with restrictions on doses, frequency of application, areas of application (Dyshlyuk, 2000). In the last decade, due to the decrease in the share of industrial wastewater in the general sewage, the content of toxicants in the SS of large cities has decreased to acceptable levels, which determines the prospects of its use for fertilizer production (Skrylnyk, 2018).

In general, at present, the problem of disposal of SS in large cities and industrial centers in the country is typical and requires urgent measures to neutralize them while maintaining the ecological balance of the environment. According to H.Ye. Merzlaya (2006) at the current pace of urbanization and agglomeration to solve the situation of rational disposal of SS in large cities and industrial centers is possible only with the implementation of innovative technologies for municipal wastewater treatment, treatment and processing into complex organo-mineral fertilizers of the new generation.

It is obvious that the use of this secondary constantly renewable organic raw material for the production of modern quality fertilizers is one of the most promising areas of soil enrichment with organic matter of humic origin, macro- and micronutrients and restoring soil fertility.

The processing of SS into complex organo-mineral fertilizers of the new generation will reduce environmental pollution and conserve natural resources, reduce energy consumption and land for sludge sites for the disposal of SS, to obtain material benefits from the use of fertilizers.

The purpose of the work:

- study the qualitative indicators of SS in a large regional city in the western part of Ukraine and to find out the possibility of using them for the production of new generation fertilizers;
- create on the basis of SS new complex organo-mineral fertilizers of new generation for use in agriculture;

- study the effectiveness of new complex organo-mineral fertilizers based on SS in the crop rotation chain on soils of eluvial type of soil formation in the Western Forest-Steppe of Ukraine.

MATERIALS AND METHODS

Objects of research: sewage sludge of a large city in the western part of Ukraine, assessment of the suitability of waste for use as organic raw material for the production of new generation fertilizers, the effectiveness of new fertilizers on eluvial soils. In the field experiment (2017-2019) we studied the effectiveness of the effect and aftereffect of new generation fertilizers in the form of organo-mineral mixtures (hereinafter - OMM) based on SS with mineral additives (mineral fertilizers, natural sorbent - agroperlite) compared to complete mineral fertilizers, traditional and non-traditional organic fertilizers in equivalent doses. The experiment was carried out in the Western Forest-Steppe of Ukraine (Lviv oblast, Pustomitivskyi district, Obroshyne village, research field of the Institute of Agriculture of the Carpathian region of National Academy of Agrarian Sciences of Ukraine (hereinafter - NAAS) on light gray forest surface gleyed coarse-dusty-light loamy soil in 4 fodder crop rotation in the chain with the alternation of crops: corn for green fodder - spring barley with sowing of meadow clover - meadow clover. The experiment consists of 6 options. The total area of the site is 26 square meters (4 m x 6.5 m), repetition in the experiment - three times. The location of the options is single-tiered, consistent.

Scheme of the experiment:

1 - without fertilizers (absolute control);

2 - complete mineral fertilizer in the dose of $N_{150}P_{90}K_{90}$;

3 - cattle manure in a dose of N_{total} 150 kg/ha;

4 - SS in a dose of N_{total}. 150 kg/ha;

5 - OMM (organo-mineral mixtures) 1 based on the dose of $N_{150}P_{90}K_{90}$;

6 - OMM 2 based on the dose of N_{total} 150 kg/ha.

The following fertilizers were used in the experiment: half- decomposed manure of cattle (straw litter), dried thermophilic-fermented SS after 5-6 years of storage on sludge sites, industrial fertilizers: ammonium nitrate (34.5%), simple granular superphosphate (19.5%) and potassium magnesium (28%), two types of new mixtures: OMM 1 (SS + industrial fertilizers (ammonium nitrate, superphosphate, potassium magnesium) + natural sorbent (agroperlite) and OMM 2 (SS + natural sorbent (agroperlite) in certain ratios. The experimental batch of new OMM was obtained by mixing in certain proportions the above components and the subsequent physical and physicochemical interaction of activated organic matter and the elemental composition of SS with mineral components. Patents of Ukraine were obtained for new types of complex OMM based on SS with mineral additives (Patents, 2017).

Doses of fertilizers were equalized by the content of total nitrogen and applied to the soil when laying the experiment in the spring of 2017 in one go in a continuous manner (scatter) before plowing for the first crop rotation.

In 2017, we studied the effectiveness of fertilizers on corn on the green mass (hybrid Pioneer - P8529), in 2018 - the aftereffect of the 1st year of fertilizers on spring barley (Galician variety) with sowing meadow clover (variety Predkarpatska 6), and in 2019, respectively, the effectiveness of the aftereffect of the 2nd year of fertilizers for sowing meadow clover (variety Predkarpatska 6) of the 1st year of use.

By setting up an experiment and conducting research, they were guided by generally accepted methods. Soil samples for research were taken from the arable layer (0-20 cm) of soil in spring and at the end of the growing season. Agrochemical, physicochemical and ecological-toxicological indicators were determined in the samples of manure of cattle, SS and OMM 1 and 2 according to the current normative documents. Assessment of the degree of contamination of SS with toxicants and new OMM was performed according to State Standard of Ukraine (DSTU 7369:2013), the level of soil micronutrients according to the Guidelines (1976), the level of soil contamination with toxicants and the suitability of plant products for for feeding agricultural animals by heavy metal content according to Departmental Normative Documents (1999).

RESULTS AND DISCUSSIONS

It is established that SS of a large regional city in the western part of Ukraine after drying and storage on silt sites is characterized by quite high fertilizing properties.

$N\text{-}NH_4$ and P_2O_5, which are contained in amounts of 285 and 366 mg/kg, respectively, predominate in SS among mobile forms of nutrition. Agrochemical indicators of SS meet the requirements of the current regulatory document (DSTU7369: 2013) (Table 1).

Table 1. Agrochemical composition of SS (average data)

Indicators	Content[1]	Norm [2]
Mass fraction of dry matter	35.85	-
Mass fraction of organic matter	47.67	No >40
Mass fraction of total carbon, C total	24.77	-
Mass fraction of total nitrogen, N	1.87	No >1.5
Mass fraction of total phosphorus, P_2O_5	1.37	No >0.7
Mass fraction of total potassium, K_2O	0.44	-
pH aqueous	7.72	6.5-7.5
Correlation C:N	13.3	-

1 - in % on dry matter

2 - standards of agrochemical indicators of SS according to DSTU 7369.

SS has high reclamation rates: the content of gross and water-soluble calcium varies between 3.8-4.2% and 0.20-0.38%, respectively, the ratio of Ca: Na in the salt composition of SS reaches 32 units. In the particle size distribution of SS, the content of physical clay is 13-15%, including sludge (coarse and fine) and colloids - 1.9-2.4%. The number of fractions with a particle size > 0.05 mm (fine, medium and coarse sand) is 65-76%. The number of fractions involved in the structure of the soil as a passive material (large, medium and fine dust) is 22-32%. According to the classification of soils according to the granulometric composition of SS with a physical clay content of 13-15% can be conditionally equated to the soil, which is characterized by sandy granulometric composition. The established indicators and properties of SS give grounds to attribute them to the material characterized by a set of agronomically valuable features.

In this regard, SS can be used as a local raw material, which has both fertilizing value and properties characteristic of ameliorant (neutral and slightly alkaline reaction of the environment, high content of gross and soluble calcium, high calcium activity, which is important for land reclamation gray forest soil: to reduce the acid reaction (actual soil pH - 4.4) and saturation of the soil-absorbing complex with calcium (the degree of saturation of the soil with bases - 34-37%). That is, it is a substrate that can improve soil properties and act as a barrier to toxicants. However, SS has an unbalanced ratio of basic nutrients (N:P:K = 1: 0.73: 0.23), increased concentrations of some toxic chemical elements with a high proportion of mobile forms, which is due to the application of these substrates in high doses/ha) can cause phytotoxic effects, translocation of heavy metals from soil to plants, etc. (Manenko AK et al., 2020). Due to these shortcomings, SS is unsuitable for direct application as a non-traditional organic fertilizer and it is advisable to use it as secondary organic raw materials for processing into high-quality organo-mineral fertilizers of the new generation.

The new OMM 1 and 2, which are based on SS with mineral additives, represent a new generation of complex organo-mineral fertilizers containing organic substances and minerals, macro- and microelements and are characterized by high fertilizing properties, high cation exchange capacity and prolongation of action, as well as the ability to convert mobile forms of heavy metals into a fixed state.

In the technological process of obtaining OMM, mineral nutrients form organo-mineral complexes with humic compounds of the organic component of fertilizers, which are able to supply plants with easily digestible forms of nutrients for a long time. Agrochemical indicators of OMM 1 and 2 meet the requirements of the current regulatory document (DSTU, 2013), fertilizers are characterized by a significantly higher fertilizing potential (especially OMM 1) than the original SS. Samples of fertilizers have low humidity (19-29%), which is important to save costs for their transportation and simplifies agricultural practices for the application of OMM in the soil (Table 2).

Table 2. Agrochemical composition of OMM (average data)

Indicators	OMM 1	OMM 2
	Content[1]	
Mass fraction of dry matter	71.11	80.52
Mass fraction of organic matter	40.25	43.50
Mass fraction of total nitrogen, N	4.53	2.24
Mass fraction of total phosphorus, P_2O_5	5.97	2.85
Mass fraction of total potassium, K_2O	4.39	0.79
pH aqueous	5.60	6.07
Correlation C:N	4.5	8.0

1 - in % on dry matter

OMM 1 and 2 differ from the original SS in a more balanced ratio of basic nutrients (for OMM 1 ratio N: P: K = 1: 1.32: 0.97; and for OMM 2 ratio N: P: K = 1: 1, 27: 0.35), high content of mobile nutrients (OMM 1), the presence of a wide range of macro-. and trace elements and the best physicochemical properties.

Thanks to the new positive qualities of OMM 1 and 2, their application allows reducing fertilizer application doses, balancing the ratio of nutrients in the soil, to prolong the action of fertilizers, which generally increases feed yields and product quality. In an experiment to study the effectiveness and aftereffects of OMM 1 and 2 compared to complete mineral fertilizers, traditional and non-traditional organic fertilizers in equivalent doses, it was found that the use of new fertilizers (OMM 1 and 2) in crop rotation at optimal doses provided obtaining an increase in plant products of regulatory quality: in the year of fertilizer application - 26.0 - 31.9 t/ha of green mass of corn, in the aftereffect of the 1st year of fertilizer - 0.90-0.95 t/ha of spring barley grain, in the after effect of the 2nd year of fertilizer - 13.2-15.0 t/ha of green mass of meadow clover (total increase for 2 slopes) compared to the control without fertilizers (yield under control: in the year of fertilizer application - 24.1 t/ha of green mass of corn; in the aftereffect of the 1st year of fertilizers - 0.84 t/ha of spring barley grain and in the aftermath of the 2nd year of fertilizers - 31.1 t/ha of green mass of meadow clover) and in efficiency they were not inferior to organic and mineral fertilizer systems.

CONCLUSIONS

New OMM based on SS with mineral additives are characterized by increased agrochemical and agrienvironmental value and high efficiency for the first crop and have a residual effect on subsequent crops of crop rotation on soils of eluvial type of soil formation (light gray forest soil).

New OMM based on SS with the main application in optimal doses on light gray forest soil are not inferior in efficiency to the year of action and aftereffects of complete mineral fertilizers, traditional and non-traditional organic fertilizers (in equivalent doses) and thanks to new positive qualities allow for single application OMM for the first crop to grow the second and third crops without the application of NPK with a yield increase of 120% (in the year of fertilizer application), 110% (the aftereffect of the 1st year of fertilizers) and 45% (of the aftereffect of the 2nd year of fertilizers) on average, respectively, according to the control without fertilizers.

Due to its high metabolic and sorption capacity, the use of natural sorbents in new OMM allows them to be considered as an effective tool for optimizing the fertilizing and reclamation properties of fertilizers, reducing unproductive losses of plant nutrients (nitrogen), preventing contamination by toxicants of plant and natural plant environment.

The establishment of new local self-government bodies creates an opportunity for the purposeful transformation of organic raw materials of man-made origin, increasing soil fertility and land productivity, preserving the ecological balance of the environment, creating additional jobs and so on.

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