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INFLUENCE OF ORGANOMINERAL FERTILIZER BASED ON FERMENTED POULTRY WASTE ON THE PHYSICO-CHEMICAL PARAMETERS OF AGRICULTURAL SOILS

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Abstract

The paper discusses aspects of the influence of organo-mineral fertilizer, which is poultry waste fermented with the help of a complex of microorganisms, on the structure of the soil. The technology for the preparation of organo-mineral fertilizer is complex and involves cascade fermentation of spent litter masses, their integration with mineral components under conditions of correction of the environmental reaction. This ensures the minimization of losses of biogenic elements (nitrogen, phosphorus, sulfur, and others) in the process of destruction. This approach, on the one hand, reduces the volume of emissions of gas fractions into the atmosphere, and, on the other hand, determines the transition of biogenic elements into mobile forms available for plants in the fertilizer composition. A reliable positive effect of the developed fertilizer on the chemical composition of the soil and its characteristics such as air and water permeability. The use of organo-mineral fertilizer on leached chernozem contributes to the preservation and increase of humus reserves, enrichment of the soil with its mobile components. A change in the characteristics of the physical state of the arable soil layer is shown, which manifested itself in soil decompaction, an increase in the proportion of structural components of an agro-valuable size and the number of water-stable aggregates. The application of fertilizer provides the best agro-physical properties of the soil by reducing the bulk density to 0.25 g/cm^3, increasing ACF by 4.5% and VA by 10.6% compared to the unfertilized background.

Key words*: poultry waste, waste bioconversion, organo-mineral fertilizers, soil structure.*

INTRODUCTION

An urgent problem of agriculture is the protection of the natural environment from pollution by organic production waste. The most dynamically developing branch of animal husbandry is poultry farming. The placement of environmentally hazardous waste in the form of manure can act as a limiting factor in scaling and expanding production. The solution to this problem can be the conversion of such waste into organic and organo-mineral fertilizers (OMF). About 640 million tons of manure and litter are produced annually in agricultural enterprises of the Russian Federation, which, in terms of fertilizer value, is equivalent to 62% of the total production of mineral fertilizers in the country (Subbotina et al., 2014).

Organic fertilizers are not only an important source of nutrients and carbon for plants and soil microorganisms, but also a means of improving the agronomic properties of the soil and replenishing the humus reserve in it, one of the main factors of soil fertility. There are reports in the literature about testing innovative fertilizers obtained by microbial fermentation of waste (Jara-Samaniego et al., 2017; Sigurnjak et al., 2019; Ahuja et al., 2020; Fernández-Delgado et al., 2021; Saleme et al., 2021). The works show the positive effect of such fertilizers on plant productivity and soil fertility, its agrochemical and agro-physical indicators. In this regard, the relevance of developing a technology for the bioconversion of poultry waste into organo-mineral effective and economical fertilizers is beyond doubt.

The aim of this work was to evaluate the effect of organic-mineral fertilizer, which is a poultry waste fermented with the help of a complex of microorganisms, integrated with mineral components, on the soil structure.

MATERIALS AND METHODS

The studies were carried out on the basis of the Penza State Agrarian University. Poultry waste was obtained from the waste storage site of the Damate Group of Companies, located in the Nizhnelomovsky district of the Penza region (Russia). These are spent litter masses containing turkey manure and straw-sawdust materials (Figure 1).

Figure 1. A sample of poultry waste - spent manure and bedding mass

The litter-litter mass was brought to 60% moisture content and placed in plastic containers in an amount of 5.0 kg. The substrates were exposed under standard conditions (20°C, 760 mm Hg) for 2 weeks, during which, an occasional stirring was done. During this period, fermentation of substrates occurred due to the enzymatic activity of the native microflora.

For the degradation of hardly decomposable materials, after a two-week period, a functional complex of microorganisms, which is a culture liquid with the remains of a nutrient medium, was introduced into the manure-litter mass that underwent primary fermentation (Figure 2).

Figure 2. Microorganism inoculum prepared for waste fermentation

As a functional group of ammonifiers, bacteria of the genus *Bacillus* were used; as nitrifiers - representatives of the genus Nitrosomonas; for the implementation of the destruction of cellulose and lignin components, cultures of filamentous fungi of the genera Thelavia, Cellulomonas and Myceliophthora and actinomycetes of the genus *Nocardia* were used.

The functional complex of microorganisms is a deep culture, namely a suspension of cells with a titer of 10.0-12.0 million cells per liter of culture fluid. For use, the concentrated culture is diluted with tap water in a ratio of 1:10 and introduced with stirring into the mass of the mineral carrier, glauconite, crushed to a fraction of 0.01-0.5 mm in the amount of 1 liter per 10.0 kg. The microbial complex immobilized on a mineral carrier is added to the mass of waste at the rate of 5:100. The fermentation process takes place in piles of 1.5-2.0 m high. Raising the temperature in piles to 50-60°C is not a critical moment, since thermophilic species of micromycetes are involved in the fermentation processes.

The resulting organo-mineral fertilizer was applied to the soil in the conditions of a peasant farm located in the Lopatinsky district of the Penza region, in the autumn period under clean fallow. The soil is leached heavy loamy chernozem, the arable layer of which contains 6.0-6.4% humus; exchangeable bases 50.0-36.0 meq/100 g; pH KCL $_1$- 5.9-6.2. The area of the plots was laid by 5 m^2, the repetition of the experiment was four times, the variants in the experiment were placed by the method of randomized repetitions. The scheme of the experiment included the following options: 1) control (without fertilizers) (C); 2) manure and litter materials without microbial fermentation (MLM); 3) organo-mineral fertilizer (OMF); 4) mineral fertilizer equivalent to OMF in terms of the content of biogenic elements (nitrogen, phosphorus, potassium) (MF).

Soil samples were taken in July of the following year after two cultivations (April, June) from a layer of 0-20 cm. Humus carbon was determined according to Tyurin (Arinushkina, 1970). The bulk density was determined according to Kachinsky, the humidity was determined by the thermoweight method (Alexandrova, 1986); structural composition according to Savvinov (Vadunina et al., 1978); water resistance of the structure - on the Baksheev (1969) device (Methodological guide). The results of the study were processed by the analysis of variance (Dospehov, 1969).

RESULTS AND DISCUSSIONS

On the basis of pre-selected functional cultures of microorganisms, the physiological and biochemical potential of which is capable of providing high efficiency of composting of manure-litter mass, functional microbial compositions were compiled. The composting process is similar to the rotting process. It is characterized by a cascade of stages that are implemented in a certain chronological order. At the first stages of destruction, readily available components are decomposed: easily degradable polysaccharides, low molecular weight carbohydrates, proteins, nitrogenous substances, which, as a rule, is accompanied by heating of the substrate, as well as a shift in the overall biochemical balance towards ammonification. At later stages, more difficult to utilize components become substrates, localized mainly in the bedding material (wood chips, sawdust, cereal straw). By their chemical nature, the main substances of these materials are polymers such as cellulose, hemicelluloses and lignin. In view of the foregoing, at the initial stages of fertilizer preparation, cultures providing ammonification were used, and at later stages, cellulose- and lignolytic complexes of microorganisms were used. In establishing the timing of the introduction of the appropriate complexes of microorganisms throughout the process, an important role is played by the pH index, which can be subject to significant dynamic changes. At the initial stages of active fermentation, the pH is in the alkaline region, and as biodegradation progresses, it shifts to the acid side. This fact is explained by the fact that in the process of ammonification, the released ammonia, interacting with water, forms a solution of ammonium hydroxide, with alkaline properties. At later stages, the hardly decomposable compounds are sequentially oxidized, resulting in products with acidic properties (carboxylic acids and phenolic compounds). Thus, the change in the pH value is largely determined by the activity of the microorganisms themselves and the gradual change in their formations. In addition to changes in the species composition of microorganisms, shifts in pH values can also contribute to the transformation of the forms of substances, the mobility of elements, and, as a result, the degree of assimilation of such important biogenic elements as phosphorus and nitrogen. However, to accelerate these changes, it seems possible to correct the pH of the substrate with acidic solutions, which can provide better adaptation of certain microorganisms and the fullest possible realization of the physiological and biochemical potential. Thus, since the final product - an organomineral fertilizer - is an integral result of the activity of all microorganisms at all stages of biodegradation of a degradable material, then the regulation of the process through the sequential release of the corresponding microbial complexes from the mineral carrier with simultaneous correction of the pH value can ensure the production of a high-quality product in the most compressed terms.

The source material - manure and bedding mass, which is a common poultry waste, also contains biogenic elements in the following quantities: 2-4% N, 3-3.5% P_2O_5 and 1.5-2.0% K_2O, humic substances were not detected.

The product obtained as a result of fermentation (OMF) is a friable mass with a moisture content of 30%, color from light brown to rich brown, with a characteristic earthy smell (Figure 3).

Figure 3. Material of organo-mineral fertilizer obtained as a result of microbial fermentation poultry waste

Physico-chemical characteristics of the product are shown in Table 1.

Table 1. Results of chemical analysis of the product (OMF), $p<0.05$

Indicator	Result
Particle size, mm	1.6 ± 0.4
Moisture content, %	12.6 ± 0.9
Indicator of activity of hydrogen ions in an aqueous suspension, pH	7.8 ± 0.3
Mass fraction of organic matter, % for dry product	82.6 ± 1.7
Mass fraction of biogenic elements, % on dry matter:	
N	51.8 ± 2.4
P_2O_5	4.8 ± 0.7
K_2O	4.2 ± 0.3
humic substances	>15.0
Nitrate nitrogen content, mg/kg dry matter	270.4 ± 11.4

The data obtained indicate the feasibility of using WMD to improve the structure of the soil and enrich it with biogenic elements.

The fertilizers used in the agrochemical experiment showed differences in quantitative estimates of the intensity of the humification process in terms of humus carbon (C_{hum}) (Table 2). A predominant effect on the content of mobile carbon forms of organic compounds (S_{mob}) and, to a lesser extent, on the parameters of a stable forms of carbon (C_{stab}) was found.

Table 2. Influence of agromeliorants on humus parameters, mgC/100 g ($p>0.05$)

Option	S_{hum}	S_{mob}	S_{stab}	% S_{mob} from Shum
Control	3581	874	2707	24.4
MLM	3714	812	2902	21.9
OMF	3983	1042	2941	26.1
MF (eq. $N_{52}P_{48}K_{42}$)	3218	716	2502	22.2

The analysis of the obtained results indicates that the introduction of organo-mineral fertilizer obtained by fermentation of manure-litter materials under fallow provides a significant increase in the content of mobile forms of carbon. This can be explained by the increased enzymatic activity of the introduced microorganisms and the role of glauconite as a phase that immobilizes microorganisms and biogenic substances, including mobile forms of carbon.

Leached chernozems themselves are distinguished by good agro-physical properties, and fertilizers are not always able to significantly improve them (Kurachenko et al., 2008). Moreover, long-term systematic use of fertilizers can have a negative impact on the bulk density and structural composition of soils (Pyatkovsky et al., 1983; Kretinina, 1989; Perveeva et al., 2004). The agromeliorants studied in the experiments change the density of the arable layer, which was established by evaluating soil samples taken after the first (spring) and second (summer) cultivations of bare fallow (Figure 4). After the first cultivation on the control variant, it was 1.1 g/cm^3. Despite a fertilized background, the density of the soil was reduced by 0.1-0.25 g/cm^3 which could be explained by the presence of organic substances at different stages of microbial destruction. After the second cultivation, a decrease in density was noted in all variants, but again the most pronounced decrease was noted in the variant with OMF, which confirms the assumption about the role of organic compounds, as well as microbial degradation processes.

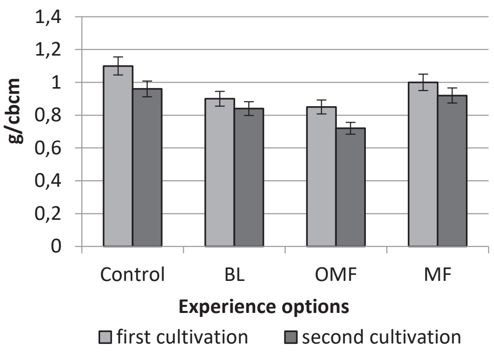

Figure 4. Density of addition of leached chernozem in the variants of the experiment: Control - control; BL - manure-litter mass; OMF - organomineral fertilizer; 4 - MF - mineral fertilizer (equiv. N52P48K42) ($p<0.05$, error bars - mean error)

The introduction of organo-mineral fertilizer into the soil increases the content of agro-valuable fractions (AVF) with aggregate sizes from 0.25 to 10 mm, which have porosity and water resistance, both after the first and after the second cultivation. This structure determines the most favorable water-air soil content. Despite, the background of mineral fertilizer, an increase in this indicator is also found, the introduction of bird litter did not have a significant effect on the share of AVF. A statistically significant increase in AVF by 4.5% after the first and second cultivations was found in the variants with the application of organic mineral fertilizer and by 3.5% - with the application of bedding materials.

An increase in the number of water-stable aggregates by 7-10.6% after the first cultivation was revealed in all variants of the experiment. Organo-mineral fertilizer (OMF) had the greatest impact on the aggregate composition. Such data can be explained by the activity of soil microbiocenosis, activated by the introduced biogens.

A variety of microbial waste products (biofilms, mucus capsules, cell wall material and other biofactors), due to their adhesive and gel-forming properties, can have a beneficial effect on soil structure and its water-holding capacity. After the second cultivation, the content of water-stable aggregates in the soil increased by 3-10.5%, and during this period, the most noticeable effect of organo-mineral fertilizer was shown.

CONCLUSIONS

A reliable positive effect of the developed organo-mineral fertilizer obtained by microbial fermentation of poultry waste on the chemical composition of the soil and its characteristics such as air and water permeability has been established.

The use of organo-mineral fertilizer on leached chernozem contributes to the preservation and increase of humus reserves, enrichment of the soil with its mobile components.

The experiment established a change in the characteristics of the physical state of the arable soil layer, which manifested itself in soil decompaction, an increase in the proportion of structural components of an agronomically valuable size and the number of water-stable aggregates.

The application of fertilizer provides the best agro-physical properties of the soil by reducing the bulk density to 0.25 g/cm^3, increasing agro-valuable fractions by 4.5% and water-stable aggregates by 10.6% compared to unfertilized background.

The obtained data testify to the expediency of using the studied organo-mineral fertilizer to improve the soil structure.

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