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ORIGINAL PAPER

USE OF VERMICOMPOST FOR RECOVERY OF SOIL FERTILITY AND INCREASE OF FIELD CROP CAPACITY UNDER CONDITIONS OF THE DRY-STEPPE ZONE*

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Abstract

This paper describes the results of applying vermicompost in various doses to soil, and its effect on the soil density as well as on the capacity of crops achieved in the Pavlodar region, the Republic of Kazakhstan. The experiment consisted of 7 objects: control, $N_{40}P_{20}$; vermicompost 1.5 t ha^{-1}, vermicompost 3 t ha^{-1}, vermicompost 5 t ha^{-1}, vermicompost 7 t ha^{-1}, vermicompost 9 t ha^{-1}. The research has shown that vermicompost use contributes to the efficient use of moisture by creating an optimal composition of the arable soil layer. On average, the application of vermicompost to soil improves the density of the arable layer, bringing its parameters closer to the established optimal values for wheat (1.26-1.30 g cm^{-3}), peas (1.23-1.29 g cm^{-3}) and buckwheat (1.23-1.26 g cm^{-3}). Productive moisture deposits in the arable layer of soil with vermicompost under wheat were from 4.6 to 7.1 mm, under pea - from 3 to 10.4 mm and under buckwheat - from 3.9 to 4.7 mm. The vermicompost use in the amount of 1.5-9 t ha^{-1} contributes to an increase in the humus content in the arable layer of soil. That is, each ton of vermicompost used increases the humus content in the soil by an average of 0.07%. On average,

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the application of 1 t ha^{-1} of vermicompost provided an increase in the content of labile phosphorus by 4.7 mg kg^{-1} of soil. The studied crops produced relatively high yields, namely wheat after the application of 5 and 9 t ha^{-1} of vermicompost, and of pea and buckwheat owing to 7 and 9 t ha^{-1} of vermicompost added to soil. At the same time, wheat achieved a yield increase of 2.7-2.9 t ha^{-1}, peas – of 4.0 and 4.2, and buckwheat – of 2.6-2.7 t ha^{-1}.

Keywords: buckwheat, crop capacity, peas, soil density, spring wheat, vermicompost.

INTRODUCTION

When cultivating crops, significant amounts of fertilizer elements are removed from the soil along with the harvested yield, and the soil reserve is renewed by mineral fertilization, the use of which is a threat to human health and the environment; it leads to the death of soil organisms, an increase in the content of nitrates and heavy metals, as well as humus mineralization in the soil. Each year, the influx of organic substances declines steadily, the humus content is gradually reduced, and such soil attributes as the structure, aeration and soil water retention capacity deteriorate (Kalimov 2009, Słowińska-Jurkiewicz et al. 2013).

Agricultural productivity, in general, relates to the preservation and recovery of crop soil fertility. The current state of soil fertility and deteriorating processes necessitate a set of measures to eliminate the consumptive use of farm land as it can lead to the exhaustion of soil, which will eventually affect the level of crop yields and agricultural productivity (Karipov 2008, Azarmi et al. 2008).

In this regard, it is necessary to switch farmers' attention to organic farming using vermicompost obtained from earthworms. Due to its biological and physical and chemical properties, vermicompost is able to recover the natural fertility of soils, with a positive effect on the agrophysical and agrochemical properties of the soil, while obtaining a significant increase in crop yields (Mozhayev et al. 2003, Bhadauria, Saxena 2010).

The aim of this paper is to study the impact of the use of organic fertilizers in the form of vermicompost for soil fertility recovery and increase of field crops' capacity in the Pavlodar region of the Republic of Kazakhstan.

MATERIALS AND METHODS

The aim has been achieved by analysing the improvement of agrochemical properties, stabilization of humus in the soils studied, improvement of hydro- and agrophysical properties of the soil owing to the application of vermicompost, increase of field crops' capacity, impact of vermicompost doses on the growth and development of plants, qualitative indicators of the crops, and the economic efficiency of vermicompost use.

Testing environment

The experimental field of the LLP Pavlodar Agricultural Research Institute is located in the dry-steppe zone, within the subzone of fescue-feather grass steppe, in the southern part of the West Siberian Lowland. The relief is represented by a gently undulating plain.

Soils of the experimental field are chestnut-brown, mature, light, low-humic, medium-deep sandy loams. The content of the total form of nitrogen is 0.22%, and that of phosphorus is 0.19%. The average soil reaction is close to neutral. Weight by volume of 0-30 cm of the soil layer is equal 1.39-1.55 g cm^{-3}. The average atmospheric temp. (°C) in the following months was: 16.5 in January, 16.7 in February, 8.9 in March, 5.0 in April, 13.5 in May, 20.0 in June, 21.8 in July, and 18.6 in August. The amount of precipitation (mm) in a year, compared to the long-time annual average precipitation, was respectively: 16, 13, 13, 17, 27, 25, 36 and 35.

Research methods

The study and experiments were demonstrated on a pilot field of the Pavlodar Agricultural Research Institute. Experiments were placed in 10 full crop rotation. The preceding crop was coulisse-strip fallow. The research concerned the influence of vermicompost and mineral fertilizer doses on the yield of field crops (wheat, peas, buckwheat). The experiment consisted of 7 groups: control (group 1), $N_{40}P_{20}$ (2), vermicompost 1.5 t ha^{-1} (3), vermicompost 3 t ha^{-1} (4); vermicompost 5.0 t ha^{-1} (5), vermicompost 7.0 t ha^{-1} (6), and vermicompost 9.0 t ha^{-1} (7). The experiment was set up using the triple analysis approach with the method of split plots. In each group, 20 samples were taken for analysis. The plot area was 240 m^2, with 80 m^2 for harvest.

All agrotechnical measures for the cultivation of field crops (soil treatment, fertilizer and vermicompost use, sowing, crop care, harvesting) were carried out in accordance with the adopted process flow system. The following observations were made during the vegetative cycle:

– phenological observations with the method of state variety testing of grain crops during the stage of tillering, earing and maturation and during the corresponding stages of the other crops;
– determination of yielding moisture in the soil layer of 0-100 cm with the method of accelerated drying before sowing, during the stage of tillering and booting of wheat, during the stage of buckwheat and pea budding and before harvesting in 6-fold replication;
– sampling for the humus content, NPK in horizons 0-20, 20-40. Identifying labile phosphorus using the Chirikov's method, nitrate nitrogen using the ionometric method, and humus using the Thurin's method;
– identifying weight by volume using the cutting ring method in the layer of 0-10, 10-20 in 10-fold replication before sowing and harvesting;

– identifying plant density during the stage of full sprouting, full ripeness in 10-fold replication with counting all emerged and preserved plants using the method of overlapping sites of 0.25 m^2;
– measuring field crop yields.

Vermicompost characteristic

The Pavlodar vermicompost used in the experiment is a crumbly, soil-like mass, similar to chernozem. It contains a large amount of humic acids, fulvic acids and humic coal. All of these give this organic fertilizer high agrochemical and growth-stimulating properties. All its nutrients are in a balanced combination and in the form of compounds bioavailable to plants. The Pavlodar vermicompost has a water stability of 95-97%, and full moisture capacity of 200-250 mm (Table 1).

The content of humus varies within the limits of 12-17%, depending on the type of waste and on the type of processing worms. Repeated agrochemical analyses confirmed that vermicompost contained all nutrients, sufficient humus and organic matter amounts (Myagkaya 2021). There were no helminth eggs in vermicompost according to the Darling method, nor any

Table 1

Composition of the Pavlodar vermicompost

Elemental composition	
Wetness (%)	45 – 50
Ignition loss (%)	34 – 45
Organic matter (%)	55 – 65
Humus substance (%)	12.20 – 17.42
Total forms	
Nitrogen (%)	0.9 – 1.5
Phosphorus (%)	0.7 – 1.2
Potassium (%)	1.93 – 2.1
Labile soil nutrients	
Nitrogen N-NO_3 (mg kg^{-1})	81 – 109
Phosphorus (mg kg^{-1})	680 – 720
Potassium (mg kg^{-1})	3200 – 4800
Calcium (mg-eq 100 g^{-1})	14 – 18
Magnesium (mg-eq 100 g^{-1})	10 – 13
Microbial flora	
Heavy metals' mass fraction (mg kg^{-1})	below critical concent. for soils
Pathogenic bacteria (microbial flora)	absent
Helminth eggs	absent
Cysts of enteric pathogenic protozoa, including Salm	absent

pathogenic microflora, cysts of enteric pathogenic protozoa, including Salm, which were determined in accordance with GOST 30519-97 (Table 1).

The results were processed statistically by ANOVA test for factorial designs, and the significance of differences between means in groups was verified by the Duncan's test, using Statistica 13.0 software (Soft Incorp.).

RESULTS AND DISCUSSION

Effect of vermicompost on soil weight by volume

Soil density largely determines the plant performance. The increase of soil density in the arable layer higher than the optimal one by 0.1 g cm^{-3} leads to the decrease of grain yield up to 2.0 t ha^{-1} and more (Karipov 2008, Shtaltovna, Hornidge 2014). The fact is that with the density increasing from 0.9 to 1.3 g cm^{-3}, the water filtration rate drops from 5.7 to 0.2 mm min^{-1}, i.e. decreases by about 28 times (Kalimov 2009). When the optimum density of soil is achieved, moisture loss from the soil moisture storage decreases by 21-25% (Turebayeva et al. 2022).

According to the results of research, by being able to glue the finest mineral particles,vermicompost can form larger lumps and thus structure soils, which to some extent can solve the problem of soil decompaction and recompaction (Table 2).

Table 2

Average dynamics of the weight by volume in 0-20 cm of soil layer depending on the doses of vermicompost use (g cm^{-3})

Variant/groups	Plants		
	wheat	buckwheat	peas
1	1.31^{a}	1.27^{a}	1.33^{a}
2	1.31^{a}	1.27^{a}	1.29
3	1.30^{a}	1.26	1.29
4	1.29^{a}	1.25	1.27
5	1.27	1.24	1.26
6	1.26^{b}	1.23^{b}	1.23^{b}
7	1.26^{b}	1.23^{b}	1.24

a, *b* – $p \leq 0.05$

Thus, the results of our three-year study allow us to conclude that the vermicompost use before sowing of the studied crops significantly improves the density of arable layer of soil, bringing its parameters closer to the established optimal values on crops of wheat – 1.26-1.30 g cm^{-3}, peas – 1.23-1.29 g cm^{-3} and buckwheat – 1.23-1.26 g cm^{-3}. i.e. by adding a certain amount of vermicompost depending on soil conditions, the problem of overconsolidation of the arable layer of soil can successfully be solved.

Effect of vermicompost on productive moisture deposits in soil

The main factor limiting the achievement of stable high yields of grain, legumes and cereal crops in the region is moisture. The highest yields were obtained when there were sufficient moisture deposits in the soil at the time of sowing. Within the conditions of Western Siberia and Northern Kazakhstan, it was established that the content of productive moisture in the arable layer of soil during the period of sprouting and tillering less than 10 mm is low, 10-20 mm is satisfactory, and 20-40 mm is optimal, while 100-150 mm in a meter-layer of the southern carbonate mould and 80-90 mm in the chestnut soils are optimal (Mustafayev 2005).

Decrease in productive moisture deposits in a meter layer of soil below these values is the first sign of deterioration of conditions for the formation of grain, legume and cereal crops (Mozhayev et al. 2003). The results of the study show that by optimizing soil's physical properties (density, porosity, structural strength), vermicompost largely determines the water properties, especially the form of moisture available to the plant (Table 3).

Effect of vermicompost on humus content in soil

On average, over the three years, the productive moisture deposits in the arable layer of soil with vermicompost under wheat were more than 4.6 to 7.1 mm, under pea – from 3 to 10.4 mm, and under buckwheat – from 3.9 to 4.7 mm. It should be noted that as the amount of vermicompost used is increased, the productive moisture deposits in the arable layer of soil also increase owing to the soil water retention (moisture-holding capacity) of vermicompost. However, this ability of the arable layer (to retain a certain amount of productive moisture) is largely determined by the initial total moisture content in the root layer of the soil. This is evidenced by the data on productive moisture deposits gained on pea fields, where the initial moisture deposits in a metre soil layer due to early sowing (May 10) were 14-21 mm more annually than on wheat fields (May 25) and on buckwheat fields (May 30 – June 2). In this regard, the productive moisture in the soil layer of 0-20 cm on pea fields was kept on an average 1.3 mm per ton of vermicompost used, when this ratio was 1.1 mm on wheat fields and 0.8 mm on buckwheat fields per ton of vermicompost used.

Thus, the application of vermicompost has proved to be an effective method of creating and preserving productive moisture deposits, which is also a means of enhancing the biological and agrochemical capacity of the soil.

Abasova (2020) reports that the application of vermicompost improved density of the arable horizon. In soil, the content of water-resistant aggregates doubled, providing an optimal water-air regime. The application of biohumus can solve the problem of soil's excessive consolidation. Regular

Table 3

Productive moisture deposition depending on vermicompost use in subsequent years (mm)

Variant/ groups	1st year		2nd year		3th year		Average	
	layer of soil							
	0-20	0-100	0-20	0-100	0-20	0-100	0-20	0-100
Wheat (tillering - booting)								
1	16.7[a]	73.5[a]	13.4[a]	65.1[a]	8.8[a]	45.3[a]	12.9[a]	61,3[a]
2	15.8[a]	73.5[a]	15.2	66.1[a]	9.2[a]	46.2[a]	13.4	61,9[a]
3	20.4	75.9	21.3	76.4	10.9	50.6	17.5	67,6
4	20.2	79.9[b]	24.2[b]	79.4[b]	11.7	52.8	18.7	70,7
5	20.5	75.9	24.3[b]	79.6[b]	12.8[b]	61.2[b]	19.2[b]	72,2[b]
6	21.4	76.6	24.5[b]	79.1[b]	12.8[b]	58.4[b]	19.5[b]	71,3
7	23.2[b]	79.0[b]	23.9[b]	79.1[b]	13.1[b]	59.3[b]	20.0[b]	72,4[b]
Buckwheat (beginning of budding)								
1	14.2[a]	69.1[a]	12.9[a]	64.2[a]	7.4[a]	37.5[a]	11.5[a]	56.9[a]
2	14.0[a]	68.2[a]	13.4	65.1[a]	7.6	38.2	11.6[a]	57.1
3	19.4[b]	78.1	17.8	79.3[b]	9.2	41.3	15.4	66.2[b]
4	18.9	78.3	19.2[b]	79.3[b]	9.5	43.4[b]	15.8	67.0[b]
5	18.6	77.4	19.3[b]	78.9[b]	10.3[b]	42.8	16.0[b]	66.3[b]
6	17.2	78.2	20.1[b]	79.4[b]	9.6	41.5	15.6	66.3[b]
7	19.1[b]	79.1[b]	18.9	79.3[b]	10.7[b]	42.4[b]	16.2[b]	66.9[b]
Peas (beginning of budding)								
1	18.6[a]	78.1[a]	16.4[a]	74.5[a]	11.6[a]	71.4	15.5[a]	74.6[a]
2	19.1	78.2[a]	16.9[a]	72.6[a]	11.2[a]	75.6[a]	15.7[a]	75.4[a]
3	22.6	90.4	19.9	85.7	13.2	72.3	18.5	82.8
4	24.2	91.3	25.2	98.3	14.4	74.7	21.2	88.1
5	26.2	100.1[b]	23.4	103.7[b]	14.3	70.2	21.3	91.3[b]
6	30.2[b]	100.0[b]	28.9[b]	104.5[b]	14.7[b]	67.8[b]	24.6[b]	90.7
7	33.4[b]	101.2[b]	29.4[b]	101.2[b]	15.0[b]	71.3	25.9[b]	91.2[b]

a, *b* – $p \leq 0.05$

use of biohumus will allow to suspend the process of soil dehumification and improve the humus conditions of the soil, as well as the mineral nutrition of plants, leading to an increase in total nitrogen, mobile forms of phosphorus and potassium, which participate and contribute to an increase in soil buffering properties, and prevent the entry of toxic substances into plants. Additionally, biohumus has a multifaceted positive effect on the agrochemical, agrophysical and biological characteristics of soils. Vermicompost also has other valuable properties, such as high moisture capacity, moisture resistance, hydrophilicity, mechanical strength, absence of weed seeds. Vermicompost is characterized by high buffering capacity, and – unlike high doses of mineral fertilizers – it does not create an excessive concentration of salts in the soil solution.

Effect of vermicompost on the content of humus in soil

Currently, the problem of humus in soil acquires the greatest practical significance, as there are losses in this soil component on a global scale (up to 1 t ha^{-1} per year and more), in addition to qualitative and structural and functional changes in soil that reduce fertility, suggesting soil degradation, which is compounded by the impact of carbon dioxide emissions contributing to the greenhouse effect. To maintain the sustainability of the biosphere, the soil humus balance in an annual cycle should be either positive or zero. A deficit in the annual balance of humus is extremely dangerous in ecological terms (Bahadori 2021). Annually, large amounts of different substances are taken out with yields of agricultural crops. Karipov (2008) reports that for each ton of spring wheat grain 38-40 kg of nitrogen, 20-22 kg of potassium, 12-13 kg of phosphorus and 13 kg of other nutrients, for the formation of which a total 800-900 kg of humus is mineralized, are removed. Many researchers, e.g. Husainov and Seidalina (2008), Bhadauria and Saxena (2010), Nouroozi (2017), Kirkorova et al. (2018), Zhulina and Stultseva (2019), have studied the quantitative changes in humus in Kazakhstan and Siberia soils used for agricultural purpose, and demonstrated that the loss of humus according over 8-40 years was from 1.7 to 20% and more. Mustafayev et al. (2011) report that the use of mineral fertilizers has a positive impact on plant growth, development and productivity, but a negative impact on both soil and the environment by polluting them. Thus, there is slow but constant dehumification of soils, i.e. the content of humus in soil decreases.

Addition of biohumus can solve the problem of soil overconsolidation. The results of Abasova (2020) research show that supplementation of biohumus into gray-brown soils in an amount of 3.0, 4.0 and 5.0 m ha^{-1} result in certain changes in the humus content, namely, an increase in the humus content in arable soil.

The results of this study (Table 4) show that vermicompost used in amounts of 1.5 (group 3), 3.0 (4), 5.0 (5), 7.0 (6) and 9 t ha^{-1} (7) contributes to certain changes in the content of humus, i.e. an increase in the humus content in the arable layer of soil compared to the control plot was 0.11%, 0.21%, 0.34%, 0.42% and 0.56% (in the first year of research), 0.08%, 0.19%, 0.35%, 0.42% and 0.55% (in the second year) and 0.07%, 0.18%, 0.34%, 0.39%, 0.52% (in the third year) according to the variant used. That is, each ton of vermicompost used increases the humus content in the soil by an average of 0.07%. Changes also occur in absolute values. The three-year average was that each ton of vermicompost used in chestnut soil of the light argillaceous texture forms 1600 kg of humus. Kalimov (2009) reports that this is equivalent to the application of 16-19 t ha^{-1} of litter manure, or 6-8 t ha^{-1} of straw.

Table 4

Humus content in 0-20 cm soil layer %/t ha^{-1} (average for all studied crops)

Variant/ groups	Seadling stage				Harvest season			
	1st year	2nd year	3th year	average	1st year	2nd year	3th year	average
1	1.22/32.4	1.24/32.9	1.21/32.1	1.21/32.4	1.18/31.4	1.21/32.1	1.20/31.8	1.19/31.5
2	1.21/32.1	1.24/32.9	1.21/32.1	1.21/32.3	1.17/31.1	1.21/32.1	1.20/31.8	1.19/31.5
3	1.33/35.3	1.32/35.0	1.28/32.9	1.31/34.7	1.30/34.6	1.32/35.0	1.28/32.9	1.30/34.6
4	1.43/38.0	1.43/38.0	1.39/39.9	1.41/37.4	1.41/37.5	1.43/38.1	1.39/39.9	1.41/37.5
5	1.56/41.4	1.59/42.2	1.55/41.3	1.56/41.4	1.54/40.9	1.59/42.2	1.55/41.1	1.56/41.4
6	1.64/43.6	1.66/44.1	1.60/42.5	1.63/43.3	1.61/42.8	1.68/44.7	1.60/42.5	1.63/43.3
7	1.78/47.3	1.79/47.5	1.73/46.0	1.76/46.9	1.76/46.8	1.79/47.5	1.74/46.3	1.76/46.8

According to the results of the three-year experiment, and based on the literature (Mustafayev et al. 2011), it can be said that the use of vermicompost in the zone of chestnut soils of the Pavlodar region will allow to suspend the process of soil dehumification and significantly improve humus conditions. In an annual cycle, it creates a positive balance of humus.

Nitrate nitrogen and labile phosphorus content depending on the application of different doses of vermicompost

All nutrients in the vermicompost are balanced in the form of bioavailable plant compounds. Compared to other organic fertilizers, it has much more of labile nutrients, e.g. potassium – 9 times, nitrogen and phosphorus – 7 times, calcium and magnesium – 2 times more. Useful substances that are contained in vermicompost when applied to soil are not lost, do not convert to other inaccessible forms, slowly dissolve in soil moisture, and provide the root system of plants with balanced and complete nutrition for a long time.

It is established that the amount of nitrogen in the soil is one of the main indicators of its fertility (Chernenok 2015). In the Pavlodar region, the leading place in nitrogen nutrition of plants belongs to nitrate nitrogen. According to the gradation of Kochergin and Gamzikov (1972), the nitrogen content in the soil layer of 0-40 cm is very low at 0-5 mg kg^{-1} of nitrate nitrogen, low at 5-10 mg kg^{-1} of nitrate nitrogen, average at 10-15 mg kg^{-1} of nitrate nitrogen, very high at more than 15 mg kg^{-1}.

The results of our study (Table 5) show that the content of nitrate nitrogen depended significantly on the amount of vermicompost used. On average, according to the results of the three-year study, at the application of 1.5 t ha^{-1} (gr. 3) of vermicompost, an increase in the nitrate nitrogen content compared to the control variant was 3.10 mg kg^{-1}. The nitrate nitrogen content following

Table 5

Nitrate nitrogen content in the 0-40 cm soil layer during the blooming period of the studied crops depending on the vermicompost application

Variant/groups	$N\text{-}NO_3$ (mg kg^{-1})			
	1st year	2nd year	3th year	average
1	6.34 ^{a}	5.61 ^{a}	6.81 ^{a}	6.25
2	9.61 ^{a}	7.29 ^{a}	8.54 ^{a}	8.48
3	10.70	8.02	9.33	9.35
4	12.42	9.41	10.67	10.83
5	14.38 ^{b}	10.63 ^{b}	11.20 ^{b}	12.07
6	16.01 ^{b}	10.91 ^{b}	11.67 ^{b}	12.86
7	16.04 ^{b}	11.84 ^{b}	12.26 ^{b}	13.38

a, *b* – $p \leq 0.05$

the application of 3 t ha^{-1} (gr. 4) of vermicompost increased by 4.58 mg kg^{-1} of soil in comparison with the control variant, and by 1.48 mg kg^{-1} of soil in comparison with the variant with 1.5 t ha^{-1} of applied vermicompost. The use of 5 t ha^{-1} (gr. 4) of vermicompost increased the quantity of nitrate nitrogen during the blooming period of the crops analysed by 5.82 mg kg^{-1} of soil in comparison with the control variant and by 1.24 mg kg^{-1} of soil against the application of 3 t ha^{-1} of vermicompost. The maximum amount of nitrate nitrogen in the soil equal 12.86-13.38 mg kg^{-1} of soil was observed when using 7-9 t ha^{-1} of vermicompost. On average, the doses of vermicompost between 1.5-3.0 t ha^{-1} provide the medium level of nitrogen supply, and doses of 5-9 t ha^{-1} ensure a higher level. Application of 1 t ha^{-1} of vermicompost increases the nitrate nitrogen content by an average of 1.60 mg kg^{-1} of soil. Therefore, the application of the vermicompost has a positive effect on the content of nitrate form of nitrogen during the growing season.

At the same time, in terms of nitrate nitrogen supply, the figures reached the level of nitrate nitrogen supply corresponding to the average grade of Gamzikov et al. (1983).

As the results of the study show, the use of 1.5 to 5 t ha^{-1} of vermicompost as an organic fertilizer increases the content of labile phosphorus in comparison with the unfertilized variant by 8.7-25.7 mg kg^{-1} of soil. The use of 7-9 t ha^{-1} of vermicompost increases of the content of labile phosphorus reaches 34.1-35,4 mg kg^{-1} of soil. On average, the application of 1 t ha^{-1} of vermicompost caused an increase in the content of labile phosphorus by 4.7 mg kg^{-1} of soil (Table 6).

Within the conditions of the experimental field, the application of vermicompost as an organic fertilizer increases the level of provision of plants with labile phosphorus for the whole vegetation period. The chemical composition of the vermicompost used contains 1.34% of total nitrogen and 0.72% of labile phosphorus. When applying 3-5 tons of vermicompost to 1 ha,

Table 6

Labile phosphorus content in the 0-40 cm soil layer during the blooming period of the studied crops depending on the vermicompost application

Variant/group	P_2O_5 (mg kg^{-1})			
	1st year	2nd year	3th year	average
1	105.4 ^{a}	109.8 ^{a}	107.0 ^{a}	107.4
2	109.3 ^{a}	105.5 ^{a}	111.1 ^{a}	108.6
3	110.4 ^{a}	121.3	116.6	116.1
4	126.8	130.3	119.1	125.4
5	132.5 ^{b}	139.6 ^{b}	127.3 ^{b}	133.1
6	138.4 ^{b}	148.9 ^{b}	137.4 ^{b}	141.5
7	140.2 ^{b}	148.3 ^{b}	140.0 ^{b}	142.8

a, *b* – $p \leq 0.05$

40.2-67 kg of phosphorus enter the soil, which is equivalent to 180-300 kg of superphosphate. This phosphorus in the soil will have an effect for 3-4 years.

Abasova (2020) reports that application of vermicompost increased the content of mobile phosphorus by 15-25%, depending on the application dose. Moreover, the favorable water-air regime is intensively created for the development of the root system of agricultural crops (Abasova 2020).

Effect of vermicompost on grain and legume yields

The yield of the studied crops and their quality were formed under the influence of the changes in important physical properties of soil, such as humus state, water and nourishment regimes, in connection with the vermicompost use, the prevailing weather and climate conditions. The fact is that the yield of agricultural crops is the main integrating indicator characterizing the level of correspondence of the complex of the studied factors to the formation of high crops capacity (Table 7).

Analysis of the three-year data shows that the crops under study formed relatively high yields when soil was enriched with vermicompost. However, more reliable yield increase was achieved on wheat fields with the application of 5 and 9 t ha^{-1} of vermicompost, and on pea and buckwheat fields treated with 7 and 9 t ha^{-1} of vermicompost. At the same time, wheat from the mentioned variants showed a yield increase of 2.7-2.9 t ha^{-1}, peas – 4.0 and 4.2, and buckwheat – 2.6-2.7 t ha^{-1}.

Thus, it is observed that the vermicompost application in the amount from 1.5 to 5 t ha^{-1} due to optimization of soil density, water and food regimes increases the yield of wheat by 34.4-44.2%, peas – by 34.5-45.2% and buckwheat - by 36-63%. Further increase of vermicompost application rates increases crop yield slightly.

Table 7

Crop yields depending on different doses of vermicompost (t ha^{-1})

Variant/ groups	1st year	2nd year	3th year	Average	Increase	
					(t ha^{-1})	(%)
Wheat						
1	4.6 ^{a}	8.1 ^{a}	5.8 ^{a}	6.1	-	-
2	4.9 ^{a}	8.8 ^{a}	6.2 ^{a}	6.6	0.5	8.1
3	5.8	11.4	7.4	8.2	2.1	34.4
4	5.6	11.8	7.2	8.2	2.1	34.4
5	6.4 ^{b}	12.1 ^{b}	8.0 ^{b}	8.8	2.7	44.2
6	6.4 ^{b}	11.9	7.7 ^{b}	8.6	2.5	40.9
7	6.9 ^{b}	12.3 ^{b}	7.9 ^{b}	9.0	2.9	47.5
HCP_{05}	0.94	1.24	1.1			
Buckwheat						
1	1.8	6.4 ^{a}	3.4 ^{a}	3.8	-	-
2	2.2	6.8 ^{a}	3.6 ^{a}	4.2	0.4	10.5
3	3.2	8.6	3.9	5.2	1.4	36
4	3.3	9.6 ^{b}	4.2	5.7	1.9	50
5	3.8	9.8 ^{b}	5.0 ^{b}	6.2	2.4	63
6	4.1	9.9 ^{b}	5.2 ^{b}	6.4	2.6	68
7	4.6	10.1 ^{b}	4.9	6.5	2.7	71
HCP_{05}	1.2	0.91	1.22			
Peas						
1	6.3	10.2 ^{a}	8.7 ^{a}	8.4	-	-
2	6.2	11.0 ^{a}	9.2 ^{a}	8.8	0.4	4.7
3	7.9	13.8	12.3 ^{b}	11.3	2.9	34.5
4	7.9	14.3	12.2 ^{b}	11.4	3.0	35.7
5	8.4	15.3 ^{b}	12.7 ^{b}	12.2	3.8	45.2
6	9.1	15.2 ^{b}	12.9 ^{b}	12.4	4.0	47.6
7	10.1	15.4 ^{b}	12.4 ^{b}	12.6	4.2	50
HCP_{05}	1.23	1.38	1.28			

a, *b* – $p \leq 0.05$

Musayev et al. (2020) indicated that vermicompost enhanced the content of organic matter in the soil from 0.12 to 0.28 t ha^{-1}. Moreover, at the same time plant density increased 1.5 times, height 2 times, the yield of the grass mixture increased from 2 to 5 t ha^{-1} on average, the quality of the products improved, which in almost all parameters corresponded to the zootechnical standard. The Authors demostrated that it is possible to increase the productivity of grasslands on sod-podzolic soil with the introduction of biohumus against the background of irrigation. The optimal variant of the experiment was established with the introduction of vermicompost at the rate of 8 t ha^{-1}. The results revealed an increase in the content of basic nutrients in the soil by 0.2 to 4 mg 100 g^{-1} of soil.

In Madiyev's (2018) research, positive impact was produced by the Biohumus fertilizer, which is a product of cattle manure processing by technological earthworms. The cited study revealed that the fertilizers favorably influenced the Sudan grass plants. Despite the unfavorable conditions during the growing season, the productivity of plants increased from 2.33 to 4.1 t ha^{-1}. The productivity of plants increased in connection with the increase of fertility and productivity of soils owing to the direct metabolism and energy between soil and plant.

In the experiment carried out by Zulin and Stultsev (2019), it was observed that biohumus used in sod-podzolic soil improved the soil efficiency and the humus content. Abdimutalip et al. (2014) revealed that biohumus is a highly efficient and environmentally friendly organic fertilizer, which improves the agrochemical properties, and increases the quality and crop capacity. Moreover, biohumus exhibits exceptional physicochemical properties: water resistance of its structure (95–97%) and total moisture capacity (200–250%). In connection with the above, vermicompost has a significantly high potential for enhancing plant growth when added as a soil conditioner, or as a component of a garden container.

CONCLUSIONS

1. On average, the application of 1.5 t ha^{-1} of vermicompost reduced the weight by volume of soil by 0.01-0.02 g cm^{-3}, 3 t ha^{-1} – by 0.02-0.06 g cm^{-3}, 5 t ha^{-1} – by 0.04-0.07 g cm^{-3}. At further increase of a dose to 7-9 t ha^{-1}, the decrease in weight by volume slightly stabilized within the limits of 0.01-0.04 cm^3.

2. On average, the application of vermicompost to soil improves the density of the arable layer, bringing its parameters closer to the established optimal values for wheat (1.26-1.30 g cm^{-3}), peas (1.23-1.29 g cm^{-3}) and for buckwheat (1.23-1.26 g cm^{-3}).

3. Productive moisture deposits in the arable layer of soil on wheat field with vermicompost were from 4.6 to 7.1 mm, on pea fields – from 3 to 10.4 mm, and on buckwheat fields – from 3.9 to 4.7 mm.

4. Each ton of vermicompost used increased the humus content in the soil by an average of 0.07%. Changes also occurred in absolute values. According to the three-year average data, each ton of vermicompost used formed 1600 kg of humus, which is equivalent to the application of 16-19 t ha^{-1} of litter manure, or 6-8 t ha^{-1} of straw.

5. The content of nitrate nitrogen depended significantly on the amount of vermicompost used. When applying 1.5 t ha^{-1} of vermicompost, the increase in nitrate nitrogen content was 3.10 mg kg^{-1}, 3 t ha^{-1} – 4.58 mg kg^{-1}, 5 t ha^{-1} – 5.82 mg kg^{-1} in comparison with the control variant.

6. On average, the application of 1 t ha^{-1} of vermicompost caused an increase in the content of labile phosphorus by 4.7 mg kg^{-1} of soil.

7. The studied crops formed relatively high yields on wheat field with the application of 5 and 9 t ha^{-1} of vermicompost and on pea and buckwheat field enriched with 7 and 9 t ha^{-1} of vermicompost. At the same time, wheat showed a yield increase of 2.7-2.9 t ha^{-1}, peas – 4.0 and 4.2, and buckwheat – 2.6-2.7 t ha^{-1}.

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