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Influence of bio-humus on soil fertility, productivity and environmental safety of spring wheat grain

L.G. Muhamedyarova*, M.A. Derkho, G.V. Meshcheriakova, O.A. Gumenyuk and S.S. Shakirova

Federal State Funded Educational Institution of Higher Education 'South-Urals State Agrarian University', Department of natural Sciences, RU457100, Chelyabinsk region, Troitsk, Russia
*Correspondence: muhamedyarovaliliya@mail.ru

Abstract. The influence of bio humus on chemical indicators of the arable layer of soil, productivity and ecological safety indicators of spring wheat of 'Chelyaba - 75' variety during the period of 2017–2019 were studied. The object of research was samples of the soil arable layer from the control and experimental field, the structure of wheat yield from control and experimental plots. Bio humus aqueous extract was introduced in the soil of the experimental field before wheat sowing and in the phase of spring tillering at the rate of 10 L/200 L /1 hm^2 using the trailer sprayer 'Zarya' (Russia) during the dark hours of day.
In the study of soil and grain samples, generally accepted methods and techniques were used. It is established that regular chernozems under the conditions of technogenic impact of emissions of thermal power plants are characterized by low humus content (4.58–4.60%) and weak acid reaction of medium (pH = 6.1–6.5); imbalance between biochemically active (copper, zinc, cobalt) and toxic (lead, nickel, cadmium) elements, as confirmed by soil contamination coefficients: for copper (C_0 = 1.50–1.58), zinc (C_0 = 0.79–0.85). The introduction of bio humus in the tilth top soil before sowing and during tillering of spring wheat contributed to the increase in humus composition by 1.88 times, the change in acidity to pH = 6.9–7.0, reduction of lead and cadmium concentrations in 1.63 and 1.20 times against the background of increased zinc and cobalt levels by 15.62% and 7.98%; increase of field germination of spring wheat from 75.0 ± 0.4 to 82.0 ± 0.9%; quantity of developed stems to be harvested per 1 m^2 by 10.15%, productive tilling capacity by 8.33%, average quantity of spikes per ear by 20.00%, average quantity of grain per ear by 7.69%, mass of 1,000 grains by 16.12%, and wheat yield increase by 10.2 hwt ha^{-1} and decrease in spring wheat grain concentration of lead and cadmium at 14.00 and 16.00%.

Key words: bio humus, soil, humus, heavy metals, detoxication, spring wheat, yield.

INTRODUCTION

One of the crucial tasks of modern crop production is creation of optimal conditions for growing strategically important grain crop wheat, taking into account agro-ecological features of its cultivation territories while preserving soil fertility (Kolesnikova, 2012; Marenych et al., 2019).

An effective method of increasing agricultural productivity is the application of fertilizers. Their use should take into account the method and mode of application, agrochemical properties of soil, biological features of crops grown, natural and climatic conditions of territories, etc. (Zharova, 2016; E et al., 2017; Zhang et al., 2017). This, on the one hand, allows to increase the useful properties of fertilizers by 25–30% (Zharova, 2016), and on the other hand, realize the genetic potential of plants and stabilize the yield, increase their resistance to adverse environmental factors (Marenych et al., 2019), improve soil fertility (E et al., 2017).

In recent years in agriculture, humin-containing fertilizers are widely used, which improve the ecological condition and fertility of the soil, saturating it with minerals, vitamins and amino acids and increase the activity of soil microflora, stimulate plant growth through better absorption of nutrients, intensify biosynthesis of proteins, carbohydrates and vitamins, increase resistance to adverse environmental factors (Marenych et al., 2019). This allows to reduce the ripening time of plant crops, increase their yield and improve the quality of produced products. In addition, humic fertilizers reduce the plant extraction degree of heavy metals and pesticides from soil, allowing to obtain environmentally sound products (Ali Mohamed Elyamine et al., 2018).

The use of bio humus (vermicompost) is a promising technique to increase soil fertility, yield and environmental safety of plant organisms. It is prepared by vermicomposting a variety of organic waste into a humus-like material (Bernard et al., 2011; Zhao et al., 2016; Strachel et al , 2017; Sartaj Ahmad Bhat et al., 2018). Bio humus has physical, chemical and biological effects on soil (Lim et al., 2015). When applied to the soil, it improves its aeration, porosity, density and moisture retention capacity, changes the content of organic and mineral substances, conductivity and pH. All this creates conditions for better plant growth and higher yield.

Given that in the territory of Chelyabinsk region (one of the industrialized regions of Russia) is concentrated a large number of nature-polluting and nature-destructive industries, the fertility of soils in most agricultural land is very low. This is due to the peculiarities of the territories' geochemical background, and the ability of the soil to accumulate and retain various pollutants in its composition for a long time (Baishanova & Kedelbaev, 2016; Huang et al., 2017; Schossler et al., 2018), and with the application of a huge amount of different inorganic fertilizers and plant protection products, and with the disregard of crop rotations, and with non-compliance to technological discipline (Antille et al., 2019). These factors together determine low crop yields (Vitkovskaya et al., 2013; Dogra et al., 2019). Therefore, there is an urgent need to restore or increase the fertile potential of arable land (Vodyanitsky, 2011; Naumkin et al., 2013; Rai et al., 2019). For these purposes, it is efficient to use bio humus, which allows to quickly replenish organic nutrients in the soil.

However, vermicompost acts positively on soil fertility, plant growth and yield when applied in a highly regulated quantity and under certain regimes (Lim et al., 2015; Doan et al., 2015). According to data (Baldotto et al., 2016) it improves plant development only in complex with mineral fertilizers. In addition, the properties of vermicompost depend on the raw materials used to produce it (Doan et al., 2015; Conselvanet et al., 2017; Sartaj Ahmad Bhat et al., 2018), as well as on cultivated agricultural crops (Manzoor et al., 2014; E et al., 2017). This determines the recommended amount, dose of application and concentration of fertilizer, compatibility with other fertilizers (Marenych et al., 2019). Therefore, the technique of using bio humus to increase soil fertility and plant growth in particular agro-ecological conditions has specific features.

Taking into account the above mentioned, the aim of the work was to study the influence of bio humus on the ecological condition of soils, germination, productivity and ecological safety of spring wheat in conditions of biogeochemical province of the Southern Urals.

MATERIALS AND CONDITIONS OF RESEARCH

Research work was carried out during 2017–2019 in the conditions of the Peasant farm holding 'PE Khayrullina R.R.' (Troitskiy district, Chelyabinsk region), Department of Natural Sciences and the Laboratory of the Innovative Research Center of the South Ural State Agrarian University (Chelyabinsk region, Troitsk, Russian Federation).

The object of the study was: a) the arable soil layer of agricultural land of the peasant farm holding 'PE Khayrullina R.R.'; b) spring wheat of the variety 'Chelyaba 75', grown in the fields of the farm.

Weather conditions during the research period are shown in Table 1 according to the data of the Troitsk weather station (Chelyabinsk region, Russia). Their analysis showed that the air temperature in the growing period of 2017–2019 was not much different from the average for previous years, although May and June were colder and July was warmer. At the same time, precipitation was unevenly distributed by months. In 2017 and 2018, precipitation was higher in May and June, with July, August and September lower than the previous year average. To some extent, this has negatively affected the growth, development and formation of plant yields. May and August of 2019 were dry, with June, July and September more rainy.

Table 1. Weather data in the growing period of 2017–2019

Indicators	Year	May	June	Jule	August	September
	Air temperature, °C					
Average monthly	2017	12.4	17.4	20.4	19.6	11.8
	2018	11.5	16.1	21.7	17.4	13.3
	2019	12.2	18.1	21.3	17.9	9.8
Average annual	1936–2019	13.2	19.1	20.1	17.8	11.7
	Precipitation, mm					
Monthly	2017	78.0	48.0	51.0	44.0	29.0
	2018	41.0	53.0	28.0	47.0	13.0
	2019	12.0	52.0	65.0	34.0	43.0
Average annual	1936–2019	39.0	43.0	63.0	48.0	31.0

Consequently, the weather conditions during 2017–2019 were not very favorable, which allowed to assess the effectiveness of bio humus impact on the studied indicators more reliably.

Bio humus was obtained from cattle manure by worm composting in a container way using earthworms 'Staratel'. Vermicomposting duration - 3 months. Aqueous extract of bio humus was prepared in 5 m^3 tanks, mixing it with water at a rate of 1:10 and using a compressor for air supply. The filtered aqueous extract was a dark brown odorless liquid with neutral to slightly alkaline medium reaction (ph 7.0–7.2).

Scientific and production experiment is performed according to the following scheme. Firstly, the influence of bio humus on the chemical composition of the arable layer of soil has been studied. To this end, in the conditions of peasant farming two fields were chosen considering the wind rose (control 9.2 h m^2, experimental 8.3 h m^2). They were located in the southern forest-steppe part of Chelyabinsk region and exposed to air emissions of thermal power complex JSC Second Generating Company of the wholesale electricity market of PJSC Branch 'Troitskaya GRES' (Troitsk) - the main source of anthropogenic pollution in the city of Troitsk and Troitsk district.

On the experimental site, aqueous extract from bio humus was applied to the soil before sowing wheat and in the tillage phase of spring tillering at the rate of 10 L/200 L /1 hm^2 using the trailer sprayer 'Zarya' (Russia) during the dark hours of day.

Monitoring plots (control, experimental) of 1 hm^2 were set on each field. On these fields spot samples of topsoil (regular chernozem) were taken by layers; samples were taken before wheat sowing (May) and after harvesting (September), using envelope method by soil tube. Average sample was formed out of spot samples using quartering.

Secondly, the influence of bio humus on environmental safety and productivity of spring soft wheat 'Chelyaba-75' has been studied. For this purpose, the control and experimental field was sown in the 2nd decade of May with reproductive seeds. Seeding standard - 5 million germination grains per 1 hm^2.

In order to assess the quality of wheat crop in control and experimental fields, record plots of 25 m^2 in 4 times repetition were laid. Harvesting was carried out in a phase of complete ripeness with the harvester 'Polesie GS12'. The actual yield was determined by weighing the grain and bringing it to a standard humidity of 14%.

METHODS OF RESEARCH

Scientific and production experiment was performed during 2017–2019. The object of the study was samples of the arable layer of soil from control and experimental fields, the structure of wheat yield from control and experimental plots and the ecological safety of the grain obtained.

The pH of_{KCl} was determined determined in the average sample of the arable layer of soil, the content of humus - according to Turin in modification of Qinao, the concentration of mobile forms of metals (copper, zinc, lead and cadmium) after ashing of 1M with nitric acid using the Minotavr device (Russia) by atomic absorption spectrophotometry on the spectrophotometer Kvant-2 (Russia) in the flame of propane-air (Kuznetsov et al., 1992).

The following indicators were taken into account in the analysis of crop structure: laboratory germination by the number (%) of normally germinated sample seeds (100 grains) on filter paper in Petri dishes at t 20 °C for 10 days and germination energy for 5 days; field germination by calculating the density of plant standing on the accounting sites in the phase of full growth; number of developed stalks for harvesting, productive tilling capacity, the average number of developed ears and the average number of grains in an ear, the mass of 1,000 grains according to the methods recommended for grade testing (Pylneva, 2016). In addition, heavy metals (lead, cadmium, copper, zinc) were determined in the samples of wheat grain; determination was carried out according to GOST 13586.3-83, 2001. by atomic absorption spectrophotometry (GOST 26929-1994, 1996).

To assess the ecological condition of soils and ecological safety of grain, the level of metals, including toxic ones, was compared with the regulatory data regulated by

GN 2.1.7.2041-2006. medical and biological requirements and sanitary standards of quality of food raw materials and food products (1996). In addition, the pollution factor was calculated in order to estimate the coefficient of soil contamination (C_0) by the formula:

$$C_0 = = \frac{Ac}{S_{MPCp}} \qquad (1)$$

where Ac – the actual content of the element in the soil; S_{MPC} – the value of the element's MPC in the soil.

The results of the research are subject to mathematical processing on the personal computer using the 'Analysis Package' add-on in the program for spreadsheets processing 'Microsoft Excel-2007'. Statistical processing of the data included determining the average value and its deviations. Reliability of differences between groups of traits was assessed using the t-criterion of Student.

RESULTS AND DISCUSSION

On monitoring sitesof control and experimental fields regular chernozem prevailed, which before wheat sowing was marked by low content of humus (4.58–4.60%) and slightly acidified medium reaction (pH = 6.1–6.5). Copper concentration fluctuated within range 4.54 ± 0.11 – 4.75 ± 0.10 mg kg^{-1}, which exceeded MPC value (Ko = 1.51–1.58). On the contrary, zinc content did not reach MPC value, which was 18.32 ± 0.21 – 19.54 ± 0.16 mg kg^{-1} (Ko = 0.79–0.85) (Table 2).

Table 2. Chemical composition of topsoil in average during 2017–2019

Indicator	Control site		Experimental site		MPC
	Before sowing	After harvesting	Before sowing	After harvesting	
pH_{KCl}	6.25 ± 0.37	6.30 ± 0.31	6.35 ± 0.34	6.95 ± 0.28*	-
Humus, %	4.58 ± 0.13	3.96 ± 0.11	4.60 ± 0.16	7.90 ± 0.14*	-
Lead, mg kg^{-1}	10.50 ± 0.36	9.75 ± 0.33	10.92 ± 0.38	6.70 ± 0.19*	-
Cadmium, mg kg^{-1}	0.32 ± 0.03	0.29 ± 0.01	0.41 ± 0.04	0.18 ± 0.006*	-
Copper, mg kg^{-1}	4.54 ± 0.11	4,62 ± 0.13	4.75 ± 0.10	4.56 ± 0.10	3
Zinc, mg kg^{-1}	18.32 ± 0.21	19,27 ± 0.56	19.54 ± 0.16	22.59 ± 0.93	23

Note: * – $p < 0.05$ compared to the control site.

Lead content in soil samples of monitoring plots of control and experimental sites was 10.50 ± 0.36 – 10.92 ± 0.38 mg kg^{-1}. The main sources of soil contamination of the peasant farm holding with lead and nickel were atmospheric emissions, as of local nature (PJSC 'Troitskaya GRES' Branch, including ash dump), and transboundary transfer from the side of the city of Magnitogorsk, which is one of the most ecologically disadvantaged cities in the world. It should be noted that lead in the soil loses its toxicity due to the formation of complex compounds with phosphates and humates (Zybalov & Popkova, 2018). Therefore, countries such as England (300 mg kg^{-1}), Canada (500–1,000 mg kg^{-1}) and the USA (2,000 mg kg^{-1}) have dramatically increased the MPC value compared to Russia (Table 2).

Although the content of the mobile cadmium form in the soil is not normalized, it is one of the most toxic elements in the environment. The main source of pollution of the territory of Troitsky district of Chelyabinsk region by this metal is emissions of PJSC

Branch 'Troitskaya GRES', which in the technological cycle uses Ekibastuz coal with high ash content. Therefore, the concentration of cadmium in arable soil samples of monitoring sites fluctuated between $0.32 \pm 0.03 - 0.41 \pm 0.04$ mg kg^{-1}. It should be noted that the presence of this element in the soil negatively affects the ecological safety of soils, slowing the growth and development of plants (Table 2).

In estimating the degree of soil pollution by the value of the pollution coefficient it was found that C_0 exceeded the unit of copper, indicating its intensive accumulation in the arable layer. Consequently, the soil monitoring plots of control and experimental sites showed degradation, as indicated by low humus content, weak acidic reaction and excessive content of, firstly, toxic elements. Together this determined the biological and physico-chemical properties of the soil and its barrier geochemical functions.

Therefore, as a method of fertility restoration and detoxification of soils, we introduced aquatic extract of bio humus in the soil of the experimental field before sowing and in the phase of spring wheat tillering. At the same time, we proceeded from the fact that bio humus is a complex fertilizer of organic origin, which contains high concentrations of humus, nitrogen, phosphorus, potassium and microelements (Ali Mohamed Elyamine et al., 2018; Rékási et al., 2019).

Analysis of samples of arable soil layer from monitoring sites of control and experimental sites after harvest showed that application of bio humus contributed to increase of organic matter (humus $7.90 \pm 0{,}14\%$). Its content in experimental field soil was increased by 1.88 times compared to the control field. Due to this, the acidity of soils also changed – the pH value was approaching the neutral level (pH = 6.9–7.0). The positive influence of bio humus is seen in the content of chemical elements in the soil of agricultural fields. Thus, in the samples of the soil of the experimental field, compared with the control site, the content of typical ecotoxicants decreased significantly: lead and cadmium by 1.63 and 1.20 times, due to their ability to form poorly soluble and stiff complex compounds with organic components of bio humus. In addition, changes in soil pH were reflected at the level of the exchange cations of biogenic elements, determining an increase in the concentration of zinc (by 15.62%) in soil samples. At the same time, the use of bio humus practically did not affect the content of iron and copper.

Similar conclusions in their studies were obtained by (Moslehi et al., 2019; Trentin et al., 2019). The authors noted that bio humus affects the bioavailability of lead and cadmium in soil, but does not have this effect on copper.

When assessing the influence of bio humus on the structure of wheat yield and its mineral composition, the following was revealed.

Laboratory germination of spring wheat seeds of the variety 'Chelyaba 75' (Table 3), from control and experimental plots had practically no difference, which indicates same-type nutrients reserve in grains. A similar dependence has been found in relation to germination energy. At the same time, the difference between laboratory germination and germination energy characterizing the activity of biochemical processes in germinating seeds was only 3%, reflecting the high quality of obtained grain.

Wheat field germination had significant differences between plots (Table 3). at the experimental plot with comparable seed control data the average field germination level was $82.0 \pm 0.9\%$ ($p < 0.05$). Therefore, the use of bio humus had a positive impact on the formation of sprouts of spring wheat.

Similar conclusions in their research was obtained by (Devi et al., 2020). They noted that the introduction of bio humus to the soil increases seed germination by

1.05–1.3 times. According to (Gong et al., 2019) the seed germination index increased by 1.46–1.48 times.

The process of plant development was associated with the plot, reflecting their ability to respond to changes in soil fertility. Thus, against the background of application of biofertilizer the best growth and development of plants was observed, which has further influenced the wheat yield structure. Thus, the number of developed stems for harvesting per 1 m^2 increased by 10.15%, productive tilling capacity increased by 8.33%, and average number of developed spikes per ear by 20.00%. This determined average grain quantity per ear, as well as the size of the formed seeds and the yield of spring wheat (Table 3).

Table 3. Structural elements of spring wheat yield in average during 2017–2019

Indicator	Control plots	Experimental plots
Laboratory germination, %	90.0 ± 0.3	91.0 ± 0.6
Germination energy, %	87.0 ± 1.1	88.0 ± 0.7
Field germination, %	75.0 ± 0.4	82.0 ± 0.9*
Quantity of developed stems for harvesting per 1 m^2	315.0 ± 2.5	347.0 ± 3.9*
Productive tilling capacity	1,2 ± 0.1	1,3 ± 0.1
Average quantity of developed spikes per ear, pcs.	10.0 ± 0.5	12.0 ± 0.4
Average grain quantity per ear, pcs.	26.0 ± 0.6	28.0 ± 0.6
Weight of 1,000 grains, g	31.0 ± 0.6	36.0 ± 0.7*
Yield, hwt ha^{-1}	25.4 ± 0.2	35,60 ± 0.2

Note: * – $p < 0.05$ compared to the control plots.

Therefore, the introduction of bio humus into the soil created more favorable conditions for the yield formation of wheat and the realization of biological potential of sowing material. According to data (Suslov et al., 2011) the use of bio humus creates conditions for stable increase of soil fertility, providing plants with necessary organic and mineral substances.

At the same time in the work of (Sarma et al., 2018) it is noted that the effect of vermicompost on yields is compatable to the action of biochar. According to (Manzoor et al., 2014) humic substances increase wheat yield only when combined with inorganic fertilizers. Perhaps the appearance of biological properties of bio humus is influenced by the type of soil of agricultural land.

When assessing the environmental safety of grain, it determined the content of elements, the level of which is controlled by regulatory documents (Medico-biological requirements and Sanitary standards for the quality of food raw materials and food products, 1996). Thus, the introduction of bio humus into the soil of the experimental site contributed to a decrease in the concentration of lead, cadmium, copper and zinc in the resulting products. The greatest impact of the use of biofertilizer had on the level of the most toxic elements (lead, cadmium), the content of which decreased in grain by 14.00 and 16.00% (Table 4). In our opinion, this is the result of reduced mobility of chemical elements in the soil due to change of its reaction medium and their binding by humus components into hardly soluble compounds. Consequently, this fact is reflected in the migration mobility of elements from soil to plants.

Table 4. Metal content in spring wheat grain (mg kg^{-1})

Indicator	Permissible level	Control site	± % to PL	Experimental site	± % to PL
Lead	0.5	0.25 ± 0.02	-50.00	0.18 ± 0.01*	-64.00
Cadmium	0.1	0.036 ± 0.002	-64.00	0.020 ± 0.003*	-80.00
Copper	10	5.40 ± 0.21	-46.00	4.50 ± 0.12*	-55.00
Zinc	50	34.66 ± 0.88	-30.68	29.33 ± 1.66*	-41.34

Note: * – $p < 0.05$ compared to the control site; PL according to biomedical requirements and sanitary quality standards of food raw materials and food products, 1996.

Research (Moslehi et al., 2019) also confirmed the effectiveness of bio humus application to reduce lead and cadmium concentration in sunflower.

Therefore, the introduction of bio humus helped to reduce the imbalance of microelements in soils of agricultural lands, increase of organic matter, which had a positive impact on the structure of yield of spring wheat and ecological safety of the received grain.

The results of the conducted tests testify to the potential of using bio humus as an element of biologized technologies and means of increasing the yield of wheat. At the same time, an important environmental problem of waste disposal of livestock is solved. At the same time, further research is needed to better assess the potential of bio humus in the soils of the southern forest-steppe.

CONCLUSIONS

1. Chernozem under the conditions of technogenic influence of emissions of thermal power plants are characterized by low humus content (4.58–4.60%) and weak acid reaction of medium (pH = 6.1–6.5); imbalance between biochemically active (copper, zinc, cobalt) and toxic (lead, cadmium) elements, as confirmed by soil contamination coefficients: for copper (C0 = 1.50–1.58), zinc (C0 = 0.79–0.85), cobalt (C0 = 0.42–0.55).

2. The introduction of bio humus in the arable layer of soil before sowing and during tillering of spring wheat contributes to the increase in humus composition by 1.88 times, the change in acidity to pH = 6.9–7.0, decrease in lead and cadmium concentrations of 1.63 and 1.20 times against the background of an increase in zinc and cobalt at the levels of 15.62% and 7.98%.

3. Bio humus has a positive effect on the value of structural elements of spring wheat yield. Field germination rate of wheat is increased from 75 to 82% at the same values of seed control of seed material (laboratory germination of 90–91%, germination energy 87–88%), as well as the processes of plant growth and development, which determine the increase in the number of developed stalks for harvesting per 1 m^2 by 10.15%, productive tilling capacity by 8.33%, average number of developed spikes per ear by 20.00%, the average number of grains in the ear by 7.69%, the mass of 1,000 grains by 16.12%, the yield of spring wheat increases by 10.2 hwt ha^{-1}.

4. Introduction of bio humus in the soil contributes to the reduction in the composition of the spring wheat received grain of lead and cadmium concentration by 14.00 and 16.00%, determining the level of its ecological safety.

Suggestions for production

Based on the obtained results of scientific and production experiment during 2017–2019, in order to increase soil fertility and spring wheat yield we recommend to introduce aqueous extract of bio humus to the soil before sowing and in the spring phase of grain culture in the dark time of the day calculated as per 10 L/200 L /1 hm^2.

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