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ORIGINAL ARTICLE

Vermiculture as an important component of ecologically tolerant agricultural ecosystems

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The special attention should be paid to vermiculture in the development of alternative agriculture. Its essence is the use of earthworm *Eisenia fetida* to obtain from various organic substances of environmentally friendly fertilizer – biohumus containing a complete set of macro- and trace elements for agricultural plants. The research, which results are described in this article, continues the work on the development of separate technologies of ecologically balanced nature use in crop and livestock production; development of methodological bases of the theory of agricultural ecosystems as primary units of the noosphere. The experimental work of the research was carried out in 2009-2017 on the research field of the scientific-production department of Uman National University of Horticulture. The article shows main methodological and technological methods for maintaining *Eisenia fetida* population under the conditions of experimental farming, as well as the use of vermiculture products in the cultivation of some vegetable crops. The future direction of the vermiculture development is associated with its active use in the cultivation of not only vegetable, but also fruit and ornamental plants, which can create a specific basis in artificial agrophytocenoses, if they are grown in private farms. In general, we consider vermiculture as the future basis for agricultural ecosystems resistant to man-made pressures.
Keywords: Vermiculture; vermiculture population; *Eisenia fetida*; biohumus; cultivating sweet pepper

Introduction

Agricultural production causes about a third of anthropogenic pollution of the environment and the inflow of xenobiotics into the human body using modern food products is about 70%. The ecological state of agricultural production in Ukraine is critical (Dobriak, 2001).

The above reasons led to the fact that the biological potential of the Ukrainian soils is used only by 20-30%, while energy inputs per unit of crop production are 2-5 times higher than energy consumption in developed countries (Baliuk, 2010). In this case, energy inputs for fertilization and plant protection in intensive growing technologies make up 32-64% of the total, depending on the growing crop. Ecological and economic losses only due to erosion of soils in Ukraine exceed 9.1 billion UAH per year. A complete abandonment of industrial methods for agricultural production leads to a sharp drop in yields and the transition to biological farming increases energy costs. All this determines the necessity to search, develop and apply alternative, environmentally safe, energy-saving, mechanized technologies for growing crops, as well as appropriate equipment for their implementation (Kovalchuk et al., 2017).

One of the reserves for enhancing soil fertility and environmental protection in today's market conditions is the efficient use of waste from the agricultural industrial complex (manure, poultry litter, waste from meat-packing plants, sugar factories, cannery, sludge treatment plants, residues of crop production, vegetable growing, horticulture, etc.) (Chatellardet, 2017).

There are many technologies in the world today for the processing of organic waste, most of which are non-waste ones (Mishra, 2014). According to world and national science data, a significant alternative to existing technologies for the recycling and processing of organic waste is their bioconversion with the help of vermiculture to produce biohumus (Chattopadhyay, 2012, Sinha, 1996). Biohumus composition and properties depend on the composition of the initial substrate and a composting technology (vermiculture) (Gunadiet, 2003; Rajiv et al., 2002). Biohumus has a large number of macro and microelements, as well as there are growth substances, vitamins, antibiotics, amino acids and useful microflora. It is hydrophilic, has high water resistance, moisture content, mechanical strength and no weed seeds. Biohumus can hold up to 70% water and 15-20 times more efficient than any organic fertilizer (Devi, 2017). However, as a result of incorrect selection of substrate components, their correlation, as well as violation of fermentation and vermiculture processes most farms of Ukraine receive low-quality biohumus.

Material and methods

At the department of ecology and safety of life, an experiment on the processing of organic waste by the method of vermicompost was laid in 2009. Over the course of 9 years, we study the dynamics of the population of the *Eisenia fetida* depending on the initial parameters of the substrate, as well as the possibility of processing such organic waste, as overgrown leaves of trees, products of processing apples and others for juice.
All calculations related to the arrangement of plots for vermiculture, settlement and feeding worms, care of them and other operations were performed in a storing bunker. Storing bunkers have standard sizes of 2 × 1 m. After the fermentation process was completed, storing bunkers were populated with *Eisenia fetida* along with the substrate in which they were located. Physical parameters of the maintenance of *Eisenia fetida* artificial populations were the same for all experimental variants. The research was carried out using different types of substrate (compost) for the maintenance of artificial populations. The following types of compost were studied, which source products for preparation were: cattle manure, a mixture of manure and any organic residues of grass, vegetable and fruit origin, herbal substrate, a mixture of manure and straw waste (after mushroom cultivation) in ratio 1:1.
The population size fluctuated under the influence of biotic and abiotic factors. The component method was the estimation of quantitative indicators of the population by the quadrate method (Zamostian, 2000). The following main ontogenetic parameters were studied: the fertilization period, coming out immature worms from the cocoon, duration of the cocoon stage, duration of the stage of immature worms and average biomass increase (Garg et al., 2005; Tripathi et al., 2004).
To study agroecological parameters of the substrate, its samples were selected twice during the growing season: the first time was in spring, with the beginning of worm population reproduction and the second time was in autumn before preparing storing bunkers for winter. Samples for analysis were selected from at least five places in one storing bunker. Sample weight was 30 g. The humus content was determined by Tiurin method, the nitrogen content was determined by Cornfield method and the phosphorus and potassium content by Chirikov method (Bondarenko, 2001).

Results and their discussion

In the summer of 2015, the experiment was carried out to observe the stages of *Eisenia fetida* development. A certain number of cocoons with the substrate were selected from four different storing bunkers in separate containers partially isolated from the environment.
The entire life cycle of *Eisenia fetida* from the cocoon stage or the egg to the stage of laying eggs was observed.
Stage of the cocoon or the egg: Outer look is about a few mm in diameter (in size like grape seed) and the color is yellow-green or lemon. The incubation period lasted about 23 days, during which the color gradually changed from yellow to green to golden yellow, sometimes brownish-red. There are 4-6 embryos of the worm in the egg but usually 2-3 worms survive. The worm has the next stage in 3-4 weeks.
Stage of immature worms: The size of the worm is not more than 5-7 cm and has a pink or pale red color. This stage lasts about 40-60 days before the worm maturity. At the end of this stage, the worm acquires a pronounced orange-red color, in size it is about 8-10 cm and the cocoon formation begins in its body.
Stage of mature worms: The worm acquired a pronounced red or orange-red color, about 8-10 cm in size and the cocoon stage began. One worm is able to have from 2 to 58 cocoons per week for a period from 6 months to a year. All this depends on the environment (humidity, temperature, accessible food, etc).
In determining the characteristics of the course of separate stages of *Eisenia fetida* ontogeny under conditions of breeding on different substrates, the high activity of *Eisenia fetida* reproduction in variants using mixture of substrates and manure after fermentation where fertilization occurred in 7 days (Table 1). In variants using herbal substrate and straw, fertilization was less frequent, especially at a reduced temperature (from +10 ° to +19 °C) after 11-15 days.
Concerning coming out immature worms from cocoons, the highest rates were noted in the variants of substrates from the mixture (3.5 worms from cocoons on average) and manure after fermentation (2.5 worms on average).
In other cases, less significant investigated parameters were observed: herbal substrate (1.5 worms from cocoons on average), straw used in the cultivation of mushrooms (1 worm from cocoons on average).

Table 1. Duration of ontogenesis stages of *Eisenia fetida* depending on the substrate type.

Indicator	Substrate type			
	Mixture	**Manure**	**Grass**	**Straw**
Fertilization, a day	7.50 ± 0.21	11.00 ± 0.50	12 ± .50	15 ± 0.61
Coming out of immature worms from cocoon, number	3.50 ± 0.21	2.50 ± 0.20	1.50 ± 0.11	1.00 ± 0.11
Duration of the cocoon stage, a day	24 ± 0.70	25.50 ± 0.71	27 ± 0.81	27 ± 0.80
Duration of the stage of immature worms, a day	39 ± 0.71	44 ± 0.70	49 ± 0.71	54 ± 0.81

The temperature regime affected the reproductive activity of *Eisenia fetida*. When determining the influence of the temperature regime on the process of embryogenesis, the indicator of which is coming out of immature worms of *Eisenia fetida* from cocoons, it is established that when cultivating at a temperature of +10 °C, coming out of worms was not observed. At +14-16 °C, coming out of immature worms from cocoons amounted to 1 and 1.5-2 worms, on average, on substrates from manure after fermentation and mixture, respectively, and it was not observed on straw and young grass substrates. After increasing temperature, indicators were improved. Cultivation at the temperature of above +20 °C showed the highest coming out of immature worms in variants using mixture and manure after fermentation. At the optimum temperature +20-25 °C, indicators increased to 3.6 and 2.6 worms on average (on the substrates of mixture and manure, respectively); on other substrates it was 1 and 1.5 worms (straw and herbal substrate, respectively).

Thus, the ecological temperature optimum for worms is from +20 °C to +25 °C. At lower temperatures (from +10 °C to +15 °C), probably, there is no egg fertilization or the embryo development in a larger proportion of cocoons which greatly slows down biohumus production. So, it is necessary to create a temperature regime from +20 °C to +25 °C for the active fertilization of worms. If necessary, it is possible to save vermiculture population by lowering the temperature to +10 °C.

According to our research (Table 2), for three months of substrate processing at the beginning of the experiment, the average weight of one adult worm was 0.35 g. The largest increase in the average worm weight at the end of the experiment was in the variant using the mixture (by 0.16g) and manure after fermentation (by 0.10 g).

Table 2. Effect of the substrate type on the production of *Eisenia fetida* biomass.

Substrate variants	**Duration of rotation, days**	**Average biomass of an adult worm, g**	
		at the beginning of the experiment	**at the end of the experiment**
Random mixture	90	0.35 ± 0.01	0.51 ± 0.03
Manure after fermentation	90	0.35 ± 0.01	0.45 ± 0.02
Herbal substrate	90	0.35 ± 0.01	0.36 ± 0.01
Straw substrate	90	0.35 ± 0.01	0.35 ± 0.01

The average increase in the worm biomass in the variant using herbal substrate was 0.06 g. This substrate does not contain enough nutrients, so worms on this substrate cannot exist for a long time.

Consequently, it is most appropriate to use substrates from mixture and manure after fermentation to obtain more significant worm biomass. Other substrates (straw and grass) must obviously be mixed with other wastes.

Also, research results were compared with references (Bhat, 2015, on the effectiveness of other types of vermiculture substrates using Lumbricusterrestris) cultivated on food waste substrates, feces, sawdust and bird dropping substrate. Comparison results are given in Table 3.

It is found that in the vast majority of cases, Eisenia foetida population indicators surpass data received by other researchers. This confirms the expediency of its use as a vermiculture object.

Table 3. Comparative characteristic of the efficiency of different types of substrate in terms of parameters of *Eisenia fetida* and Lumbricusterrestris as vermiculture objects.

Indicators	**Substrate variants**							
	Eisenia foetida				**Lumbricusterrestris.**			
	mixture	**manure substrate**	**herbal substrate**	**Straw**	**bird dropping**	**feces**	**sawdust**	**food wastes**
Fertilization, a day	7.50 ± 0.21	11 ± 0.51	12 ± 0.51	15 ± 0.61	7.50 ± 0.21	11 ± 0.51	12 ± 0.51	15 ± 0.61
Coming out of immature worms from cocoon, number	3.50 ± 0.22	2.5 ± 0.21	1.5 ± 0.11	1 ± 0.12	3.5 ± 0.21	2.5 ± 0.22	1.5 ± 0.11	1 ± 0.11
Duration of the cocoon stage, a day	24 ± 0.71	25.5 ± 0.72	27 ± 0.81	27 ± 0.81	24 ± 0.72	25.50 ± 0.72	27 ± 0.81	27 ± 0.81
Duration of the stage of immature worms, a day	39 ± 0.81	44 ± 0.92	49 ± 0.91	54 ± 0.71	40.5 ± 0.71	43 ± 0.81	50 ± 0.82	40 ± 0.61
Biomass growth during the experiment, g.	0.51 ± 0.03	0.45 ± 0.02	0.36 ± 0.01	0.35 ± 0.01	0.48 ± 0.03	0.47 ± 0.02	0.36 ± 0.01	0.35 ± 0.01

Thus, as a result of this research it is found that such abiotic and biotic factors influence food and reproductive activity, production of biomass of Eisenia foetida artificial population, as temperature, humidity and qualitative composition of substrate formers, especially a trophic factor that will undoubtedly affect the biohumus output.

All demeoecological parameters and peculiarities of the ontogenetic stages of the object of research indicate that the best substrate for vermiculture is the substrate from a mixture of cow manure after the fermentation process (70%), land, organic grass, vegetable and fruit origin (30%). In this case, the basis of this mixture is cow manure. It is quite natural, since cow manure contains water (75%), organic matter (21%), total nitrogen (0.5%), digestible phosphorus (0.25%) and potassium oxide (0.6%). In addition, it contains elements such as boron, manganese, copper, zinc, cobalt and more. A large number of microorganisms are introduced into the soil with manure which decomposes organic matter, turning nutrients into easily accessible compounds.

However, it must be emphasized that the addition of organic residues of different fruit and vegetable origin leads to better

obtained indicators than other substrates.
Direct biotechnological processing of organic waste with the help of vermiculture is the important stage in their utilization which is based on the use of natural circuit of substances.
That is why various combinations of organic wastes of agricultural production are studied as components for compost which became the substrate for Eisenia foetida population.
As a result of compost redistribution by Eisenia foetida, the vermicompost (biohumus) was obtained which is 70-80% composed of water resistant structural units (coprolites) and also has more favorable physico-chemical and biological properties compared to the original compost.
In the course of passing through worm intestines, mechanical destruction, maceration of fragments of plant tissues, gluing them with mucous secretions, mineralization of organic matter with the release of a number of nutrition elements in a mobile form and stimulation of certain groups of microorganisms is carried out (Suthar, 2002).
Agrochemical analysis of the substrate was performed twice during the season of maintenance of Eisenia foetida. That is why at the beginning of the season and at the end of it, there is a noticeable difference in the content of humus, nitrogen, phosphorus and potassium in the substrate which is due to the direct impact on the life of the worm (Table 4).

Table 4. Dynamics of the agroecological state of the substrate after vermiculturing with various combinations of organic waste (average for 2015-2017).

No.	Experiment variant	Beginning of the season element content, %				End of the season element content, %			
		humus	total nitrogen	Phosphorus	Potassium	humus	total nitrogen	phosphorus	potassium
1	Cattle manure (check variant)	7.2	1.1	1.4	1.1	15.4	2.4	2.2	1.7
2	Random mixture	4.9	0.8	0.9	0.7	13.2	2	2	1.5
3	Herbal substrate	3.6	0.6	0.6	0.5	10.5	1.6	1.6	1.2
4	Cattle manure+straw (1:1)	4.1	0.8	0.8	0.7	13	1.9	1.9	1.5

Thus, studies have shown that vermiculture contributed to positive changes in agrochemical indicators in the substrate to maintain Eisenia foetida. The difference in the indicators at the beginning and at the end of the season is quite tangible and is explained by the influence of vermiculture biomass. At the end of the season, we get ready-made organic fertilizer-biohumus which has much better fertilizer properties than the components used for composting.
Based on the figures given, the biohumus produced by traditional organic fertilizers and various variants of compost. It also contains more nitrogen. This is due to the large number of nitrogen fixing bacteria in worm coprolites. The content of phosphorus and potassium in the prepared biohumus increases twice, compared with the agrochemical composition of the substrate at the beginning of the season. It should be noted that the agrochemical state of the substrate for the entire season is greater than the research variant where the source component of composting was cattle manure (check variant). However, the purpose of our research was to identify the best compost variants for the processing (utilization) of plant residues. Therefore, from this point of view, the best variant for the experiment is the combination of cattle manure and plant residues in a ratio of 1:1 for composting.
According to the research results, the agrochemical composition of the biohumus is dependent on the type of organic wastes which are elements of the starting compost for Eisenia foetida.
Thus, the humus content in the prepared biohumus was greater in the variant where compost was prepared from cattle manure. Combining it in various combinations with vegetable wastes reduced the humus content.
The best variant for humus content is the combination of cattle manure and random mixture. With further “dilution” of manure residues, the content of humus decreases. This trend is observed throughout all growing seasons. As for the combination of cattle manure compost and straw after mushroom cultivation, the humus content is lower than that of the combination of cattle manure and random plant residues.
The analysis of nitrogen, phosphorus and potassium content allows us to make similar conclusions, depending on the season. Indicators for the nutrient content in the final biohumus in 2016 were larger than in 2015 and 2017. The research results can be explained by peculiarities of the weather conditions of the research years (growing conditions are open ground) and, in particular, by the force of Eisenia foetida population, since at the end of the season it is transferred to a new fermented substrate having the same composition and parameters. However, the population of the second year, that is, is more adapted to the conditions of cultivation, respectively, has the best demo ecological parameters which significantly affects the final composition of the biohumus.
Lower values (compared with 2016) of the studied biohumus parameters at the end of the season of Eisenia foetida population in 2017 can be explained by a decrease in the moisture content of the substrate. Water in the vermiculture body continuously enters and is released into the environment. Thus, its body is always rinsed with water. Therefore, vermiculture requires environment conditions that would provide access of water to its body in significant quantities for normal physiological processes.
Consequently, as a result of the research, it is established that a different ratio between manure and vegetable wastes

determines the change in starting agroecological parameters of the substrate for Eisenia foetida. The difference in the indicators at the beginning and at the end of the season is quite tangible and is explained by the influence of vermiculture biomass. At the end of the season, we get ready-made organic fertilizer-biohumus which has much better fertilizer properties than the components used for composting. Indicators of the agrochemical state of the substrate for the entire season are larger than the research variant where the source component of composting was cattle manure (check variant). However, from the point of view of processing (utilization) of plant residues, the best variant of the experiment is considered as a variant of the combination of cattle manure and random plant residues in a ratio of 1:1 for composting.

Ready biohumus has a positive effect on crop yields which is determined by the fact that it contains essential nutrients for plants in a well-balanced and easily digestible mobile form (Zucco et al., 2015). In 2016-2017, on podzolized chernozem under the conditions of Uman National University of Horticulture, researches were conducted to study effectiveness of introducing biohumus in various ways for cultivating sweet peppers in open soil.

The stimulation of growth and development of sweet pepper plants (as well as flowering and planting of fruits) by biohumus led to an increase in the plant yield of the experimental data (Figures 1&2).

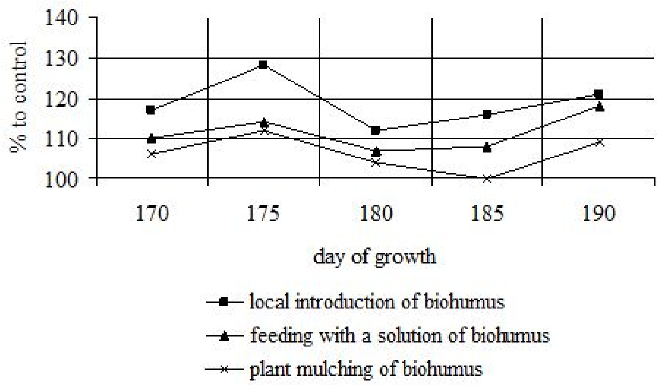

Figure 1. Dynamics of the change in the length of sweet pepper, depending on the biohumus application method (on average in 2016-2017), % to check variant.

Treatment of sweet pepper plants with biohumus led to an increase in the length of the fruit and on the 175th day of vegetation, plants of the local biohumus injection variant had the highest indicator. The difference with the indicator of the check variant was 29%. Treatment of plants with biohumus in the form of foliar feeding with solution and mulching also led to an increase in the length of the fruit but with smaller difference, compared with plants of the check variant (without processing).

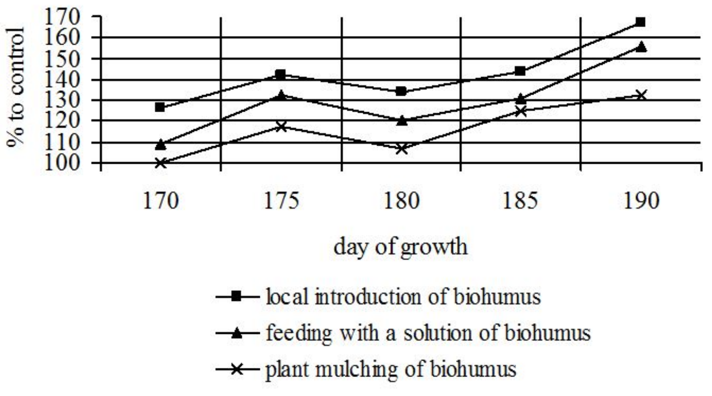

Figure 2. Dynamics of the change in the weight of sweet pepper fruit depending on the method of biohumus use (on average in 2013-2014), % to check variant.

Sweet pepper fruit weight collected on the 170th day of growth exceeded check variant in all variants of the experiment. During the period of last harvest (190th day), the weight gain of fruits in plants of the local biohumus injection was the largest and was 68% compared to check variant.

Better development of sweet pepper plants treated with biohumus resulted in an increase in the parameters of length and weight of the fruit compared to the check variant plants which led to an increase in the crop yield. Thus, the highest yield was obtained when cultivating sweet pepper with the use of biohumus through local pre-plant application (37.5 t/ha on average over the years of research). The difference with the indicator of the check variant (without processing) was 9.1 t/ha. Other methods of using biohumus also showed a positive effect of increasing yield: when mulching plants with biohumus, the increase in yield was 3.7 t/ha; plant nutrition with the biohumus solution (8.0 t/ha). Statistical data processing shows that the

difference between variants is true.
It is established that the use of natural plant growth stimulants, which is also biohumus, provides the production of the environmentally safe sweet pepper yield which is characterized by high quality indicators (Figure 3).
The results indicate that under the influence of biohumus regardless of the application method, nitrate content in sweet pepper fruits decreased compared with the check variant.

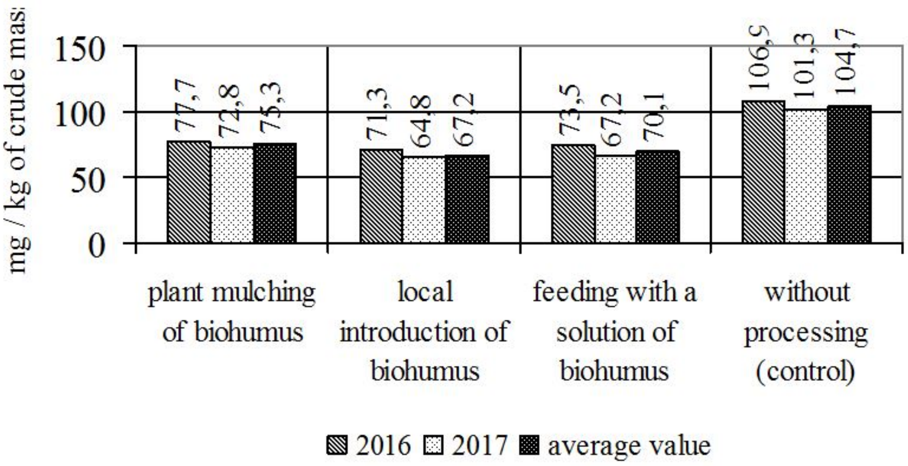

Figure 8. Nitrate content in sweet pepper fruits depending on the methods of using biohumus, (MAC-200) mg/kg of raw mass.

Consequently, under the conditions of the educational and scientific production department of Uman NUH, it is advisable to grow sweet peppers with biohumus treatment. Considering different ways of using biohumus, it can be concluded that the best of them is the way of local pre-planting. Such treatment stimulates the growth and development of plants best of all. Thus, the duration of phenological phases of growth and development decreases and biometric parameters of plants increase. In turn, this allows you to get the most developed plants and, accordingly, the highest yield of sweet pepper fruits. In addition, the resulting products are environmentally friendly due to the low content of nitrates. That is, the local application of biohumus before planting sweet pepper seedlings can be included as an effective element in the modern technology of growing this crop.

Conclusions

Vermiculture and vermiculture technology directly relate to the mechanisms of the material-energy exchange of the biosphere, described both in the classical works of Vernadsky, Timofeev-Resovskii and in the works of soil scientists on the soil structure and mechanisms of soil formation, as well as in the modern works of biologists and environmentalists on the role of biota in the biosphere. The importance of vermiculture is also the possibility of its use as a means of biological disposal of organic wastes, biological conversion and obtaining organic products of high consumer quality.
1. The activity of Eisenia foetida positively affects the state of the original compost increasing the relative amount of humus (by 28%), total nitrogen (by 52%), phosphorus (by 42%) and potassium (by 78%). The acidity of the substrate is close to the neutral reaction (pH 6.9-7.2). There is a high concentration of nutrients in the substrate cultivating Eisenia foetida artificial populations. It results in high fertilizing properties of the biohumus which is obtained from the substrate as a result. Moreover, the higher the density of the population is, the better its agroecological situation can be.
2. As a result of the research, the schemes of cultivating agricultural crops (tomatoes, sweet peppers, spice vegetable and berry crops, peppermint, cucumbers, eggplants, coriander, true cornflowers and strawberries) were developed with high ecological and consumer quality using vermicompost and biohumus extract. Studies were conducted on the use of vermiculture products as bio stimulants for the cultivation of ornamental plants.
3. The research results on the territory of experimental plots showed that technologies of biological waste utilization using vermiculture are quite suitable for use under the conditions of peasant farms with a small land area and a high degree of autonomy in the choice of ways of development. In particular, having a garden of about 100 hectares, the university annually has about 100 tons of apple juice and the mushroom laboratory after the mushroom cultivation as waste receives a sufficiently large volume of cereal straw. Vermiculture is at the very beginning of an environmentally closed technological cycle which scheme was developed by the scientists of the department (Sonko et al., 2015, 2018).

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