Production of biological fertilizers based on worm technology in Yakutia

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Abstract. The article presents the results of research on the production of biological fertilizers based on worm technology in Yakutia. Scientific experiments were conducted on the basis of the greenhouse complex of the Pokrovskoe experimental production farm in the Khangalassky district of Central Yakutia. We studied the features of worm composting in the production of biological fertilizers from different local substrates. Cattle manure and horse manure, as well as bird droppings, were used as substrates for worm composting. A hybrid of the Red California worm (Eisenia fetida) was selected for processing the substrates. The chemical composition of the substrates and the produced biological fertilizers, as well as the processing time of the substrates, and the physical properties of coprolites were studied. The substrate from cattle manure was processed by worms in 140 days, and horse manure in 60 days. At the same time, the volume of fertilizer produced was 2.90 and 2.95 kg. In the course of research, it was established that biological fertilizers had an optimal content of organic matter, biogenic elements of plant nutrition (nitrogen, phosphorus, potassium), while the content of heavy metals (zinc, copper, manganese, lead, cadmium) did not exceed the norms. The use of biological fertilizer produced from horse manure in tomato cultivation has shown that the introduction of a small dose of worm compost contributed to the reduction of heavy metals in the fruit of the plant. It was also found that increasing doses of biological fertilizers from horse manure increased the microbiological activity in soil from 18.9x10⁶ to 31.5x10⁶ CFU/g. Thus, these studies proved the effectiveness of worm composting from local substrates in the production of biological fertilizers in the vegetable growing system of Yakutia.

1. Introduction
Growing vegetable crops in the protected soil of Yakutia is dictated by unfavorable climate conditions, as well as the characteristics of permafrost soils. Optimal conditions for root nutrition of greenhouse crops are provided by a constant supply of nutrients in the ground: nitrogen - 12-31 g/m³, potassium - 28-42 g/m³, phosphorus - at least 4 g/m³. The fertility of greenhouse soils is supported by the application of organic and mineral fertilizers while ensuring the irrigation rate of up to 800 l/m² [1].
Worm compost (worm fertilizer, biological humus, and coprolite) is a high molecular organic biological fertilizer obtained as a result of processing by worms of organic substances (animal manure, bird droppings, vegetation residues, waste from the food industry and municipal services). Worm excrements (coprolites) are rich in various nutrients [2, 3], characterized by increased water-retaining properties [4, 5]. According to the All-Russian Research Institute of Agricultural Chemistry named after D.N. Pryanishnikov – biological fertilizers (worm compost) contain organic matter up to 66%, phosphorus up to 2.7%, potassium up to 1.9%, total nitrogen up to 1.4% and ammonium nitrogen up to 0.2%. According to the main indicators of worm compost, such as pH, ash content, nitrogen, phosphorus, and potassium content, it is close to litter manure [6]. The depth of humification in worm compost is much higher than in peat compost and manure, with the predominance of humic acids [7, 8, 9].

In Japan, worm biomass is used for the production of medicines, fish food, etc. Since 1989, more than 1,500 enterprises have been established for processing manure into biological fertilizer using worms, processing up to 150 tons of litter manure per day [10, 11]. To date, effective methods of worm composting of organ-containing waste and their application in the vegetable growing system of Yakutia have not been developed yet.

**Research goal:** to evaluate the production of biological fertilizers created from various local substrates of cattle and horse manure;

**Research objectives:**
- to study the chemical composition of the obtained biological fertilizers and initial substrates;
- to study the effect of biological fertilization from horse manure on the microbiological activity of greenhouse soils.

2. Material and research methods

Scientific experiments to determine the efficiency of production of biological fertilizers (worm compost based on local substrates) were carried out on the basis of the greenhouse complex of the experimental production farm “Pokrovskoe” in Khangalassky district. A hybrid of the Red California worm (Eisenia fetida) was selected for scientific experiments to study the influence of various worm compost based on local substrates (cattle and horse manure).

Worm composting of local substrates was performed in a warm room with an air temperature of +21 °C, the substrate humidity was within 77%.

Biological testing was performed using the method of I.A. Melnik (1989) [12]. All observations were made in cultivation boxes with a volume of 0.060 m³.

The preparatory stage included preparation of the substrate was carried out using pre-fermentation (for Yakut horse manure - 2 weeks and cattle manure - 4 weeks). The analysis of the quality of substrates and worm compost was performed using the method of N.M. Gluntsov (1977) [13] in the agrochemical station of Yakutsk.

Small plot farming experience - the area of the plot is 3.3 m². At the end of the scientific experiment, the influence of worm compost on the agrochemical properties of soil and its microbiological activity was studied.

The chemical composition of samples of biological fertilizers, substrates and soils was analyzed in the laboratory of mass analysis and biochemistry of the Yakut Research Institute of Agriculture in Yakutsk (Yakut Research Institute of Agriculture) using an infrared analyzer NIR SCANNER model 4250, calibrated using generally accepted standard methods.

3. The results and discussion

Horse manure is used in small quantities when growing vegetable crops in the protected soil of the private sector [1]. For the preparation of biological fertilizers (worm compost), it is practically not used in the absence of information about the effectiveness of local substrates. In this regard, it is necessary to establish the possibility of using a local substrate (Yakut horse manure) for the production of biological fertilizers.
The chemical composition of different types of local substrates (animal manure) is shown in table 1.

| Types of substrates | Humidity, % | Organic matter, % | Nitrogen, % | (P<sub>2</sub>O<sub>5</sub>) Phosphorus, % | (K<sub>2</sub>O) Potassium, % | pH  |
|---------------------|-------------|-------------------|-------------|-----------------------------------------|----------------------------|-----|
| Horse manure        | 1.9         | 45                | 2.3         | 0.4                                     | 1.8                        | 6.7 |
| Bird droppings      | 70          | 14                | 0.3         | 2.3                                     | 1.3                        | 2.4 |
| Cattle manure       | 82          | 48                | 1.5         | 1.1                                     | 2.8                        | 8.7 |

From the above data, it is established that horse manure has a good medium reaction - pH 6.7, rich in nitrogen, which meets the basic requirements for worm cultivation.

The 5 kg substrate was populated with adult worms - 1000 individuals per box. To maintain the purity of the experiment, additional fertilizing of the substrates was not performed. The number of worms and cocoons was calculated after 10 days. During the preparation of worm compost was carried out by watering the substrate once every seven days, as the horse manure loses moisture quickly. At the end of the preparation of worm compost, 70 days later, the amount of biological fertilizer produced was taken into account.

In the conditions of Yakutia, the cattle manure from livestock complexes is removed and frozen close to livestock farms in the form of frozen heaps with a weight of up to 20 kg. In the spring, thawing masses of animal manure create an unfavorable condition for the environment. When the manure is thawed, harmful gases escape from it, and fermentation is carried out in 3-4 weeks.

To determine the speed of making substrates of local raw materials, biological testing was performed, 50 worms were put into the substrate. The biological testing data is presented in table 2.

| Substrate                        | The day after laying the compost |
|----------------------------------|----------------------------------|
|                                  | 5                  | 10                | 15 | 20    |
| Horse manure                     | not suitable enough  | suitable          | suitable | suitable |
| Cattle manure                    | unsuitable          | unsuitable        | not suitable | not suitable |

Regardless of the period of local substrates fermentation, worms, at first, show insufficient activity. Only after 18 days, the worms were ready for intensive processing of the horse manure substrate. At the same time, the substrate from cattle manure was suitable for digestion by worms after 25-30 days. It should be noted that the worms were repelled by the dryness and excessive humidity of the substrate.

Table 3 shows the dynamics of worm reproduction in the local substrate based on horse and cattle manure.

| Observation dates | Age distribution | Growth, % |
|-------------------|------------------|-----------|
|                   | Adults | Cocoons | Young |               |
| 3.05 Beginning    | 1000   | -       | -     | -              |
| 13.05 in 10 days  | 1000   | 1       | 2     | 0.2            |
In the substrate based on horse manure, mass deposition of cocoons began on the 20th day, and after 30 days, 100% deposition of cocoons was observed. In the substrate based on cattle manure, the mass deposition of cocoons occurred on the 50-60th day. Activity in the first days in the horse manure substrate on the 60th day decreased due to lack of food. Therefore, fertilizing of substrates should be carried out periodically.

In the substrate of cattle manure at the beginning of cultivation, worms died due to insufficient fermentation. After 40-50 days, there is an active recovery of the number of worms. The complete processing of the cattle manure substrate (5 kg) took 140 days or 4.5 months. In the variant of the Yakut horse manure substrate of the same volume, it took 45-60 days. When comparing the volume of worm biomass, a significant amount was found in cattle manure and amounted to an additional 294%, and in horse manure substrate, this figure was equal to 64%, respectively.

In terms of the volume of biological fertilizer produced, there is no significant difference between the substrates (2.90-2.95 kg, respectively). It should be noted that after worm composting of cattle manure, twice much worm biomass was obtained.

From the first formed cocoons, 70 pieces were selected for further observation of the emergence of young ones (table 4).

**Table 4.** The emergence of young worms from the cocoons in the substrate of horse manure.

| Type          | Beginning of experiment number of cocoons 04.06 | in 3 days | in 10 days | in 13 days | in 16 days | in 20 days | in 26 days | in 30 days | in 37 days | in 52 days | in 109 days | in 140 days |
|---------------|-----------------------------------------------|-----------|------------|------------|------------|------------|------------|------------|------------|------------|-------------|-------------|
| Control Cocoon| 6                                             | 6         | 20         | 35         | 14         | 4          | 5          | 4          | 2          | 7          | 2           | -           |
| Young specimen| 23                                            | 23        | 24         | 24         | 29         | 32         | 41         | 40         | 39         | 36         | 28          | 6           |
| The average for the repetition | Cocoon 70                                      | 70        | 64         | 60         | 70         | 32         | 29         | 25         | 51         | 26         | 12          |
| Young          | 1                                             | 4         | 10         | 41         | 65         | 89         | 118        | 123        | 102        | 130        |             |             |

In the substrate based on horse manure, mass deposition of cocoons began on the 20th day, and after 30 days, 100% deposition of cocoons was observed. In the substrate based on cattle manure, the mass deposition of cocoons occurred on the 50-60th day. Activity in the first days in the horse manure substrate on the 60th day decreased due to lack of food. Therefore, fertilizing of substrates should be carried out periodically.

In the substrate of cattle manure at the beginning of cultivation, worms died due to insufficient fermentation. After 40-50 days, there is an active recovery of the number of worms. The complete processing of the cattle manure substrate (5 kg) took 140 days or 4.5 months. In the variant of the Yakut horse manure substrate of the same volume, it took 45-60 days. When comparing the volume of worm biomass, a significant amount was found in cattle manure and amounted to an additional 294%, and in horse manure substrate, this figure was equal to 64%, respectively.

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| The average for the repetition | Cocoon 70                                      | 70        | 64         | 60         | 70         | 32         | 29         | 25         | 51         | 26         | 12          |
| Young          | 1                                             | 4         | 10         | 41         | 65         | 89         | 118        | 123        | 102        | 130        |             |             |
The beginning of hatching of worms from cocoons was on the 10th day and activity increased on the 20th day, while in the control group, hatching activity increased only on the 26th day. The maximum number of young worms is set for 52 days - 137 individuals. In Yakutia, no more than 1-2 individuals hatch from 1 cocoon. The color of the cocoons changed from light beige to transparent dark brown. In the conditions of Yakutia, the sexual maturity of worms comes at the age of 140 days or 4.7 months. Therefore, the increase in the number of adults is slow.

During the full cycle of one turn of processing of horse manure substrate, the number of individuals increased by 64%, and in the substrate from cattle manure for 140 days, the indicator was at the level of 294%, respectively. In other words, for a year 1000 individuals in the horse manure substrate can add up to 7593 individuals, excluding cocoons.

The intensity of processing of local substrates is more intense in horse manure, relatively more time is spent on processing cattle manure because the substrate is more diverse and complex, for these reasons, its processing is slower. The decrease in the amount of cocoon separation can be explained by the fact that after rapid processing, worms have limited food resources, as some researchers point out [15].

According to our observations, in summer, worm composting differs from winter by a smaller volume. In the conditions of Yakutia in the summer, larger number of lodges can be laid. In Yakutia, the frost-free period is up to 60-90 days, which is equal in time to one term for processing horse manure. Prepared directly on the ground in a heap, animal manure substrates are populated with worms. At this time of year, it is necessary to monitor the moisture content of the substrate. At the end of worm composting of the summer warm period, when the air temperature drops to +10°C by September 1; the worms are transferred to a warm room for subsequent worm composting in the winter cold period. Produced biological fertilizer after drying is packed for further storage and use.

Thus, on the 52nd day, the maximum number of young worms is observed, after which it is restored in the dynamics of the number.

It was found that 1-2 young worms are hatched from one cocoon, regardless of the content (separately or together with the brood stock). Observations showed that an adult worm can lay one cocoon per month or two cocoons per 50 days in horse manure substrate.

It is established that in the produced biological fertilizers in comparison with the original local substrates, the mineral part increases with a decrease in organic matter, the data are presented in Table 5.

**Table 5. The chemical composition of the obtained biological fertilizer and initial substrates.**

| Indicator          | Measure unit | Manure cattle | Biological fertilizer based on manure | Biological fertilizer based on horse manure |
|--------------------|--------------|--------------|---------------------------------------|------------------------------------------|
| Humidity           | %            | 67-82        | 50-60                                 | 54                                       | 50                                       |
| Acidity            | pH           | 6.9          | 6.0-7.3                               | 7.0                                      | 7.73                                     |
| Content in dry matter: |             |              |                                       |                                          |                                          |
| Total nitrogen     | %            | 1.5          | 2.3                                   | 2.0                                      | 1.6                                      |
| Ammonia nitrogen   | %            | -            | 0.46-0.47                            | 0.6-1.3                                  | 0.06-0.12                                |
| Nitrogen nitrate   | %            | -            | 0.04                                  | 0.1-1.0                                  | 0.18-0.36                                |
| Total phosphorus (P2O5) | %       | 0.5-1.1      | 0.5                                   | 0.6-1.5                                  | 0.23-0.45                                |
| Total potassium (K2O)  | %        | 0.5-2.9      | 0.92-0.95                            | 0.6-1.3                                  | 1.8                                      |
| Organic matter     | %            | 48           | 45                                    | 34                                       | 35                                       |
| C:N Ratio          |              | 16           | 10                                    | 9                                        | 11                                       |
| Cu                 | mg/kg        | 4            | 13                                    | 3                                        | 10                                       |
| Cd                 | mg/kg        | 0.8          | 1.5                                   | 0.3                                      | 0.1                                      |
| Pb                 | mg/kg        | 2.6          | 2.9                                   | 1.5                                      | 1.0                                      |
| Ni                 | mg/kg        | 14           | 0.9                                   |                                          |                                          |
| Zn                 | mg/kg        | 126          | 68.7                                  | 32                                       | 10.5                                     |
Table 6 presents data on the physical composition of coprolites, and it is found that the smallest fraction accounts for up to 43% of organic matter.

| № of sample | Measure unit | Fraction diameter, mm |
|-------------|--------------|-----------------------|
|             |              | up to 1               |
|             |              | 1.5                   |
|             |              | 2.0                   |
|             |              | 3.0                   |
|             |              | More than 3           |
| 1           | %            | 43.0                  |
| 2           | %            | 41.7                  |
| 3           | %            | 43.0                  |

Table 6. Data on the physical composition of coprolite from horse manure.

An important role in the production of fertilizers is assigned to the assessment of compliance with environmental requirements, especially the criteria for the content of heavy metals. When using biological fertilizers produced using worm technologies (processing by worms) from local horse manure substrates, as well as the use of raw substrates, affected the content of heavy metals (table 7).

Table 7. The content of heavy metals in the substrate and biological fertilizer (worm compost from horse manure).

| Substrate / biological fertilizer | Content in dry matter, mg/kg |
|----------------------------------|-----------------------------|
|                                  | Zn  | Cu  | Mg  | Pb  | Cd  |
| Soil without worm compost        | 3.7 | 0.89| 58.64| 0.88| 0.03|
| Horse manure                     | 68.7| 12.98| 149.05| 10.32| 1.52|
| Biological fertilizer from Yakut horse manure | 10.5 | 1.9 | 118.6 | 1.04 | 0.102 |
| Soil with biological fertilizer  | 4.04| 0.52| 65.9 | 1.01 | 0.04 |

When composting horse manure with worms, there was a decrease in heavy metals in the resulting biological fertilizer. It should be noted that the content of heavy metals in the biological fertilizer did not exceed the permissible concentrations of heavy metals.

Table 8. Effect of biological fertilizer from horse manure on the chemical composition of tomato fruits.

| Groups                                      | Fe, mg/00 g | J, mg/00 g | Cd, mg/00 g | Co, mg/00 g | Mn, mg/00 g | Cu, mg/k g | Se, mg/k g | Pb, mg/k g | Hg, mg/k g | F, mg/k g | Zn, mg/00 g |
|---------------------------------------------|--------------|-------------|--------------|--------------|-------------|-------------|-------------|-------------|-------------|-----------|--------------|
| Control – greenhouse mixed soil             | 1.0          | 4.0         | 5.0          | 4.0          | 40.0        | 73.0        | 30.0        | 3.0         | 0.4         | 2.0       | 248.0        |
| Greenhouse mixed soil + 200 g/plant worm compost from horse manure | 0.8          | 3.0         | 2.0          | 3.0          | 29.0        | 51.0        | 26.0        | 2.0         | 0.3         | 1.0       | 195.0        |
| Greenhouse mixed soil                       | 1.1          | 5.0         | 5.0          | 5.0          | 47.0        | 88.0        | 32.0        | 3.0         | 0.5         | 3.0       | 282.0        |
Only a small dose of worm compost could reduce the content of heavy metals in tomato fruits. It was found that the introduction of biological fertilizers from different substrates into the greenhouse soil contributed to an increase in microbiological activity (table 9).

**Table 9. Effect of biological fertilizer from horse manure on the microbiological activity of greenhouse soil.**

| №  | Groups                               | Total number of microorganisms, CFU/g |
|----|--------------------------------------|---------------------------------------|
| 1  | Greenhouse mixed soil                 | 17.0x106                              |
| 2  | Greenhouse mixed soil + worm compost 100 g/plant | 18.9x106                              |
| 3  | Greenhouse mixed soil + worm compost 300 g/plant | 21.0x106                              |
| 4  | Greenhouse mixed soil + worm compost 500 g/plant | 31.5x106                              |

With increasing rates of application of biological fertilizers from horse manure from 100 to 500 g/plant, the number of microorganisms increased. Biological fertilizers contained 42.0 x106 CFU/g. Summary microbiological studies are presented in table 10.
Table 10. Effect of biological fertilizer from different substrates on the microbiological activity of greenhouse mixed soil.

| Groups                                      | Number of microorganisms, CFU/g | Total number of microorganisms, CFU/g |
|---------------------------------------------|---------------------------------|--------------------------------------|
|                                             | Nutrient medium meat-peptone agar (for bacteria) | The nutrient medium of chapek (for fungi) in experiments | at full reproduction, CFU/g |
| Greenhouse mixed soil                       | 0.65                            | 0.45                                 | 2.1                           | 44.1 x 106 |
| Greenhouse mixed soil + worm compost from cattle manure 100 g/plant | 1.60                            | 1.64                                 | 2.3                           | 48.3 x 106 |
| Greenhouse mixed soil + worm compost from bird droppings 100 g/plant | 2.2                             | 3.2                                  | 5.4                           | 113.4 x 106 |
| Greenhouse mixed soil + horse manure 100 g/plant | 1.7                             | 3.2                                  | 4.9                           | 102.9 x 106 |

It was found that in the greenhouse soil without the use of fertilizer, fungi predominated (on the Chapek medium) – 1.64 million, and when using biological fertilizer (worm compost based on cattle manure), the number of microorganisms was up to 1.6x106 CFU/g or 76.2%. When using worm compost from bird droppings in a greenhouse mixed soil, the fungal community increased by 3.2 million CFU/g, and accounted for 59.3% of the total number of microorganisms. The introduction of a variant of biological fertilizer (worm compost from horse manure) also contributed to an increase in the fungal community to 3.2x106 CFU/g or 65.3%. Thus, the research proved the opinion of experts that in Northern ecosystems, the fungal community takes a more active part in the biological cycle of substances.

4. Summary
In the conditions of Yakutia, cattle manure is harvested in the form of frozen rectangular piles weighing up to 20 kg, which pollutes the environment with the onset of positive temperatures. The use of this resource in agriculture is relevant not only from the point of view of agronomy, but also ecology.

Research showed that horse manure is suitable for the production of biological fertilizers from the local manure substrate. Our research also revealed that in the conditions of winter worm composting in a room with a temperature range of +20-25°C, the production time of biological fertilizers using worm technologies is reduced to 45-60 days. The average yield of biological fertilizer production from fresh horse manure is 50%.

The resulting biological fertilizer from horse manure contains the optimal amount of organic matter (up to 35%), total nitrogen - 1.6%, potassium - 1.8%, phosphorus - 0.45%, in dry matter. Thus, the use of biological fertilizers produced by processing worms from local substrates (farm animal manure) in greenhouse soils improves the chemical composition and physical properties, increasing their microbiological activity.

5. References
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