

Vermicompost Production as a Means of Inclusive Green Economy Development in Rural Settlements

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Abstract – The article deals with the theoretical aspects of inclusive green economy and practical prospects for its elements' introduction in rural areas of Russia. Discursive variety of interpretations of the green economy allowed identifying the green economy of rural areas with decoupling effect as elimination of direct correlation between the growth of agricultural production and anthropogenic load on agrobiocenoses. Practical implementation of the green economy's inclusive component consists in creation of new production chains in rural settlements and small towns with similar socio-economic conditions. These chains should be affordable for small enterprises and profitable enough for the formation of financial flows that would ensure socio-economic development of rural areas of Russia and prevent their decay and depopulation. Scientific and industrial cooperation in the field of biotechnology can solve this problem in combination with ensuring environmentally sustainable development. The production of vermicompost as an effective organic fertilizer that provides enhanced reproduction of soil fertility is the most affordable and cost-effective means of rural areas' development. The article analyzes the influence of vermicompost on agrobiocenoses, the prospects of its sale, the raw materials used for its production, as well as replicability and scalability of these technologies. This provides for a socio-economic basis of expanded reproduction of soil fertility and improving living standards of the rural population.

Keywords: *earthworms, vermiculture, vermicompost, economic efficiency of vermicomposting, inclusive green economy*

I. INTRODUCTION

Green economy is a relatively new scientific category characterized by a wide range of discursive interpretations. For example, the United Nations Environment Programme (UNEP) formulated the Green Economy Initiative (GEI), based on improving human well-being and social equality at significant reduction of environmental risks.

The World Bank promotes the Green Growth conception based on the creation of ecological and economic systems with positive feedback provided by the development of new

biotechnology-based industries that provide jobs for the population [1].

Green economy as a theoretical category is closely related to bioeconomics, based on high-tech technologies, the introduction of which creates new chains of added value. Financial flows of these chains allow for comprehensive solution of both social and economic problems [2].

According to Y. Lokko, M. Heijde et al., the capacity of the global market of such technologies exceeds USD 300 billion, but their importance exceeds purely economic, quantifiable indicators due to their practical contribution to sustainable development tasks conceptually formulated in UN documents [3].

The issues of bioeconomics are widely reflected in the EU framework programs, in particular in the 7th Framework Programme (2007-2013) including the conception of Knowledge-Based Bio-Economy (KBBE), which became the main EU Strategy on Bioeconomy [4].

Today, the conception of *Circular Economy*, based on integration of economic activity and environmental well-being in a sustainable way, has been spread in scientific literature and legal acts of the European Union. Economically rational and environmentally responsible use of waste is considered to be the means of practical implementation of the circular economy. This conception is also used in the 11th and the 12th 'Five Year Plans', which are strategic programs for China's economy development [5].

Thus, the diverse interpretations of the green economy and associated concepts allow extracting the key theoretical content – decoupling effect as elimination of direct correlation between economic development and production-caused anthropogenic load. Issues of inclusion and human capital development is the basis for developing the environmental and economic components of the system as well, since disadvantaged population involvement in the process of new added value creation ensures economic stability, while scientific and industrial cooperation and

upgrade qualifications of staff involved in the production chain enables cost-effective and environmentally sustainable production.

Conceptual development of the green economy doctrine, especially in the part of social equality as its component, has led to its expansion and enhancement in the UNEP, where it has been called Inclusive Green Economy (IGE). Inclusive Green Economy pays special attention to equality of opportunities of the population, provided by socio-economic policy with a high level of social and environmental guarantees [6].

However, socio-economic development of rural areas of Russia is far from these standards. At present, real incomes of about 60% of the rural population in Russia are at a level close to the subsistence minimum – a sum of about 2400 USD per year, while up to 35% of the population have even lower incomes. At the same time, the number of jobs is reduced by 0.2 million annually, which leads to a steady process of depopulation of small towns and rural settlements.

The socio-economic crisis experienced by rural areas and small towns with similar socio-economic conditions is a subsystem of the long-term systemic crisis of Russian agriculture associated with insufficient profitability of agricultural production. Record grain yields in the history of Russia, achieved in 2018, were provided primarily by large agricultural enterprises, which managed to take advantage of optimal weather conditions and favorable export terms. However, these enterprises are not able to provide rural areas with a required number of jobs for sustainable socio-economic and spatial development. Besides, Russian agriculture is predominantly extensive. Average revenue from the sale of crops from 1 hectare of arable land in 2019 amounts to 550 USD, while in the USA, China and the EU, these figures are 1320, 1170 and 1090 USD, respectively.

These imbalances create the need for subsidizing agriculture and rural areas from the state budget of Russia, mainly coming through three institutional channels:

funding of agricultural research, support for agricultural production through direct and indirect subsidies, and subsidization of local budgets of rural settlements and small towns. At the same time, funding of science does not produce an adequate budgetary and socio-economic effect due to the lack of implementation and commercialization of results obtained, and agricultural production is not sufficiently effective due to the lack of opportunities to apply high-tech technologies. Socio-economic development of rural settlements in the absence of jobs, as well as entrepreneurial opportunities, remains insufficient.

Thus, instability of Russian rural areas' development caused by both world trends of urbanization and by specific negative factors of national economy, determines necessity of applying high-tech biotechnologies characterized by replicability and scalability. This will allow creating new jobs in small enterprises and cooperatives of rural settlements. However, inclusive schemes are not always successfully implemented even in European countries with their developed local communities and rich experience of peasant cooperation. P. Swagemakers and co-authors have carried out a case-study of cooperative processing of organic

waste in Spain, which is close to the subject of this article. The high environmental and economic potential of this circular economy project faced the difficulties of practical implementation associated with the scaling of this technology and administrative barriers, primarily related to the construction of waste treatment plant and institutional aspects of public-private partnership [7].

Thus, development of rural areas' green economy requires simpler and less capital-intensive schemes that will allow for cost-effective production on the scale of family peasant economy, without requiring complex interactions of a horizontal and vertical nature. This can be ensured by scalable and replicable technologies of vermicompost production as an effective and demanded fertilizer providing expanded reproduction of soil fertility.

II. MATERIALS AND METHODS (THE MODEL)

The research aims at studying the production of biocompost in Russian conditions as a means of forming a virtuous circle for the development of a binary ecological and economic system of rural areas' green economy. Research materials are represented with Russian and foreign works in the field of vermicompost production and its application in agriculture, as well as statistical data on agricultural development indicators in Russia. The research is based on the methodology of system analysis, economic-statistical and economic-mathematical methods.

III. RESULTS AND DISCUSSION

In the conditions of intensive conventional agriculture, the processes of soil fertility reduction due to its removal with crops, require increased chemization for the sake of simple, rather than expanded reproduction of soil fertility and crop yields. The rate of destructed humus layer's natural recovery is about 1 cm per 100 years [8].

However, it is possible to artificially humify soils with compost material formed by decomposition of organic waste widely varied in composition. The bioconversion process is an artificially optimized natural process of organic degradation due to vital activity of bacteria and earthworms in the nutrient substrate. Worms increase quality of the final product and the speed of its processing by transforming the absorbed substances in intestinal cavity and releasing coprolites, which contain nutrients that improve the quality of plants and soil. In addition, worm mucus contained in coprolites contributes to the vital activity of valuable bacteria in the substrate, accelerating the conversion process, and at the same time inhibiting pathogenic microorganisms [9].

Vital activity of earthworms as a key factor of soil fertility was studied by Charles Darwin in the 19th century, but the active scientific development of vermiculture problems began only in recent decades, which is primarily due to organic markets' development and to the need of improving sustainability of conventional agriculture through biotechnology. Besides, vermicomposting enables economically profitable processing of livestock waste, as well as organic fraction of municipal waste [10] and sewage sludge of various origins [11].

Waste from livestock complexes and poultry factories is surely the most optimal raw material for vermicompost production, which allows for efficient solution of economic and environmental problems, since these wastes are unsafe for the environment of rural areas, and their processing by other methods is excessively capital-intensive (industrial bioreactor plants for biogas production, etc.) and therefore is affordable only to large agricultural enterprises.

According to the research of the leading Russian vermiculture specialist A.M. Igonin, farm animals and poultry absorb no more than 50% of nutrients from feed, while the rest is released from the body with excrements. Therefore, manure, especially cow manure, has a high content of organic nutrients. One ton of dry manure contains up to 800 kg of fiber, up to 90 kg of raw protein, carbohydrate compounds, enzymes, fats [12].

Processing of such manure by a symbiotic population of worms and bacteria creates up to 0.6 tons of coprolites, which contain up to 35% of humus compounds. Increased product output and high concentration of humus are the result of artificial selection of hybrids of manure worms *Eisenia fetida* on the basis of quantity and quality of the released coprolites. The red Californian worm, bred at the California Institute of Technology (CIT) in 1959, is the most common in the world among such hybrids. Staratel hybrid, bred by A.M. Igonin from populations of *Eisenia fetida* found in Central Asia and Northern Russia is also common in Russia. Earthworms living in natural conditions can also be successfully domesticated and used in vermiculture, but their coprolites contain only about 15% humus compounds [13].

At the same time, humus produced by worms has a number of advantages in comparison with humus formed by bacteria both in the conditions of natural decomposition of organic matter in biocenoses and in the conditions of its artificial composting. The digestive tract of earthworms contains molecules of humic and fulvic acids, which enter into chemical reactions with mineral components of the organics digested by worms, which leads to formation of soluble and insoluble humus in coprolites. Soluble humus, formed by lithium, potassium and sodium humates, provides plants with easily digestible nutrients that stimulate seed germination, enhance photosynthesis and digestibility of mineral salts from the soil. This is especially important for plants in the initial phase of development characterized by the most intense biochemical processes and under non-optimal external conditions in agrobiocenosis during droughts and frosts.

Humates decompose pesticides and nitrates in the soil, and the introduction of vermicompost accelerates the processes of detoxification of agrobiocenosis, which allows restoring agricultural landscapes with reduced fertility as a result of excessive chemization. Application of vermicompost also reduces the nitrate content in plants, which allows, for example, conducting intensive vegetable growing without exceeding the maximum permissible concentrations of nitrates in the final product. Humates themselves are not toxic and are not absorbed by plants.

Humates of calcium, magnesium and heavy metals are insoluble humus formed by hydrophilic, mechanically strong aggregates that persist in the soil for a long time,

providing meliorative aftereffect of vermicompost for up to 8-9 years by structuring the soil, giving it air and moisture permeability and preventing the processes of water and wind erosion, leaching of nutrients from soil during irrigation. Thus, artificial soil humification is an important factor in the development of intensive agriculture in irrigated agrobiocenoses with high rates of irrigation and fertilization.

In artificially created conditions of the processed substrate with close to optimal values of temperature (20-25 °C), humidity (80-95 %), C/N ratio (20-30:1 in the initial phase of bioconversion, followed by a decrease in nitrogen content to 10-15:1) and close to a neutral pH value of 6.5-7.5, *Eisenia fetida* reproduce exponentially. Two-parent animals give 1200-1500 worms annually. Their life span in such conditions makes up to 15 years.

Bioconversion of one ton of bovine manure with straw as a bulking agent, i.e. the optimal combination of raw organic material and bulking agent, yields up to 0.1 ton of earthworms, which are valuable feed biomass with a protein content of about 70%. This creates new prospects for sustainable development of the rural economy through formation of production chains of poultry, cattle and aquaculture. With regard to the latter, we should note the special importance of its combination with vermicomposting, since worms are a valuable protein feed for hydrobionts, and silt formed in aquaculture reservoirs is as much valuable substrate base for vermiculture as cow manure [14].

Cost-effective utilization of waste of agricultural animals and poultry is an important factor of rural areas' sustainable development for several reasons. Firstly, it is connected with the increase in profitability of animal husbandry for producers of organic fertilizers and for their consumers, in particular at combining vermiculture with animal husbandry in one farming household. Secondly, the use of non-bioconverted manure in plant crop production has a number of environmental and economic problems. Standards of organic fertilizers' application prescribe using 20–80 tons of manure per 1 hectare of arable land that demands considerable expenses on work, fuel and agricultural machinery. Besides, the manure contains pathogenic microorganisms and potentially germinating seeds of weed plants which number can reach 5 million per 1 ton of manure. That is why using manure as a raw material (1.5-3 tons of vermicompost per 1 hectare) for bioconversion allows achieving an increased economic effect with a longer meliorative aftereffect. In the course of bioconversion *Eisenia fetida* absorb not only plant detritus and weed seeds, but also protozoa, including pathogenic ones. Coprolites of worms, produced in an artificial environment of vermicomposting, contain the remains of intestinal microflora of worms, which has bactericidal properties. That is why application of vermicompost into agrobiocenoses prevents development of pathogenic protozoa in soil and form a nutrient medium to increase the activity of beneficial bacteria [15]. Besides, bioconversion of the substrate purifies it from heavy metals, in particular copper, zinc, cadmium and lead, which are accumulated in the tissues of worms [16].

Vermicompost is qualitatively superior to manure in its compactness, transportability and storage period comparable

to those of mineral fertilizers. Availability of bovine in Russia is not sufficient for its introduction into agrobiocenoses as an organic fertilizer according to the above standards, but it makes it possible to form a raw material basis for industrial vermicomposting. In 2019, cattle livestock in Russia totals more than 18 million heads, and the average annual production of manure per 1 head is 20-25 tons, which in total provides about 450 million tons of manure. Most of it is not used in agriculture, but is stored in an environmentally unsafe way.

Sheep and goat manure is also a qualitative substrate base for vermiculture, slightly inferior to cattle manure in terms of nutrient content. Pig manure and poultry waste are also suitable for composting, although their higher toxicity levels require longer fermentation and more thorough substrate preparation. Wastewater sediments and organic fractions of municipal solid wastes are even less favorable for *Eisenia Fetida*. However, being mixed with manure in an optimal proportion, they are also suitable for bioconversion and biocompost production complying with environment safety requirements [17, 18].

Vermicompost production has not yet received sufficient development in Russia. It is mainly small-scale and focused on non-industrial, amateur gardening and horticulture. Since this type of activity is more of a hobby than a business, its main priority is the quality of products, not the profitability of production. Therefore, Grin-Pik company as the largest Russian producer of vermicompost at the moment (Kovrov, Vladimir Region) sells its product at the price of 500 USD per 1 ton. This price is affordable for hobbyists who do not consider production costs, but is hardly economically acceptable for commercial production of agricultural products by the rural population.

However, the development of vermicompost production on an industrial scale has the potential of reducing the cost of final product to an economically acceptable level. The use of vermicompost in crop production can solve the problems of sustainable development of rural areas and the practical implementation of the green economy.

For example, a number of field studies have proved significant positive effect of biohumus on winter wheat yields in Russian conditions. The experiments by N.G. Tolstopyatova and S.V. Gerasimov show an increase in winter wheat yield to 5, 1 t/ha with an increase in the content of protein and gluten in the grain [19]. Field research by B.A. Mustafaev demonstrates an increase in winter wheat yield by 34.4% when applying 1.5 tons of vermicompost per 1 hectare, while an increase in the amount of this fertilizer in a one-factor experiment from 1.5 tons to 9 tons per 1 hectare gave a yield increase of 47.5% [20].

Thus, the use of vermicompost forms an economic utility curve with a qualitative increase in productivity from a small dose of coprolites introduced into the arable land and a subsequent decrease in the specific efficiency of vermicompost, which will allow consumers of vermicompost as a fertilizer either reducing costs due to a reduced dose of its application, or increasing productivity. At the same time, long-term reclamation aftereffect of vermicompost is also particularly important from the ecological and economic viewpoint of rural areas' green economy.

Among the crops responsive to the influence of vermicompost, amaranth is of special importance for rural economy. Under the influence of coprolites this plant increases the amount of green mass and the content of protein in it [21]. Amaranth as a valuable feed for farm animals is superior to alfalfa and other traditional forage crops in nutrient content. In combination with vermicompost it is able to form new highly profitable chains of livestock production in households.

Therefore, vermicompost has almost universal utility in agriculture. It is especially efficient in the cultivation of crops that remove nutrients from the soil, such as corn, sunflower, rape, which is especially important in view of their demand by the market and profitability of their production. Soybeans and other nitrogen-fixing plants are not much effected by vermicompost, but the reclamation properties of insoluble humus have indirect positive effect on yield and long-term expanded reproduction of soil fertility in any crop rotation. These factors prove high potential of vermicompost sales both within Russia and abroad on the scale of hundreds of millions of tons annually. Russian acreage in 2019 has amounted to almost 80 million hectares, including more than 46 million occupied by grain crops, which are characterized by high-quality yields under the influence of even small doses of vermicompost. This makes its application a priori profitable in economic terms even for such a low-margin crop as winter wheat.

Production of vermicompost on such a scale is theoretically quite possible due to the low capital intensity and high profitability, and its main technical and economic parameters can be described as follows. Preliminary preparation of soil substrate for the population of worms consists in ensuring the required parameters of structural composition, C/N ratio and pH by mixing with various substances and fermentation (thermophilic phase). The use of a semipermeable membrane film to cover the substrate increases the speed and quality of fermentation process, as well as reduces substrate's malodorous emissions [22]. Then the substrate is populated with *Eisenia fetida* with a density of 150-300 thousand worms per 1 ton. This population can absorb organic matter and produce coprolites both in special heated premises with optimal conditions and in the open air. The optimal ratio of *Eisenia fetida* population is 10-25% of adults, 60-80% of the young, 10-15% of cocoons. Adult worms are very sensitive to changes in composition of the substrate they inhabit, hard to tolerate migration and often die, while the young ones are more adaptive. Weather conditions in the South of Russia allow worms conducting their life in such conditions for 200-250 days a year. Construction or re-equipment of premises allows creating much more optimal conditions for effective life of the population in the substrate, but in Russian conditions the cost of insulation and re-equipment of livestock premises (cowshed, pigsty, etc.), as well as the cost of construction of hangar, is about 30-50 thousand USD. In the conditions of family farms and small rural enterprises, it is possible to use available small-area utility rooms and place the substrate in boxes and containers. The larger scales of production provide for such a method of composting as placing the substrate in bales which implies migration of worms from one end to the other. This reduces the labor intensity and allows for collection and filtration of the finished

vermicompost from the area of 300-500 m² by means of manual labor of one handyman. There are also more advanced methods of vermicomposting associated with continuous bioreactor plants with mechanized processes of preparation and loading of the substrate and unloading of vermicompost. All these methods, however, have their drawbacks. Breeding worms in containers ensures quite optimal conditions for reproduction and coprolites production, but is characterized by extremely high labor intensity. The bale method is characterized by low labor costs, but there are technological difficulties with ensuring uniform optimal conditions inside the bale, particularly the conditions of humidification and aeration. Bioreactor systems are distinguished by high capital intensity, which is aggravated by the lack of batch production in Russia, therefore, this trend has wide opportunities for technological innovation, especially for the production of inexpensive and compact bioreactors available to small enterprises in rural areas.

Depending on the worm population conditions associated with nutrient content of the substrate, its temperature, humidity and aeration, one iteration of bioconversion takes from 30 to 60 days in an indoor environment. The average cost of bovine manure makes about 20 USD per 1 ton in Russia due to its low demand in agricultural practice and storage problems at livestock enterprises. Market value of 1 kg of pedigree specialized worms for vermicomposting (red Californian worms or Staratel worms) is about 40 USD that is the cost of populating approximately 1.5 tons of substrate. Uniformity and sufficient quality of preliminary preparation of the substrate makes it possible to exponentially increase the number of worms in the population, which will not only eliminate the costs of their purchase, but will also bring additional income through the use of worm biomass in livestock and poultry production chains of diversified economy or the sale of biomass to third-party consumers. Thus, the technological primecost of 1 ton of vermicompost obtained from bovine manure will make about 40 USD in the first iteration and about 15 USD in the following ones. Full primecost factors are diverse and depend on the method of composting. However, low capital intensity of production, low cost of manure as a raw material for processing, the possibility of using other organic waste and high potential of vermicompost sales will allow making advantage of scale effect and qualitatively reduce transformation costs. Profitability of these technologies will form financial flows in rural areas that can affect their socio-economic development and ensure the introduction of more capital-intensive technologies related to development of the green economy and digital transformation of Russian agriculture.

IV. CONCLUSION

Thus, the almost unlimited replication and scalability of vermicomposting technologies, creating the possibility of cost-effective production of vermicompost even at the level of family farms is the key factor of vermicompost production's high potential for inclusive green economy development in small towns and rural settlements of Russia.

There is a developed raw material basis for this purpose. Bovine annually produce more than 470 million tons of

manure in the territory of the Russian Federation. At the same time, the production primecost of 1 ton of vermicompost in the first iteration of bioconversion, where the main costs are generated by purchase of initial worm population, does not exceed 40 USD for 1 ton. In the following iterations the primecost becomes equivalent to the cost of purchased substrate because of exponential breeding of worms, and may be additionally docked by selling excessive worm biomass. Sale of worms has broad prospects of application for the production of feed in poultry and aquaculture breeding.

Universal characteristics of vermicopost as a means of expanded reproduction of soil fertility, increase in the quantitative and qualitative indicators of the harvest of almost all agricultural crops creates a significant potential for its sale both in Russia and abroad. Application of even small amounts (1.5-3 t/ha) of vermicompost ensures qualitative yield increases, which can exceed 30%. At the same time, with regard to sales prospects, it should be mentioned that, as of 2019, the acreage in the Russian Federation amounted to more than 79.5 million hectares, most of which were cultivated in the conditions of intensive, chemicalized agriculture, where vermicompost particularly reveals its potential both in the short-term economic effect of crop growth, and in the long-term aftereffect of reclamation and soil humification. Storage duration, relatively small volume, possibility of producing more concentrated preparations with increased content of coprolites on the basis of vermicompost give a high potential to the export of Russian vermicultural products.

A particularly important ecological and economic aspect of vermiculture consists in the possibility of using vermicompost in purely organic crop production, corresponding to Russian and international standards of organic production, and its high efficiency in combination with chemical fertilizers and pesticides. The ability of vermicompost to reduce the content of nitrates in the final product creates quite attractive opportunities for high-intensity crop production, achieving maximum yields and profits per 1 hectare of arable land.

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