

Directions for Developing Industrial Bioconversion of Organic Waste in Russia

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Abstract- This work's purpose is to study the industrial composting of organic waste as an environment for the development of research and production cooperation. The problem of the organic waste processing of the agro-industrial complex and housing and public services is one of the key factors of environmental safety while having a high potential for the introduction of innovative biotechnologies. In the western world, organic waste is practically not subjected to unsafe disposal for the environment, instead of being the raw material for bioconversion into environmentally sound substances, including those subject to further profitable use in agricultural and industrial production. The scalability and replicability of these biotechnologies allow them to be adapted for implementation in Russian conditions. The technologies of bioconversion of agricultural and municipal organic waste, represented primarily by wastewater mud of different chemical composition, as well as livestock breeding complex and litter manure, based on their processing by earthworms, specialty crops of microfauna and microflora, were studied, for which the methodology of system analysis, comparative and monographic methods were used. The result of the work is the generalization and system integration of the most advanced experience of biotechnological processing of organic waste, which allowed to develop a provisional concept of expanded reproduction of soil fertility as a binary ecological and economic system and to offer innovative technologies for the processing of organic waste, adapted to Russian conditions.

Keywords: *composting of organic waste, waste water mud, vermiculture, vermicompost, biohumus*

I. INTRODUCTION

The direction of sustainable development, commonly referred to as "green economy", which is relevant both in scientific and practical aspects, is a system of environmental and economic problems associated with the break-in correlation between the growth of industrial and agricultural production on the one hand, and the increase in the burden on the environment on the other.

The concept origin is associated with the UN Organization on environmental protection, which in 2008 formulated the so-called "Green economic initiative", where the concept of "green economy" was identified with the improvement of human well-being and social equality while significantly reducing environmental risks [1].

At the same time, the diversity of environmental problems and the risks created by them, combined with the diversity of the scientific achievements that can potentially solve these problems in a way that is beneficial for the national economy, allows us to consider the prospects filling of this doctrinal international paradigm with real content. The economic component of the "green economy" as a binary system has an equal priority with the environmental one, since its main task is sustainable development in the interests of live and future generations of mankind, increasing their incomes and life quality in general.

In this aspect, particularly relevant opportunities for systemic unity of environmental and economic factors are formed by the problems of the introduction of innovative technologies for processing municipal and agricultural waste. It is well known that even in medium-sized settlements, the annual generation of waste amounts to hundreds of thousands of tons, and the vast majority of these volumes are buried in landfills, and sometimes outside them with particularly gross violations of environmental legislation. The need to process organic waste is a global problem. S.A. Bhat and co-authors note that the annual output of municipal and industrial waste is up to 4 billion tons, while only about 1.2 billion tons of this garbage is a relatively environmentally sound of solid waste [2].

In Russia, there are currently more than 15 thousand registered landfills with waste, the number of illegal places of waste storage for obvious reasons is difficult to calculate. However, even legal and regulatory waste disposal creates

significant environmental risks, as the waste degradation processes, as well as their periodic ignition, bring a lot of toxins into the soil, atmosphere, water bodies and underground water levels. At the same time, landfills used for waste disposal, due to their proximity to human settlements and advantageous logistic location, potentially have significant economic value. The landfill territory freed from waste can be reclaimed for its introduction into agricultural circulation or used for construction.

Also, the disposal of solid municipal waste leads to economic losses and underutilization of suitable for cost-effective recycling of raw products. Thus, in Russia, landfills annually receive up to 9 million tons of paper and cardboard, up to 1.5 million tons of non-ferrous and ferrous scrap metal, up to 2 million tons of polymers, and edible by-product in this mass is up to 20 million tons [3].

According to A. Cesaro, A. Conte and co-authors, among solid municipal waste generated in the EU, the organic fraction is 30-40% [4].

In Russia, due to the undeveloped system of waste sorting and of animal waste conversion, about 70% of waste volume is organic nature, which enables the extremely wide potential of biotechnology composting with rather simple and known to mankind through many centuries the technological basis, the effectiveness of which qualitatively increases with the use of the latest achievements of microbiology, vermiculture, and a diverse engineering solutions for more effective processes of preparation, placement and rotation of the processed substrate. The bioconversion final product is an effective means of increasing crop yields and reclamation soil qualities, which allows us to consider the composting development of organic waste as an important mechanism for ensuring the extended reproduction of soil fertility in the country.

II. MATERIALS AND METHODS

Purpose of the article is to study the prospects for the development of industrial composting of organic waste in Russia as an environment for the development of research and production cooperation and the basis for the practical implementation of elements of the green economy.

The article materials are foreign and Russian studies of waste processing biotechnologies, the replicability, and scalability of which will allow their implementation in the conditions of small and medium enterprises in rural areas. The research is based on the methodology of system analysis, the comparative and monographic methods. The work result is the generalization of the most advanced experience of biotechnological processing of organic waste, which allowed to develop a provisional concept of extended reproduction of soil fertility as a binary ecological and economic system and to offer new technical solutions for the processing of organic waste, adapted to Russian conditions.

III. RESULTS AND DISCUSSION

Composting of organic waste is a biological process in which cultures of microorganisms and macro-organisms living in the substrate formed from waste feed on organic substances, converting them into waste products. The waste products give compost as the final product of bioconversion

qualitatively new properties, namely environmental safety, absence of toxins and pathogenic microorganisms and high nutrients content for plants, which allows its wide and profitable application in agriculture.

In the natural processes of organic decomposition involved more than 2 thousand bacterial species and about 50 fungal species, while composting is a process at the same time destructive and synthetic, which implies the saturation of the processed substrate valuable waste products of the organisms inhabiting it, in particular, humic and fulvic compounds. Both natural and artificial decomposition of organic matter can be carried out only by microorganism populations, but the most rapid and high-quality processing is carried out by earthworms in a complex symbiosis with bacteria, where the protozoa provide food for worms. Vermicompost has a higher microorganism population useful for worms and plants. Worm populations of the species *Eisenia fetida*, which are most effective in processing the substrate, carry out their activities in symbiosis with microorganisms such as *Bacillus* spp.: *B. megaterium*, *B. pumillus*, *B. subtilis* [5].

Composting is similar to natural processes of organic decomposition, which created optimal technological conditions that accelerate bioconversion and improve the quality of the final product.

This process is based on the decomposition of the complex compound of processed organic into simple substances in the form of carbon dioxide, water, minerals, and compost. The thermal energy released during bioconversion destroys pathogenic microorganisms and weed seeds in the substrate.

The speed and quality of substrate processing can be very diverse and depend on many conditions, but in general they correlate with the optimal composition of the prepared substrate, providing a balanced nitrogen and carbon content and close to neutral acid-base balance, as well as the temperature inside the substrate and the availability of oxygen for the composting population of organisms.

The nitrogen and carbon ratio in the substrate is particularly important in the technological aspect of waste processing. Carbon is an energy source for the growth of substrate organisms, nitrogen is their protein source.

In a generalized sense, the optimal composition of the substrate is characterized by an indicator of 25-30 parts C per 1 part N, but the characteristics of the life of different organisms and raw materials can change this proportion from 20:1 to 40:1, and its excess in one direction or another creates the need for mixing in the substrate of various wastes and the addition of minerals. Thus, the most optimal balance of carbon and nitrogen on average 30:1 has different manure types, the ratio for poultry manure close to 20:1. The wastewater mud on average is particularly saturated with carbon (100-130:1), and food waste is characterized by ratios in the range of 10-40:1, but the carbon content of fruit residues is increased and can reach 80:1. Waste conversion on an industrial scale is particularly demanding to the optimal C/N ratio, which affects the rate of bioconversion and several other parameters since industrial composting carries the risk of mixing different categories of waste and substrate of varying degrees of readiness [6]. The C/N ratio

decreases during bioconversion as nitrogen fixation are absorbed by the substrate population, and the final product with optimal quality is 10-15:1.

The composting process is completed as the exhaustion of suitable nutrients in the substrate, so the timely rotation of the latter at an industrial scale of production is a labor-intensive process when using manual labor or has a relatively high capital intensity in its mechanization and automation.

Cultured organisms in the substrate are particularly in need of water for their metabolic processes, so, as a rule, the optimal moisture content of the substrate is from 40 to 60 %, below this indicator, the activity of the population decreases, ceasing at a humidity below 15%. When exceeding 65 %, air access to the substrate becomes difficult, which forms anaerobic conditions that slow down the bioconversion process. The bioconversion process requires significant amounts of oxygen, the optimal content of which in the substrate is on average from 16 to 18.5 %, which creates the need for either the optimal size of containerized and containerless of the substrate layings or its ventilation and mixing with special equipment in the version of mechanized production. On an industrial scale, oxygen delivery to the substrate is a key factor in temperature and humidity control.

The air intake affects the activity of microorganisms in the substrate, aeration below 0.2 liters per kg of substrate per minute slows down the assimilation of organic matter by the substrate population, leads to a loss of temperature and humidity, content reduction of NH₃. The index in the range of 0.2-0.6, according to the data A. Cesaro and A. Conte [4] has the opposite effect on the speed and quality of substrate bioconversion.

With regard to the acid-base balance in bioconversion, it should be noted that its optimal level, depending on the conditions, is from 6.5 to 8.

The duration of a single iteration of the bioconversion process, depending on these main factors, ranges from two weeks to nine months. An important factor in the bioconversion rate is also the physical and chemical properties of the so-called bulking agent, which is an organic material with high carbon content. The optimal bulking agent is straw, but shredded paper, cardboard, and dry leaves are suitable for this purpose, which is important for recycling municipal waste, and various other lignocellulosic substances can be used [7]. However, for the conditions of Russia with its developed timber manufacturing industry, the possibility of using the bark of softwood trees as such is relevant. It, in comparison with straw, slows down the bioconversion process of the substrate, but provides a higher content of humic substances in the final product, improving its efficiency as a fertilizer [8].

Thus, obtaining a quality substrate provides a wide variability for mixing recyclable waste with other organic and mineral substances. For example, greater efficiency is demonstrated by the addition of slime phosphorites to the substrate, which increases the conversion degree of organic matter into humic compounds and fulvic acids. The bio-coal use is also effective [9].

The most traditional method of bioconversion is cultivation in the substrate of natural and artificial microorganism populations, thus, waste processing can be successfully carried out extensively with minimum investment. Nevertheless, the science-intensive composting with the use of the preparations of effective microorganisms has a special efficiency and demand in modern conditions [10].

However, vermicomposting provides the greatest prospects for solving the organic waste problem in both environmental and economic aspects. Worms, eating organic matter in the substrate and passing it through the digestive system, disinfect the substrate, clean it from heavy metal compounds and other harmful substances, accumulating them in their tissues, and give the resulting compost several useful physical and chemical properties, saturating it with their coprolites. Mucus contained in the digestive tract of worms stimulates the activity of microorganisms, increases the biodiversity of their populations, thus accelerating the decomposition courses of organic and the substrate humification [11].

The main aspect of the fundamental scientific content of this direction is the worm selection with the development of the hybrids, qualitatively superior to the natural worm species in the number and quality of coprolites, as well as adaptability to different substrate species. The most significant merit of the Russian biological science here is the derivation of A. M. Igonin hybrid "Prospector" from worms soil-inhabiting of the European North of Russia and the Chuya valley. This hybrid in the number of indicators exceeds even the most common in the world vermiculture Red California Hybrid, obtained by scientists of the California Institute of Technology (CIT) in 1959 [12].

Among the Russian patents related to organic waste bioconversion, the largest share is occupied by vermicomposting (18 patents), followed by the use of effective microorganisms (7 patents).

Biohumus obtained by substrate processing of earthworms, qualitatively superior to the microbial products without symbiosis with worms. Worms coprolites contain up to 35 % of the active substance in the form of soluble and insoluble humus. The introduction of coprolite concentrate increases the yield of agrobiocenosis, depending on the soil and cultivated crops, by an average of 15-30 %, also, the quality of final agricultural products increases, the concentration of nitrates and other undesirable chemical compounds decrease. Concentrated organic fertilizers obtained from coprolites have even greater economic efficiency, in the conditions of Russia increasing the profitability of winter wheat cultivation with the use of such concentrates to 55 %, and sunflower to 167 % [13].

Also, the vermicompost introduction increases the bioremediation efficiency of heavy metals, in particular, lead, allowing them to clean the soil by cultivating certain industrial crops [14].

However, a particularly relevant aspect of vermicomposting is forcing the soil humification process, which in natural conditions increases only about a centimeter of the humus layer per century. Insoluble humus contained in coprolites improves and structures the soil,

binding in insoluble forms of heavy metal compounds, qualitatively improving the granulometric structure. Soluble humus is a source of high nutrient humic acids for plants, and, also, affects the immunostimulation of plants, their resistance to droughts and frosts. At the same time, vermiculation technologies have an extremely wide potential for replication and scalability, allowing for profitable production of vermicompost on a large scale with special equipment, and in small family farms by placing the substrate in storage pits with their maintenance by human labor.

However, the high potential of production efficiency and vermicompost application, proven by many scientific types of research and practical experience, in the Russian conditions faces significant limitations of natural and technical nature. Climatic conditions allow vermicomposting of organic waste outdoors, but in such conditions bioconversion will be extremely long, processing by worms of 1 ton of substrate can take 120 days or more, it can be carried out no more than 250 days a year. The final product quality will also be reduced due to suboptimal temperature and humidity conditions in the substrate, depressing populations of worms and microorganisms. The use of buildings is associated with certain economic constraints. The currently developing small-scale industry of vermicompost by the simplest container technology, focused on gardening and carried out in basements, sheds, garages, etc. small-scale utility rooms can be economically viable and environmentally useful, but it is not able to reveal the ecological and economic potential of this direction on a national scale. This requires industrial processing of the substrate in heated rooms of a large area, where possible options are either the conversion of livestock facilities or the construction of hangars. In both cases, the scale of lump-sum capital investment in their arrangement on average is not less than 30-50 thousand us dollars. As a rule, both cowsheds and hangars differ in the considerable height of internal volume in 4 and more meters. However, the currently existing technical solutions do not have a vertically oriented modular structure, which would allow the most effective use of the heated capacity, qualitatively increasing the economic efficiency of the expensive area. Also, heating the substrate has a qualitatively higher energy efficiency than maintaining the desired temperature in the room as a whole. Artificial populations of *Eisenia fetida* are very demanding of the temperature and humidity conditions of their habitat, with a departure from the optimum substrate temperature of 20-25 °C, the population is oppressed, significantly reducing the biomass yield of worm and coprolites. Currently, a few Russian enterprises engaged in commodity production of vermicompost, mainly use the storage pit method, which is characterized by a slow process of bioconversion, the physical parameters of the storage pit create limits of its effective size and do not allow evenly provide optimal conditions for reproduction of worm biomass and coprolite production. However, there is a reserve of efficiency improvement storage pit method of composting due to technological innovations, including applications for covering storage pit of semipermeable membrane Gore-Tex that allows to optimize the operating temperature condition of the substrate and contribute to the development in it of thermophilic microorganisms involved

in hydrolysis of organic substances and speed up the substrate processing [15].

The use of nonmechanized container technologies for vermicomposting of organic waste due to its complexity is difficult to scale for large-scale production, since the cost of paying for manual labor will significantly increase the product cost.

Russian bioreactor installations of continuously-operated exist only patents on development, and their foreign analogs are mainly built-in piece copies for each specific project and differ in capital intensity inaccessible for small and medium enterprises. At the same time, ecological and economic sustainability of village development in Russia can be achieved only through the creation of new cost-effective lines of production in rural areas, and the creation of replicable and scalable vermicomposting technologies can serve as a key means of solving this problem and ensuring extended reproduction of soil fertility.

Vermicompost production in continuously-operated bioreactors is the most promising variant for solving these problems. In the interests of sustainable development of Russian rural areas, it is necessary to take into account the interests of small and medium enterprises, which are not available to capital intensive individual projects for the construction of large bioreactors, so replicable and scalable technologies with lower expenditures connected with their acquisition are necessary.

The best basic substrate for vermiculture on an industrial scale is litter manure, especially from cattle. But at the same time, the exceptional ecological significance of this direction is given by the possibility of processing various wastewater mud, food waste and other environmentally unsafe organics. For example, there is an experience of successful processing of wastewater mud of paper manufacture when they are mixed with the biowaste of cattle in a proportion of 50-75% with cultivation in the substrate of the worms population *Eisenia fetida* and fungus *Oligoporus placenta* [16]. Worms also most effectively apply themselves in symbiosis with effective microorganisms in the processing of dairy waste [17].

Also, the vermiculture use in bioconversion of wastewater mud significantly reduces the emission of associated greenhouse gases [18].

The relationship between vermiculture and aquaculture is particularly important for the development of end-to-end technologies in agriculture and sustainable rural areas. *Eisenia fetida*, two species which in optimal conditions for the year leave up to 1500 offspring species, which allows the processing of 1 ton of substrate to get up to 100 kg of worms biomass, is a valuable feed additive, including for aquatic organisms. Thus, flour from the dried biomass of red Californian worms contains about 67 % protein, 20 % fat, 7-8 % carbohydrates. At the same time, the hopper bottoms saturated with organic substances, which is formed both in high-tech recirculating aquaculture system and in ordinary ponds for fish and crayfish breeding, is a valuable substrate for vermicompost production, comparable to cattle manure. According to A. Kouba and R. Lunda, the survival rate of the initially inhabited worm population in such a substrate exceeds 90 %, the number of young *Eisenia fetida* is up to

1500 species per 1 kg of substrate, and the content of heavy metals and other undesirable substances in the vermicompost does not exceed the admissible concentration limit established for such fertilizers by EU standards. Moreover, their content in the tissues of the worms themselves is safe for further use of the resulting biomass in feeding aquaculture organisms [19].

In all studies, the optimal mixing of waste with different types of manure, preferably cow, is noted, which is associated with the creation of acceptable conditions of nutrition and life in general for the worms population, oppressed by several physical and chemical factors of wastewater mud as a substrate.

Thus, the wide potential of worms adaptability to various substrates, including unfavorable for their life, has its limits, mainly associated with the toxic level of the substrate, but its preliminary chemical cleaning, fermentation and mixing with high-quality manure allow for full composting.

By themselves, wastewater mud on the content of nitrogen, phosphorus, and potassium are not inferior to manure. The least toxic varieties can be used without treatment as an organic amendment with manure-like technologies and rate applications. However, there is an increased content of lead, copper, chromium, and zinc in such agrobiocenosis [20], which gives the greatest relevance to vermicomposting of wastewater mud, since worms eliminate pathogenic organisms and toxins, and heavy metals are absorbed in their body. The population, which has carried out bioconversion of this kind, loses the suitability for further biomass use for animal feeding, but the life span of the species *Eisenia fetida* is up to 15 years, which allows their long-term cost-effective use in waste processing. Also, worm populations are suppressed and die when changing the nutrient substrate, especially suboptimal, so excess biomass with accumulated heavy metals in the tissues will ensure uniformity and stability of the recycling process.

With the proper quality of substrate preparation and composting itself to eliminate pathogenic organisms and toxins, the availability of nitrogen for crops in wastewater mud is up to 85 %, and phosphorus is from 20 to 100 % compared to superphosphate. At the same time, the content of the primary nutrient in the bio humus obtained during composting of wastewater mud can be up to 57 %.

IV. CONCLUSION

Thus, the biotechnologies development for the organic waste processing by worms and microorganisms, due to their extremely wide replication and scalability, as well as the almost universal applicability of the final product in agriculture, contains the potential for sustainable development at a qualitatively new level. The possibility of profitable conduct of both large and small enterprises in this area with the demand for science-intensive solutions and in that and this scale will create a sustainable economic basis for environmental safety and expanded reproduction of soil fertility in the interests of future generations.

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