SCIENTIFIC CULTURE
www.sci-cult.com

SCIENTIFIC CULTURE, Vol. 11, No. 3, (2025), pp. 1739-1750
Open Access. Online & Print

DOI: 10.5281/zenodo.11312625

IMPLEMENTING CLOSED-LOOP ECONOMY PRINCIPLES IN THE FIELD OF CROP WASTE AND FOOD SURPLUS RECYCLING

Irina Leonidovna Bukharina[1], Konstantin Evgenievich Vedernikov[1], Otari Nazirovich Didmanidze[2], Andrey Gavrilovich Kovalchuk[1] & Maxim Viktorovich Larionov[3*]

[1]Udmurt State University, Izhevsk, Russia. buharin@udmlink.ru, Izhevsk, ORCID: https://orcid.org/0000-0001-8084-2547
[2] Udmurt State University of Management, Moscow, Russia. wke-les@rambler.ru, Izhevsk, ORCID: https://orcid.org/0000-0002-9112-6383
[1]Udmurt State University, Russia. kovalchuk_ag@udsu.ru, Izhevsk
[2]State University of Management, Moscow, Russia. on_didmanidze@guu.ru, ORCID: https://orcid.org/0000-0003-2558-0585
[3]Russian Biotechnology University (ROSBIOTEC'H University), Moscow, Russia. m.larionow2014@yandex.ru, ORCID: https://orcid.org/0000-0003-0834-2462

Received: 27/05/2025
Accepted: 27/08/2025

Corresponding Author: Maxim Viktorovich Larionov (m.larionow2014@yandex.ru)

ABSTRACT

The article presents the comprehensive approach to solving the problems of the closed-loop economy using the example of recycling organic waste of plant origin and food surpluses in the agro-industrial complex. The comprehensive approach includes an analysis of the raw material base, waste inventory, search for and formation of the specific database of organic waste recycling technologies, provision of equipment, development of standard process flow charts and issues of developing a regulatory framework for the implementation of closed-loop economy elements in terms of testing, economic and environmental assessment of the closure of production cycles. The study focused on the Western Middle Ural Region, where crop production and livestock farming are well-developed. The study compiled the register of 400 enterprises in the district, 107 of which participated in the survey. The annual volume of unsorted food waste (130.32 tons) and crop waste (65788.2 tons) was calculated, including cereal straw (18082 tons), corn leaf and stalk mass (26711.5 tons), substandard grain (883 tons) and others. Standard waste processing process flow charts have been developed, including bioconversion by the Hermetia illucens fly larvae to produce feed additives and biohumus, and mechanized processing of plant residues into pelleted feed, biofuel, and building materials. Fundamental approaches to developing technology and product testing programs within the framework of circular economy development have been proposed, including: product life cycle assessment, material flow analysis, waste collection and recycling infrastructure development, and testing the use of secondary resources in production.

KEYWORDS: Organic Waste, Waste Recycling, Biorecycling of Waste, Secondary Raw Materials, Biotechnology, Rationalization of Nature Management, Rationalization of Agriculture, Closed Production Cycles, Economics of Natural Resource Management.

1. INTRODUCTION

The traditional economic system is focused on the production, consumption, and, ultimately, disposal of products that become waste. The vast majority of waste in this system is not recyclable, meaning this model assumes infinite natural resources and unlimited waste storage capacity. Public economic activity and the accompanying processes of waste formation and increase are now a serious problem in the modern world (Bukharina, Didmanidze, Pashkova et al. 2024; Larionov, Galstyan, Ghukasyan et al. 2024; Shama, Rajpoo & Nayak 2025). Considering that agriculture (Gorlov, Fedotova & Sergeev 2021; Galstyan, Sayadyan & Sargsyan 2023) and including crop production (Lai, Hong, Lim et al. 2016; Larionov, Minakova, Sentishcheva et al. 2021; Phiri & Chibomba 2025) is a strategic sector of the economy (Osipova, Mkrtchyan, Ghukasyan et al. 2024; Yu, Li, Si & Zhang 2024; Barooah, Sen & Chetri 2025), the issue of agricultural waste management is becoming more pressing every year. Globally, agriculture produces up to 140 billion tons of biomass, including crop and livestock waste (Barooah, Sen & Chetri 2025). With such a large volume of biomass produced, waste generation and pollution of surrounding landscapes are inevitable. At the same time, approximately 5 billion tons of crop waste are generated annually in agriculture (Barooah, Sen & Chetri 2025).

The production and sale of finished agricultural products also poses waste management challenges. Globally, the total volume of food waste reaches 1.3 billion tons annually (Lin, Chiu, Chiu et al. 2025). According to the FAO, such annual food loss amounts to 30%; this waste is mainly discarded, including into the environment (Shinde, Patwardhan, Kshirsagaret et al. 2025). The growing global population (Jabin, Nipa, Liza et al. 2025) is projected to lead to increased demand for agri-food products (Larionov, Sargsyan, Sayadyan et al. 2024; Barooah, Sen & Chetri 2025).

An environmental crisis has developed across virtually the entire territory of the Eurasia (Larionov 2013; Yu, Li, Si & Zhang 2024; Gubiy, Isa, Zhang & Kozlov 2025; Lin, Chiu, Chiu et al. 2025; Todde, Sole, Sara et al. 2025). For example, Russia is among the leading countries that still practice the disposal of unsorted waste. The largest volume of such unauthorized (spontaneously generated) waste landfills is located near settlements (up to 58%), water protection zones (up to 16%), agricultural lands (up to 15%), and forest lands (up to 8%) (Osipov 2021). Waste incineration, a practice common in a number of Western countries and being developed in Russia, is recognized as economically and environmentally damaging (Osipov, Galitskaya & Zaikanov 2022). The practice of burning crop residues is widely used worldwide. In particular, burning crop residues is a major contributor to CO2, PM2.5, and a number of other pollutants in the environment (Yu, Li, Si & Zhang 2024).

Agricultural waste can also be considered agricultural products. This is true if they are incorporated into circular production (Vivallos Soto, Ruiz Bertín, Robles Calderón et al. 2022; Bukharina, Didmanidze, Pashkova et al. 2024). However, these materials pose environmental risks to biota, soil and other environments, and public health. Agricultural waste from extensive economic activities contributes to the pollution and degradation of cultural landscapes (Vivallos Soto, Ruiz Bertín, Robles Calderón et al. 2022; Gebrehana, Mesfin, Chernet et al. 2025), an increase in greenhouse gas formation (Vivallos Soto, Ruiz Bertín, Robles Calderón et al. 2022; Bukharina, Didmanidze, Pashkova et al. 2024; Singh & Monica Rajpoot 2025), and an increase in fire hazard (Vivallos Soto, Ruiz Bertín, Robles Calderón et al. 2022;), especially in dry weather and under conditions of global warming (Slavskiy, Litovchenko, Matveev et al. 2023; Sargsyan, Tovmasyan, Gharakhanyan et al. 2025; Slavskiy, Vodolazhsskiy, Mironenko et al. 2025). Waste from crop production and the agro-industrial sector is declining the resource value and ecosystem services of cultivated landscapes and surrounding natural ecosystems (Debsingha, Choudhury, Choudhury et al. 2025). The environmental trend toward increased waste generation and its increasing hazards to living organisms, humans, and the environment is projected to continue to grow globally (Saxena, Khan, Bhattacharya et al. 2025).

Currently, the closed-loop economy model is actively developing, based on a systems-oriented approach that includes restorative or regenerative industrial processes. Resources used in such processes retain their value for as long as possible through the elimination of waste and improved design of materials, products, and systems (including business models). A circular economy reduces material use, recycles materials and products, making them less resource-intensive, and returns "waste" as a resource/raw material for the production of new materials and products (Moreau, Sahakian, Van Griethuysen et al. 2017; What is a Circular… 2025). It is stated that greening of waste management consists of three main components: consumption reduction, composting of organic waste, recycling of waste into useful materials (resources and goods), into energy and into related services (Shama, Rajpoot & Nayak 2025). That is, the implementation of a circular economy is based on the idea and search for opportunities for the rational consumption of natural resources and the maximum implementation of waste recycling (Ahmed, Nabi, Mia et al. 2025; Elhrari, Abdalgader, Elaziby et al. 2025). This is a serious environmental and economic challenge in the current production reality (Bukharina, Didmanidze, Pashkova et al. 2024; Castillo 2025). Thus, the primary goal of a circular economy is to ensure that natural resources consumed in production have an indefinite lifespan through the reuse of waste generated in production and the products derived from it.

In this paper, we focused on organic waste from the agro-industrial complex, as it offers significant potential for use in closed-loop production cycles in the agricultural sector. A pressing challenge is to produce new products for the agro-industrial complex (such as feed additives, organomineral fertilizers, and fuel and feed pellets) from organic waste. The system for recording organic waste in the agro-industrial complex (and specifically in crop production) is imperfect, preventing the development of production chains. Therefore, an inventory of sources of organic waste and plant-based waste is highly relevant for the organic waste recycling industry (Druzhakina 2020; Artahov 2021; Subrakova 2021; Lavrova 2023; Epishov 2025; Stol 2025).

In this regard, the main objectives of the work were: inventorying the sources and volumes of plant-based waste; obtaining data on the technological and production processes of agricultural enterprises as sources of waste generation; determining the quantity, morphological composition, and movement of waste in order to develop standard process flow diagrams for recycling and disposal, creating secondary raw materials, closing production cycles, and compiling a package of materials for a database for the creation of a multivariate digital model of technological processes that close the production cycles of agricultural production.

The research was conducted in the Western Middle Ural Region (the Alnashsky District of the Udmurt Republic). The register of business entities was compiled using the information system of the Alnashsky District Administration, which contains over 400 registered businesses and organizations.

A differentiation was made between enterprises and organizations whose economic activities generate organic waste of plant origin based on a survey of 107 economic entities.

Requests were also made to the Ministry of Natural Resources and Environmental Protection of the Udmurt Republic; the West Ural Interregional Office of the Federal Service for Supervision of Natural Resources Management for the provision of data contained in federal statistical monitoring forms (No. 2-TP (waste)); and the Territorial Office of the Federal State Statistics Service for the Udmurt Republic on sown areas, gross harvest, and crop yields in the Alnashsky District of the Udmurt Republic. Purpose and objectives of the study. The main objectives of the study were: inventory of sources and volumes of plant-based waste; obtaining data on technological and production processes of agricultural enterprises as sources of waste generation; determining the quantity, morphological composition, and movement of waste in order to develop standard process flow diagrams for recycling and disposal, creation of secondary raw materials, closing production cycles, and the formation of a package of materials for a database for the creation of a multivariate digital model of technological processes that close production cycles in agricultural production.

2. MATERIALS AND METHODS

The objects of the study were economic entities of the Western Middle Ural Region (on the territory of the Alnashsky District of the Udmurt Republic) generating organic waste of plant origin. The analysis focused on enterprises of the agro-industrial complex (AIC), including agricultural organizations, canteens of educational and medical institutions, and catering establishments (cafes, restaurants). The main categories of waste studied were: unsorted food waste from kitchens (vegetable peelings, substandard products) (Elinder, Colombo, Patterson et al. 2020; Pancino, Cicatiello, Falasconi et al. 2021; Heiges, Lee, Vollmer et al. 2022; Pahmeyer, Siddiqui & Pleissner 2022), by-products of crop production (cereal straw, corn leaf and stem mass, husks, low-quality grain), and agricultural processing waste (Haryanto, Isbintara, Juniarsih et al. 2023).

The methodological basis of the study included a comprehensive approach combining a number of methods: inventory of waste sources – formation of a register and differentiation of agricultural enterprises based on information on production processes, morphology, volumes and movement of waste; statistical and analytical methods – processing of data from federal statistical observation forms No. 2-TP (waste) provided by the West Ural Department of the Rosprirodnadzor, as well as Udmurtstat data on agricultural crop yields for 2021–2023; normative and calculation approaches – the application of approved standards for waste generation and coefficients for converting raw materials into by-products (for grains, corn, legumes); technological modeling — development of standard processing schemes, including bioconversion using Hermetia illucens fly larvae to obtain feed and zoohumus, as well as mechanized processing of plant residues (drying, grinding, granulating) into feed, biofuel and building materials; experimental verification – comparison of estimated waste volumes (based on standards) with actual disposal data obtained from contracts and acceptance certificates; information and reference analysis – use of specialized sources (Bukharina, Zhuravleva & Vedernikov 2020; Bukharina & Kovalchuk, 2023; Bukharina IL, Didmanidze, Pashkova et al. 2024; Bukharina, Pashkova & Kovalchuk, 2024).

3. RESULTS AND DISCUSSION

Food waste from kitchens and public catering establishments. Waste generated as a result of the activities of public catering establishments is regulated by the SanPiN 2.1.3684-21 (Sanitary and epidemiological. 2025).

The calculation of annual waste generation was made using the example Federal Budgetary Institution "Federal administration for safe storage and destruction of chemical weapons" under the Ministry of industry and trade of the Russian Federation (FBI "FASSDCW"). The number of dishes prepared is 108,186 items per year, 100 of which are served. The standard for food waste generation per dish prepared is 0.01 kg per day (Collection of specific… 1999; Sanitary and epidemiological… 2025). Summary data on waste generation standards and maximum annual waste generation amounts are provided in Table 1.

Table 1: Summary Data on Waste Generation Standards and Maximum Annual Amount of Waste Generation.

Name of the type of waste according to the Federal Classification of Waste	Code according to the Federal Classification of Waste	Indicator,dishes per year	Waste generation standards		Maximum annual amount of waste generation
			Unit of measurement	Size	
Food waste from kitchens and catering establishments (unsorted)	73610001305	108186 dishes per year	t/dish	0.000010	1.081860

The practice of food waste disposal shows that 95% of food waste from the canteen is waste of plant origin (Elinder, Colombo, Patterson et al. 2020; Pancino, Cicatiello, Falasconi et al. 2021; Heiges, Lee, Vollmer et al. 2022; Pahmeyer, Siddiqui & Pleissner 2022), by-products of crop production (cereal straw, corn leaf and stem mass, husks, low-quality grain), and agricultural processing waste (Haryanto, Isbintara, Juniarsih et al. 2023). In the process of food waste disposal at the Federal Budgetary Institution "Federal administration for safe storage and destruction of chemical weapons" (FBI "FASSDCW"), the estimated annual amount of food waste was determined (Table 2).

Table 2: Food Waste Removed and Accepted for Disposal by the Federal Budgetary Institution "Federal Administration for Safe Storage and Destruction of Chemical Weapons".

Month, 2024.	Mass, t
January	0.074
February	0.081
March	0.080
April	0.090
May	0.080
June	0.081
July	0.090
August	0.091
Total	0.667

The ratio of the generation standard to the actual value of recycled waste for the first 8 months of 2024 was: 0.721/0.667 = 1.08. Thus, the waste generation standards for unsorted food waste of the FBI "FASSDCW" can be used to calculate the maximum annual amount of unsorted food waste generated by canteens and catering establishments (cafes, restaurants, etc.).

Based on inquiries to the Alnashsky District Administration (the Western Middle Ural Region), it was determined that the total number of food service establishments was 31, including six cafes, 24 cafeterias at educational institutions, and one cafeteria at the Varzi-Yatchi sanatorium. When calculating the number of dishes to be prepared, the meal schedules of schoolchildren, preschoolers, staff, and visitors were taken into account. The estimated annual volume of unsorted food waste was 130.32 tons.

3.1. Standard Technological Scheme for Complex Processing of Waste from Public Catering Enterprises

Based on the results of the inventory of organic waste of plant origin, it is possible to recommend the use of the scheme for processing and creating secondary products/closing production cycles) (Figure 1) using the black soldier fly larva (Hermetia illucens), which has the ability to utilize a variety of wastes, having high bioconversion rates. Both the larva and the product of its vital activity (zoohumus) have valuable properties for the production of feed additives and organomineral fertilizers for the agro-industrial complex and other industries (antimicrobial peptides, vitamins, immunostimulants, zoohumus for the restoration of degraded and disturbed lands, MSW landfills at the biological stage of reclamation) (Peters 2020; Ferdousi, Sultana, Al-Helal et al. 2021; Bongiorno, Gariglio, Zambotto et al. 2022; Rasdi, Hua & Shaifuddin 2022; Salam, Seyedalmoosavi, Mielenz, Veldkamp et al. 2022; Shahzadi, Zheng et al. 2022; Phongpradist, Semmarath, Kiattisin et al. 2023).

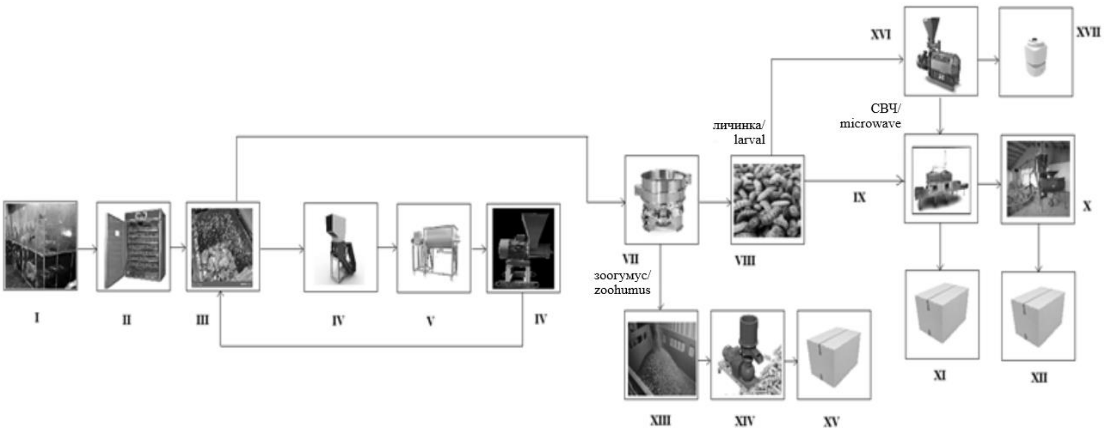

Figure 1: Principal Typical Technological Scheme of Complex Processing of Wastes of Cereal Grains, Corn, Leguminous Crops (Including Products Based on Them That Have Lost Their Consumer Properties [Fodder, Forage]), Vegetable Crops, and Wastes of Vegetable Origin during Cooking by the Larva of the Black Soldier Fly (H. illucens).

3.2. Calculation of the Maximum Annual Amount of Plant Waste from Agricultural Enterprises in the Western Middle Ural Region (Alnashsky District, Udmurt Republic)

There are no standards for the generation of plant-based waste from agricultural production. Various information sources were used to calculate the annual amount of plant-based waste from agricultural enterprises (Collection of specific… 1999; Bogatyreva, Seraya, Biryukova et al. 2016; Food production. ITS… 2017; AGRO-S 2025; Development designers, engineers. 2025).

Grain waste is generated during the cleaning, drying, storage, and processing of grain. For cereal crops, the volume of grain waste accounts for up to 75% of the raw material mass (Food production. ITS… 2017). The results of calculating the annual amount of corn waste based on the average yield and the percentage of grain, cobs (excluding grain), leaves, and stems relative to the total plant mass are presented in Table 3. The raw material base of corn waste for the preparation of animal feed was established at 35766.2 tons/year.

Table 3: Results of Calculating the Annual Amount of Corn Waste from the Average Yield for the Period 2021–2023.

Average gross yield, t	The ratio of the mass of grain, cobs (without grain), leaf-stem mass to the total mass of plants, %	Mass of different parts of the plant, t
56592	Corn grain – 36.8%	Corn grain – 20825.8
	Corn cobs (without grains) – 16.0%	Corn cobs (without grains) – 9054.7
	Leaf and stem mass – 47.2%	Leaf and stem mass – 26711.5

The results of calculating the annual amount of waste from other grain crops are presented in Table 4. Thus, 22662 tons/year of waste from grain crop production can be used as raw material for the production of secondary products.

Table 4: Results of Calculation of the Annual Amount of Waste Grain Crops.

Name of the crop	Average gross yield, t	Grain, t	Straw, t	Husk, t	Substandard grain, t
Winter rye	2419	726 (30%)	1392 (57.5%)	242 (10%)	60 (2.5%)
Spring wheat	8230	3170 (38.5%)	4120 (50.1%)	823 (10%)	117 (1.4%)
Spring barley	19782	7815 (39.5%)	9450 (47.8%)	1978 (10%)	539 (2.7%)
Oats	6541	2600 (39.7%)	3120 (47.7%)	654 (10%)	167 (2.6%)

Peas are the primary legume crop grown in the Western Middle Ural Region. Calculations of the annual pea waste (with the green mass yield of 200–300 c/ha) are presented in Table 5.

Table 5: Results of Calculating the Annual Amount of Pea Waste.

Name of the crop	Average sown area, ha	Green mass (raw), t
Peas	368	7360

Thus, 65788.2 tons/year of plant waste from agricultural production in the Western Middle Ural Region can be used as raw material for the production of secondary products (Table 6).

Table 6: Quantity of Waste of Plant Origin Serving as Raw Material for the Production of Secondary Products of the Agro-Industrial Complex of the Western Middle Ural Region (Alnashsky District).

Name of waste	Mass, t/year
Straw of grain crops	18082
Husks of grain crops	3697
Substandard grain of cereal crops	883
Green mass of grain legumes (raw)	7360
Corn cobs (without grains)	9054.7
Corn leaf and stem mass	26711.5

The following typical technological scheme for processing and creating secondary products, closing production cycles, can be recommended for the disposal of plant waste (Kryuchkov 2024; Markin & Kryuchkov 2025) (Fig. 2).

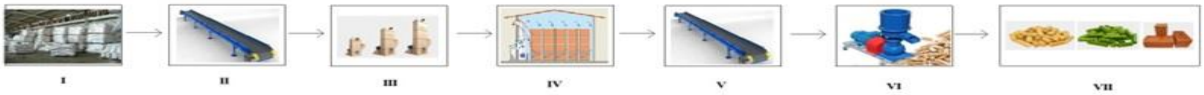

Figure 2: Typical Technological Scheme of Processing and Creation of Secondary Products, Closing of Production Cycles; I – Warehouse of Raw Materials (Straw, Grass Mixture [Stalks and Leaves of Corn, Peas, Including in a Mixture with Bark Grasses]), II – Transporters for Separate Feeding of Raw Materials for Drying and Grinding, III – Units for Drying and Grinding of Raw Materials, IV – Heat Generators (Bringing to the Required Humidity), V – Transporters to the Pelletizing Line, VI – Granulators, VII – Packaging of Finished Products (Animal Feed, Including Vitaminized; Production of Grass Meal; Biofuel; Use for Production of Building Materials [Porous Bricks, Etc.]).

Thus, a pressing and common goal for developing a circular economy in all countries is to increase the use of recycled materials for the production of new products. In an ideal resource recycling model, natural resources should serve as a reserve source. Such conditions for agricultural production have been created in many countries. In Russia, the complexity of solutions is due to the wide variety of climatic conditions, agricultural crops and their productivity (e.g., grain ripening), meteorological conditions during the growing season, complex territorial logistics, etc.

In our work, using the example of one of the agricultural regions of the Udmurt Republic, based on an inventory of waste from crop production and public catering enterprises, we proposed an algorithm for calculating the resource base for recycling and obtaining secondary products, as well as standard technological schemes for complex processing, which can be replicated in other regions, including two blocks of technologies: recycling of production and consumption waste in the agro-industrial complex (including solving the problem of "multi-production"); and recycling of production and consumption waste, ensuring "closing the loop."

We believe that our developments have advantages in the conditions of the Western Middle Urals (agricultural crops, coefficients, and yields are taken into account). The developments have undergone targeted testing in the production conditions of a developed agricultural region of one of the constituent entities of the Russian Federation.

The development and implementation of circular economy principles and technologies require more than just a digital environment for selecting and analyzing the effectiveness of production solutions. A system of standardization and regulatory frameworks must be developed. Testing both the technologies and products themselves, as well as the closed-loop system, is crucial (Pozdeev 2021; Pozdeev & Astrakhanceva 2022; Shamsutdinova, Astrakhantseva, Ignatiev et al., 2022; Antonov 2024).

The closed-loop manufacturing test program is not a standard document, as the concept of the "Circular Economy" focuses on the principles of waste minimization and resource maximization, rather than a specific production test program. Instead, implementing circular economy principles requires testing that includes: product life cycle assessment, material flow analysis, waste collection and recycling infrastructure development, and testing the use of secondary resources in production. In our opinion, **such the program should include the following stages**

1. Product life cycle analysis (LCA): examining all stages – from raw material extraction to disposal or recycling – to identify opportunities to reduce waste and resource consumption;
2. Waste collection and recycling system development: analyzing infrastructure and technologies for efficient waste collection, sorting, and recycling;
3. Recycled resource use testing: trials aimed at integrating recycled materials (from recycled waste) into existing or new production processes;
4. Prototyping and pilot production: creating and testing product samples developed with circular economy principles in mind, and launching pilot batches in real-world conditions;
5. Modeling and evaluating economic/ecological efficiency: calculating the costs and benefits of implementing circular processes and comparing them with traditional linear models;
6. Traceability system: implementing technologies (e.g., blockchain) to track the movement of waste and recycled resources throughout the value chain.

4. CONCLUSION

The inventory of the sources and volumes of formation of organic plant waste and consumption waste in the agro-industrial complex (AIC) in the Western Middle Ural Region (Udmurt Republic) was conducted. The resource base assessment algorithm can be replicated.

Standard technological schemes for the integrated processing of waste and the closure of production cycles have been developed.

It is essential to develop a system of standardization and regulatory frameworks for the circular economy. The testing phase of both the technologies and products themselves, as well as the closed-loop system, is crucial. We have formulated the key stages of the program for testing closed-loop production technologies as a key element of standardization in the circular economy.

Acknowledgements: The article was funded by the Ministry of Science and Higher Education of the Russian Federation, Agreement No. 075-15-2024-542.

REFERENCES

AGRO-S. 2025. URL: http://agro-s.com/ (accessed 20.09.2025).

Ahmed, M., Nabi, H.B., Mia, S., et al. 2025. Valorization of Plant-Based Agro-Waste into Sustainable Food Packaging Materials: Current Approaches and Functional Applications. Applied Food Research 5(2): 101368. https://doi.org/10.1016/j.afres.2025.101368

Antonov, S.A. 2024. Formation and development of the standardization system in ensuring the transition to a closed-loop economics. Abstract of the Dr. of Sci. St. Petersburg.

Artakhov A.B. 2021. Entomo-Industry of Hermetia Illucens. Vestnik of the Plekhanov Russian University of Economics (4): 61-70. https://doi.org/10.21686/2413-2829-2021-4-61-70

Barooah, M., Sen, S. & Chetri, P. 2025. Biotechnological Approaches for Agricultural Waste Management. In: Biotechnological Applications in Industrial Waste Valorization. Interdisciplinary Biotechnological Advances. Singapore: Springer. https://doi.org/10.1007/978-981-96-2302-0_7

Bogatyreva, E.N., Seraya, T.M., Biryukova, O.M., et al. 2016. Conversion coefficients of grain and seed in by-products and the content of main nutrients in by-products of agricultural crops in the Republic of Belarus. Soil Science and Agrochemistry 2: 78-89.

Bongiorno, V., Gariglio, M., Zambotto, V., et al. 2022. Black soldier fly larvae used for environmental enrichment purposes: Can they affect the growth, slaughter performance, and blood chemistry of medium-growing chickens? Front. Vet. Sci. 9: 1064017. https://doi.org/10.3389/fvets.2022.1064017

Bukharina, I.L. & Kovalchuk, A.G. 2023. Experience in creating a research and production site for bioprocessing of such waste. Technologies for waste processing with the production of new products. Kirov, pp. 114-117.

Bukharina, I.L., Didmanidze, O.N., Pashkova, A.S., et al. 2024a. Biorecycling of Organic Waste as a Universal Ecoclimatic Project and Increasing the Resource Capacity of Cultural and Natural Ecosystems. Journal of Ecohumanism 3(8): 667–685. https://doi.org/10.62754/joe.v3i8.4759

Bukharina, I.L., Pashkova, A.S. & Kovalchuk, A.G. 2024b. Technologies for the utilization of such waste using biological objects. Technologies for waste processing with the production of new products. Kirov: Vyatka State Univ. Publ., pp. 61-63.

Bukharina, I.L., Zhuravleva, A.N. & Vedernikov, K.E. 2020. Training of personnel in the field of waste management (project-oriented programs and activity-based approach in education). Technosphere Management 3: 296–304. https://doi.org/10.34828/UdSU.2020.80.96.003

Castillo, J.J. 2025. From Waste to Wonder: Valorization of Colombian Plant By-Products for Peroxidase Production and Biotechnological Innovation. Processes 13(10): 3198. https://doi.org/10.3390/pr13103198

Debsingha, S, Choudhury RK, Choudhury D, et al. 2025. From waste to worth: Innovative strategies for mitigating agricultural pollution and advancing renewable energy solutions. Plant archives 25(2): 1131–1149. https://doi.org/10.51470/PLANTARCHIVES.2025.v25.supplement-2.141.

Development designers, engineers, technologists. 2025. https://razvitie-pu.ru/?page_id=6621 (date of access 2025.08.02).

Druzhakina, O.P., Bukharina, I.L. & Kovalchuk, A.G. 2020. Waste disposal in the Udmurt Republic: analysis of the raw material base and current trends. Theoretical and Applied Ecology 4: 123–128. https://doi.org/10.25750/1995-4301-2020-4-123-128

Elhrari, W., Abdalgader, A., Elaziby, N., et al. 2025. Transforming waste into value: cellulose extraction from native Libyan plant species for sustainable resource management. Euro-Mediterr J Environ Integr. https://doi.org/10.1007/s41207-025-00953-5

Elinder, L., Colombo, P.E., Patterson, E., et al. 2020. Successful Implementation of Climate-Friendly, Nutritious, and Acceptable School Meals in Practice: The OPTIMAT™ Intervention Study. Sustainability 12: 8475. https://doi.org/10.3390/su12208475

Epishov, A.P., Zhura, S.E. & Voronov, A.V. 2023. Problems of food waste treatment and ways of their resolving. Vestnik of the Plekhanov Russian University of Economics 20(3): 183-189. https://doi.org/10.21686/2413-2829-2023-3-183-189.

Ferdousi, L., Sultana, N., Al-Helal, M.A., et al. 2021. Molecular identification and life cycle of Black Soldier fly (Hermetia illucens) in laboratory. Bangladesh Journal of Zoology 48: 429–440. https://doi.org/10.3329/bjz.v48i2.52381

Galstyan, M.H., Sayadyan, H.Y., Sargsyan, K.S. 2023. Assessment of Ecological and Toxicological State of Soils and Waters in the Neighborhood of Mining Industry Enterprises in the Armenian Highlands. Life 13(2): 394. https://doi.org/10.3390/life13020394.

Gebrehana, Z.G., Mesfin, T., Chernet, M., et al. 2025. Valorizing agricultural wastes through composting vermicomposting and anaerobic digestion for sustainable soil fertility management in Ethiopian smallholder systems. Discov Sustain. 6: 1026. https://doi.org/10.1007/s43621-025-01769-7

Gorlov, I.F., Fedotova, G.V. & Sergeev, V.N. 2021. Problems of reducing losses of agricultural products. Agrarian-and-food innovations 14(2): 82–89. https://doi.org/10.31208/2618-7353-2021-14-82-89

Gubiy, E., Isa, Y., Zhang, Y. & Kozlov, A.N. 2025. Comparative analysis of biomass energy potential in BRICS countries. Biofuels, Bioproducts and Biorefining https://doi.org/10.1002/bbb.70061

Haryanto, L.I., Isbintara, R., Juniarsih, D.A., et al. 2023. Utilization of black soldier fly's larvae for integrated waste management at farmer household. Russian Journal of Agricultural and Socio-Economic Sciences 137(5): 56–65. https://doi.org/10.18551/rjoas.2023-05.06

Heiges, J., Lee, D.L., Vollmer, L., et al. 2022. Evaluating food packaging waste in schools: a systematic literature review. International journal of environmental research and public health 19(9): 5607.

Food production. ITS 44-2017. 2017. Moscow: NDT Bureau.

Jabin, N.J., Nipa, N., Liza, S.A., et al. 2025. Investigation on Household Waste Management and the Effects of Compost and Dilute Parts of Waste on the Growth of Plants. Asian Journal of Environment & Ecology 24(7): 111–121. https://doi.org/10.9734/ajee/2025/v24i7755.

Kryuchkov, A.I. 2024. Global practices and innovations in black soldier fly farming: from home cultivation to large-scale enterprises. International research journal 12: 1-5. https://doi.org/10.60797/IRJ.2024.150.67

Kryuchkov, A.I. 2025. Potential and prospects for utilization of black soldier fly larvae in modern agricultural fodder systems. International research journal 1: 1-6. https://doi.org/10.60797/IRJ.2025.151.65

Lai, W.T., Khong, N.M.H., Lim, S.S., et al. 2016. A review: Modified Agricultural By-products for the Development and Fortification of Food Products and Nutraceuticals. Trends in Food Science & Technology 59: 148–160. https://doi.org/10.1016/j.tifs.2016.11.014

Larionov, M.V. 2013. Features of technogenic heavy metals accumulation in soils of cities in Middle and Lower Volga Region. Tomsk State University Journal 368: 189–194. WOS:000421536700037.

Larionov, M.V., Galstyan, M.H., Ghukasyan, A.G., et al. 2024a. The ecological and sanitary-hygienic assessment of the river systems located in the technogenic polluted zone of the Caucasus. Egypt. J. Aquat. Res. 50(2): 1–11. https://doi.org/10.1016/j.ejar.2024.03.006

Larionov, M.V., Minakova, I.V., Sentishcheva, E.A., et al. 2021. Creation of artificial phytocenoses with controlled properties as a tool for managing cultural ecosystems and landscapes. IOP Conf. Ser.: Earth and Environ. Sci. 848(1): 012127. https://doi.org/10.1088/1755-1315/848/1/012127

Larionov, M.V., Sargsyan, K.S., Sayadyan, H.Y., et al. 2024b. The Influence of Cultivation, Storage and Processing Technology on the Nitrate Content in Potato Tubers and Vegetable Crops as the Example of Ecologically and Hygienically Oriented Organic Agricultural Nature Management. Journal of Ecohumanism 3(8): 292–302. https://doi.org/10.62754/joe.v3i8.4731

Lavrova, L.Y., Ermakov, S.A. & Krupchik, P.M. 2023. Poluchenie pishchevogo poroshkoobraznogo ingredienta iz vtorichnykh zernovykh resursov. Scientific and Technical Bulletin: Technical Systems in the Agro-Industrial Complex 1(17): 28-34.

Lin, T.Y., Chiu, S.Y., Chiu, Yh., et al. 2025. Agricultural production efficiency, food consumption, and food waste in the European countries. Environ Dev Sustain. 27: 6281–6302. https://doi.org/10.1007/s10668-023-04133-9

Markin, S.Y. & Maltsev, I.V. 2024. Bioconversion of agricultural waste as an element of the closed cycle economy. Vladimir agricolist 4: 54-59. https://doi.org/10.24412/2225-2584-2024-4110-54-59.

Moreau, V., Sahakian, M., Van Griethuysen, P., et al. 2017. Coming full circle: Why social and institutional dimen-sions matter for the circular economy. J. Ind. Ecol. (21): 497-506.

Osipov, V.I. 2021. Is It Better To Incinerate Municipal Solid Waste or Degrade It? Her. Russ. Acad. Sci. 91: 492–500. https://doi.org/10.1134/S1019331621040146

Osipov, V.I., Galitskaya, I.V. & Zaikanov, V.G. 2022. Landfill Technology of Waste Management. Water Resour. 49(2): 25–35. https://doi.org/10.1134/S0097807822080097

Osipova, R.H., Mkrtchyan, A.T., Ghukasyan, A.G., et al. 2024. Evaluation of the Effect of Herbicides and Growth and Development Regulators on the Biological and Economic Properties of Plants in Various

Landscapes. Journal of Ecohumanism 3(8): 3035–3048. https://doi.org/10.62754/joe.v3i8.4949

Pahmeyer, M.J., Siddiqui, S.A., Pleissner, D. 2022. An automated, modular system for organic waste utilization using Hermetia illucens larvae: Design, sustainability, and economics. Journal of Cleaner Production (379): 1-8.

Pancino, B., Cicatiello, C., Falasconi, L., et al. 2021. School canteens and the food waste challenge: Which public initiatives can help? Waste Manag Res. 39(8): 1090-1100. https://doi.org/10.1177/0734242X21989418

Peters, A. 2025. This Giant Automated Cricket Farm is Designed to Make Bugs a Mainstream Source of Protein. URL: https://www.fastcompany.com/40454212/this-automatedcricket-farm-is-designed-to-make-bugs-a-mainstream-source-of-protein (accessed 20.09.2025).

Phiri, R. & Chibomba, K. 2025. Analyzing the Effects of Agricultural Productivity on Household Living Conditions: A Study of Chisamba District in Zambia. Journal of Agriculture Aquaculture and Animal Science 2(1): 151–163. https://doi.org/10.69739/jaaas.v2i1.346

Phongpradist, R., Semmarath, W., Kiattisin, K., et al. 2023. The in vitro effects of black soldier fly larvae (Hermitia illucens) oil as a high-functional active ingredient for inhibiting hyaluronidase, anti-oxidation benefits, whitening, and UVB protection. Front Pharmacol. 14: 124.

Sanitary and epidemiological requirements for the maintenance of urban and rural areas, water bodies, drinking water and drinking water supply, atmospheric air, soils, residential premises, operation of industrial and public premises, organization and implementation of sanitary and anti-epidemic (preventive) measures (with amendments and additions). SanPiN 2.1.3684-21. 2025. Moscow: AO Kodeks.

Pozdeev, V.L. & Astrakhantseva, E.A. 2022. Circular Economy and Sustainable Development Goals. Russian journal of management 10(4). URL: https://naukaru.ru/ru/nauka/article/54910/view?ysclid=mhdh8h1v2k467586075#article-info (accessed 20.09.2025).

Pozdeev, V.L. 2021. Forecasting in the Economic Security System. Innovative Economic Development 4(64): 276-282. https://doi.org/10.51832/2223-798420214276

Rasdi, F., Hua, A.R. & Shaifuddin, P. 2022. Growth and Development of Black Soldier Fly (Hermetia illucens (L.), Diptera: Stratiomyidae) Larvae Grown on Carbohydrate, Protein, and Fruit-Based Waste Substrate. Malaysian Applied Biology 51: 57–64.

Salam, M., Shahzadi, A., Zheng, H., et al. 2022. Effect of different environmental conditions on the growth and development of Black Soldier Fly Larvae and its utilization in solid waste management and pollution mitigation. Environmental Technology and Innovation 28: 1–16.

Sargsyan, K.S., Tovmasyan, G.A., Gharakhanyan, K.A., et al. 2025. Ecological state of the natural and agricultural phytocenoses as the marker of ecosystem services: taking into account differences in natural and anthropogenic conditions under global climate change. Journal of Geographical Sciences 35(11): 2335–2362. https://doi.org/10.1007/s11442-025-2415-3.

Saxena, P., Khan, M.A., Bhattacharya, S., et al. 2025. Optimizing Waste Sorting Techniques to Mitigate Environmental Impacts within Agricultural Regions. In: Parray JA, Shameem N, Haghi AK. (eds) Producing Healthy Food with Healthy Soils. Sustainable Landscape Planning and Natural Resources Management. Cham: Springer. https://doi.org/10.1007/978-3-031-82536-1_6.

Collection of specific indicators of production and consumption waste generation. 1999 Moscow: Goskomekologiya.

Seyedalmoosavi, M.M., Mielenz, M., Veldkamp, T., et al. 2022. Growth efficiency, intestinal biology, and nutrient utilization and requirements of black soldier fly (Hermetia illucens) larvae compared to monogastric livestock species: a review. J Animal Sci Biotechnol. 13: 31.

Shama, N., Rajpoot, S. & Nayak, A. 2025. Waste Management: Tackling Challenges, Sustainable Practices, and Transforming Waste into Value. In: Innovative Technologies for Waste Management. Sustainable Environmental Waste Management Strategies. Cham: Springer. https://doi.org/10.1007/978-3-031-97184-6_16

Shamsutdinova, M.R., Astrakhantseva, E.A., Bimurzaeva, A.M., et al. 2022. Creation of an optimization mechanism to increase the economic potential of an enterprise. In: Lecture Notes in Networks and Systems, vol. 245. Cham: Springer. https://doi.org/10.1007/978-3-030-77000-6_103

Shinde, A., Patwardhan, S., Kshirsagaret, R., et al. 2025. Agricultural Waste Biomass Management and Biochar Production. In: A Precious Resource from Biological Waste. Singapore: Springer.

https://doi.org/10.1007/978-981-95-0425-1_6.
Singh, A. & Monica Rajpoot, S. 2025. Promoting the Global Economies by Sustainable Use and Management of Agricultural Waste. In: Innovative Technologies for Waste Management. Sustainable Environmental Waste Management Strategies. Cham: Springer. https://doi.org/10.1007/978-3-031-97184-6_10.
Slavskiy, V., Litovchenko, D., Matveev S., et al. 2023. Assessment of Biological and Environmental Factors Influence on Fire Hazard in Pine Forests: A Case Study in Central Forest-Steppe of the East European Plain. Land 1: 103. https://doi.org/10.3390/land12010103.
Slavskiy, V.A., Vodolazhsskiy, A.N., Mironenko, A.V., et al. 2025. Assessment of anthropogenic factors and recreational indicators of plantings influencing the occurrence of a fire hazard situation in the Central forest-steppe. Lesotekhnicheskii zhurnal (Forestry Engineering journal) 15(3): 101–120. https://doi.org/10.34220/issn.2222-7962/2025.3/7.
Stol, A.V. 2024. Development of higher education institutions as a condition for the formation of professional choice of youth. MCU Journal of Economic Studies 80-95. https://doi.org/10.24412/2312-6647-2024-442-80-95
Subrakova, L.K. 2021. Economics of food waste management in Russia. Proceedings of the Voronezh State University. Series: Economics and Management 1: 37-48. https://doi.org/10.17308/econ.2021.1/3322.
Todde, G., Sole, S., Sara, G., et al. 2025. Field-to-wire: the environmental sustainability of bioenergy generation from the biomass of agricultural residues. Sustainable Energy Technologies and Assessments 81: 104433.
Vivallos Soto, C., Ruiz Bertín, F., Robles Calderón, C., et al. 2022. Biodigestion System Made of Polyethylene and Polystyrene Insulator for Dog Farm (on the Example of the Republic of Chile). Life 12: 2039. https://doi.org/10.3390/life12122039
What is a Circular Economy? 2025. US EPA: URL: https://www.epa.gov/circulareconomy/what-circular-economy. (accessed 20.09.2025).
Yu, Z., Li, F., Si, W. & Zhang, W. 2024. From Agri□Waste to Sustainable Use: A Case Study of Straw Management Reform in Northeast China. Sustainable Development 33(3): 3818–3830. https://doi.org/10.1002/sd.3315