SCIENTIFIC CULTURE
www.sci-cult.com

SCIENTIFIC CULTURE, Vol. 11, No. 3, (2025), pp. 1751-1766
Open Access. Online & Print

DOI: 10.5281/zenodo.11312725

BIORESOURCE AND INDUSTRIAL-ECOLOGICAL CHARACTERISTICS OF THE HEMP AND ITS USE FOR CLOSING PRODUCTION CYCLES AND INCREASING ECONOMIC SUSTAINABILITY

Irina Leonidovna Bukharina[1], Konstantin Evgenievich Vedernikov[1], Maxim Viktorovich Larionov[2], Marina Yurievna Karelina[3], Anna Sergeevna Pashkova [1], Andrey Gavrilovich Kovalchuk[1]

[1]Udmurt State University, Russia. buharin@udmlink.ru, Izhevsk, ORCID: https://orcid.org/0000-0001-8084-2547
[1]Udmurt State University, Russia. wke-les@rambler.ru, Izhevsk, ORCID: https://orcid.org/0000-0002-9112-6383
[1]Udmurt State University, ORCID: https://orcid.org/0000-0002-0869-9663, elena7108@ya.ru, Izhevsk, Russia.
[1]Udmurt State University, Russia. kovalchuk_ag@udsu.ru, Izhevsk
[2] Russian Biotechnological University (ROSBIOTEC'H University), Moscow, Russia. m.larionow2014@yandex.ru, ORCID: https://orcid.org/0000-0003-0834-2462
[3]State University of Management, Moscow, Russia. myu_karelina@guu.ru, ORCID: https://orcid.org/0000-0003-0335-7550

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

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

ABSTRACT

The article analyzes business models of the closed-loop economy in world practice, and based on the analysis of the situation in the field of processing plant waste, the model for closing production cycles in the system of processing industrial waste and food surpluses from crop production of enterprises of the agro-industrial complex is proposed. This model should become the basis for the multi-variant digital model for managing technological processes that close production cycles in plant growing. The article also examines the specifics of the hemp (Cannabis sativa L.) processing and the development of the algorithm aimed at the efficient use of its morphological parts to obtain various products. The object of the research was the agroclimatic conditions of the East European Plain (the Western Middle Urals), which allows us to analyze the possibilities of growing this crop in the temperate zone. The main goal is to determine the algorithm that will allow the most efficient use of all parts of the plant to create various useful products and to estimate the possible volumes of their production. The study highlights three key objectives: studying the technological features of the hemp cultivation, analyzing the morphological structure of the plant, and developing the mathematical algorithm for predicting yield and processing. The advantages of the hemp as a versatile crop suitable for food, textile, pharmaceutical and other industries, as well as its ability to absorb greenhouse gases, which highlights its

environmental importance, are considered in detail. However, the process of introducing of the hemp into agricultural production faces the number of difficulties, including the need for specialized equipment and technology for harvesting and processing. The data provided on the area of crops and the economic potential of the hemp emphasize its importance for the economy on the East European Plain, but it is noted that the need to comply with regulatory legal acts also creates additional barriers. In addition, the article describes the chemical and morphological properties of the hemp, and develops recommendations for optimal cultivation and processing methods based on the analysis of the yield stage and the possibilities of using individual plant organs. The work contains an ecologized motive for the development of rational resource use in the modern economy. The program for processing industrial hemp presented in this work corresponds to the concept of rational resource use and environmental culture in modern social production.

KEYWORDS: Ecological Culture, Modern Agricultural Economy, Closed-Loop Economy, Sustainable Operation, Cyclical Production, Rational Use of Bio-resources, Environmental Sustainability, Cannabis sativa L., Bio-resource Characteristics, Use of Plants, Processing Algorithm, Yield, Morphological Structure, Cellulose.

1. INTRODUCTION

The problem of increasing economic loads is relevant in almost the entire modern world (Sadh, Duhan & Duhan 2018; Galstyan, Sayadyan & Sargsyan 2023; Bukharina et al. 2024; Baharane et al. 2025). The maximum share of developed territories (within the boundaries of settlements and mainly in suburban areas and in areas remote from urbanization centers and other populated areas) in different landscapes falls on various agricultural objects (Bukharina et al. 2024; Pogibaev 2024). Waste formation appears to be an unintentional industrial impact on cultural ecosystems and on surrounding natural objects. At the same time, organic waste from agricultural lands, agro-industrial enterprises and agricultural holdings, as well as from the food industry, represent a factor of potential damage to biotic, abiotic and bio-inert components of the environment.

Many countries around the world, including Russia, are moving towards a circular economy. Russia is implementing the Federal Project "Closed Cycle Economy" as part of the national project "Environmental Well-Being". The main goal of the law is to significantly increase the share of recycled waste and sharply reduce the waste stored in municipal solid waste (MSW) landfills. The regulatory document under development pays special attention to the recycling of organic waste; the task is to involve up to 15% of generated waste in biological cycles, while this figure currently stands at 1% (Druzhakina Bukharina & Kovalchuk 2020; Bukharina & Kovalchuk 2023; Bukharina Pashkova & Kovalchuk 2024; Bukharina et al. 2024).

The circular economy is gaining popularity in academia, industry and politics as an alternative model that minimizes resource depletion, waste and emissions. Business models are an important lever for implementing this concept at the organizational level (Geissdoerfer et al. 2020). The analysis of existing models for implementing the concept of the circular economy is presented in Table 1.

Table 1: Existing Models within the Framework of the Implementation of the Concept of the Closed-Loop Economy.

Models	Country	Business Case
Closed-loop Models		
Use of recovered alternative materials	France	Automobile corporation *Renault* produces cars from recycled materials. 36% of the mass of new cars in Europe consists of recycled materials. Cars can be recycled by 85%
Use of renewable materials	Sweden, Finland	Forest products company *Stora Enso* produces biocomposites, molded fibers, pellets, and market pulp from wood of rationally managed forests. It helps to replace fossil fuel materials in construction, packaging, chemicals, and other industries.
Resource Recovery Models		
Downcycling	USA	*Veolia North America* offers a solution for recycling (grinding) wind turbine blades for subsequent use as a raw material replacement in cement production
Upcycling	Singapore	*Singapore Airlines* donates parts from decommissioned commercial aircraft to selected organizations that then recycle them and use them to make products (furniture, clothing, accessories, works of art)
Industrial symbiosis	India	*KK Plastic Management Ltd*, a plastic waste management service provider, collects plastic waste, processes it into flakes (approximately 30 tons of waste/day) and uses them for road construction
Product Life Extension Models		
Designing durable products	Denmark	*Rexcon system* constructs buildings from modular blocks that can be reused after dismantling the buildings
Reuse	Norway	Food hub chain *Madsentralen* redistributes unwanted food from cafes and retailers to non-profits
Repair, restoration, improvement	Russia	*Bricktiles* is a company that restores and sells 19th century brickwork
Product Service Models		
Product-oriented system	Japan	*Canon* offers camera repairs at service centers during and after the warranty period, and also provides warranties for equipment repairs
Client-oriented system	Germany	Software company *Lendis* has created a digital office management service offering rental of furniture and office equipment
Result-oriented model	Netherlands	*Phillips* offers sustainable lighting leasing on a "*pay per lux*" basis, meaning it commits to providing a specific amount of lighting
Sharing models		
Joint ownership	Netherlands	*Peerby* app lets you borrow household tools and other things
Sharing	USA	*Tulerie* platform allows you to expand your wardrobe through clothing sharing

The European (EU) Action Plan for the Circular Economy emphasizes that the development of the circular economy concept will create new jobs and increase the competitiveness of the integration union economy by creating new business opportunities, innovative production methods and more rational consumption. The EU also attaches great importance to the problem of resource depletion as a result of human activity, the solution to which is to establish reasonable proportions between the volume of resource consumption and the volume of their natural increase as a result of each reproduction cycle.

The European Action Plan involves implementing the concept at every stage of the product value chain from production to consumption, repair and refurbishment, recycling and secondary raw materials returned to the economy (Waste Prevention Programme… 2021). Attention is also paid to promoting collective consumption. The following priority areas for the development of the circular economy have been identified: plastic production; food waste; scarce raw materials; construction and demolition; biomass and bio-products; innovation, investment and other measures.

The idea of saving resources was reflected in the initiative launched in the European Union back in 2008, which is aimed at ensuring and improving access to raw materials (European Raw Materials Initiative). Since 2011, a list of scarce raw materials has been published. The list includes those raw materials that reach or exceed thresholds for economic significance and supply risk.

Table 2: The Projected Benefits of Implementing the Concept of the Closed-Loop Economy (According to the Explanatory Note of the Draft Federal Law "On the Closed-Loop Economy").

Mechanisms	Description	Benefits/Results
Ecodesign and energy labeling	The dual aim is to ensure that more energy efficient products enter the market (through ecodesign) while encouraging consumers to buy the most efficient products based on information provided by the regulator (through energy labelling)	– by 2030, the implementation of the program should lead to energy savings of 154 million toe of primary energy annually; – for consumers, this means annual savings on bills and electricity in the amount of 470 euros per family; – additional revenue of 58 billion euros per year for industry. For wholesale and retail trade; – ensuring energy security by reducing imported energy equivalent to 1.1 billion barrels of oil each year; – reducing carbon dioxide emissions by 320 million tons per year
EU Ecolabel	The mechanism was created in 1993 as a voluntary environmental policy instrument to encourage businesses to develop products with lower environmental impacts throughout their life cycle and to support consumers in finding the most environmentally friendly products. The labelling approach is based on multiple criteria, is supported by scientific evidence, is subject to third party certification and is regularly reviewed in line with technological developments.	Encourages the development, production, marketing and consumption of goods and services that are less harmful to the environment throughout their life cycle
"Green" public procurement	Public authorities can contribute to sustainable consumption and production through the public procurement system	It is the state that plays a key role in stimulating demand for more environmentally friendly goods and services
Extended Producer Responsibility	The scheme obliges producers to take operational or financial responsibility for the last phase of their products. It is an integral part of the effective waste management reflected in the EU legislation. The EU Waste Framework Directive, revised in 2018, sets new minimum requirements for the EPR. The requirements oblige producers to bear the costs of separate waste collection, transport and treatment, provision of information, monitoring and reporting.	The instrument ensures that producers invest in waste disposal costs and thus indirectly stimulates innovation in product development (so-called ecodesign).
Source: Report on the implementation of the Circular Economy… (Report on the implementation… 2019)		

Within the concept of the circular economy, the objective is to increase the use of secondary raw materials for the production of new products; in the ideal model of resource recycling, natural resources should become a reserve source of supply. For the EU, which specializes in the manufacturing industry, the main suppliers of scarce raw materials are foreign countries (primarily China, but also the USA, the

Russian Federation and Mexico). The European Union applies the concept of the circular economy as a method for reducing the risks associated with the supply of raw materials that are important for the regional economy. In addition, the European Commission notes that when secondary raw materials are used in industry, the volumes of energy and water consumption are lower than in the case of primary resources. The initiative for the reuse of scarce raw materials covers the following sectors: mining, landfills, electrical and electronic equipment, batteries, automotive industry, renewable energy, defense industry, chemicals and fertilizers.

The examples provided give an understanding that the concept of the circular economy is spreading almost everywhere in the EU. Legislation is being improved and comprehensive initiatives are being adopted for its full-scale implementation. Among the most significant instruments aimed at increasing the environmental sustainability of products are Ecodesign and Energy Labelling mechanism, the EU Ecolabel, Green Public Procurement (GPP) and the Extended Producer Responsibility (EPR) scheme. Table 2 provides the brief description of these mechanisms and the benefits expected from their implementation.

The complex nature of the circular economy, which includes many sectors and uses a whole range of instruments, requires significant investments in innovation and measures to adapt the production base. Over the period 2016–2020, more than 10 billion euros of budgetary funds have been allocated in both areas. Of these funds, 5.3 billion euros, allocated within the framework of the implementation of the EU regional policy (Cohesion Policy), were used for the implementation of waste management legislation.

In Russia, short-term, medium-term and long-term benefits were considered for the implementation of the "Closed Cycle Economy" project (Table 3).

Table 3: The Advantages of Moving to the Closed-Loop Economy.

In the short term	In the medium term	In the long term
• Reduction of material costs and warranty risks; • The ability to sell or lease used products; • New markets and price offers; • Increasing customer interaction and loyalty	• Innovative product design that provides additional value to the customer; • Improving the business model to maintain competitiveness; • Strengthening the brand and reputation; • Enhancing the positive impact on sustainable development	• Reduction of strategic risks associated with the long-term process of global development; • Low dependence on commodity price volatility; • Increasing operational efficiency

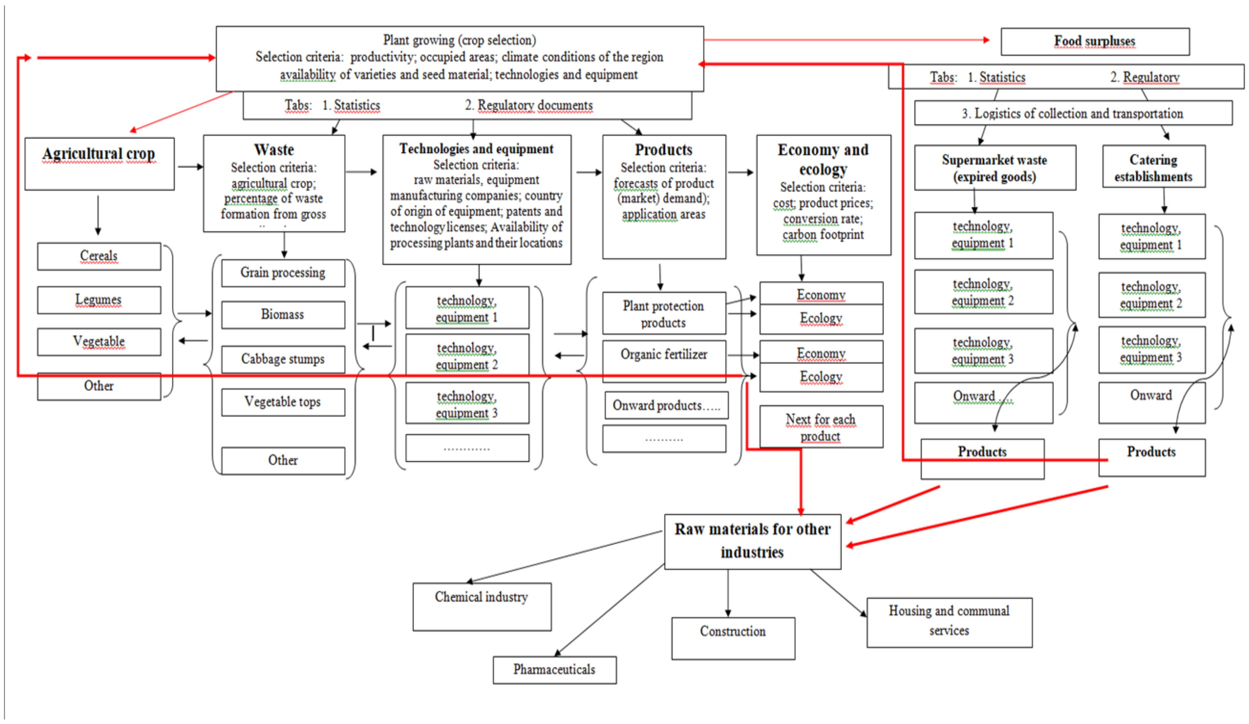


Figure 1: The Model of the Circular Economy in the System of Processing Industrial Waste and Food Surpluses of Plant Origin of the Agro-Industrial Complex.

Based on the conducted analysis of technologies, tasks of development of circular economy, we have developed the model of circular economy in the system of processing of industrial waste and food surplus of plant origin of the agro-industrial complex, created on the basis of analysis of one of the agricultural crops of the Cannabis sativa L., which is the multi-profile raw material crop, in connection with this it is actively introduced in the agro-industrial complex of the East European Plain (Russia, the Western Middle Urals, Udmurt Republic). It should be noted that Udmurtia in terms of climatic features meets the technological requirements for cultivation of the crop (Fig. 1).

2. MATERIALS AND METHODS

The object of research tests (hereinafter referred to as the test object) is the algorithm for processing of the hemp with a possible list of obtained products and their volumes. The purpose of the tests is to study the possibility of creating the algorithm for using various morphological parts of the Cannabis sativa L. with the production of products and the calculation of their volumes.

Objectives of the tests: 1. To study the technological features of growing of the Cannabis sativa L. in the temperate zone and to identify the main factors influencing the yield of this crop; 2. To study the morphological structure of the Cannabis sativa L. and the possibilities of using various plant organs in certain technological operations; 3. To develop a mathematical algorithm for predicting the yield of the Cannabis sativa L. and processing various crop organs with possible product yields.

The tests are carried out using the example of the agricultural crop of the Cannabis sativa L., grown in one of the farms in the temperate zone (the East European Plain, Western Middle Urals, Udmurt Republic, subtaiga natural zone).

The hemp is the universal agricultural crop (industrial/food) that can be used as food for people and as feed for livestock, for the production of clothing, paper, oil, it is used for biofuel and raw material for the pharmaceutical industry (Chamov 1973).

The possible range of finished products obtained from the industrial hemp (Cannabis sativa L.) numbers thousands of names. Interest in this agricultural crop is growing annually, while the rate of development is low.

At the same time, the hemp is unpretentious, can be grown almost throughout the entire territory of the country and produces a good harvest of both seeds and above-ground mass (Khrennikov & Tollochko 1953; Plotnikov Gladkov Subbotin 2018).

The hemp seeds have the high nutritional value. They contain B vitamins, and the proportion of easily digestible protein reaches 30% of the mass. The hemp oil contains a high amount of the Omega-3 fatty acids, which may indicate its pharmacological properties. The cake formed after oil extraction is a raw material for the food and feed industries. The hemp stem is of particular importance. The yield of the aboveground mass can reach 500 c/ha (depending on agricultural technology and soil conditions). The hemp stem contains up to 70% cellulose, which can be used to make paper and cardboard. In this sense, the hemp is an alternative raw material for pulp and paper production (Minevich et al. 2022). In addition, the hemp actively absorbs greenhouse gases, and the production of building materials and biopolymers based on it helps absorb carbon dioxide (Gibadullin et al. 2023).

The Cannabis sativa L. has attracted much attention due to its versatility, short production cycle, low capital intensity of cultivation, potential for carbon-negative processing, and ease of carbon sequestration (Faiz Ahmed et al. 2022).

The industrial hemp has become a highly successful commercial crop due to its ability to sequester carbon, higher biomass production, and diverse end products. Researchers believe that it can be successfully used as a cover crop (Portugal et al. 2020) because it can remediate contaminated soils through phytoremediation and can be grown without pesticides. Even hemp residues can act as botanical insecticides or miticides, as well as inhibitors of soil nematodes and pathogenic fungi (Adesina et al. 2020). It can replenish soil by killing and displacing other small crops or weeds and absorbing heavy metals from the soil. The hemp can be used for insulation and soundproofing in construction, paper industry, medical purposes, textile industry, biofuels, cosmetics (Jacob et al. 2020), food and beverages (Tedeschi et al. 2020), and the fiber can be used as a reinforcement material in polymer matrix composites or in biocomposites as a replacement for glass and carbon fiber (Campiglia et al. 2020).

Thus, Cannabis sativa L. has the status of a strategic crop capable of solving the most important global problems of humanity. It has significant potential as a sustainable crop for the production of many existing industrial and consumer goods, and many more are likely to be realized (Ely et al. 2022).

Active introduction of the hemp into agricultural production in Russia is impossible without analysis and development of technological solutions for its processing, including intermediate waste from different stages of processing.

According to the Rosstat, in 2020, only 10.8 thousand hectares were sown with the hemp, while at the beginning of the 20th century, 680 thousand hectares were occupied by the hemp in Russia. Thus, the total volume of the modern market can reach more than 1000000 hectares. For the long time, hemp was banned, and hemp cultivation did not develop due to the narcotic substances in this plant. According to forecasts of the Ministry of Agriculture of the Russian Federation, by 2025, the total area of crop sowing will increase to 20 thousand hectares. The economic potential of this crop can exceed 100 billion rubles (5166988 MYR; 8817720 CNY; 1234940 USD). The development of this niche faces certain difficulties: harvesting and processing of raw materials. These stages require specialized equipment and technology. Due to modern trends, extraction technologies are constantly being improved and revised, but still do not keep up with market demands (Valizadehderakhshan et al. 2021). Significant financial investments are required to purchase/develop the particular technological line. In this case, the producer and developer of the hemp must realize that the crop that generates economic profit is not only the conditional "seeds", but also other plant organs that can generate profit.

Pre-processing methods for natural fibrous biomass, including harvesting and grinding, are critical for sustainable production (Akbarian-Saravi Sowlati Milani 2025).

The hemp is a strategic crop and a source of raw materials for important sectors of the economy, including military production (production of nitrocellulose).

In this regard, the cultivation and processing of the hemp in the Russian Federation is regulated by regulatory legal acts: the RF Government Resolution No. 101 of 06.02.2020 "On the establishment of varieties of narcotic plants permitted for cultivation for the production of narcotic drugs and psychotropic substances used for medical and (or) veterinary purposes, for cultivation for industrial purposes not related to the production or manufacture of narcotic drugs and psychotropic substances, as well as requirements for varieties and conditions of their cultivation"; GOST 9158-76. The hemp seeds. Industrial raw materials. Specifications; GOST 27024-86. The hemp straw. Specifications; GOST 58957-2020. Uniform non-oriented hemp; GOST 19222-2019. Arbolite and products made from it; GOST 17401-80. Technology of production of pulp and paper semi-finished products; GOST 11694-66. The hemp cake (GOST 11694-66 1966; GOST 9158-76 1976; GOST 17401-80 1980; GOST 27024-86 1986; GOST 19222-2019 2019; Decree of the Government… 2020; GOST 58957-2020 2020).

4. RESULTS AND DISCUSSION

To assess the morphological structure of the hemp stems, plants grown in the East European Plain (the Western Middle Urals, the Malopurginsky District of the Udmurt Republic) were used; the soils were sod-medium podzolic loamy. The average height of the plants was 1.66±0.34 m. The data on the morphological structure of the raw materials are presented in figure 2.

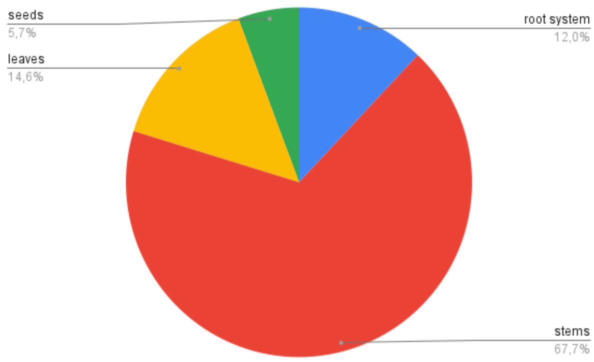


Figure 2: Organ ratio of the Cánnabis sativa L., %.

The next step in the study was to determine the ratio of fiber mass to total stem mass. The average fiber amount determines the potential fiber mass obtained from each plant. The results are presented in Table 4.

Table 4: Morphological Structure of the Cannabis Stems.

Value	min.	Max.	Mean value ±m
Total weight of the plant, gr.	1.365	1.401	1.380±0.011
Mass of stem, gr.	0.838	2.395	1.432±0.636
Mass of fibre, gr	0.293	1.050	0.591±0.306
Fibre proportion to mass of stem, %	34.964	45.086	40.249±4.422
Hurds proportion to mass of stem, %	54.914	65.036	59.751±4.420

The raw material moisture content was determined by drying in the drying cabinet at the temperature of 100-105 °C. The dryness coefficient was 0.924. The chemical structure of the raw material was determined by acid hydrolysis. As a result, it was found that the average lignin content was 27.193±7.523% of the absolutely dry mass (a.d.m.), and cellulose 72.807±6.841% of the a.d.m. The chemical composition of the hemp leaves was determined by gas chromatography.

The average content of cannabidiols was 0.304%. The technical concept for determining the processing algorithm for the Cannabis sativa L. is based on the stage of crop formation and the stage of possible processing directions. The stage of determining the potential yield is based on the influence of dependent (depend on a person, tables 5) and independent factors (do not depend on a person). The matrix of dependent factors is based on the theory of the «prisoner's dilemma». Independent factors (natural factors) expressed in terms of correction factors affecting the yield: soils (soddy-medium podzolic) 0.8; precipitation during the growing season 1.0; temperature (sum of positive temperatures) 1.0.

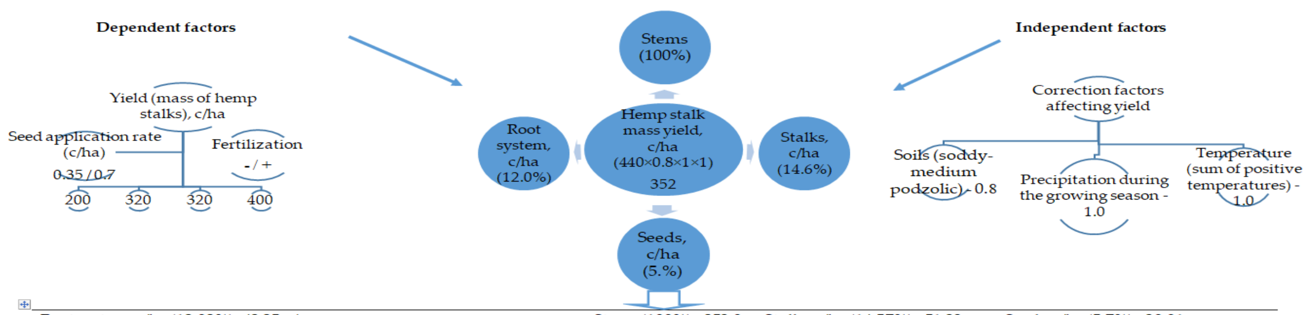
Table 5: Dependent Factors. Yield (Mass of the Cannabis Stalks), c/ha.

Seed application rate (c/ha)	Fertilization	
	-	+
0.35	200	320
0.70	320	440

The seeds obtained during cultivation do not provide controlled germination, therefore agricultural producers buy seeds from seed-growing enterprises every season. Due to the high cost of seeds, seeding rates are reduced. Seeding rates are also reduced due to the lack of production capacity for processing the entire harvest (stems). In this regard, mineral fertilizers are not introduced into the soil.

The system for assessing crop yields through the yield of the hemp stem mass (440×0.8×1×1=352), c/ha, is proposed. The strategy of the hemp processing algorithm is built taking into account the patterns of the morphological structure of this plant. The identified patterns allow predicting the yield (biomass, c/ha) of various plant organs, which can be involved in various production processes (taking into account the development of technologies and equipment): root system – 42.35; stems – 352.00; leaves –51.29; seeds –20.01.

We have developed the standard production flow chart for hemp products (Figure 3), taking into account the utilization rates of different plant parts as a technological resource. For example, the flow chart shows the various uses of the hemp stems (wood concrete, cellulose, and fiber). It should be noted that the raw material preparation for wood concrete and cellulose is the same. Therefore, individual production stages for some products can be combined. Currently, there are no technological solutions for extracting and processing the root system. The diagram indicates the ways of use, including promising ones (obtaining cannabidiols hereinafter CB).



Root system, c/ha (12.03%)=42.35 ц/га			
Extraction, c/ha 41.50			
Roots, c/ha 0.67	Stalks, c/ha 4.96		
Arbolite, c/ha 40.67+8.13+1.62=50.42 344.96+68.99+13.80=427.75 (20% Concrete 4% Mineral supplements)	Alkaline hydrolysis		
	Roots, c/ha	Stalks, c/ha 4.96	
	Lignin sludge	Cellulose	
	Roots, c/ha 13.42 Stalks, c/ha 113.84	Roots, c/ha 27.25	Stalks, c/ha 231.12
	Drying (Dryness coefficient 0.92)12.35+104.73 c/ha	Drying (Dryness coefficient 0.92) 25.07+ 212.63 c/ha	

Stems (100%) =352.0		Stalks, c/ha (14.57%) =51.29		Seeds, c/ha (5,7%) =20.01		
Decortication, c/ha		Harvesting, 50,26 c/ha		Seed material, c/ha 0.7	Processing, c/ha 19.31	
Fiber, c/ha 126.72: - Long fiber, c/ha 82.37 - Hemp fiber, c/ha 44.35	Hurds, c/ha 90.08	Obtaining CB, c/ha 0.153	Herbal tea, c/ha 46.24 Fermentation + Drying (Dryness coefficient 0.92)		Oilcake, c/ha 13.52	Oil, c/ha 5.79
	Pellets, c/ha				Granulated feed, c/ha 12.44 (Dryness coefficient 0.92)	

Note: CB – cannabidiol (content in leaves 0.304%), During technological processes, losses of an average of 2% occur (a coefficient of 0.98 was used), Min. add. – Mineral additives/plasticizers, Dryness coefficient (0.92 obtained in laboratory conditions) for conversion to air-dry mass

Figure 3: The Cannabis Sativa L. Processing Algorithm.

As an example of the implementation of the closed production cycle and recycling methods to obtain in-demand products, the testing program has been developed for the slab material obtained as a result of the hemp processing.

1. The object of research tests is the slab material created by grinding of the hemp stems measuring 100±3 mm, autoclaved and adding polyurethane glue, followed by pressing with the force of 28 kN.
2. The purpose of the tests is to determine the density and strength of the obtained material.
3. Conditions for presenting the test object for testing: tests are carried out on three copies with material parameters (length × width × thickness, mm) 120.00±0.12×59.53±0.36×11.24±0.28 and moisture (%) 12.1±0.11.
4. Requirements for testing equipment and conditions:

a) Measuring instruments subject to state metrological control and supervision must be verified in accordance with the Order of the Ministry of Industry and Trade of Russia dated 02.07.2015 No. 1815 "On approval of the Procedure for verification of measuring instruments, requirements for the verification mark and the content of the verification certificate", and those not subject to state metrological control and supervision must be calibrated according to the PR 50.2.016 or verified.

b) The room must provide for the installation of the test object on a flat horizontal surface. The tests must be carried out under normal climatic conditions: ambient temperature, °C 20 ± 10; relative humidity, % from 45 to 80; atmospheric pressure, mm Hg from 630 to 800.

c) The mass of the samples is determined with an error of no more than 0.01 g. To recalculate the density at the time of testing moisture to the density at 12% moisture, the mass of the samples is determined in weighing bottles with the error of no more than 0.001 g. The cross-sectional dimensions and length are measured with an error of no more than 0.1 mm along the axes of symmetry of the samples.

d) Testing is permitted to be performed by personnel who have undergone training and/or preparation, studied the operating documentation for the testing equipment, trained in accordance with the "Rules for the Technical Operation of Consumer Electrical Installations" and "Rules for Safety in the Operation of Consumer Electrical Installations" and have the electrical safety certification level of at least Group III. There are no requirements for the presence of special permits for the personnel performing the testing.

5. The test program. The list of types of research tests and the studied indicators is given in Table 6.

Table 6: The Test Program.

No.	Type and content of research tests conducted	Changeable parameter	The value under study
1	Checking the compliance of the test object with its parameters	length×width×thickness, mm	Compliance with design documentation
2	Raw material moisture content study	Moisture, %	Moisture, %
3	Study of mass indicators of the slab	Mass, g	Slab mass, g
4	Specific gravity study	specific gravity, g/cm³	Mass/volume ratio, g/cm³
5	Investigation of static bending strength	strength, kN	Static bending strength, kN

During the tests, the parameters of the slab material were compared with the parameters of birch plywood (Table 7).

Table 7: Specific Gravity of the Studied Materials.

Changeable parameter		Hemp (*Cannabis sativa* L.)	Birch plywood
Parameters (length×width×thickness), mm	length	120.00±0.12	121.54±0.10
	width	59.53±0.36	45.50±0.21
	thickness	11.24±0.28	11.00±0.01
Moisture, %		12.10±0.11	11.90±1.35
Mass, g		70.91±1.06	40.13±0.66
Specific gravity, g/cm³		0.44	0.63
Specific gravity, kg/m³		444.51	633.50
Note: * mean value ± standard deviation; ** estimated value based on mean values			

Tests have shown that the hemp material has the lower specific gravity compared to plywood (lighter by 29.83%). Testing of strength characteristics showed that 10 mm thick plywood withstood the maximum force of 1.7 kN, and the hemp-based biopolymer withstood the maximum force of 1.2 kN. At the same time, despite the fact that the maximum load was 1.2 kN, no damage to the material (mechanical destruction) occurred. After the pressure was removed, the material returned to its original position, minimally changing its geometric shape. Thus, the possibility of using of the hemp to produce the plate material comparable in strength characteristics to plywood has been demonstrated. The created technology does not require unique, complex equipment, does not generate waste (in addition to stems, other plant organs can be involved) and is available to small-scale production.

5. DISCUSSION

Certainly, the future, and even the present, is linked to circular agricultural and industrial production. The concept of a circular economy is currently being actively discussed (Sadh Duhan & Duhan 2018; Singh et al. 2022; Groff et al. 2025). Industrial policies are being updated, including those aimed at sustainable bioresource use. The idea of circular production is particularly relevant in the context of sustainable synergies between crop production and agro-industrial production (Bao et al. 2025).

The framework has been developed describing the circular economy model for crop production and recycling plant waste, as well as recycling surplus food and food industry waste. It forms the basis for the model of technological processes for closing production cycles in agricultural production. This development exemplifies sustainnable bioresource management.

It is interesting and economically useful that a number of plants have unique bioecological, biochemical, biomechanical and economic characteristics (Larionov et al. 2021, 2023; Slavskiy Litovchenko & Ivanova 2024; Chen et al. 2025). In general, the introduction of processing and use of plants with special bioresource qualities (Singh et al. 2022; Coelho Junior et al. 2024; Chen et al. 2025; Groff et al. 2025) may be a small and at the same time the most rational option for handling the resulting phytomass from modern agriculture (Fedorenko 2019; Nair et al. 2023; Gowlla Abdul Salam. & Sahu 2025; Groff et al. 2025). In addition, the cultivation of plants for further industrial processing, for example, as a structural or building material (Tate Adekunle & Dmitri 2009; Foulk et al. 2011; Rana & Evitts 2014; Mbakop Lebrun & Brouillette 2018; 44,45,46), is dictated by growing economic and industrial needs. This is considered in the context of biological and hygienic safety in the functioning of the agro-industrial complex and the materials directly obtained (Khadka 2022; Pogibaev 2024). Moreover, this is an opportunity to diversify agricultural natural resource management into environmentally significant agricultural and agro-industrial production (Foulk et al. 2011; Göswein et al. 2022; Khadka 2022; Ochi 2025).

According to modern concepts (Oksman et al. 2002; Khadka 2022; Ochi 2025), such industrial production based on phytomaterials and biorecycling is the most environmentally friendly form of resource use. Such conditions have been created for environmentally sustainable (rational) agricultural production in many countries. On the territory of the East European Plain, the complexity of solutions is due to the wide variety of climatic conditions (Lubimov et al. 2016; Vedernikov et al. 2022; Cherenkova et al. 2024; Slavskiy et al. 2023), agricultural crop (Zakshevsky Novikov & Polunina 2023; Kamalova et al. 2025), and their productivity characteristics (Druzhinin Shkiperova & Prokopiev 2015; Novikova et al. 2015; Koshkin Andreeva Guseinov 2019; Siptits Romanenko & Evdokimova 2021; Volodkin 2022) (e.g., grain ripening) due to meteorological conditions during the growing season, complex territorial logistics, etc.

We have proposed the algorithm for creating the production cycle management system (based on the database). There are a number of such systems exist (Bogatyreva et al. 2016; Geissdoerfer 2020; Waste Prevention Programme… 2021; Agro-S 2025; Development for Designers… 2025). However, they are not adapted to agricultural waste and food service establishments, and do not include criteria for economic and environmental efficiency. We have defined criteria for technology selection and developed the description of the technology package(s) comprising two sets of technologies: processing of production and consumption waste in the agro-industrial complex (including solving the problem of "multi-production"); recycling of production and consumption waste, ensuring "closing the loop." This results in a comprehensive, programmatic industrial biorecycling system and, at the same time, full-fledged production based on the principles of the circular economy and environmental sustainability.

We believe our developments have advantages in the conditions of the East European Plain, and in particular the Western Middle Urals (taking into account cropping patterns, coefficients, and yields). They have undergone specific testing in the production conditions of a developed agricultural region (the Udmurt Republic) of the East European Plain.

The system can be replicated. It can be used in similar climatic conditions of different regions. The introduction of yield indicators and coefficients for the conversion of biomass/raw materials from one production stage to another are based on the study of the specifics of technological processes and will be consistent across different crops (this is demonstrated using the hemp as an example). Our development also demonstrates the possibility of more fully utilizing the biological and bioresource properties of plants used as industrial crops.

Agricultural production is a strategic area of social production (Singh et al. 2022; Bao et al. 2025; Sargsyan et al. 2025). Such economic activity is accompanied by an increase in anthropogenic loads (Briassoulis et al. 2010; Larionov et al. 2024a; Lackner & Besharati 2025). As a result, on the one hand, the share of degraded and alienated lands increases due to irrational, intensive and extensive agricultural use of natural resources (Larionov et al. 2021; Pogibaev 2024). On the other hand, the level of degradation has reached critical values in many regions, especially in South America (Walder et al. 2024), in Europe (Briassoulis et al. 2010; Prăvălie et al. 2024), in Russia (Larionov & Siraeva 2020; Larionov & Kotegov 2025) and adjacent territories (Bogatyreva et al. 2016; Galstyan et al. 2023; Sargsyan et al. 2025), in different regions of Asia (Singh et al. 2022; Wang & Cui 2024; Liu et al. 2025), in Africa (Baharane et al. 2025; Lackner & Besharati 2025) and other territories (Adesina et al. 2020; Liu et al. 2025; Sargsyan et al. 2025) al. 2025). Therefore, comprehensive reclamation and ecological-economic rationalization in the organization and management of natural resource use are required. This can certainly be achieved through the comprehensive engineering, chemical, and biological rehabilitation of damaged and degraded components of cultural ecosystems (Larionov et al. 2023, 2024a; Bukharina et al. 2024; Pogibaev 2024). Of course, a special role in such work should be given to the biologization of agriculture, biorehabilitation and bioprotection of soils (Larionov et al. 2024b), agrocenoses and water bodies (Bukharina et al. 2024; Larionov et al. 2024a), restoration of agroforestry ecosystems (Larionov et al. 2023, 2024b) and nature conservation complexes (Larionov & Siraeva 2020; Volodkin 2021; Larionov et al. 2021, 2023). Through sound environmental management, including phytoremediation, phytomelioration and complex ecological-protective landscaping of disturbed landscape components (Larionov et al. 2021, 2024a,b; Bukharina et al. 2024; Sargsyan et al. 2025), as well as through the selection of highly productive crops resistant to limiting factors (including anthropogenic impacts) (Chamov 1973; Novikova et al. 2015; Lubimov et al. 2016; Plotnikov, Gladkov & Subbotin 2018; Koshkin, Andreeva & Guseinov 2019; Slavskiy et al. 2023; Larionov et al. 2024a,b; Pogibaev 2024) and (preferably) by restoring natural biodiversity in ecotones and in surrounding native Ecological systems (Volodkin 2021, 2022; Larionov et al. 2021, 2023; Slavskiy, Litovchenko & Ivanova 2024). These established phytocenoses, with their special environment-regulating and environment-optimizing role, are essential in areas where agricultural, agro-industrial, and food waste is collected and accumulated. These areas pose potential and actual damage to the environment, the health of farm and wild animals, and pose a risk to humans. Phytocenoses based on remediation, melioration, and bioprotection plantings can improve the geochemical background in the medium and long term (through adjustment of species composition, maintenance, and sanitary and environmental monitoring of the plantings). It is possible to stabilize biogeochemical cycles in relevant landscape components, including waste collection sites and landfills, as well as by creating sanitary protection zones on the territories of industrial waste recycling facilities.

In this context, environmental management plays a significant role, including through the sound management of agricultural waste (Briassoulis et al. 2010; Bukharina et al. 2024; Liu et al. 2024; Lackner & Besharati 2025). The amount of agricultural, agro-industrial, and food waste generated has been growing annually (Fedorenko 2019; Waste Prevention Programme… 2021; Bukharina et al. 2024). This economic, industrial, and environmental problem is becoming more acute with population growth and the diversification of national economies (Bogatyreva et al. 2016; Sadh, Duhan & Duhan 2018; Waste Prevention Programme… 2021; Wang & Cui 2024). The level of agricultural and agro-industrial development is increasing in the East European Plain (including the Middle Ural Region) (Druzhakina, Bukharina & Kovalchuk 2020; Bukharina et al. 2024), in different areas of Russia (Gibadullin et al. 2023), and in neighboring countries (Bogatyreva et al. 2016; Larionov et al. 2024a; Sargsyan et al. 2025). In general, the same trend is observed worldwide (Adesina et al.

2020; Lackner & Besharati 2025). Improving the management system of agricultural, agro-industrial, and food waste is aimed at reducing the anthropogenic load on cultural ecosystems. The implementation of our circular production system meets the requirements of economic feasibility and sustainable environmental and economic development.

Increasing the level of involvement of agricultural, agro-industrial and food waste in circular production meets the need for sustainable management while reducing resource costs in order to reduce the costs of supply chains and production operations (Campiglia et al. 2020; Geissdoerfer et al. 2020; Ely et al. 2022; Bukharina et al. 2024; Liu et al. 2024; Agro-S. 2025). In addition, the economic problem of ensuring the compliance of enterprises and lands sources of waste generation with environmental and hygienic safety requirements is also addressed (Sadh, Duhan & Duhan 2018; Waste Prevention Programme … 2021; Bukharina et al. 2024; Larionov et al. 2024a; Liu et al. 2024; Pogibaev 2024; Wang & Cui 2024). Because the implementation of circular production, involving waste in circular production chains, should be considered an environmental and economic norm and an objective condition for sustainable green development. Taken together, the measures outlined are designed to improve the geo-ecological situation through the scaling and widespread use of our proposals in the agricultural, agro-industrial, processing, housing and utilities, and other (related) sectors of the national economy.

6. CONCLUSION

The diagram has been developed that describes the model of the circular economy in the field of plant growing and processing of plant waste, processing of food surpluses and waste from food enterprises, which formed the basis for the creation of the model of technological processes that close the production cycles of agricultural production.

Technological features of the Cannabis sativa L. cultivation in the temperate zone were studied and the main factors influencing the yield of this crop were identified. The morphological structure of the Cannabis sativa L. and the possibilities of using various plant organs in certain technological operations were investigated. The mathematical algorithm for forecasting the yield of the Cannabis sativa L. and processing various crop organs with possible product yields was developed.

The example of one of the building materials obtained as a result of processing raw materials and recycling waste from hemp production demonstrates the possibility of using this technology and products in a circular economy. Thus, we have proposed an environmentally friendly and promising technology for the industrial use of the hemp plants in a moderate climate within the context of the circular economy. This is the example of synergy and sustainable and environmentally friendly bioresource management applied to crop production, environmental management, and the industrial sector.

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

REFERENCES

Adesina, I., Bhowmik, A., Sharma, H. & Shahbazi, A. 2020. A review on the current state of knowledge of growing conditions, agronomic soil health practices and utilities of hemp in the United States. Agriculture 10(4). https://doi.org/10.3390/agriculture10040129

Agro-S. 2025. URL: http://agro-s.com/ (date of access 2024.07.28).

Akbarian-Saravi, N., Sowlati, T. & Milani, A.S. 2025. Cradle-to-gate life cycle assessment of hemp utilization for biocomposite pellet production: A case study with data quality assurance process. Cleaner Engineering and Technology 27. https://doi.org/10.1016/j.clet.2025.101027

Bao, A., He, M., Zhou, Q. & Gao, H. 2025. The impact of industrial policies oriented to-ward the digital economy on the resilience of the agricultural industrial chain. Front. Sustain. Food Syst. 9: 1634474. https://doi.org/10.3389/fsufs.2025.1634474

Baharane, V., Shatalov, A.B., Larionov, M.V. & Igwe, E. 2025. Examining the interplay between air pollution, surface vegetation cover, and stroke prevalence in East Africa: An ecological perspective. Research Square https://doi.org/10.21203/rs.3.rs-5694027/v1

Bogatyreva, E.N., Seraya, T.M., Biryukova, O.M., et al. 2016. Conversion factors of grain and seeds into by-products and the content of essential nutrients in by-products of agricultural crops in the Republic of Belarus. Soil Science and Agrochemistry 2(57): 78-89.

Briassoulis, D., Hiskakis, M., Scarascia, G. et al. 2010. Labeling scheme for agricultural plastic wastes in Europe. Quality Assurance and Safety of Crops & Foods 2(2): 93-104. https://doi.org/10.1111/j.1757-837X.2010.00061.x

Bukharina, I.L. & Kovalchuk, A.G. 2023. The experience of creating a scientific and production site for bio-processing of organic waste. Waste processing technologies to produce new products. Kirov, pp. 114-117.

Bukharina, I.L., Didmanidze, O.N., Pashkova, A.S., et al. 2024. Biorecycling of Organic Waste as a Universal Ecoclimatic Project and Increasing the Resource Ca-pacity 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. 2024. Technologies for the disposal of organic waste using biological objects. Waste recycling technologies to produce new products. Kirov: Vyatka State University, pp. 61-63.

Campiglia, E., Gobbi, L., Marucci, A., et al. 2020. Hemp seed production: environmental impacts of Cannabis sativa L. Agronomic practices by life cycle assessment (LCA) and carbon footprint methodologies. Sustain. Times 12. https://doi.org/10.3390/su12166570

Chamov, Yu.S. 1973. Bast crops. Moscow: Kolos.

Chen, W.-Y., Aklilu, A., Ketema A. & Chang, L.-C. 2025. Extraction and Characterization of Sustainable Cellulosic Fibers from Urera Hypselodendron Plant. Journal of Natural Fibers 22(1).

Chen, Y., Wang, D., Wang, X., et al. 2025. Enhanced adsorption of phenol using EDTA-4Na- and KOH-modified almond shell biochar. Sustain Environ Res 35: 4.

Cherenkova, E.A., Georgiadi, A.G., Zolotokrylin, A.N. & Kashutina, E.A. 2024. Observed and Expected Climate Changes on the East European Plain and Their Influence on River Flow (Case Study of the Don River). Izvestiya Rossiiskoi Akademii Nauk. Seriya Geograficheskaya 88(3): 349-364. https://doi.org/10.31857/S2587556624030075

Coelho Junior, L.M., Santos Júnior, E.P., da Silva, C.F.F., et al. 2024. Supply of bioelectricity from sugarcane bagasse in Brazil: a space–time analysis. Sustain Environ Res 34: 17.

Decree of the Government of the Russian Federation No. 101 dated 02/06/2020 "On the establishment of varieties of narcotic plants permitted for cultivation for the production of narcotic drugs and psychotropic substances used for medical purposes and (or) veterinary medicine, for cultivation for industrial purposes not related to the production or manufacture of narcotic drugs and psychotropic substances, as well as requirements for varieties and conditions of their cultivation."

Development for Designers, Engineers, Technologists. 2025. URL: https://razvitie-pu.ru/?page_id=6621 (date of access 2025.08.10).

Druzhakina, O.P., Bukharina, I.L. & Kovalchuk A.G. 2020. Waste disposal in the Udmurt Republic: an analysis of the raw material base and current trends. Theoretical and applied ecology 4: 123-128.

Druzhinin, P.V., Shkiperova, G.T. & Prokopiev, E.A. 2015. Impact of Climate Change on Agriculture of Russia's Regions. Regionology 2: 56-63.

Ely, K., Podder, S., Reiss, M. & Fike, J. 2022. Industrial Hemp as a Crop for a Sustainable Agriculture. In: Cannabis/Hemp for Sustainable Agriculture and Materials. Singapore: Springer.

Faiz Ahmed, A.T.M., Islam, M.Z., Mahmud, M.S., et al. 2022. Hemp as a potential raw material toward a sustainable world: A review. Heliyon 8(30): e08753.

Fedorenko, V.F. 2019. Trends in Biotechnological Development of Agriculture. Agricultural Machinery and Technologies 13(4): 8-15. https://doi.org/10.22314/2073-7599-2019-13-4-8-15

Foulk, J., Akin, D., Dodd, R. & Ulven, C. 2011. Production of Flax Fibers for Bio-composites. In: Cellulose Fibers: Bio- and Nano-Polymer Composites. Berlin, Heidelberg: Springer.

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

Geissdoerfer, M., Pieroni, M., Pigosso, D. & Soufani, K. 2020. Circular business models: A review. Journal of Cleaner Production 277: 123741.

Gibadullin, M.R., Averyanova, N.V., Borisova, A.I., et al. 2023. Obtaining composite material from renewable biopolymer raw materials. Bulletin of the Technological University 26(9): 26-29.

GOST 11694-66. 1966. Hemp cake.

GOST 17401-80. 1980. The technology of production of pulp and paper semi-finished products.

GOST 19222-2019. 2019. Arbolite and products made from it.
GOST 27024-86. 1986. Hemp straw. Technical specifications.
GOST 58957-2020. 2020. The hemp is of the same type, undirected.
GOST 9158-76. 1976. Cannabis seeds. Industrial raw materials. Technical specifications.
Göswein, V., Arehart, J.H., Huy, P., et al. 2022. Barriers and opportunities of fast-growing biobased material use in buildings. Buildings and Cities 3(1): 745-755. https://doi.org/10.5334/bc.254
Gowlla, J., Abdul Salam, B. & Sahu, P.K. 2025. Cleaner energy production by combined use of biomass plants and thermal plants: a novel approach for sustainable environment. Sustain Environ Res 35: 10. https://doi.org/10.1186/s42834-025-00248-y
Groff, M.C., Flores, L.F., Vaidya K. & Priyanka, P.P. 2025. Agricultural Renewable Res-idues for a Sustainable Agro-Industrial Production. In: Soils and Sustainable Agriculture. Frontier Studies in Soil Science. Cham: Springer. https://doi.org/10.1007/978-3-031-91114-9_34
Jacob, S.R., Mishra, A., Kumari, M., et al. 2020. A quick viability test protocol for hemp (Cannabis sativa L.) seeds. J. Nat. Fibers 1-6. https://doi.org/10.1080/15440478.2020.1764451
Kamalova, A.R., Danilova, N.V., Kuryntseva, P.A., et al. 2025. Technical hemp Cannabis sativa L. growth and functional diversity of soil micro-biota in a model cultivation under elevated air temperatures. Agricultural Biology 60(1): 110-124. https://doi.org/10.15389/agrobiology.2025.1.110rus
Khadka, R. 2022. The use of fibrous plants in the production of building materials. Rural development 2021(1): 101-105. https://doi.org/10.15544/RD.2021.034
Khrennikov, A.S. & Tollochko Y.M. 1953. Hemp growing. Moscow: Selkhozgiz.
Koshkin, E.I., Andreeva, I.V. & Guseinov, G.G. 2019. Impact of Global Climate Change on Productivity and Stress Tolerance of Field Crops. Agrochemistry 12: 83–96. https://doi.org/10.1134/S0002188119120068
Lackner, M. & Besharati, M. 2025. Agricultural Waste: Challenges and Solutions, a Review. Waste 3(2): 18. https://doi.org/10.3390/waste3020018
Larionov, M.V. & Kotegov B.G. 2025. Technogenic Pollution and Salinization of Man-Made Reservoirs in the Cis-Urals: Main Causes and Consequences for the Composition of Fish Communities. Biology Bulletin 52: 42. https://doi.org/10.1134/S1062359024613193
Larionov, M.V. & Siraeva, I.S. 2020. Ecological and aesthetic significance of an auto-trophic component of artificial ecosystems in ensuring of the environmental comfort and the public health protection. IOP Conf. Ser.: Earth Environ. Sci. 421(8): 082002. https://doi.org/10.1088/1755-1315/421/8/082002
Larionov, M.V., Dogadina, M.A., Tarakin, A.V., 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., 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. Egyptian Journal of Aquatic Research 50(2): 1–11. https://doi.org/10.1016/j.ejar.2024.03.006
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
Larionov, M.V., Volodkin, A.A., Volodkina, O.A., et al. 2023. Features of the Territorial Distribution, Composition and Structure of Phytocenoses with the Participation of Fraxinus excelsior, Their Resource Qualities, Ecological and Economic Importance (Southeastern Part of the East European Plain). Life 13(1): 93. https://doi.org/10.3390/life13010093
Liu, J., Liu, J., Zhang, H. & Zhou, T. 2024 How does agricultural land scale affect recycling behavior of agricultural wastes: evidence from CLES. Front. Sustain. Food Syst. 8: 1440786. https://doi.org/10.3389/fsufs.2024.1440786
Liu, L, Wang, L.-J., Ma, S. et al. 2025. Unraveling the Dual Impacts of Urbanization on Agricultural Habitats: A Telecoupling Perspective From Zhejiang Province, China. Land Degradation & Development. https://doi.org/10.1002/ldr.70075
Lubimov, V.B., Melnikov, I.V., Avramenko, M.V., et al. 2016. Prospects of employing the ecological method of plant introduction while establishing the man-made ecosystems of different designated use. Research Journal of Pharmaceutical, Biological and Chemical Sciences 7(4): 1481-1486. WOSUID: WOS:000410760200192.

Mbakop, R.S., Lebrun, G. & Brouillette, F. 2018. Experimental analysis of the planar compaction and preforming of unidirectional flax reinforcements using a thin paper or flax mat as binder for the UD fibers. Composites Part A: Applied Science and Manufacturing 109: 604-614.

Minevich, I.E., Nechiporenko, A.P., Goncharova, A.A., et al. 2022. Study of macronutrients of cannabis seeds in the process of short-term germination. Izvestiya vuzov. Applied chemistry and biotechnology 12(4): 576-588.

Nair, R.R., Kißling, P.A., Marchanka, A., et al. 2023. Biochar synthesis from mineral and ash-rich waste biomass, part 2: characterization of biochar and copyrolysis mechanism for carbon sequestration. Sustain Environ Res 33: 14. https://doi.org/10.1186/s42834-023-00176-9

Novikova, L.Y., Travina, S.N., Zhigadlo, T.E., et al. 2015. Quality of crop yield in the european territory of the Russian Federation under the conditions of climate change. Proceedings on applied botany, genetics and breeding 176(4): 391-401. https://doi.org/10.30901/2227-8834-2015-4-391-401.

Ochi, K. & Matsumoto, M. 2025. Plant Bridge: Connecting Separated Objects Using Plant Growth. Biomimetics 10(5): 321. https://doi.org/10.3390/biomimetics10050321

Oksman, K., Wallström, L., Berglund, L.A. & Toledo Filho, R.D. 2002. Morphology and mechanical properties of unidirectional sisal-epoxy composites. Journal of Applied Polymer Science 84(13): 2358-2365. https://doi.org/10.1002/app.10475

Plotnikov, A.M., Gladkov, D.V. & Subbotin, I.A. 2018. The yield of cannabis seeds in the application of mineral fertilizers and herbicides. International Scientific Research Journal 3. https://doi.org/10.23670/IRJ.2018.69.022

Pogibaev, D.Y. 2024. The organizational and environmental characteristics of environmental management, taking into account the structural and ecological features of landscapes, climate and vegetation cover of the Middle Russian Plain in the context of the trend towards carbon neutrality. International agricultural journal (Mezhdunarodnyi Sel'skokhozyaistvennyi Zhurnal) 67(1): 57–62. https://doi.org/10.55186/25876740_2024_67_1_57

Portugal, J.R., Arf, O., Buzetti, S., et al. 2020. Do cover crops improve the productivity and industrial quality of upland rice? Agron. J. 112: 327-343. https://doi.org/10.1002/agj2.20028

Prăvălie, R., Borrelli, P., Panagos, P. et al. 2024. A unifying modelling of multiple land degradation pathways in Europe. Nat Commun 15: 3862. https://doi.org/10.1038/s41467-024-48252-x

Rana, A. & Evitts, R. 2014. Development and characterization of flax fiber reinforced biocomposite using flaxseed oil-based bio-resin. Journal of Applied Polymer Science 132(15). https://doi.org/10.1002/app.41807

Report on the implementation of the Circular Economy Action Plan [COM/2019/190]. European Commission. 2019. URL: https://ec.europa.eu/commission/publications/report-implementation-circular-economy-action-plan-1_en (date of access 2024.07.30).

Sadh, P.K., Duhan, S. & Duhan, J.S. 2018. Agro-industrial wastes and their utilization using solid state fermentation: a review. Bioresour. Bioprocess 5: 1. https://doi.org/10.1186/s40643-017-0187-z

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

Singh, T.A., Sharma, M., Sharma, M., et al. 2022. Valorization of agro-industrial residues for production of commercial biorefinery products. Fuel 322: 124284. https://doi.org/10.1016/j.fuel.2022.124284

Siptits, S.O., Romanenko, I.A. & Evdokimova, N.E. 2021. Model Estimates of Climate Impact on Grain and Leguminous Crops Yield in the Regions of Russia. Studies on Russian Economic Development 32(2): 168-175. https://doi.org/10.1134/S1075700721020106

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 12(1): 103. https://doi.org/10.3390/land12010103

Slavskiy, V.A., Litovchenko, D.A. & Ivanova, A.V. 2024. Verification of Earth remote sensing data in order to determine the aboveground phytomass of plantings in the Voronezh Region. Lesotekhnicheskii zhurnal [Forestry Engineering journal] 14(4): 63-84. https://doi.org/https://doi.org/10.34220/issn.2222-7962/2024.4/5

Tate, J., Adekunle, T.A. & Dmitri, K. 2009. Bio-based Nanocomposites: An Alternative to Traditional

Composites. The Journal of Technology Studies 35(1): 25-32. https://doi.org/10.21061/jots.v35i1.a.4
Tedeschi, A., Volpe, M.G., Polimeno, F., et al. 2020. Soil fertilization with urea has little effect on seed quality but reduces soil N2O emissions from a hemp cultivation. Agric. For. 10: 1-14. https://doi.org/10.3390/agriculture10060240
Valizadehderakhshan, M., Shahbazi, A., Kazem-Rostami, M., et al. 2021. Extraction of Cannabinoids from Cannabis sativa L. (Hemp) Review. Agriculture 11: 384. https://doi.org/10.3390/agriculture11050384
Vedernikov, K.E., Bukharina, I.L., Udalov, D.N., et al. 2022. The State of Dark Coniferous Forests on the East European Plain Due to Climate Change. Life 12(11): 1874. https://doi.org/10.3390/life12111874
Volodkin, A.A. 2021. Changes in the structure of forest communities in Penza region under the influence of natural factors. IOP Conf. Ser.: Earth and Environ. Sci. 808(1): 012064. https://doi.org/10.1088/1755-1315/808/1/012064
Volodkin, A.A. 2022. Dynamics of reproduction of forest plantations in the forest-steppe zone of the Middle Volga Region. IOP Conf. Ser.: Earth Environ. Sci. 979(1): 012101. https://doi.org/10.1088/1755-1315/979/1/012101
Walder M.T., de Oliveira C.L., Morante-Filho J.C. & Benchimol M. 2024. Agricultural Expansion and Landscape Heterogeneity Explain Vegetation Degradation in Brazilian Atlantic Forest Landscapes. Land Degradation & Development 36(4): 1121-1132. https://doi.org/10.1002/ldr.5415
Wang, Y. & Cui, X. 2024. Modeling and quantification of agricultural waste recycling for agricultural industrial structure optimization in a novelty multi-village industrial complex. Environmental Impact Assessment Review 106(5): 107484. https://doi.org/10.1016/j.eiar.2024.107484
Waste Prevention Programme for England Evaluation and description of potential waste prevention measures. 2021. London: Defra. URL: https://consult.defra.gov.uk/waste-and-recycling/waste-prevention-programme-for-england2021/supporting_documents/WPP%20Evaluation%20and%20description%20of%20potential%20waste%20prevention%20measures%20FINAL.pdf (date of access 2024.07.30).
Yano, H. & Fu, W. 2023. Hemp: A Sustainable Plant with High Industrial Value in Food Processing. Foods 12(3): 651. https://doi.org/10.3390/foods12030651
Zakshevsky, V.G., Novikov, V.M. & Polunina, N.Yu. 2023. Development of hemp and flax production in Russia: trends, problems, prospects. Technical crops Scientifical agricultural journal 2(3): 64-71. https://doi.org/10.54016/SVITOK.2023.81.57.008