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Prospects of Algolization of Rice Fields in Osh Oblast

Gulbarchin Salimovna Israilova [1], *Zhazgul Suyunbaevna Abdyrakhmanova* [2*], *Baigeldi Turgumbaevich Zhusupov* [1], *Guliza Mamatisa kyzy* [1], *Nurbek Zhakypovich Ermekbaev* [1]

[1] *Institute of Technology and Nature Management, Osh Technological University, Osh 723500, Kyrgyzstan*

[2] *Institute of Natural Sciences and Agricultural Technologies, Osh State University, Osh 723500, Kyrgyzstan*

ABSTRACT

The article discusses the prospects of using algae in the soil—to improve the fertility of rice fields in the Osh oblast of Kyrgyzstan. The authors note that the Fergana Valley, where Osh oblast is located, is an important rice-growing region, and there are currently plans to expand rice fields. In this regard, the study of methods to increase rice yields, such as algolization, is of particular relevance. The article emphasizes that rice fields are unique aquatic ecosystems where microorganisms, especially algae, play an important role. Algae, particularly blue-green algae (cyanobacteria), are capable of fixing nitrogen from the air and enrich the soil with it, which is especially important for rice, which needs nitrogen for growth. The algolization method helps to improve soil structure, reduce the need for mineral fertilizers, control weeds and is an environmentally friendly method of fertility improvement. The authors provide data on the species composition of cyanobacteria found in rice fields in Osh oblast, noting the predominance of *Chroococcus* and *Hormogonium* forms. They also indicate seasonal fluctuations in algae abundance associated with climatic conditions. In conclusion, the authors highlight the promising application of algolization in rice farming in Osh oblast and the need for further research to identify the most effective algal species and develop optimal methods of their application.

Keywords: Algolization; Rice Fields; Osh Region; Algae; Cyanobacteria; Nitrogen Fixation; Soil Fertility; Rice Yield

*CORRESPONDING AUTHOR:
Zhazgul Suyunbaevna Abdyrakhmanova, Institute of Natural Sciences and Agricultural Technologies, Osh State University, Osh 723500, Kyrgyzstan; Email: jazgulabdyrahmanova@gmail.com

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1. Introduction

The Fergana Valley is the most fertile area for the cultivation of different types of crops, including rice.

According to the data provided by the Statistical Committee of the Kyrgyz Republic, as of 2024, the area of rice plantations in the country is 11,909 hectares. At the same time, the analysis predicts a significant expansion of planted areas - up to 50 thousand hectares, which can provide the concept of food security and development of the agro-industrial complex of the country [1]. Joint partnership efforts with scientific and production teams of rice-growing countries of Western and Central Asia, and the Middle East on the development of rice growing are also considered, which will help to bring the industry to a high level. Currently, rice is grown in Uzgen, Aravan, and Karasuu districts of Osh oblast, as well as in Batken and Jalalabad oblasts. The development of most rice varieties cultivated in Central Asia requires flooding of rice fields consisting of individual limited checks. Rice checks are peculiar reservoirs with regulated drainage. They are shallow, so with sharp fluctuations of air temperature during the day, especially in areas with a continental climate, water in rice fields can warm up strongly during the day and cool down at night, i.e., the range of water temperature fluctuations in a short period of time can be significant.

Rice development in Kyrgyzstan contributes to a number of Sustainable Development Goals, particularly SDG 2 "End Hunger", by ensuring food security in the region [2]. Expanding rice plantations and increasing rice yields can meet the growing demand for food and reduce dependence on imports. In addition, rice farming can contribute to SDG 8 "Decent Work and Economic Growth" by creating new jobs in rural areas and stimulating economic development in rice-growing regions. Finally, sustainable rice farming based on the principles of water management and biodiversity conservation can contribute to SDG 6 "Clean Water and Sanitation" and SDG 15 "Protect terrestrial ecosystems" [3]. Rational use and protection of soil, water resources, the atmosphere, fauna, and flora is the basis for sustainable development of agriculture. The increase in production of agricultural crops (cotton, rice, tobacco, etc.) in Kyrgyzstan is being achieved by significant increase in crop yields through increased development of new irrigated lands, as well as the improvement of their meliorative condition.

Rice fields, as an object of biological research, attract the attention of specialists - researchers to study the increase of water body productivity, accumulation of organic matter, fixation of atmospheric nitrogen and improvement of water quality. The results of global research are directed to the application of sustainable integrated farming methods based on strategies for optimizing productivity and environmental sustainability of the integrated ecosystem [4–6].

The role of microorganisms, in particular, algae, is of particular importance in solving these problems. Many researchers have noted the great importance of algae in increasing soil fertility and their role in fixing atmospheric nitrogen [7–13].

The flora of blue-green algae of the plain-predmont areas of the Fergana Valley is characterized by the presence of many tropical species and their significant development in the warm season. Among them, many are nitrogen-fixing forms, which should be introduced into many branches of agriculture [14]. Microalgae biotechnology includes a wide range of activities such as the regulation of algae development by methods of agrotechnics and land reclamation; algolization of rice checks; the use of algae to protect agricultural plants from diseases and pests; liberation of soil from xenobiotics; the use of algae as biostimulants and biopesticides in greenhouse and greenhouse farming; and the use of microalgae in fish farming, poultry farming, and animal husbandry.

Using the potential of microalgae to fix nitrogen and improve soil fertility can be a good alternative to the use of chemical fertilizers. The researchers note that biologically active compounds produced by microalgae strains play an important role not only in the processes of plant growth and development, but also under the influence of negative environmental factors. In particular, the potential of microalgae as biofertilizers, biostimulants and biopesticides in sustainable agricultural practices to increase overall crop yields is emphasized [15].

Soil fertility is ensured due to the active metabolism of soil algae. Forming a biological film of organic compounds on the soil surface, microalgae produce biologically active substances with antibacterial, antiviral and fungicidal effects. Many scientists have proved that algae increase crop yields and enrich the soil with organic matter, macro- and microelements, improve its structure, and stimulate the growth of useful soil microorganisms. In addition, they are a source of physiologically active substances that play an important role in soil processes, and affect the pH of the soil environment [16].

Cyanoprokaryotes inhabit various soils and are characterized by positive effects in different environmental situations [17–19]. The soil contains many species of nitrogen-fixing cyanobacteria that enrich the soil with nitrogen. Scientific literature has data on the importance of nitrogen-fixing cyanoprokaryotes as a green fertilizer in increasing the yield of cotton and other agricultural crops [20].

In Indonesia, 11 strains of cyanoprokaryotes are used for the productive cultivation of maize in mountainous areas. It was experimentally proved that inoculation of seeds with cyanoprokaryotes suspension increased plant growth by 10-15% [21].

A limited number of microorganisms called nitrogen-fixing organisms have the ability to fix nitrogen. Nitrogen fixers are usually in symbiotic relationships with certain plants, providing them with nitrogen and using many substances formed in plants for their own life [22].

Today, the interests of biologists are focused on the search for new microbial-plant nitrogen-fixing cenoses and the development of a set of agrobiological technologies to increase the productivity of nitrogen fixation in crop production [23–25]. Sufficient attention is paid to the study of the nature of associations of cyanoprokaryotes with higher-water plants, especially with cereal crops [26]. Scientists have achieved significant success in the correction of wheat metabolism by inoculation of roots with strains of *Anabaena laxa* and *Calothrix* sp., where an increase in plant crude weight by 30-60% and an increase in nitrogen fixation potential by 20 times were observed [27,28].

Nitrogen-fixing cyanoprokaryotes are of particular importance in the restoration of arid lands and the renewal of their soil functions. Studies conducted by scientists have shown a 46% increase in total organic carbon and total organic nitrogen in soil [29].

Algolization is the process of introducing a culture of certain algae into soil or water and has been used since the 1950s by introducing dried biomass of cyanoprokaryotes into the soil, which has improved soil fertility and crop yields by 15-20%. The authors noted the naturalness, acceptability, and cheapness of the method [17].

It should be noted that the process has been widely studied and applied in many countries, mainly in rice fields [30–33].

2. Materials and Methods

The research objects of this work were expeditionary collections of algae samples from rice fields of Osh oblast. More than 500 algae samples were collected during the research period. Laboratory studies were conducted at the Department of Agricultural Processing Technology of Osh Technological University named after M.M. Adyshev.

Algae samples were collected on a decadal basis. Qualitative samples of phytoplankton were taken with a plankton net (gas No. 76), quantitative, liter-scale samples were taken with a bathometer, sedimented, and a part was filtered through membrane filter No. 6. Phytobenthos samples (fouling, plaques, films) were collected with a scraper, scalpel, and clusters of filamentous were collected manually. All samples were fixed with 40% formalin (3-4 drops).

Methods for qualitative study of the material: Collected material was previewed under a live microscope on the day of collection to indicate the qualitative state of the algae before the onset of changes due to storage of live material or sample fixation.

The collected material was processed in a fixed state according to the generally accepted methodology of algological studies [34,35].

Quantitative phytoplankton samples were counted in a Goryaev counting chamber with volumes of -1/400 and 1/22 mm2 [36,37]. Four to five drops were examined. The average number of organisms was determined with the subsequent recalculation per liter of water. Biomass was established by direct microscopic counting using a Goryaev chamber, counting the number of cells in a certain volume. In addition, the material was processed by sowing on dense nutrient medium in Petri dishes with subsequent counting of colonies.

Algae productivity was determined according to the method of M.T. Vladimirova and V.E. Semenenko [36].

Water transparency was determined by Seki disk. Dissolved oxygen content was determined by the Winkler method. Water samples were fixed on-site with the addition of NaOH, KJ, and $MnCl_2$. The pH value was determined by a set of indicators according to Michaelis and a universal indicator. Chemical analyses of water were carried out jointly with the staff of OshGorSES.

3. Results

Rice fields of Osh province belong to the type of shallow, low-flow water bodies, consisting of a large number of checks that receive water from the irrigator. Water depth in the checks varies from 10 to 30 cm, with an average depth of 13–15 cm. Transparency of the upper checks is low (5–12 cm), and consistently increases toward the bottom.

During the study of the algoflora of collector-drainage systems of Osh oblast 64 species and varieties of cyanoprokaryotes were identified (**Figure 1**).

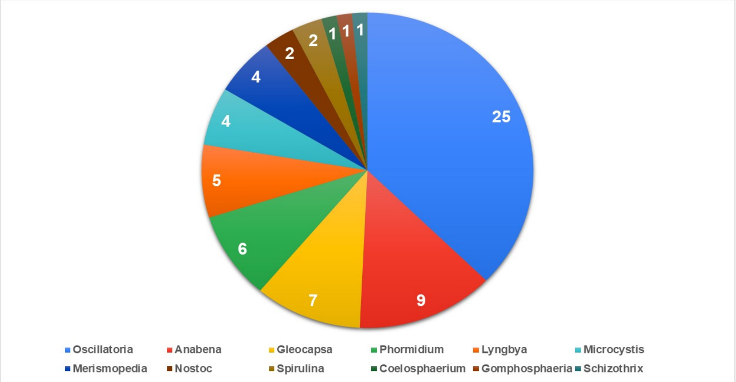

Figure 1. Number of cyanoprokaryotes species/varieties found in water bodies of collector-drainage networks in Osh oblast.

Species composition of cyanoprokaryotes on areas cultivated under agricultural land in Osh oblast is represented mainly by representatives of *Chroococcus* and *Hormogonium*. Representatives of the genera *Merismopedia*, *Microcystis*, and *Gloeocapsa* were identified from chroococcaceae. Among chorococcal algae, the most frequently encountered were *Merismopedia elegans* A.Br., *M.glauca* (Ehr.)Naeg., *Microcystis aeruginosa* (Kuetz.) emend. Elenk., *Gloeocapsa limnetica* (Lemm.) Hollerb [38].

Representatives of hormogonium algae belong to the following genera: *Anabaena*, *Oscillatoria*, *Schizothrix*, *Phormidium* and *Lyngbya*. The genera *Oscillatoria* and *Anabaena* are characterized by a diversity of species.

Hormogonium cyanoprokaryotes *Oscillatoria irriqua* (Kuetz.) Gom, *O. acuminata* Gom., *O.boryana* (Ag.) Bory, form filamentous thalloms in the form of blue-green film (on wet soil, at the bottom of irrigation ponds, as well as in the form of "cakes" on the water surface). Together with them, there are species of genera *Anabaena Bory* - *Anabaena solitaria* Kleb., *A.variabilis* (Kuetz.), *A.flos-aqua* (Lyngb.) Breb. All the above-mentioned species are included in the dominant forms of algae of the studied areas. Taking into account the ability to nitrify some representatives of cyanoprokaryotes, let us consider the details of their morphological structure.

According to Hollerbach's definition, trichomes of representatives of the family *Anabaenaceae* Elenk. may be straight and curved, of equal width, solitary or connected in turfs. Trichomes are surrounded by almost imperceptible, colorless mucus. Vegetative cells are of various shapes, terminal cells are cone-shaped and pointed, heterocysts are intercalary and terminal, and spores are solitary or occur in groups [34].

Representatives of the genus *Anabaena* have straight or curved trichomes, of equal width, single or connected in mucous turfs. Heterocysts are of intercalary type, spores are solitary or arranged in chains, and can be distant from heterocysts or adjacent to them [34].

Anabaena azollae Strasburg. - trichomes 4-5 µm wide, variously curved or almost straight, without sheaths, forming small tubules of blue-green coloration. Cells are cylindrical with rounded ends, 5-9.5 µm long. Terminal cells are rounded-cone-shaped, 2.7 µm wide, and about 4 µm long. Heterocysts measure 9.5 µm to 11.5 µm in length. Spores rounded-cylindrical to ellipsoid, and wider than vegetative cells. It lives in symbiosis with the aquatic fern *Azolla*, inside the air-bearing cavities of the plant (Hollerbach and Kosinskaya, 1953). *Azolla caroliniana*

Willd is a plant that lives on the surface of drenches and wetlands. This fern species is interesting as a nitrogen fixer with agricultural potential [39].

Anabaena sphaerica Borb. et Flah. - Trichomes 5-6 µm wide, straight, parallel, with indistinct sheaths, connected in thin blue-green turfs. The cells are globular. The terminal cell is rounded. *Heterocysts* are *globular*, 6-7 µm in diameter. Spores are globular or broadly ellipsoid, 12 µm wide, spores are rounded-cylindrical, 12-18 µm long, with smooth, yellow-brown shells, located on one or both sides of the heterocyst, singly or several in a row. They are inhabitants of standing water [34].

Anabaena variabilis Kuetz. - Turf is mucous, black-green in color; trichomes are curved, 4–6 µm wide; cells are barrel-shaped, 2.5–6 µm long, weakly constricted at transverse partitions. *Heterocysts globular* - oval, 6–8 µm long. Spores are barrel-shaped, 7 to 11 µm wide and 8–14 µm long, with smooth colorless shell, arranged in rows. It occurs in standing water at the bottom of reservoirs and on moist soil surface [34].

The second potentially significant group in nitrogen fixation is represented by the family *Nostocaceae* Elenk. - with single-row trichomes of equal width, not branching, with well-formed sheaths, heterocysts are intercalary, spherical, and ellipsoidal; colonies are clearly formed, macroscopic, gelatinous, and of mucous consistency.

Nostoc paludosum Kuetz. - colonies are microscopically small, hardly visible to the naked eye, up to 0.5 mm across, mucous, without strong periderm, blue-green in color. Vaginae are broad, and colorless. Trichomes are loose, pale bluish-green, 2.5 to 4.5 µm, cells are barrel-shaped, less often ellipsoid, up to 5 µm long. Heterocysts are globular or ellipsoid, 4-6 µm wide, spores are ellipsoid, almost globular, 4-4.5 µm wide and 6-8-9 µm long, with smooth colorless or slightly brownish shell. It is an inhabitant of standing water bodies and moist soils [34].

Nostoc pruniforme Ag. - Colonies are spherical or ellipsoid, smooth, 1-1.5 cm in dia., rarely up to 4 cm wide, and up to 5 cm long, soft inside, with a cavity, outside with strong periderm, bright blue-green, olive. Sheaths are usually well visible, colorless, and less often yellowish. Trichomes are loosely intertwined, radially extending from the center to the periphery, 4-6 µm wide. Cells are short-bobon-shaped, slightly elongated, and heterocysts are almost spherical, 6-7 µm in dia. Spores are spherical, about 10 µm wide [34].

Cyanoprokaryotes grow in great abundance on the surface of various substrates, as well as in fouling on various higher aquatic plants and in the periphyton of irrigation canals. Cyanoprokaryotes reach their maximum development in terms of species diversity and quantitative composition in summer (July-August) and in autumn (September-October), when their abundance in phytoplankton ranges from 700 to 1000 million cells/liter. The minimum development is observed in winter (January), their total abundance in phytoplankton on average varies from 0.04 to 0.34 million cells/liter (January).

According to ecological characterization, of them planktonic forms - 7 species (mainly representatives of genera *Microcystis* and *Anabaena*), benthic (mainly species of genera *Oscillatoria*, *Phormidium*) - 23 species, planktonic-benthic - 34 species (mainly species of genera *Oscillatoria*, *Gleocapsa*, *Merismopedia*) (**Figure 2**)

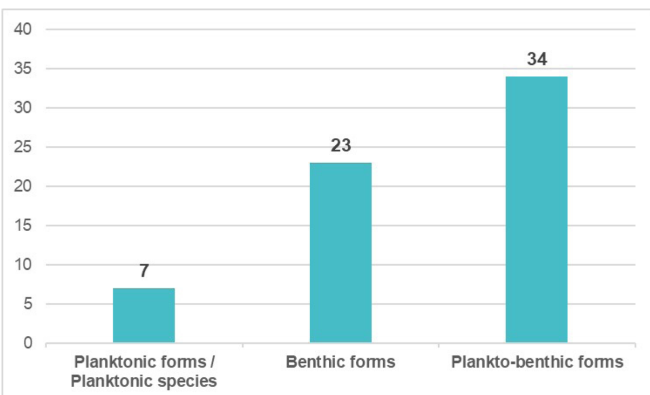

Figure 2. Distribution of cyanobacterial species by ecological group.

4. Discussion

Water of drains and collectors is rather saline (from 0.33 to 2.14 g/l). In relation to water salinity cyanoprokaryotes are arranged as follows: freshwater forms - 4 species, freshwater-saline-water - 57 species and brackish-water - 3 species (**Figure 3**).

According to the degree of pollution, water bodies of collector-drainage systems belong to α-β- mesosaprobic zones. In these water bodies, 23 species of saprobic algae were found, including oligosaprobic and α- β- mesosaprobic forms [40].

Application of cyanoprokaryotes to the soil or water of rice fields gives a good effect, as cyanoprokaryotes accumulate quite a large amount of nitrogen, fixing it, produce biologically active substances and enrich the soil with organic matter. It is proven that during the vegetation period cyanoprokaryotes fix up to 50 kg of nitrogen per 1 ha of area. Half of this amount of nitrogen is assimilated by crops [16].

To increase the yield of cereal crops, especially rice, the most commonly used strains of cyanoprokaryotes belong to the genera *Anabaena*, *Nostoc*, *Scytonema*, *Tolypothrix*, *Spirulina*, and *Calothrix* [41,42]. This method of enrichment with algal flora can be used in the cultivation of rice and a number of other cereal crops grown under irrigated farming conditions.

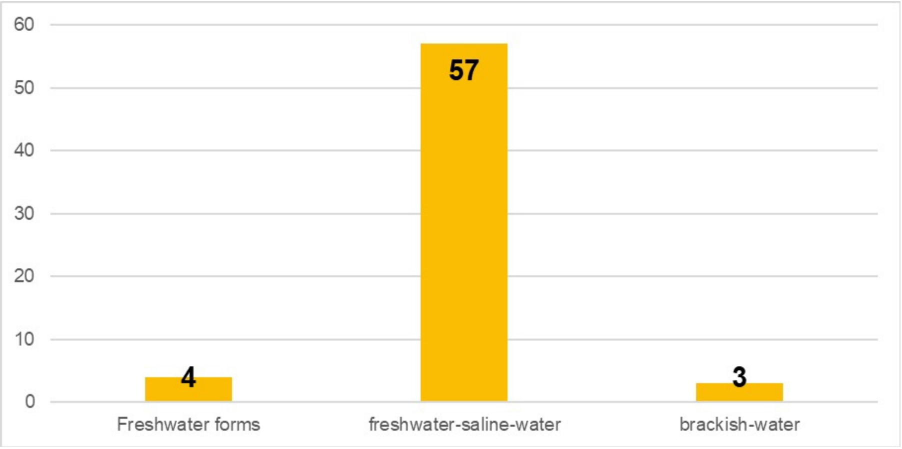

Figure 3. Distribution of cyanobacterial species by ecological group (planktonic, benthic and planktonic-benthic).

The results of the conducted study of algoflora of collector-drainage systems of Osh oblast revealed significant species diversity of cyanobacteria represented by 64 species and varieties belonging mainly to Chroococcal and Hormogonium forms. The dominance of genera *Oscillatoria*, *Anabaena*, *Gloeocapsa*, *Phormidium*, *Lyngbya*, *Merismopedia* and *Microcystis* is consistent with the data of Muzafarov and Taubaev (1984) on the flora of blue-green algae of the plain-predmont areas of the Fergana Valley, who noted the presence of many tropical species and their active development in the warm season [14].

The detection of a large number of species of the genus *Anabaena*, many of which are known nitrogen fixers [7–9], confirms the presence of a significant potential for natural biological nitrogen fixation in the studied water bodies and adjacent agricultural lands, in particular, in rice fields. The morphological characteristics of the identified species *Anabaena azollae*, *A. sphaerica* and *A. variabilis* correspond to the descriptions in the identifications by Hollerbach and Kosinska, which suggests their potential nitrogen-fixing ability. Of particular interest is *Anabaena azollae*, known for its symbiosis with the aquatic fern *Azolla* and effective nitrogen fixation, which opens prospects for studying the possibility of using the *Azolla-Anabaena* symbiosis in rice production in the region [34].

Seasonal dynamics of cyanobacteria development with peak abundance in summer-autumn period (July-October), coinciding with the rice vegetation period, indicates favorable conditions for their growth and potential impact on agroecosystems in this period. Minimal development in winter is explained by low temperatures, which is a typical pattern for water bodies with continental climate.

The ecological characterization of reservoirs of collector-drainage systems as α-β- mesosaprobic zones and predominance of freshwater-saline-water forms of cyanobacteria (57 species) indicate a certain level of water salinity (0.33 to 2.14 g/l) and pollution by organic substances. Despite this, the active development of cyanobacteria algae under such conditions emphasizes their adaptability and potential role in the processes of self-purification of water bodies and biogeochemical cycling.

The obtained data on species diversity of nitrogen-fixing cyanobacteria in collector-drainage systems of Osh oblast are promising for development of algolization method in local rice farming. As noted in the world literature, introduction of nitrogen-fixing cyanobacteria into rice fields can significantly increase their fertility and yield due to biological fixation of atmospheric nitrogen, production of biologically active substances and enrichment of soil with organic matter [16,17,30–32].

5. Conclusions

In this work, water bodies of collector-drainage networks of Osh oblast were investigated to identify promising species of nitrogen-fixing cyanobacteria for their application in rice farming. Significant species diversity of cyanobacteria was found, which was represented by *Chroococcus* and *Hormogonium* forms. The dominant genera are *Oscillatoria*, *Anabaen*a, *Gloeocaps*a, *Phormidium*, *Lyngbya*, *Merismopedia* and *Microcystis*.

The study of seasonal dynamics of growth and development of cyanobacteria showed that the optimal season is the summer-autumn period, from July to October, which corresponds to the period of vegetative activity of rice. Winter period is marked by minimal development of these microorganisms associated with low ambient temperature.

It is necessary to note the ecological role of cyanobacteria actively vegetating on various substrates, on the surface of higher aquatic plants, and on the fouling of irrigation canals, which indicates their integral role in the ecosystem of drains, collectors and rice fields.

The abundance of *Anabaena* species shows that the region has full potential for natural nitrogen fixation.

The prospect of applying the algolization method in rice farming requires detailed studies to identify the ability of nitrogen-fixing cyanobacteria to regulate soil nitrogen content and activate yield improvement.

Consequently, there is a potential for successful application of algolization method in agriculture in our region. Rich species diversity of the main nitrogen-fixing forms of cyanobacteria in reservoirs of collector-drainage networks indicates optimal conditions for the development of this algae department in the southern region. Application of the innovative method in rice farming in Osh oblast will lead to increased yields, reduced fertilizer costs and improved environmental sustainability of agricultural production.

For the practical application of algolization method in rice farming in Osh oblast the following studies and activities are necessary:

1. Detailed inventory and identification of the most effective nitrogen-fixing strains of cyanobacteria dominating in local collector-drainage systems and rice fields. Particular attention should be paid to species of the genus *Anabaena*, as well as other known nitrogen-fixers such as *Nostoc*, *Scytonema*, *Tolypothrix* and *Calothrix*.
2. Laboratory studies to determine optimal cultivation conditions for isolated strains, including temperature, lighting, nutrient medium composition and pH, to maximize biomass and nitrogen-fixing activity.
3. Conducting vegetation and field trials to assess the effectiveness of different strains of cyanobacteria and methods of their application (algolization) on rice yield in local agroclimatic conditions. It is necessary to study the effect of algolization on various indicators of plant growth and development, as well as on agrochemical properties of soil.
4. Development of practical recommendations on the application of algolization method for rice growers of Osh oblast, including optimal doses of algae biomass application, terms and methods of rice fields treatment.
5. Exploring the possibility of using symbiotic associations such as *Azolla-Anabaena* to improve nitrogen fixation efficiency in rice agrocenoses in the region.
6. Assessment of economic feasibility and environmental safety of the introduction of the algolization method in rice farming, including cost analysis of algae cultivation and application and potential reduction of the need for mineral nitrogen fertilizers.

Implementation of these proposals will allow scientific substantiation and practical implementation of an environmentally safe and economically beneficial method of increasing rice yields in Osh oblast based on the use of the potential of local nitrogen-fixing cyanobacteria, which will contribute to the sustainable development of agriculture in the region and the achievement of food security goals.

For a full-fledged transition to organic crop production, further research is needed to determine the optimal conditions for cultivation and application of cyanobacteria to the soil. It is advisable to conduct field trials to assess the effectiveness of algolization on rice yield under local conditions. Implementation of algolization is associated with the need to select suitable cyanobacteria culture for local conditions. Further algolization of rice fields will require a thorough study of the dominant species in order to identify the most productive strains of microalgae.

Author Contributions

All authors made significant contributions to this study. Z.S.A. developed the study concept; G.S.I. and N.Z.E. developed the methodology; B.T.Z. contributed to data collection and resources; Z.S.A. supervised the data; G.M.k. prepared the initial draft, and Z.S.A. and G.S.I. reviewed and edited the manuscript. G.S.I. supervised the study. All authors have read and approved the final manuscript.

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Data Availability Statement

All data supporting the reported results are provided within the manuscript. Additional data can be made available upon reasonable request.

Conflict of Interest

All the authors also declare that there is no conflict of interest in relation to the research, authorship, and publication of this study.

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