Concept of forming individualization of smart village methodology using AI cognitive processes

Yury Shvets[1], *Sergey* Tolkachev[2], *Igor* Molchanov[2,3], *Valery* Nezamaikin[4], *Andrey* Kharlamov[5], and *Dmitry* Morkovkin[2*]

[1]V.A. Trapeznikov Institute of Control Sciences of Russian Academy of Sciences, Profsoyuznaya str. 65, Moscow, 117997 Russian Federation
[2]Financial University under the Government of the Russian Federation, 49/2, Leningradsky avenue, Moscow, 125167, Russian Federation
[3]Lomonosov Moscow State University, building 1, Leninskie Gory, Moscow, 119991, Russian Federation
[4]Russian State University for the Humanities, 6, pl. Miusskaya, Moscow, 125047, Russian Federation
[5]St. Petersburg State University of Economics, 30-32-A, Griboedov Canal, St.Petersburg, 191023, Russian Federation

Abstract. The study examines the role of digital agriculture in rural transformation and optimization of agricultural production, especially in the context of Russia. The article discusses the application of advanced sensors for soil and fertility analysis, which helps in determining potential yields and effective fertilizer application. Digital agriculture is presented as a tool to improve efficiency and productivity in rural areas, contributing to their economic growth. In addition, the study emphasizes the importance of adequate use of data and modern technology in farming. The analyses presented are based on extensive use of statistical and mathematical methods using various Python software packages. The conclusions of the study emphasize the need to integrate digital technologies in agriculture for sustainable rural development.

1 Introduction

The role of digital agriculture in transforming rural areas into smart villages is becoming increasingly important. With the rapid advancement of technology, digital agriculture is a key component in making rural areas more efficient, productive and accessible to people. Digital agriculture can revolutionize rural areas by providing access to the latest information and tools, increasing efficiency and productivity, and promoting economic growth. Digital agriculture uses technology to improve the quality of life in rural areas.

Smart villages can also lead to better management of resources such as soil, water and labor. Russia, with its vast territory and diverse climatic conditions, is particularly in need of efficient agricultural management.

* Corresponding author: morkovkinde@mail.ru

2 Materials and methods

For the basis of the research, we applied the following methods: analysis, generalization, observation, systematization, and statistical and numerical approaches. The most important statistical data were analyzed in detail, which made it possible to determine the relationships between them and identify key areas for investment. We processed the given data using statistical tools such as pandas, numpy, scipy, geopandas and sklearn in the Python programming language. To visualize the results, we used the matplotlib and seaborn graphical tools in the same programming language.

3 Results

According to the European Network for Rural Development (ENRD), smart villages are communities in rural areas that use innovative solutions to improve their sustainability, building on local strengths and capabilities. They rely on a collaborative approach to develop and implement their strategy to improve their economic, social and/or environmental condition, in particular by mobilizing digital solutions [1]. Thus, the main objective is to benefit from locally available resources and opportunities and develop cost-effective schemes to overcome individual obstacles at the community level and strive to create an autonomous and empowered community. Rural community participation, multi-stakeholder involvement and improved communication are considered key features of this concept.

The smart village concept was promoted in the EU in 2016 at the CORK 2.0 European Conference on Rural Development. Promoting rural development, supporting rural economy and entrepreneurship, promoting rural vitality and sustainability, preserving rural atmosphere and natural deposits, developing climate awareness, promoting knowledge and creativity, strengthening rural administration, effective implementation and policy advocacy, and monitoring productivity and developing a sense of responsibility were announced as the basis for a thorough and integrated rural and agricultural policy at CORK 2.0. An important contribution of this initiative is the formation of a thematic group composed of leaders and professionals from all over Europe to create a model plan to promote and advance the smart village concept. The Common Agricultural Policy (CAP), one of the most influential policies for rural improvement, is co-financed by the European Agricultural Fund for Rural Development (EAFRD) and the European Agricultural Guarantee Fund (EAGF) [2].

There are already results of the implementation of smart villages in European countries. The use of modern equipment and automation along with information and communication technologies (ICT) to improve decision-making and production has changed agriculture as an important part of the digital revolution. Increased yields, reduced costs and less damage to crops and the environment are possible through the use of GPS, remote sensing, the Internet of Things, artificial intelligence and machine learning. Technology has revolutionized agriculture and enabled farmers to maximize their productivity.

The development of smart villages in Russia should be accompanied by significant investment in the digitalization of agriculture. In order to accurately evaluate the current picture on the development of the agricultural sector and the sufficiency of investment in it, it is necessary to identify a number of the most important indicators that characterize these sectors and check their status: the share of investment in fixed capital of agriculture, forestry, hunting and fishing in the breakdown of all incomes and agricultural production.

The first indicator reflects the share of investments in agriculture in the total volume of investments. Let us evaluate the graph of distributions by the federal subjects of Russia.

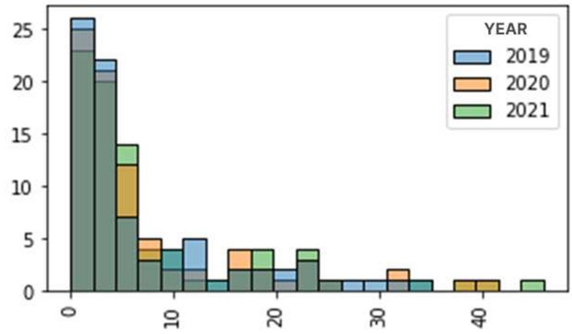

Fig. 1. Graph of distribution of the investment share in agriculture.

The indicator distribution graph shows strong differences in the level of investment between regions. Some regions demonstrate a consistently high level of the indicator, but in most of Russia the share of investment in fixed capital of agriculture, forestry, hunting and fishing in the breakdown of all incomes remains very low. At the same time, the level of the indicator in some regions with a low share of investment is slightly increasing. And in the regions with a high share of investment there was a decrease in the indicator in 2020, which affected the average value of the share of investment in agriculture across Russia.

Our analysis showed that the largest share of investments in fixed capital of agriculture is shown by the following regions: Bryansk, Orel, Pskov Oblasts and Kamchatka Krai. It can be noted that the Orel and Pskov Oblasts, with an average volume of investments, spend a significant part of them on financing agriculture. For example, in Primorsky Krai the situation is the opposite - with the amount of "above average" investments in agriculture, their share, on the contrary, is "below average" in the total volume of investment in fixed capital.

Moscow Oblast is of particular interest, where the indicator of investment in agriculture is high, but its share in the total volume of investment is extremely small. And this is not an isolated case. That is, those regions that have money spend a smaller share of funds on agriculture than the "poorer" regions. This allows us to conclude that the potential for the development of rural areas is insufficiently used.

Let us assess the situation on the heat maps (Figure 2).

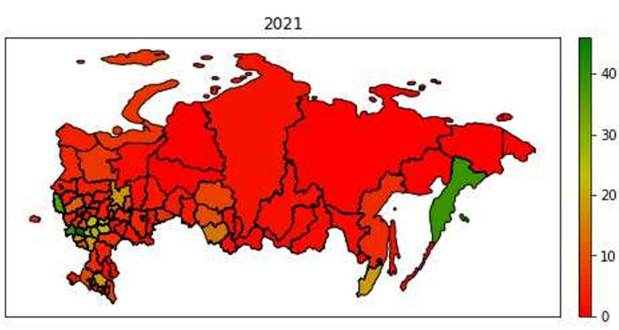

Fig. 2. Heat maps of investment indicator in 2019-2021 timeframe.

The picture on the heat maps is disappointing - most of Russia invests a disastrously small share of funds into agricultural development. Only a few regions in the east of the country and central Russia are exceptions.

Let us consider the situation in each federal district (Figure 3).

BIO Web of Conferences **71**, 01115 (2023) https://doi.org/10.1051/bioconf/20237101115
CIBTA-II-2023

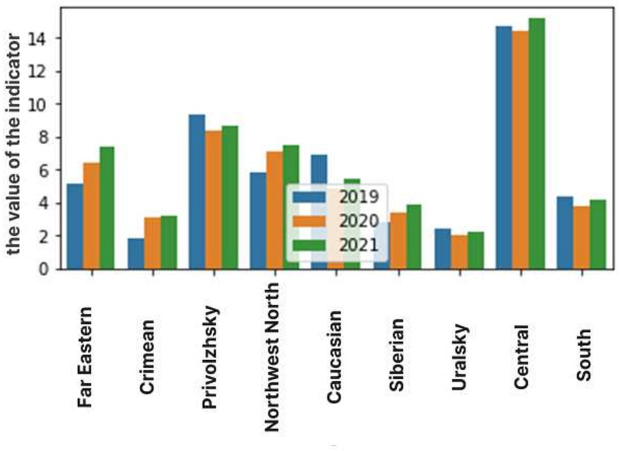

Fig. 3. Indicator distribution by federal districts of Russia.

The Central Federal District, as in the previous indicator, takes the leading position, i.e., the regions located in this district can sufficiently use the potential of their rural areas. The Far Eastern and Volga Federal Districts are catching up. The rest spend an insufficient share of all investments on agricultural development.

Let us evaluate the second indicator - the agricultural output. One of the indicators of the performance of the subjects' rural territories is the quantity/value of agricultural output. According to the indicator distribution graph, it can be seen that one or several regions demonstrate a jump in production volumes in 2021, and there are also several regions with stable high values of the indicator, but in most regions the volume of agricultural output remains at a low level.

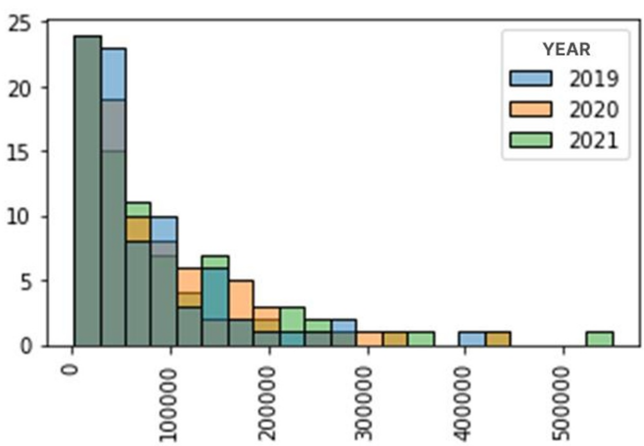

Fig. 4. Distribution by agricultural production indicator.

Most agricultural output is produced in Krasnodar Krai, Belgorod, Voronezh, Rostov Oblasts, Stavropol Krai and the Republic of Tatarstan. These 6 regions provide most of the production of the whole country, and therefore any changes in the volumes in these subjects will have a very strong impact on the overall result. The dynamics of the indicator is generally positive everywhere, but still most regions do not produce agriculture, which will also be confirmed by the heat maps below.

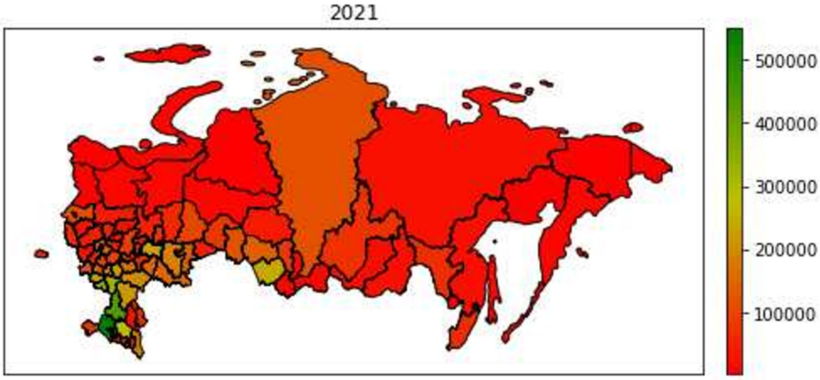

Fig. 5. Heat maps of agricultural production indicator.

The overwhelming part of the country is colored red, which means a low or negligible level of agricultural production. As in previous heat maps, the highest values are found in central and southern Russia. The conclusion is that despite all the jobs, shares and actual investments in agriculture created, only 6 regions can effectively provide the country with agricultural products, including exports. Let us consider the situation in the context of federal districts.

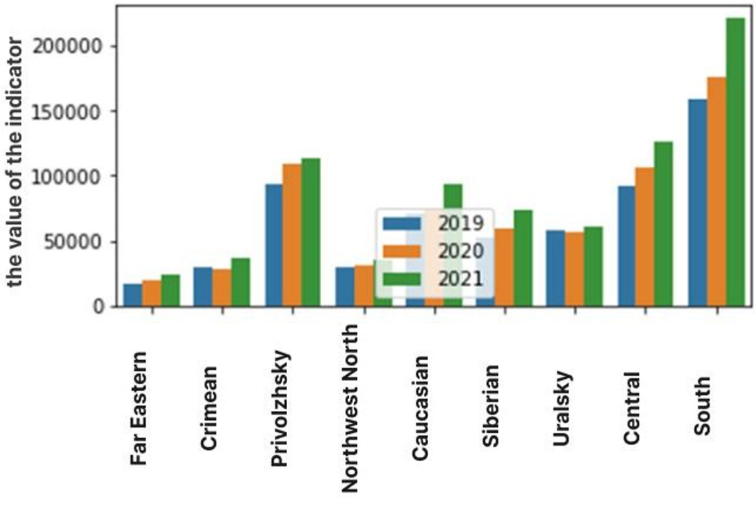

Fig. 6. Distribution by federal districts of Russia.

First of all, we should point out the widespread growth of the indicator, which is more pronounced in the North Caucasus and Southern Federal Districts. The Southern Federal District is the undisputed leader among federal districts, followed by the Volga and Central Federal Districts. In the other districts this indicator is at a low level, which was proved earlier.

The analysis shows that the agricultural potential is not fully developed in the regions of Russia. Most of the agricultural products are produced on a small territory. Based on this, it can be assumed that the introduction of smart villages can make it possible to use the territories more efficiently and with less labor input. Existing digitalization tools can be used for implementation.

Ideas such as precise farming, which involves extensive data collection and analysis of crop-specific factors, contribute to higher yields. Below we summarize the contributions of digital agriculture into four main categories [3]:

- Precise irrigation.
- Detection and control of crop diseases and pests.
- Soil fertility analysis.

3.1 Precise irrigation

In regions with irregular rainfall, irrigation is essential for food production. The irrigation system needs to be carefully monitored to get the best crop yields. This is time consuming, labor intensive and costly. The required water flow depends on a wide range of factors including soil moisture, temperature, plant condition, etc., which means that crop water requirements are not constant and vary with the season and crop growth. While farmers around the world, especially in underdeveloped countries, are using outdated methods according to their invaluable experience, digital agriculture has started to make the job easier.

IoT or Internet of Things is an expanding network of interconnected objects or devices with embedded sensors that can collect and share data among themselves. Incorporating the Internet of Things into irrigation system is gradually gaining momentum. Industrial sensors available for irrigation and agricultural systems are still quite expensive for farmers. But lately, a lot of attention has been given to low-cost sensors. This has been a huge push for IoT-based smart agricultural systems. Research is being conducted on various applications of sensors for measuring parameters such as plant water stress. Along with traditional soil moisture sensors, new low-cost and low-energy technologies such as leaf detection are being evaluated [4]. Different proposed smart irrigation models use different approaches to collect data using different types of sensors, improving the process technology. The improvement of these sensors allows accurate measurement of data and in turn makes data-driven decision making easier and more accurate.

The improvement of these IoT systems has also been fueled by improvements in wireless technology. Wi-Fi is the most utilized form of communication technology because of its availability and low financing costs, although large coverage area is a challenge for this technology. In most cases, Global System for Mobile Communications (GSM) is used for long-distance communication between the sensor array and the system. Another notable wireless technology is LoRa, which has been mainly used in unattended regions over a large area. Improvements in this sector mean that IoT systems can be embedded in even the most peripheral locations [5].

Different irrigation scheduling tools work according to different approaches depending on the crop or plant. Smart irrigation monitoring can be divided into three main categories: soil-based, weather-based and plant-based. These tools can help to significantly reduce water and energy consumption if plant-based indicators are applied. The typical third world farmer uses their own experience to determine the amount and timing of irrigation having no accurate or convincing data. This process involves a lot of manual experimentation and frequent checking of several factors mentioned above. Irrigation scheduling tools help mitigate human judgment errors. Thus, the integration of irrigation scheduling automation reduces the use of surplus water [6].

When evaluating the performance in the case study compared to conventional irrigation models, smart irrigation scheduling systems were able to reduce water and electricity consumption by 59.61% and 67.35%, respectively, while increasing yields by 22.58%. For optimal utilization of all available resources such as water, energy, labor and time, there is no replacement for digital irrigation systems. The ever-increasing population and global climate change will have an unfavorable impact on the earth's natural resources in the coming days. Therefore, now is the right time to prioritize technologies such as smart irrigation and precision farming to secure water supplies.

3.2 Detection of pests and diseases of agricultural crops [7]

Pest control is the process of eliminating species that are considered harmful to plant or crop health and yield. One of the main problems associated with pest control is their early detection.

Traditionally, farmers try to manually detect the presence of pests. This is an inefficient method to find such small anomalies in a huge area of crops. The tedious process of manual pest detection involves frequent monitoring and does not guarantee any concrete results. The potential crop loss due to pests is about 18%. In traditional agricultural systems, pest attacks are often detected at later stages of spread. As a result, a large number of pesticides are used to control agricultural damage. The use of pesticides leads to soil damage, contamination of water bodies, death and depletion of aquatic species. In addition, excessive use of pesticides often harms the health of people who consume food produced on pesticide-dependent land for pest control. Consequently, sustainable agriculture requires adoption of better technologies to detect pest attacks in the early stages of infestation.

In recent years, much effort has been directed towards long-range and more accurate diagnosis of diseases and pests. Image processing techniques have proven to be very useful in such applications. Through the use of digital image processing, visual elements that are important to a particular application can be highlighted, while details that are not as important to the application can be softened. The processed image is then used to collect relevant features. Image processing has been used according to various smart sensors, microcontrollers and predictive algorithms to effectively detect pest attacks.

In one such application combining image processing and sensory data, passive infrared (PIR) sensors and motion sensors are used to detect the presence of any pests based on heat trace and motion. Once the pests are detected, the images are captured and processed to be sent to the microcontroller. Acoustic sensors are then used to collect the sounds produced by the pests laying eggs and feeding. By collecting both images and audio data, false alarms for environmentally friendly pests are avoided. This data is then compared to a database using a microcontroller to determine if a pest is potentially harmful. If pests are found to be harmful, an ultrasonic generator is used to create a sound (at a frequency not audible to humans) that stresses the pests' nervous system. As a result, the pests are scared away from the source of the sound. This is an excellent implementation of IoT system for pest control [8].

3.3 Soil mapping, fertility analysis and fertilizing

The potential yield of a particular crop on a particular piece of land depends on many factors, such as: weather conditions, soil moisture, soil fertility, pH level, etc. Soil fertility analysis and yield prediction are some of the most important topics in digital agriculture. With an ever-increasing population and demand for food comes continuous harvesting. As a result, the fertility of arable land has been rapidly depleted. Using fertilizers without proper knowledge and analysis is not enough to solve the problem. Extensive soil nutrient analysis and sound soil management decisions based on accurate data are needed to deal with the increasing demand for food. In addition, the decision to grow a crop on a particular piece of land requires careful data-driven consideration.

Sensors for extracting information from soil samples have been extensively studied. Electrical or electromagnetic sensors can be used to determine many important soil properties such as soil structure, salinity, moisture, etc. The main advantages of these sensors are low cost and fast response. Optical sensors provide efficient soil mapping using the principles of spectroscopy - reflectance, absorption and transmittance of light. Researchers have been successful in measuring soil organic matter, moisture content and various soil nutrients such as CEC, pH, etc. Electrochemical sensors usually take longer to analyze than other soil sensors. These sensors are mainly based on the principle of ion selective electrode or ion selective field-effect transistor (ISFET). These sensors provide high resolution mapping of potassium (K^+) levels [9].

One of the most important parts of agriculture is fertilizer application. Fertilization is the process of adding nutrients absorbed by the last batch of crops. This is necessary for a better crop yield. One of the modern ideas of changing the form of fertilization is variable rate fertilization or variable rate nutrient application (VRNA). The basic idea of variable rate application is to use fertilizer, water, seed, etc. throughout the field in varying amounts depending on the conditions of a particular area. Variable rate application is economically and environmentally efficient for obvious reasons. Application of variable rate fertilizer depends on proper soil mapping and soil fertility analysis as soil properties vary spatially. Classification of the land under discussion into soil mapping units or management zones is an adequate approach to handle spatial variability.

The role of digital agriculture in transforming rural areas into smart villages is becoming increasingly important. With the rapid advancement of technology, digital agriculture is a key component in making rural areas more efficient, productive, and accessible to the public. In this study, we discussed the fact that digital agriculture can revolutionize rural areas by providing access to the latest information and tools, increasing efficiency and productivity, and promoting economic growth. Digital agriculture uses technology to improve the quality of life in rural areas. This includes access to new information and tools such as precise farming, remote sensing and GIS mapping. By giving farmers access to new information and tools, digital agriculture can help them increase yields and reduce costs [10].

Digital agriculture can also enable better management of resources such as soil, water and labor. Farmers can use digital agriculture to optimize crop production and manage their resources more efficiently. In addition to improving the quality of life in rural areas, digital agriculture can also contribute to economic growth. By providing access to new information and tools, digital agriculture can help increase the value of land and increase the productivity of farmers. This can lead to increased agricultural production and economic opportunity. By increasing the value of land, digital agriculture can also help attract new businesses.

4 Discussion

Digital agriculture in Russia is still in its infancy. Precision farming, the use of sensors and remote sensing will allow farmers to manage their land plots more efficiently, which is especially important in the context of climate variability and soil diversity. Special attention in Russia should also be paid to the problems of providing access to modern technologies in remote regions of the country [11].

However, the introduction of new technologies in Russia faces a number of challenges, including infrastructural constraints, lack of qualified staff in some regions, and socio-cultural characteristics of the local population. Nevertheless, given Russia's geographical and economic peculiarities, the potential for digital agriculture in the country is immense.

https://doi.org/10.1051/bioconf/20237101115

5 Conclusion

Digital agriculture is a powerful tool for modernizing Russia's agriculture, making it possible to overcome a number of traditional problems and improve the quality of life in rural areas. Despite the challenges and complexities Russia faces, the integration of digital technologies in agriculture can significantly improve its sustainability, productivity and environmental friendliness. Realizing this potential requires government support, investment in education and infrastructure, and active collaboration among all stakeholders.

References

1. O.A. Okorokova, E.I. Udodova, V.I. Suminskaya, Assessment of investment attractiveness of rural areas, Bulletin of the Academy of Knowledge, 23 (2019)
2. M.R. Chowdhury, M.S. Sourav, R.B. Sulaiman, The Role of Digital Agriculture in Transforming Rural Areas into Smart Villages, 10012 (2023)
3. S. Stojanova, G. Lentini, P. Niederer, T. Egger, N. Cvar, A. Kos, Smart Villages Policies: Past, Present and Future sustainability, Smart Villages Policies: Past, Present and Future, 2 (2021)
4. L.A. Rudwiarti, A. Pudianti, A.W.R. Emanuel, V.R. Vitasurya, P. Hadi, *Smart tourism village, opportunity, and challenge in the disruptive era*, IOP Conf. Ser. Earth Environ. Sci., 780 (2021)
5. W.Z. Li, H. Zhong, Development of a smart tourism integration model to preserve the cultural heritage of ancient villages in Northern Guangxi. ‖Herit. Sci., **10**, **1**, 1–15 (2022)
6. G. Schoneveld, F.D. Matteo, F. Brandao, P. Pacheco, I. Jelsma, A systematic mapping protocol: what are the impacts of different upstream business models in the agriculture and forestry sector on sustainable development in tropical developing countries? Environmental Evidence, **3**, 1 (2015)
7. I.P. Chupina, N.N. Simachkova, Ye.V. Zaubina, L.A. Zhuravleva, Development of the "Smart Farming" market in Russian regions, International agricultural journal, **5**, 310-321 (2022)
8. C.A. Hidalgo, Economic complexity theory and applications, Nature Reviews Physics, **3**, 92–113 (2021)
9. N.A. Polushkin, Sustainable development of rural areas - improving the quality of human capital in the village. Sovremennye nauchnye issledovaniya i innovacii, **11**, 434-437 (2016)
10. Yu.V. Lyshchikova, Mechanisms of institutionalization and implementation of the concept of “smart region” in the management of sustainable spatial development of territories, Economy. Informatika, **2**, 229-243 (2021)
11. R.V. Shkhagoshev, A.A. Bakhunov, Indicators for assessing the “smart” development of the territory, State and municipal administration, Scientific notes, **2**, 50-61 (2022)
12. O. Hajili, D. Rustamova, I. Salimov, S. Alekberli, S. Bakhshaliyeva, *Using plastic waste with reconstructed plastic*,. E3S Web of Conferences, **411**, 02019 (2023)
13. M. Lukyanova, V. Kovshov, Z. Zalilova, N. Faizov, Modeling the Expansion of Agricultural Markets, Montenegrin Journal of Economics, **18**, **2**, 127–141 (2022)
14. D. Morkovkin, I. Hutarava, E. Ogloblina, A. Gibadullin, S. Kharchenko, E3S Web of Conferences, **176**, 05002 (2020)

15. D.E. Morkovkin, D.S. Lopatkin, T.N. Shushunova, B.K. Sharipov, A.A. Gibadullin, Journal of Physics: Conference Series, **1515**, **3**, 032002 (2020)
16. G. Salimova, A. Ableeva, T. Lubova, Z. Zalilova, A. Sharafutdinov, The Role of Agriculture in Gross Added Value, Montenegrin Journal of Economics, **16**, **1**, 183–191 (2020)