Modeling the development of agricultural production by cluster analysis

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Abstract. The article carried out a multidimensional grouping of the regions of the Central and Volga Federal Districts of the Russian Federation according to indicators characterizing the state and development of agricultural production. The cluster analysis method was applied twice: when constructing a system of indicators for grouping regions and when combining regions into clusters. This approach made it possible to enhance the practical significance of the study, made it possible to objectively analyze and formulate reasonable specific conclusions and recommendations for the regions of each cluster. As a result, four groups (clusters) of indicators and three clusters of regions were identified according to the level of development of agricultural production.

1 Introduction

Agriculture is a strategically important sector of the country, its development is one of the foundations and guarantees for ensuring the country's food security, well-being and health of the population, and sustainable development of rural areas. Scientists in their research touch upon various aspects of the current stage of functioning and development of agricultural production. C. Castillo and others note that urbanization, demographic changes, the transition to digital and energy technologies, climate change and increased inequality affect the development of the territory and agricultural production [1, 2]. Scientists widely touch upon the issues of digitalization of the industry. Jakku, E. et al. conclude that digital transformation in agriculture, including advances in information and communication technologies, will increase productivity and efficiency while reducing risks and negative consequences [3]. Xia, J. at the same time notes that the introduction of digital technologies in agricultural production should be carried out taking into account the socio-economic, technological and institutional features of the state and territories of the point of view [4]. Fan, Z. et al. suggest that next-generation information and communication technologies such as 5G, big data and artificial intelligence continue to influence development in the construction of digital countryside and agricultural production [5]. Poudel, J.M. and others, touching on the topic of digitalization of the industry, they also talk about the use of modern technologies in weather forecasting. At the same time, it is noted that the traditional

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knowledge of farmers in the field of weather forecasting should become a resource of great potential value [6].

Thus, a significant part of modern research on agricultural production concerns the digitalization of the industry, the study of the characteristics of the area, the distribution of the population, and the concentration of the product sales market by territory. At the same time, studies of the development of agricultural production from the standpoint of its resource availability and the results obtained are relevant. The purpose of this study is to build models that characterize the development and efficiency of agricultural production. In accordance with the goal, the tasks are defined:

- Develop a system of indicators for grouping regions.
- To form clusters of regions that are similar in terms of the considered indicators.
- To characterize the selected clusters by the average values of the system indicators.
- Develop recommendations for the regions of each cluster to improve the efficiency of agricultural production and develop food security policies.
- To determine directions for further scientific research.

2 Materials and methods

The research methodology is presented by the method of cluster multivariate analysis. Cluster analysis allows you to use an array of data with different economic content, units, scales of measurement, in the aggregate. The source of information for the analysis was official data presented in statistical publications characterizing the socio-economic situation of the regions of the Russian Federation [7]. The statistical aggregate is represented by the regions of the Central and Volga Federal Districts of the Russian Federation. In Russia, these two districts are leaders in the production of agricultural products. However, the Moscow region was excluded from the analysis due to the incomparability of data related to the proximity of the territories of this region to the federal city of Moscow.

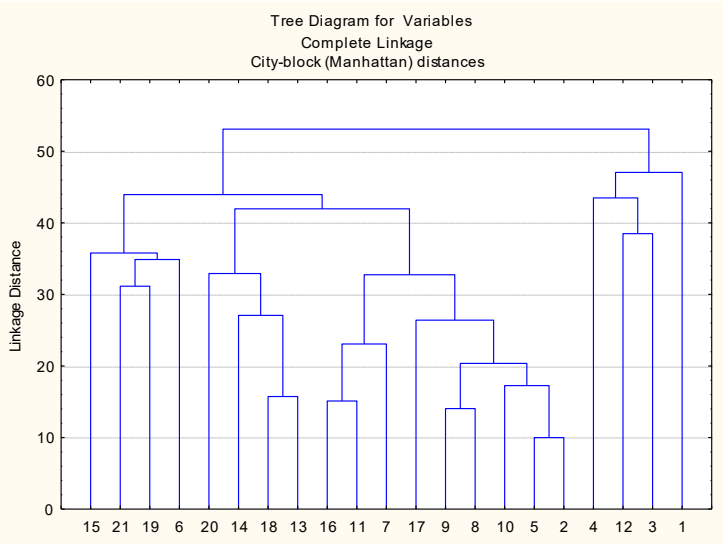

Fig. 1. Dendrogram of combining indicators to build a model into a system..

In the analysis, we moved away from the traditional grouping of indicators that reflect various aspects of agricultural production: the provision of production with resources, economic and social efficiency. For the indicators used, their clustering was carried out,

which made it possible to distinguish four groups. The resulting clusters of indicators and the system of indicators built on their basis for grouping regions has not only a theoretical, but also an empirical basis.

The combination of indicators and regions into clusters was carried out using the Manhattan distance, in which the distance between two points is calculated by summing the absolute value of the difference between the sizes.

The system of indicators obtained on the basis of multidimensional grouping is presented in Table 1.

Table 1. Clusters of regions of the Volga Federal District of the Russian Federation.

Group (cluster)	Index	Number in Figure 1
1	Potato yield, centners per 1 hectare	1
	Depreciation of fixed production assets of agricultural sectors, in % of the value of the initial cost of fixed assets	3
	The value of gross output in agriculture, rubles of production per 1 ruble of the cost of fixed production assets (indicator of capital productivity)	12
	Feed consumption per 1 conditional head of livestock, centners of feed units	4
2	Productivity of grain and leguminous crops, centners from 1 hectare	2
	Mineral fertilizers applied per 1 hectare of agricultural crops, kg of active ingredient	5
	Amount of investments in fixed assets, thousand rubles per 100 hectares of agricultural land	10
	Fixed assets accounted for per 1 hectare of agricultural land, thousand rubles (funds ratio of agricultural land)	8
	The value of gross output in agriculture per 1 hectare of agricultural land, thousand rubles	9
	Potato production per capita, kg	17
	Fixed assets accounted for per 1 employed in agriculture, thousand rubles (labor capital-labor ratio)	7
	The value of gross output in agriculture, thousand rubles per 1 employed (indicator of labor productivity)	11
	Grain produced per capita, kg	16
3	Financial result in agriculture per 1 enterprise, million rubles	13
	Meat production per capita, kg	18
	Profitability of sales of crop products, %	14
	The value of internal costs for research and development, thousand rubles per 1 researcher in the field of agricultural sciences	20
4	Provision of labor force, pers. per 1000 hectares of agricultural land	6
	Milk produced per capita, kg	19
	Milk yield per cow in agricultural organizations, kg	21
	Profitability of sales of livestock products, %	15

The data processing program "STATISTICA" was used for cluster analysis. Instead of the initial values of the variables included in the analysis when grouping regions, we use standardized variables obtained as a result of a normalized transformation. Standardization allows you to bring indicators measured in different scales and expressed in different units

of measurement into a single form. For the purpose of visual representation of the formed clusters, a graphical method is used - a cartogram of the distribution of clusters of regions across the territory is built.

3 Results

As a result of the cluster analysis, the regions of the Central and Volga Federal Districts were divided into 3 clusters. The dendrogram of the association is shown in Figure 1.

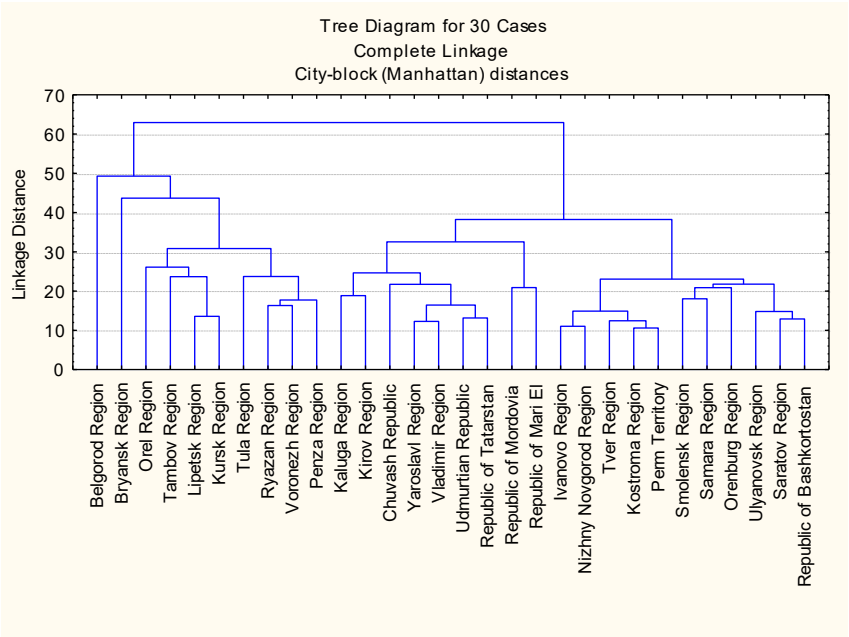

Fig. 2. Dendrogram of the regions of the Central and Volga federal districts.

The selected groups of regions are presented in Table 2.

Table 2. Clusters of regions of the Volga Federal District of the Russian Federation.

Cluster	Cluster regions (numbers of regions on the cartogram are given in parentheses)
I	Regions: Saratov (2), Ulyanovsk (3), Orenburg (4), Samara (5), Smolensk (6), Kostroma (8), Tver (9), Nizhny Novgorod (10), Ivanovskaya (11); Republics: Bashkortostan (1); Perm region (7)
II	Regions: Vladimir (16), Yaroslavl (17), Kirov (19), Kaluga (20); Republics: Mari El (12), Mordovia (13), Tatarstan (14), Udmurt (15), Chuvash (18)
III	Regions: Penza (21), Voronezh (22), Ryazan (23), Tula (24), Kursk (25), Lipetsk (26), Tambov (27), Oryol (28), Bryansk (29), Belgorod (30))

The distribution of regions by clusters is clearly shown in Figure 3.

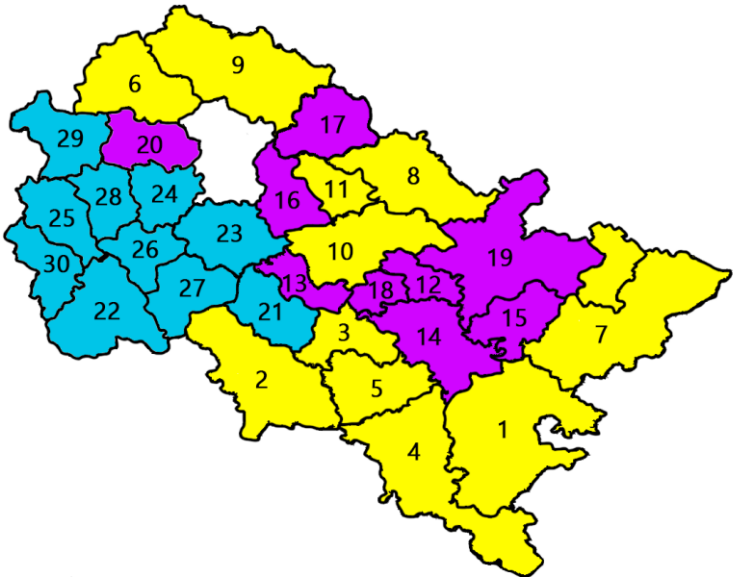

Fig. 3. Cartogram of the distribution of the regions of the Central and Volga Federal Districts by clusters.

Cluster 1 included 11 regions (35.5% of the entire analyzed population). Cluster 2 united 9 regions (29.0% of the entire analyzed population). Cluster 3 included 10 regions (32.3% of the entire analyzed population). Let us characterize each cluster by the average values of the indicators of the system (Table 3).

The data in Table 3 allow us to conclude that the third cluster includes regions that are characterized by the most favorable natural and climatic conditions for both crop production and livestock production. In addition, the enterprises of the third cluster are best provided with resources, including labor, land resources, technical equipment, scientific achievements and developments. This made it possible to achieve higher results of agricultural production.

The regions of the second cluster are characterized by average values of resource endowment indicators, in most cases comparable with the levels of these indicators in the Russian Federation. But at the same time, production performance indicators are much lower. Therefore, the regions of this cluster are recommended to pursue an effective pricing policy, increase the intensity of production, conduct research and implement developments in the agricultural sector.

The first cluster includes regions with a minimum level of production efficiency, which is a consequence, first of all, of low availability of production resources. The regions of the first cluster are characterized by a large territory. The size of the territory for these regions acts as a deterrent to their development, which is especially evident in agriculture. It is recommended that scientific research be directed to modeling optimal transportation plans, logistics solutions, and the development of the transport industry. We propose to form a management center for rural areas not only on the scale of one region, but to apply methods of cooperation and industrial integration.

Table 3. Values of indicators in clusters of regions of the Central and Volga Federal Districts of the Russian Federation.

Indicators	Cluster 1	Cluster 2	Cluster 3	Average in Russia
Number of regions, units	11	9	10	×
Potato yield, centners per 1 hectare	150.7	164.4	157.5	160.0
Depreciation of fixed production assets of agricultural sectors, in % of the value of the initial cost of fixed assets	46.1	41.6	41.4	43.2
The value of gross output in agriculture, rubles of production per 1 ruble of the cost of fixed production assets (indicator of capital productivity)	1.13	0.87	1.04	0.96
Feed consumption per 1 conditional head of livestock, centners of feed units	30.3	34.7	27.5	28.6
Productivity of grain and leguminous crops, centners from 1 hectare	15.8	18.2	38.0	26.7
Mineral fertilizers applied per 1 hectare of agricultural crops, kg of active ingredient	34.0	52.7	130.1	74.6
Amount of investments in fixed assets, thousand rubles per 100 hectares of agricultural land	150.3	392.8	789.9	36.7
Fixed assets accounted for per 1 hectare of agricultural land, thousand rubles (funds ratio of agricultural land)	23.48	52.51	75.23	4.68
The value of gross output in agriculture per 1 hectare of agricultural land, thousand rubles	23.96	45.23	77.10	4.50
Potato production per capita, kg	111.0	204.9	351.9	125.5
Fixed assets accounted for per 1 employed in agriculture, thousand rubles (labor capital-labor ratio)	1578	1895	3194	1783
The value of gross output in agriculture, thousand rubles per 1 employed (indicator of labor productivity)	1621	1569	3202	1717
Grain produced per capita, kg	500.5	440.4	2654.2	832.3
Financial result in agriculture per 1 enterprise, million rubles	2.04	4.81	36.14	8.74
Meat production per capita, kg	46.9	143.6	321.4	77.8
Profitability of sales of crop products, %	25.77	2.53	68.29	48.50
The value of internal costs for research and development, thousand rubles per 1 researcher in the field of agricultural sciences	212.2	166.1	334.0	264.0
Provision of labor force, pers. per 1000 hectares of agricultural land	15.14	30.08	25.07	2.62
Milk produced per capita, kg	222.9	454.3	312.4	221.7
Milk yield per cow in agricultural organizations, kg	6012	7470	7707	7007
Profitability of sales of livestock products, %	7.80	12.13	16.23	12.60

4 Discussion

The results of our study are consistent with the directions and results of other scientists studying rural areas and agricultural production. Cavallaro, F., Dianin, A. note that the main attention in the organization of production in the countryside is given to transport [8]. Chan, B.R.A. and others say that rural roads mean a lot for the economic and social development of society [5,9]. C. Castillo et al. state that service availability is lower in some rural areas and people have to travel long distances to reach a service area or facility. A comprehensive sustainable territorial development is needed, taking into account future technological changes (innovations, digitalization, transport systems, housing, migrants, etc.) [1]. In our study, we also came to the conclusion that, in particular, for the regions of cluster 1, it is

necessary to develop transport infrastructure in order to develop agricultural production and increase its profitability, as well as sustainable development of rural areas, improve the level and quality of life of the rural population, potential tourism development. Miroro, O.O. et al. consider the factors influencing the decisions of farmers to join agricultural cooperatives [10]. We are also talking about the need to develop a system of cooperation.

C. Castillo and others note that the development of spatial planning, taking into account the biophysical, socio-economic and cultural characteristics of the regions, can help realize the potential of rural areas [1]. We also believe that a multi-level system of regional management is needed, which makes it possible to involve local, regional and national authorities in the creation of effective systems for monitoring and evaluating the development of territories, to support the development of a coordinated strategy and long-term planning beyond the borders of territories [1]. We consider it necessary to strengthen ties between regions, create a single center for managing the development of rural areas and agricultural production, in particular, within the framework of the resulting clusters. C. Castillo et al. note the importance of using analytical and forecasting methods to effectively assess the problems facing agricultural production [1]. We develop an analysis methodology and apply a multidimensional approach to the analysis of the development of agricultural production.

M. Henning, H. Westlund, K. Enflo believe that the difference in population between regions is not in itself a problem if it corresponds to the growth of welfare and productivity per capita on a par with the rest of the country [11]. We agree with this statement and consider it important to develop agricultural production as the basis for the well-being of the population not only in rural areas, but in the whole country. Kulshrestha, S.K. notes that an integrated, collaborative and proactive approach to regional spatial planning is needed that promotes sustainable, inclusive and sustainable development, able to adapt to technological innovation and climate change [2]. Poudel, J.M., Sigdel, M., Chhetri, R.B., Sudarsan, K.C. note that weather forecasting requires the joint work of local and scientific communities to reduce gaps in knowledge [6]. Thus, scientists combine traditional and new knowledge, which, in our opinion, must be carried out when determining the directions and potential for the development of agricultural production. We also talk about the importance of a scientific approach to the organization of agricultural production, observation of natural conditions and actions in accordance with them [12]. We come to the conclusion about the importance of management organization for the sustainable development of agricultural production, which is confirmed by the results and conclusions of other scientists.

5 Conclusion

The results of the analysis show that the regions of the third cluster achieve higher results of agricultural production and are better provided with resources. The regions of the second cluster are recommended to pursue an effective pricing policy, increase the intensity of production, conduct research and implement developments in the agricultural sector. The regions of the first cluster are recommended to direct scientific research to the modeling of optimal transportation plans, logistics solutions, and the development of the transport industry. We propose to form a management center for rural areas not only on the scale of one region, but to apply methods of cooperation and industrial integration.

The system of indicators for the grouping of regions is identified by means of a multidimensional grouping of indicators of agricultural production. We applied the method of cluster analysis when constructing a system of indicators, i.e. they are grouped not only theoretically, but also by empirical data, established proportions and patterns. This is the novelty of the study. In further developments, we plan to explore the historical aspect of the

empirical inclusion of certain indicators in certain groups in order to study the dynamics, factors, causes of violation of economic laws, and the content of the changes.

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