REGIONAL DIFFERENCES IN CROP PRODUCTION AT THE LEVEL OF SLOVAKIA'S DISTRICTS BETWEEN 2004 AND 2022

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Abstract: The aim of this study was to analyse the similarity between the districts of Slovakia with regard to the structure of the cropping area of eight crops in each of the three periods 2004–2009, 2010–2015 and 2016–2022, and to compare the results between these periods. We used cluster analysis, specifically the *k*-means method, to analyse similarity. For each district, the average cultivation area of each crop was determined for the periods of years under study. For the similarity of the cropping area structure, we used the percentage share of each crop in the cropping area of the district. The results of the study indicate regional differences in crop production in Slovakia and the identification of two clusters in each period under study. Comparing the profiles of clusters 1 and 2 for the periods we can see a considerable similarity, which indicates the stability of crop cultivation in Slovakia over the last 20 years. In cluster 1, cereals, grain maize and oilseeds gained higher shares of the district's cropping area. Districts with the most favourable natural conditions for crop production and with higher crop diversification were included in this cluster. Cluster 2 included districts with higher shares of cropping areas of multi-annual fodder crops, potatoes and leguminous crops. The districts are characterised by less favourable soil-climatic conditions for crop cultivation.

Keywords: crop production, regional differences, cluster analysis, Slovakia

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Introduction

Crop production is a branch of agriculture focused on the cultivation of crops that are directly used as food and animal fodder or represent raw materials for the food and other processing industries. Currently, there is a growing interest in the use of agricultural crops for energy purposes, which may threaten the food security of each country in the future. The main objective of crop production is therefore to ensure sufficient and safe food for the world's population. Food security is a paramount concern and necessity for every country, and crop diversification is a dynamic tool to ensure food security in a sustainable manner. Crop diversification is also an effective tool to mitigate the adverse effects of climate change. With the accession of the Slovak Republic to the European Union (EU) in 2004, Slovak agriculture started to adapt to the EU's Common Agricultural Policy (CAP) and to the conditions of the European Common Market. The

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CAP, through its instruments, motivated farmers to reduce livestock production and develop more crop production, focusing on the cultivation of large-area crops (e.g. cereals and oilseeds) whose production process can be managed through mechanisation and a small number of workers (Serenčéš, Mučaji 2014). According to Bičík and Jančák (2005), such specialisation of crop production can threaten the economy of agricultural farms. On the contrary, the development of cropping areas in Slovakia shows that farmers are able to respond relatively quickly to changing market demands and introduce crops with higher market demand into the crop production structure. Slovakia is characterised by suitable natural conditions for growing crops, a high degree of arable land (more than 50% of agricultural land is arable) and good soil quality, which is why our research has been directed towards this sector of agricultural production. Within crop production, it is necessary to investigate long-term structural changes that are influenced by market conditions and climate change. These changes strengthen the position of crops such as cereals and oilseeds, which are now increasingly used for industrial purposes and biofuel production, and therefore their sowing areas and production are increasing all the time. However, there are crops, mainly potatoes and vegetables, whose sowing areas are constantly decreasing. Despite Slovakia's favourable natural conditions, the cultivation of these crops is less important. In the future, given the importance of the issue of the study, it is necessary to carry out further research in the context of food self-sufficiency and national security. The highest share of arable land in Slovakia is occupied by cereals (57%). The cultivation of cereals and also maize for grain is concentrated in the lowland areas – Podunajská, Východoslovenská and the lower-lying basins of Košice. These are the natural regions, particularly in the south-western and south-eastern parts of Slovakia, which are mostly used for crop production because of their most suitable soil and climatic conditions. These regions have the highest shares of cereals in the region's sown area (50%–60%) and the highest average annual production of more than 3,200,000 tonnes.

Since there are no studies in the academic sphere focused on the evaluation and analysis of agricultural production in Slovakia, which would use statistical methods, we decided to carry out this research, the results of which are beneficial not only to the academic community but also to applied practice. Given the availability of statistical data at the district level, it was most appropriate for us to direct our research to that regional unit and to compare the districts with each other, to find out their similarities in relation to cropping and to highlight their agricultural use. The analysis of crop production using the clustering method at different time horizons is a contribution to applied research and socioeconomic practice. With our knowledge, we can contribute not only to the study of crop production in the sectoral structure of agriculture but also to the knowledge of regional disparities in agriculture in Slovakia. The knowledge from the scientific study can help the regional self-government to adjust the development of agriculture in different regions of Slovakia. The obtained results and geographically presented knowledge could be used in the formation of the new CAP in the next programming period or in the creation of national strategic documents.

The aim of this study was to use the statistical method of cluster analysis to identify the similarity between districts of Slovakia with respect to the structure of the cropping area of eight crops (cereals, grain maize, oilseeds, legumes, potatoes, vegetables, sugar beet and multi-annual fodder crops) in each of the three periods 2004–2009, 2010–2015 and 2016–2022, and to compare the results of these periods.

Literature review

In Slovakia, there are no studies on the spatial distribution of agricultural production at different regional levels in Slovakia which would use statistical methods. This issue has long been addressed in Slovakia by the work of experts (e.g. Némethová, Vilinová 2022), and the results of their study using cluster analysis confirmed that crop cultivation for industrial purposes is gradually becoming more prevalent in Slovakia than for food and fodder purposes. Although Slovakia has sufficient natural potential to produce raw materials for the food industry and to ensure the food self-sufficiency of its population, it is becoming a producer of only basic agricultural raw materials such as cereals, oilseeds and roughage. Owing to the lack of processing capacity in Slovakia (the existing capacity is underused and inefficient), the raw materials of crop production have to be exported abroad for processing and finished products with higher added value are imported, the price of which is considerably higher. According to Némethová and Rybanský (2021), the typical agricultural regions of Slovakia are the regions of Nitra, Trnava and Košice, located on the Podunajská and Východoslovenská lowlands, which are characterised by the largest area of agricultural, arable land and the highest production of agricultural crops. The regions are characterised by highly favourable soil and climatic conditions. State support for special crop production (e.g. growing vegetables, potatoes and legumes), greater diversity in crop cultivation, achieving the highest possible self-sufficiency in food production, and ensuring quality and safe food for the population through domestic production are the necessary strategic objectives of Slovak agriculture.

The importance of cereal production in EU countries and regional differentiation in cereal production was highlighted by Nowak (2020). She states that because of the growing demand for cereals and their high production potential, EU Member States are able to compete in the global market. The results of the study (Li et al. 2016) show that maize cultivation has great potential to adapt to ongoing climate change, which may be beneficial for future maize production, especially in more northern, colder regions. Climate change has altered the spatial distribution of maize, where temperature in particular has a significant impact on maize production. Maize is an important crop for the food security of several countries.

Robles (2011) analysed the socioeconomic aspects related to the use of oilseeds (sunflower and oilseed rape) as energy crops for biofuel production. Energy crops can contribute to promoting the participation of biofuels in the energy supply and achieving the objectives of the current energy policy, while at the same time supporting the agricultural sector, which is clearly in crisis. Oilseed rape prices have risen due to demand for renewable energy. In terms of the current use of oilseed rape, there is strong competition between the food and petrochemical industries (Bełdycka-Bórawska et al. 2016). The oilseed rape is a dominant oilseed in the EU. The EU is one of the world's largest producers of rapeseed and rapeseed products, but the demand for oilseed rape in EU countries exceeds domestic production. As the EU imports significant quantities of oilseeds from Ukraine, the current crisis is putting pressure on the oilseed market and making world agricultural commodity markets, including the oilseed market, highly volatile (Krautgartner et al. 2022).

The EU stresses the importance of increasing the production of grain legumes as well in order to reduce the EU's dependence on soybean imports from the United States and also to reduce the negative environmental impacts associated with intensive grain production. Grain legume production is often perceived as risky by European farmers, who tend to favour the cultivation of non-legume species such as cereals, oilseeds and tuber crops (Cernay et al. 2015). According to Ferreira et al. (2021), it is necessary to diversify cropping systems by adding more legumes to crop rotations. According to Zander et al. (2016), crop diversification has a positive impact on the sustainable development of territories.

Sugar beet production has been regulated in EU countries by the Common Market Organisation System for Sugar, in particular by sugar production quotas until the end of the 2016/2017 marketing year. The reform of the sugar market in the 2006/2007 marketing year and in the following years had a negative impact on the economy and employment in many sugar beet-oriented rural areas. During this period, more than 80 sugar mills in EU countries closed down and tens of thousands of sugar beet producers had to switch to other production (Řezbová et al. 2013, Aragrande et al. 2017, Věžník, Jadlovský 2021). The EU and its individual countries continue to protect their sugar market with tariff measures and import quotas and also subsidise sugar beet cultivation (Kubeš, Nárovec 2019).

Especially in the countries of north-western Europe, the soil and climatic conditions are highly favourable for potato cultivation, with roughly 60% of EU-28 production in these regions before Brexit. Over the last 60 years, Europe has seen a decline in potato production of more than 50%. This decline has been caused by a significant drop in demand for potatoes over the last decades. This is mainly due to the declining use of potatoes as livestock feed in Eastern Europe, where potatoes have gradually been replaced by cereals. Another reason is the changing dietary habits of the population towards a wider variety of foods and the trend towards semi-processed foods, especially in Western European countries (Devaux et al. 2020, Goffart et al. 2022). Vegetable cultivation is mainly concentrated in the fertile and warmest areas of the lowlands. Organic vegetable cultivation, new production technologies, species diversity and competitiveness are major challenges for all European countries. The vegetable market is volatile, as shown by large fluctuations in production volumes and areas under cultivation. Small farms, which are predominantly vegetable producers, are not able to supply sufficient and consistent volumes of vegetables to the market (Némethová, Rybanský 2021). The importance of the last crop, perennial forages as roughage for livestock production, is decreasing due to the overall decline in the number of individual livestock species. Their production is more significant, especially in mountain and foothill areas where there is a higher concentration of livestock production. In these areas, natural conditions for crop production are less favourable (Némethová et al. 2020).

Data and methods

This study uses freely available statistical data from the Statistical Office of the Slovak Republic (SO SR). The Office collects data on crop production only at the district level (LAU 1). We chose the period 2004–2022 for the analysis. The year 2004 is the year of Slovakia's accession to the EU. The last year monitored was 2022, which is the most recent year of available data. The main indicator monitored was the size of the cropping area in hectares of the eight most cultivated crops in Slovakia: cereals, grain maize, oilseeds, legumes, potatoes, vegetables, sugar beet and multi-annual fodder crops. Some crops, such as sugar beet, were not grown at all or were grown only in a small area in certain districts in some years. Therefore, we decided to aggregate the data for the periods 2004–2009, 2010–2015 and 2016–2022. For each district, we have thus determined the average percentage of the cropping area for each of the eight most cultivated crops. Administratively, Slovakia is divided into 79 districts. The districts of south-western Slovakia are the most agriculturally exploited, thanks to the most suitable soil and climatic conditions, which suit most of the crops grown, and a high degree of arable farming of more than 60%. The districts are located on the Podunajská lowland. Suitable natural conditions for growing crops are also found in the districts of the south-eastern part of Slovakia, which is in the Východoslovenská lowland, and also in the southern part of Slovakia in the Juhoslovenská basin. The other districts of Slovakia are characterised by a lower proportion of arable land, higher forest cover and less favourable natural conditions for crop production. Livestock production is more important in these districts.

In seeking to answer the research question, it is necessary to first select an appropriate cluster method that divides the districts (objects) into an optimal number of clusters for each of the three periods and then to determine the degree of agreement between the results of each cluster. This type of comparison will provide us with information on the stability of similarity of the districts in the structure of cropping areas use in these districts. The aim of clustering is to identify naturally occurring groups of objects (clusters) in the data. Clusters are formed in such a way that objects within a cluster are similar with respect to a chosen similarity measure and clusters are dissimilar to each other. Thus, the aim is to minimise intra-cluster variability while maximising inter-cluster variability. Clustering algorithms use the underlying data structure and define rules for grouping objects with similar properties. This process results in the partitioning of a set of objects based on the clustering criteria, without any prior knowledge of the objects. Clustering procedures play an important role in pattern recognition (Bai et al. 2018), image processing (He, Zhang 2018) and many other research areas.

We chose to use hybrid *k*-means clustering (Stanforth et al. 2007) to analyse the similarity of the use of cropping areas at the district level. The hybrid *k*-means algorithm is a combination of the hierarchical clustering method and the *k*-means method. In the *k*-means method, the initial cluster centres can be selected in different ways. They are mostly chosen randomly, but the clustering result then depends on their choice, which makes the results obtained by this procedure unstable after multiple runs of the algorithm. To solve this problem, a hybrid algorithm is used to determine the initial cluster centres in the *k*-means method. First, starting from the distance matrix, a dendrogram is constructed by the hierarchical clustering method and the optimal number of clusters *k* is determined based on the silhouette value. The centroids of these clusters are then chosen as the initial cluster centres in the *k*-means method.

More than 30 different methods have been developed to determine the optimal number of clusters. The most widely used methods are the elbow method (the optimal number of clusters is that which minimises the intra-cluster sum of squares), and the silhouette method (the optimal number of clusters is that which maximises the value of the average silhouette) (Rousseeuw 1987).

To determine the degree of agreement between the results of two clustering procedures, the Rand index can be used, which takes values in the interval from (−1) to 1, where a value of 1 represents a perfect match, a value of 0 represents a random match and a value of (−1) represents a completely opposite classification (Jain, Dubes 1988). However, the Rand index suffers from the shortcoming that its mean value for two random clustering procedures is not constant, and it appears more appropriate to choose a generalised hypergeometric distribution as the randomness model and introduce the adjusted rand index (ARI) (Gates, Ahn 2017).

Results

Similarity of Slovak districts with regard to the structure of the cropping area of the eight selected crops

In this study, to analyse the similarity of the districts of Slovakia, we have compiled statistical data concerning the development of the cropping area of the most widely cultivated crops (cereals, grain maize, oilseeds, legumes, potatoes, vegetables, sugar beet and multi-annual fodder crops) for each district in the period 2004–2022. For each district, the average cropping area of each crop was determined for the periods 2004–2009, 2010–2015 and 2016–2022. Owing to considerable differences in both district size and cropping area, it is not very meaningful to analyse the similarity between districts with respect to cropping area. We therefore analysed the similarity of the cropping pattern – the percentage share of each crop in the cropping area of the district.

We used a hybrid *k*-means clustering method to analyse the similarity of districts in each of the three periods analysed (2004–2009, 2010–2015 and 2016–2022). We used Ward's method to determine the optimal number of clusters and their centroids, and chose the squared Euclidean distance as the dissimilarity measure for standardised values of the variables. In all three periods studied, the two-cluster solution appears to be the most appropriate (for the period 2004–2009, the silhouette is equal to 0.60; for the period 2010–2015, the silhouette is equal to 0.32 and for the period 2016–2022, the silhouette is equal to 0.32). Subsequently, using the *k*-means method, districts were assigned to two clusters, with 47 districts in cluster 1 and 32 districts in cluster 2 in the first period (2004–2009), while the numbers of districts in the clusters were the same in other two periods (2010–2014 and 2016–2022): 45 districts in cluster 1 and 34 districts in cluster 2. In terms of the proportion of districts assigned to each of the six- and seven-year periods, cluster 1 was the most numerous. This cluster included the largest number of districts in the period 2004–2009 (59.5%) and in the periods 2010–2015 and 2016–2022 (57.0%). The percentage of districts from cluster 2 is 40.5% in the period 2004–2009 and 43.0% in other two periods 2010–2015 and 2016–2022.

By the adjusted random index (ARI), we found that the degree of agreement of inclusion of districts in the clusters is large for all three pairs of periods compared (ARI = 0.89 for 2004–2009 vs. 2010–2015; ARI = 0.78 for 2004–2009 vs. 2016–2022 and ARI = 0.89 for 2010–2015 vs. 2016–2022). Figure 1 shows the average structure of the cropping area with respect to the cluster affiliation of the districts. Comparing the profiles of clusters 1 and 2 for the periods 2004–2009, 2010–2015 and 2016–2022, we can see considerable similarity. Districts in cluster 2 have a significantly higher share of multi-annual fodder crops cultivated in the cropping areas than that of districts in cluster 1 (2004–2009: 44.4%, 2010–2015: 43.6% and 2016–2022: 43.8%). Despite the overall decline of

Fig. 1. Structure of cropping areas in districts of Slovakia according to the cluster affiliation based on Statistical Office of the Slovak Republic (2024).

livestock production in Slovakia, as evidenced by the decrease in the share of the fodder crop in the cropping area in the last two periods under review, the cultivation of multi-annual fodder crops on arable land is still significant, especially in the mountain and foothill areas of northern Slovakia. In these areas, livestock production predominates over crop production and there is also more permanent grassland. In the districts with more favourable natural conditions, which are part of cluster 1, crop production is more widespread, while cattle with marketable milk production, pigs and poultry are bred for livestock production. In the districts from cluster 1, the share of multi-annual fodder crops in the cropping area is gradually decreasing (2004–2010: 10.7%, 2010–2015: 9.6% and 2016–2022: 9.4%). Similarly, districts in cluster 2 also have a higher share of potatoes in the cropping area compared to the districts in cluster 1 (2004–2010: 2.6%, 2010–2015: 2.7% and 2016–2022: 2.6%). In the lowland districts which we include in cluster 1, the share of potato cropping area is consistently very low at 0.4%.

There is very little difference in the share of the cropping area for vegetables and legumes. As determined in the previous analyses, these are crops with a share in the structure of the cropping area below 1%. Legume crops reach a slightly higher share of the cropping area in cluster 2, ranging from 0.8% to 1.1%. Vegetables are more suited to the warmer climate of the lowlands, hence the higher percentage of the cropping area in cluster 1 (0.4%).

Compared to the districts in cluster 2, the districts in cluster 1 have higher percentage of cereals (2004–2009: 54.0%, 2009–2015: 54.3% and 2016–2022: 54.2%), grain maize (2004–2009: 11.7%, 2009–2015: 12.1% and 2016–2022: 12.2%) and oilseeds (2004–2009: 19.9%, 2009–2015: 20.3% and 2016–2022: 20.6%). This means that the share of the cropping area designated for these crops has been increasing over the periods under review. A slightly higher share of the cropping area (2% in cluster 1 in all periods) is also found for sugar beet. These crops are best suited to the favourable natural conditions of the districts of south-western, southern and south-eastern Slovakia from cluster 1.

Typical representatives of cluster 2 districts in the three periods under study are Banská Bystrica, Banská Štiavnica, Bardejov, Brezno, Čadca, Dolný Kubín, Gelnica, Humenné, Kysucké Nové Mesto, Levoča, Liptovský Mikuláš, Martin, Považská Bystrica, Ružomberok, Stropkov, Svidník and Žilina (Figs 2–4). These are districts with less favourable soil and climatic conditions for crop production. Livestock production is more widespread in these districts. Cluster 1 includes mainly the districts in south-western or western Slovakia (e.g. Dunajská Streda, Komárno, Nitra, Levice, Nové Zámky, Topoľčany, Galanta, Bánovce nad Bebravou, Partizánske, Senec and Trnava) and also some districts in south-eastern Slovakia (e.g. Sobrance and Trebišov). These are districts in which natural conditions are suitable for the cultivation of several types of agricultural crops.

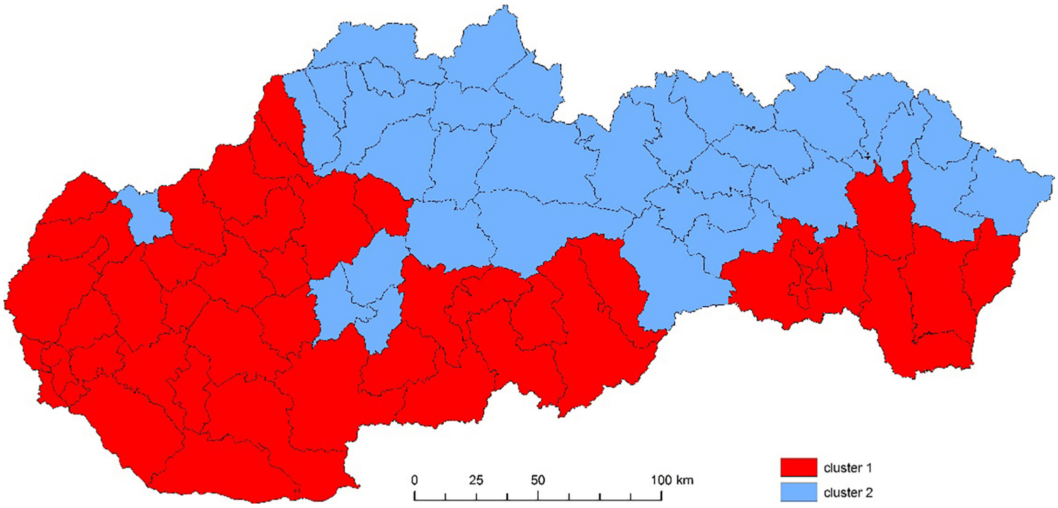

Fig. 2. Cluster analysis of Slovak districts in crop production (2004–2009) based on Statistical Office of the Slovak Republic (2024).

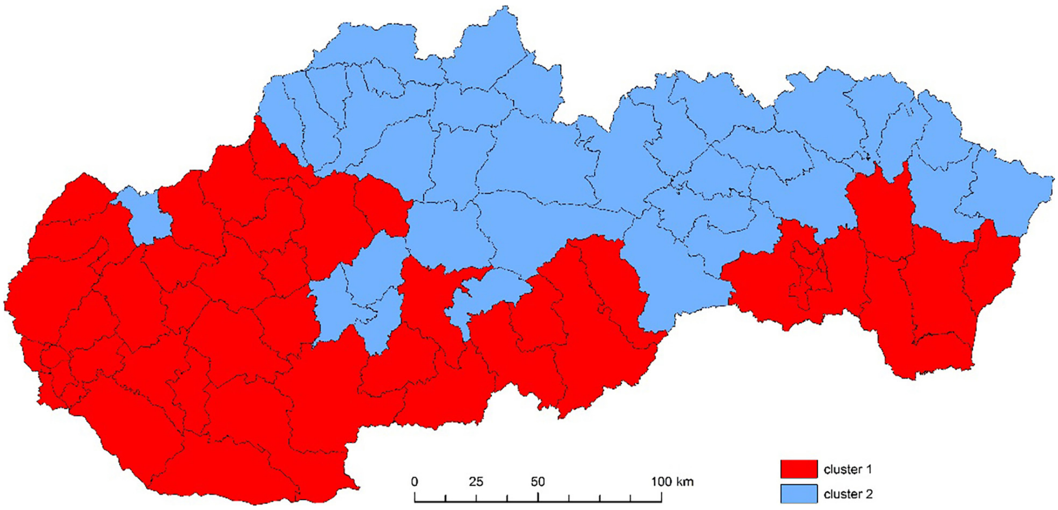

Fig. 3. Cluster analysis of Slovak districts in crop production (2010–2015) based on Statistical Office of the Slovak Republic (2024).

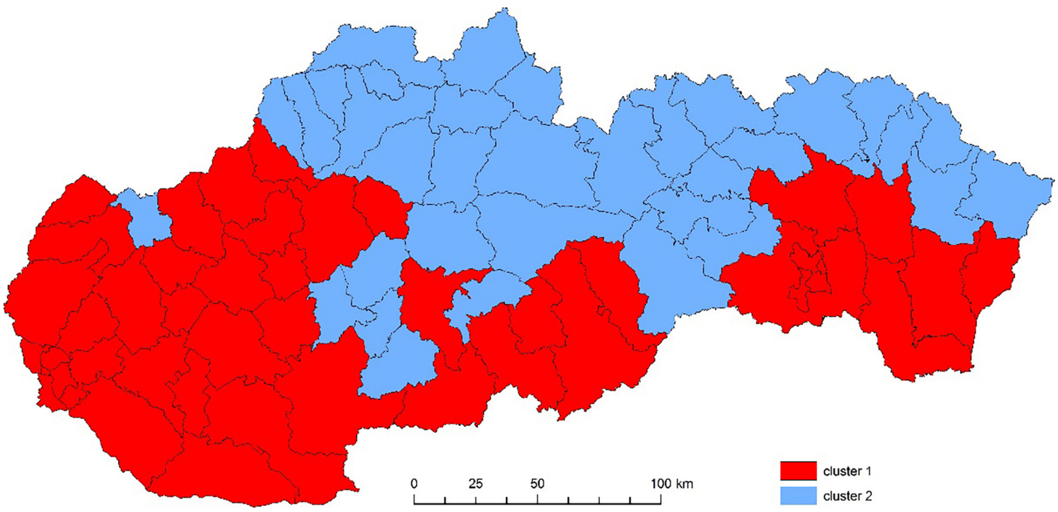

Fig. 4. Cluster analysis of Slovak districts in crop production (2016–2022) based on Statistical Office of the Slovak Republic (2024).

Of course, some districts were not included in the same cluster in all three periods analysed. For example, Detva and Púchov were included in cluster 1 in the first period, but they were included in cluster 2 in the other two periods analysed. Similarly, Krupina was included in cluster 1 in the first two periods and in cluster 2 in the last period. Another such district is Prešov which was included in cluster 2 in the first two periods and in cluster 1 in the last period.

Discussion

The results of our study confirm that the arable land in Slovakia in the period 2004–2022 is predominantly cultivated with monoculture crops such as oilseed crops, cereals and grain maize. The use of cereals and oilseeds is wide, not only as food and fodder but also as an important source of biomass for biogas plants. Almost 70% is used as livestock feed, 25% in human nutrition and about 5% as raw material for further industrial processing (Hauptvogel 2022). These are the crops that occupy the largest arable land area in Slovakia. Therefore, their share in the crop production structure of Slovakia has been increasing in recent years. In addition, it must be taken into account that it is not possible to grow an annual crop continuously in the same place for several years. To maintain soil fertility, crop rotation is essential and the introduction of multi-annual crops increases biodiversity in the landscape compared to growing a single crop every year (Fürtner et al. 2022). Diversification significantly helps to improve the income stability of farms and can influence their economic efficiency, which can ultimately contribute to the growth of agricultural production (Coelli, Fleming 2004, Rahman 2009, Kurdyś-Kujawska et al. 2021, Rahman et al. 2022). In terms of food security, greater diversification in crop production leads to better food security outcomes of the state (Mulwa, Visser 2020).

The Slovak Republic is practically at the bottom of the EU countries in national food security. Surveys carried out by many expert institutions have confirmed that currently more than 50% of the food sold is imported to replace domestic commodities, yet these are not irreplaceable commodities that would not have been produced in Slovakia in the past. According to Škamlová (2022), food production does not even cover Slovakia's own consumption. Slovakia imports many products that could be produced in its climatic conditions, which is reflected in the level of food self-sufficiency. A typical example is traditional commodities such as potatoes and vegetables grown in Slovakia. Such a trend in the development of the agricultural sector is contrary to the Concept for the Development of the Slovak Agriculture for 2013–2020, which, in addition to the positive development of the agricultural sector, also declared achievement of the target of 80% food self-sufficiency of the Slovak Republic by 2020. At the moment, the food self-sufficiency of Slovakia is at the level of 40%. It is necessary to increase the level of self-sufficiency in the cultivation of crops and production of products in which Slovakia was already self-sufficient; this concerns not only the cultivation of potatoes, vegetables and fruits but also legumes. In Slovakia, an average of 4,304,000 tonnes of cereals, 1,105,000 tonnes of grain maize, 850,000 tonnes of oilseeds, 1,407,000 tonnes of sugar beet and 551,000 tonnes of multi-annual fodder crops are produced annually. These crops are characterised by larger areas under cultivation. The lower production concerns 135,000 tonnes of potatoes, 140,000 tonnes of vegetables and 35,000 tonnes of legumes. An increase in production, particularly of crops with smaller areas, would have a positive impact on increasing the food self-sufficiency and security of the country. Slovakia's problem is still the absence of processors of basic agricultural raw materials, e.g. oilseeds for food purposes, and the lack of processing capacity in the case of cereals. These factors have a less favourable impact on the need to increase crop production or the area under cultivation.

Diversification and greater variability in crop production would also increase biodiversity in the agricultural landscape. Diversification in agricultural production would also contribute to increased employment in rural regions of Slovakia, and the state would be more self-sufficient in the food economy, thereby increasing the share of Slovak food in supermarket chains. Diversity is greater in crop production in the Podunajská lowland, which has the most favourable natural conditions for growing most crops. Crop diversity has a significant impact on the overall structure of crop production (Donfouet et al. 2017) and is essential in farming systems to help farmers adapt to increasing climate variability in the future (Lin 2011, Aribi, Sghaier 2020, Myeni, Moeletsi 2020). To cope with and mitigate the adverse effects of climate change, the development of high-yielding, heat- and drought-tolerant crop varieties is needed to ensure national food security (Ali et al. 2017). In the context of a changing climate, novel heat- and drought-tolerant crop seeds should be developed to increase agricultural production (Mulwa et al. 2017). The EU CAP has had a positive impact on the decisions of crop producers promoting diversification (Capitanio et al. 2016). Crop diversification can reduce the risks associated with low farmer incomes from agricultural production and national food security (Mango et al. 2018). According to Renard and Tilman (2019), ensuring a stable food supply for the population is a challenge that is likely to require multiple solutions. The results suggest that increasing effective crop diversification within the state may be another way to address this challenge. Several studies have shown that global crop production needs to be doubled by 2050 to meet the projected demands of the growing population, changing population diets and increasing biofuel consumption. Food security, reducing the risk of climate change and meeting growing energy demand will be increasingly serious challenges for EU countries in the coming years. Sustainable agricultural production is therefore becoming a major objective in food systems. Sustainability can be increased by crop diversification (Iocola et al. 2020). In this context, legumes could play an important role in providing multiple services in line with the principles of sustainable agricultural production (Stagnari et al. 2017). Traditional agricultural landscapes need to be given increased attention through the establishment of an appropriate support scheme under the Restoration and Resilience Facility in the context of the Common Agricultural Policy Strategic Plan 2023–2027 (Izakovičová et al. 2022).

Conclusions

In this study, we used cluster analysis, namely, the *k*-means method, to analyse the similarity between districts of Slovakia with respect to the structure of the eight crop areas in each of the three periods 2004–2009, 2010–2015 and 2016–2022, and to compare the results between these periods. This statistical method has not been used before in similar studies. Using the cluster analysis method, a spatial polarisation of crop production in Slovakia was obtained based on the similarity between districts in the sown areas of the most cultivated crops in Slovakia. As a result of the cluster analysis, two regions were created, which differ from each other in terms of natural conditions and the structure of the crops grown.

Cereals constitute a key group of crops for crop production in the Slovak Republic, despite a slight decline in cropping areas that started already in the 1990s. Oilseed cultivation has been increasing rapidly since the 1990s and still accounts for a high proportion of arable land. More legumes, potatoes, multi-annual fodder crops and vegetables are still lacking in rotations. In all three periods of the 2004–2022 time horizon, a two-cluster interpretation of the issue was most appropriate, while the largest number of districts in all periods under study were included in cluster 1. These are districts with suitable natural conditions for vegetable production. There is greater diversification of crop production in these districts, as confirmed by higher shares of the cropping areas under several crops grown in the area. In the last two periods, the proportion of districts in this cluster has slightly decreased from 47 districts to 45. Comparing the profiles of clusters 1 and 2 for the periods 2004–2009, 2010–2015 and 2016–2022, we can see a considerable similarity, which indicates the stability of crop cultivation in Slovakia over the last 20 years. In cluster 1, cereals, grain maize and oilseeds gained higher shares of the district's cropping area. Their share of the district's cropping area has gradually increased over the periods under review. The change in the purpose of oilseed production from food to industrial production increased Slovakia's self-sufficiency in the production of this commodity; however, it did not contribute to the overall food self-sufficiency of the country. The natural conditions of the districts from cluster 1 also suit the cultivation of vegetables and sugar beet. Cluster 2 included districts with higher shares of cropping areas of multi-annual fodder crops, potatoes and leguminous crops. The cluster analysis of the cropping areas under crops grown in Slovakia confirmed a greater preference for more stable crops on the market (oilseeds and cereals, especially grain maize) and crops with a higher market demand as a result of their use for non-food purposes as well. The results of our study confirmed a more stable production of potatoes, legumes, vegetables and sugar beet; a slight decrease in the cropping areas in both clusters was confirmed for multi-annual forage crops. Our study has shown that there is a need to increase the cultivation of higher value-added crops (e.g. legumes, potatoes and vegetables) in Slovakia, which would positively contribute to the increase of biodiversity in the country and would increase Slovakia's food self-sufficiency. To achieve this objective, the cultivation of monocultures in the form of cereals and oilseeds needs to be reduced. Only a more diversified crop production structure will increase crop diversification and can also have a positive impact on mitigating the effects of climate change in the agricultural landscape.

Precision farming is increasingly employed in agriculture today, using modern technologies that allow more precise planning of agricultural activities. Demand for agricultural products will grow dynamically in the coming decades, which can only be met by more efficient production. Therefore, our research will focus on the contribution of precision agriculture to sustainable food production in the Slovak context of food self-sufficiency and sustainability of the agricultural sector.

Authors' contribution

Conceptualisation: JN; methodology: JN, ĽR, KV; software: ĽR; validation: JN; formal analysis: JN, ĽR, KV; investigation: JN; resources: JN, ĽR, KV; data curation: JN; writing – original draft preparation: JN, ĽR; writing – review and editing: JN; visualisation: ĽR, KV; supervision: JN.

Conflict of interest

The authors declare no conflict of interest in this study. All authors have read and agreed to the published version of the manuscript.

References

Ali S., Liu Y., Ishaq M., Shah T., Abdullah, Ilyas A., Ud Din I., 2017. Climate change and its impact on the yield of major food crops: Evidence from Pakistan. *Foods* 6(6): 39. DOI 10.3390/foods6060039.

Aragrande M., Bruni M., Loi A., Esposti R., 2017. The effect of EU 2006 sugar regime reform on vertical price transmission. *Agricultural and Food Economics* 5(18): 1–20. DOI 10.1186/s40100-017-0087-8.

Aribi F., Sghaier M., 2020. Determinants and strategies of farmers' adaptation to climate change: The case of Medenine Governorate, Tunisia. *Agrofor* 5(2): 122–129. DOI 10.7251/AGRENG2002124A.

Bai L., Liang J., Guo Y., 2018. An ensemble clusterer of multiple fuzzy k-means clusterings to recognize arbitrarily shaped clusters. *IEEE Transaction on Fuzzy Systems* 26(6): 3524–3533. DOI 10.1109/TFUZZ.2018.2835774.

Bełdycka-Bórawska A., Bórawski P., Dunn J.W., 2016. Factors of the development of oilseed rape production in Poland on the background of the world. *Journal of Advanced Agricultural Technologies* 3(3): 175–179. DOI 10.18178/joaat.3.3.175-179.

Bičík I., Jančák V., 2005. *Transformační procesy v Českem zemědelství po roce 1990*. Univerzita Karlova, Praha.

Capitanio F., Gatto E., Millemaci E., 2016. CAP payments and spatial diversity in cereal crops: An analysis of Italian farms. *Land Use Policy* 54: 574–582. DOI 10.1016/j.landusepol.2016.03.019.

Cernay C., Ben-Ari T., Pelzer E., Meynard J.-M., Makowski D., 2015. Estimating variability in grain legume yields across Europe and the Americas. *Scientific Reports* 5: 11171. DOI 10.1038/srep11171.

Coelli T., Fleming E., 2004. Diversification economies and specialisation efficiencies in a mixed food and coffee smallholder farming system in Papua New Guinea. *Agricultural Economics* 31(2–3): 229–239. DOI 10.1111/j.1574-0862.2004.tb00260.x.

Devaux A., Goffart J.P., Petsakos A., Kromann P., Gatto M., Okello J., Suarez V., Hareau G., 2020. Global food security, contributions from sustainable potato agri-food systems. In: Campos H., Ortiz O. (eds), *The potato crop: Its agricultural, nutritional and social contribution to humankind*. Springer Science and Business Media, Luxemburg: 3–35. DOI 10.1007/978-3-030-28683-5_1.

Donfouet H.P.P., Barczak A., Détang-Dessendre C., Maigné E., 2017. Crop production and crop diversity in France: A spatial analysis. *Ecological Economics* 134: 29–39. DOI 10.1016/j.ecolecon.2016.11.016.

Ferreira H., Pinto E., Vasconcelos M.W., 2021. Legumes as a cornerstone of the transition toward more sustainable agri-food systems and diets in Europe. *Frontiers Sustainable Food Systems* 12: 1–9. DOI 10.3389/fsufs.2021.694121.

Fürtner D., Perdomo Echenique E.A., Hörtenhuber S.J., Schwarzbauer P., Hesser F., 2022. Beyond monetary cost-benefit analyses: Combining economic, environmental and social analyses of short rotation coppice poplar production in Slovakia. *Forests* 13(2): 349. DOI 10.3390/f13020349.

Gates A.J., Ahn Y.Y., 2017. The impact of random models on clustering similarity. *Journal of Machine Learning Research* 18: 1–28.

Goffart J.P., Haverkort A., Storey M., Haase N., Martin M., Lebrun P., Ryckmans D., Florins D., Demeulemeester K., 2022. Potato production in northwestern Europe (Germany, France, the Netherlands, United Kingdom, Belgium): Characteristics, issues, challenges and opportunities. *Potato Research* 65(3): 503–547. DOI 10.1007/s11540-021-09535-8.

Hauptvogel R., 2022. Kolekcia obilnín v slovenskej genovej banke. *Naše pole* 6(6): 32–33.

He L., Zhang H., 2018. Kernel K-means sampling for Nyström approximation. *IEEE Transactions on Image Processing* 27(5): 2108–2120. DOI 10.1109/TIP.2018.2796860.

Iocola I., Angevin F., Bockstaller C., Catarino R., Curran M., Messéan A., Schader C., Stilmant D., Van Stappen F., Vanhove P., Ahnemann H., Berthomier J., Colombo L., Dara Guccione G., Mérot E., Palumbo M., Virzì N., Canali S., 2020. An actor-oriented multi-criteria assessment framework to support a transition towards sustainable agricultural systems based on crop diversification. *Sustainability* 12(13): 5434. DOI 10.3390/su12135434.

Izakovičová Z., Špulerová J., Raniak A., 2022. The development of the Slovak agricultural landscape in a changing world. *Frontiers Sustainable Food Systems* 6: 862451. DOI 10.3389/fsufs.2022.862451.

Jain A.K., Dubes R.C., 1988. *Algorithms for clustering data*. Prentice-Hall, Inc., Upper Saddle River, NJ. Online: http://dl.acm.org/citation.cfm?id=SERIES10022.42779 (accessed 24 September 2023).

Krautgartner R., Omnes M.A., Rehder L., Boshnakova M., Flach B., Wilson J., Faniadis D., Guerrero M., Bolla S., FAS EU Oilseeds Specialists. 2022. *Oilseeds and Products Annual*. United States Department of Agriculture, Foreign Agricultural Service, Vienna: 1–58. Online: https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Oilseeds%20and%20Products%20Annual_Vienna_European%20Union_E42022-0031 (accessed 24 September 2023).

Kubeš J., Nárovec V., 2019. Development of world and European sugar beet production 1961–2017 – Geographic view. *Listy Cukrovarnické a Reparské* 135(11): 370–374.

Kurdyś-Kujawska A., Strzelecka A., Zawadzka D., 2021. The impact of crop diversification on the economic efficiency of small farms in Poland. *Agriculture* 11(3): 250. DOI 10.3390/agriculture11030250.

Lin B.B., 2011. Resilience in agriculture through crop diversification: Adaptive management for environmental change. *Bioscience* 61(3): 183–193. DOI 10.1525/bio.2011.61.3.4.

Li Z., Tan J., Tang P., Chen H., Zhang L., Liu H., Wu W., Tang H., Yang P., Liu Z., 2016. Spatial distribution of maize in response to climate change in northeast China during 1980–2010. *Journal of Geographical Sciences* 26: 3–14. DOI 10.1007/s11442-016-1250-y.

Mango N., Makate C., Mapemba L., Sopo M., 2018. The role of crop diversification in improving household food security in central Malawi. *Agriculture & Food Security* 7(7): 7. DOI 10.1186/s40066-018-0160-x.

Mulwa C., Marenya P., Rahut D.B., Kassie M., 2017. Response to climate risks among smallholder farmers in Malawi: A multivariate probit assessment of the role of information, household demographics, and farm characteristics. *Climate Risk Management* 16: 208–221. DOI 10.1016/j.crm.2017.01.002.

Mulwa C.K., Visser M., 2020. Farm diversification as an adaptation strategy to climatic shocks and implications for food security in northern Namibia. *World Development* 129(1): 104906. DOI 10.1016/j.worlddev.2020.104906.

Myeni L., Moeletsi M.E., 2020. Factors determining the adoption of strategies used by smallholder farmers to cope with climate variability in the Eastern Free State, South Africa. *Agriculture* 10(9): 410. DOI 10.3390/agriculture10090410.

Némethová J., Rybanský Ľ., 2021. Development trends in the crop production in Slovakia after accession to the European Union – Case study, Slovakia. *Sustainability* 13: 8512. DOI 10.3390/su13158512.

Némethová J., Svobodová H., Křejčí O., Věžník A., 2020. Development of crop production in the Slovakia and Czechia after the year 2004 in comparison with V4 countries. *Bulletin of Geography. Socio-economic Series* 50(50): 7–22. DOI 10.2478/bog-2020-0028.

Némethová J., Vilinová K., 2022. Changes in the structure of crop production in Slovakia after 2004 using an example of selected crops. *Land* 11: 249. DOI 10.3390/land11020249.

Nowak A., 2020. Differentiation in cereal production among Member States of the European Union. *Polish Journal of Agronomy* 40: 7–15. DOI 10.26114/pja.iung.395.2020.40.02.

Rahman S., 2009. Whether crop diversification is a desired strategy for agricultural growth in Bangladesh? *Food Policy* 34(4): 340–349. DOI 10.1016/j.foodpol.2009.02.004.

Rahman S., Anik A.R., Sarker J.R., 2022. Climate, environment and socio-economic drivers of global agricultural productivity growth. *Land* 11(4): 512. DOI 10.3390/land11040512.

Renard D., Tilman D., 2019. National food production stabilized by crop diversity. *Nature* 571: 257–260. DOI 10.1038/s41586-019-1316-y.

Řezbová H., Belová A., Škubna O., 2013. Sugar beet production in the European Union and its future trends. *Agris On-line Papers in Economics and Informatics* 5(4): 165–178. DOI 10.22004/ag.econ.162299.

Robles R., 2011. The economics of oil-seed crops for energy use: A case study in an agricultural European region. *Scientific Journal Warsaw University of Life Sciences. Problems of World Agriculture* 11(3): 116–126. DOI 10.22004/ag.econ.195667.

Rousseeuw P.J., 1987. Silhouettes: A graphical aid to the interpretation and validation of cluster analysis. *Journal of Computational and Applied Mathematics* 20: 53–65. DOI 10.1016/0377-0427(87)90125-7.

Serenčéš R., Mučaji I., 2014. Spoločná poľnohospodárska politika EÚ a SR. In: Proceedings of the Reviewed Articles of 13th International Scientific Conference, International Scientific Days 2014: Improving Performance of Agriculture and the Economy: Challenges for Management and Policy, High Tatras, 21–23 May 2014.

Škamlová L., 2022. Food self-sufficiency in Slovakia from the perspective of land use and production approach. *European Countryside* 14(1): 121–139. DOI 10.2478/euco-2022-0007.

Stagnari F., Maggio A., Galieni A., Pisante M., 2017. Multiple benefits of legumes for agriculture sustainability: An overview. *Chemical and Biological Technologies in Agriculture* 4(1): 2. DOI 10.1186/s40538-016-0085-1.

Stanforth R., Kolossov E., Mirkin B., 2007. Hybrid k-means: Combining regression-wise and centroid-based criteria for QSAR. In: Brito P., Cucumel G., Bertrand P., De Carvalho F. (eds), *Selected contributions in data analysis and classification. Studies in classification, data analysis, and knowledge organization*. Springer, Berlin, Heidelberg: 225–233. DOI 10.1007/978-3-540-73560-1_21.

Statistical Office of the Slovak Republic, 2024. Online: http://www.statistics.sk (accessed 11 September 2023).

Věžník A., Jadlovský F., 2021. Development of sugar factories in Czech Republic. *Geographical Informatics* 25(2): 88–108. DOI 10.17846/GI.2021.25.2.88-108.

Zander P., Amjath-Babu T.S., Preissel S., Reckling M., Bues A., Schläfke N., Kuhlman T., Bachinger J., Uthes S., Stoddard F., Murphy-Bokern D., Watson Ch., 2016. Grain legume decline and potential recovery in European agriculture: A review. *Agronomy Sustainable Development* 36(2): 26. DOI 10.1007/s13593-016-0365-y.