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ORIGINAL ARTICLE

Spatial and temporal yield dynamics of corn for grain within the Volyn region

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Aim. To establish the spatial and temporal variability in yield of corn for grain in the Volyn region in 1965-2017. **Methods.** Agricultural research, multivariate statistics, cluster analysis, geographic information technology. **Results.** From 1965 to 2015, the highest yield of corn for grain in the Volyn region was observed in the southern regions, and the lowest yield level was established for the northern regions. According to the peculiarities of the temporal dynamics of corn yields, the administrative regions are classified as allocating spatially homogeneous complexes consistent with the Forest-steppe, Polissia, and the Transitional Zone. The indicators of the dynamics of corn yields in all regions are characterized by a positive asymmetry coefficient, indicating an asymmetric distribution with a shift to the left. The presence of asymmetry indicates the heterogeneity of conditions and the cultivation of corn for grain during the study period and the possibility of identifying qualitatively homogeneous time intervals, that is, for the periodization of the investigated hour interval following the yield indicators of corn for grain. The geography of homogeneous clusters identified based on indicators of the dynamics of grain corn, which to a certain extent corresponds to the physical and geographical zoning of the region, is evidence of the ecological conditionality of corn yield by modes that correlate with factors of physical and geographic heterogeneity of the region. Of the ecological and geographic factors, climatic conditions were the most variable over the corresponding period. From 1965 to 2015, the nature of the dynamics of grain corn yields underwent qualitative transformations, which are the basis for appropriate periodization. Essential markers of the respective periods are the general yield level and the yield trend's general direction. **Conclusions**. The highest yield of corn for grain in the Volyn region was observed for the administrative districts located in the forest-steppe zone, and the lowest was characteristic for the districts within Polissia. The level of grain corn yields in the region may differ by almost 2.9 times, resulting from the soil's heterogeneity and climatic conditions. The dynamics of the production process in the forest-steppe zone and Polissia are in antiphase: favorable conditions for increasing yields in one geographic zone are accompanied by opposite conditions for the adjacent zone and vice versa. Grain corn yield in 1965–2015 showed cyclical dynamics, during which periods with two local maximums were observed: in the ninth decade of the 20th century and the second half of the first decade of the 21st century.
Keywords: corn, dynamics, contemporary models, fluctuations, product potential, trend

Introduction

Today's urgent need is to increase the production of quality agricultural products due to the steady global human population growth (Godfray et al., 2010; Tscharntke et al., 2019). Crop yields significantly depend on the genetic characteristics of varieties, edaphic regimes, climatic conditions, and agricultural techniques (Diacono et al., 2012). Several studies have identified long-term grain yields globally (Aizen et al., 2008; Aizen et al., 2009; Lesk et al., 2016; Ray et al., 2013). In modern crop production, corn is one of the most important crops due to the high yield and the various possibilities of its use (Agnolucci et al., 2019). Ukraine is an essential producer of corn in the world. The global trend of corn yield is characterized by gradual or rapid growth (Ray et al., 2012). Ukraine's share in global corn production increased from 0.23% in 1994 to 2.51% in 2013 due to a significant increase in this crop yield and the area where corn is grown (FAOSTAT, 2020). The general trend of increasing corn yield is due to agronomic reasons (Fuglie et al., 2011; Duvick 2005), although the possibilities of this factor decrease lately, but real reasons of perspectives of yield stagnation remain unidentified (Hawkins et al., 2013). Thus, in the United States between 1984 and 2013, a 27% increase in corn yields was due to increased solar radiation rather than technology development, as previously predicted (Tollenaar et al., 2017). Global climate change can also be a significant factor in the dynamics of corn yields (Schlenker et al., 2009; Butler et al., 2013). An essential aspect of the study of production potential is establishing patterns of interannual variation in yields. It was shown that the year-on-year variation in wheat and corn yields in France decreased between 1961 and

2010 (Iizumi et al., 2016). In most administrative districts of Polissia and the Forest-Steppe of Ukraine for the period 1991–2017, the dynamics of corn yield reached the stage of stagnation. It was assumed that this result is not due to the full use of the territory's productive potential (Matviichuk et al., 2020).
Temperature, precipitation, and solar radiation are the essential climate drivers for corn yields. (Xu et al., 2016). Corn as grain is a thermophilic plant (Hatfield et al., 2011), but rising temperatures can lead to negative consequences due to changes in culture development phenology. The time of occurrence of the maximum need for moisture changes, the time of pollination changes, and there is a desynchronization with the activity of pollinators (Harrison et al., 2011). The temperature increase shortens the maturation time of the plant (Iqbal et al., 2009). Short-term temperature variations can negatively impact metabolic processes, resulting in reduced carbon assimilation intensity and pollination efficiency (Moriondo et al., 2011). Against the background of changes in precipitation patterns, high temperatures can lead to water stress of plants due to a decrease in soil moisture (Lobell et al., 2013).
Analysis of the spatial and temporal dynamics of grain and legume yields in the Polissia and Forest-Steppe zones of Ukraine has shown the complex nature of the processes that determine it. A common feature of changes over time is a trend that a fourth-degree polynomial can describe. The trend is considered agrarian-economic and agrarian-technological (Kunah et al., 2018; Pysarenko et al., 2020; Matviichuk et al., 2020). Cluster analysis of the dynamics of winter wheat yield in the Dnipropetrovsk region's administrative districts allowed the identification of geographically defined districts that form spatially connected complexes. Temporal winter wheat yield dynamics resulting from the interaction of endogenous and exogenous environmental factors is the main principle of opening such ecologically homogeneous territories (Zhukov et al., 2018). The study of sunflower yield dynamics in agricultural enterprises of Poltava region by administrative districts for the period 1995–2016 allowed to establish the role of a spatial and agroecological component of variation and performed agroecological zoning of Poltava region based on dynamic features of sunflower yield (Zhukov et al., 2017). Landscape management is essential for biodiversity conservation (Lindenmayer et al., 2007; Andrushenko et al., 2016; Tscharntke et al., 2019). Aggregation of agricultural fields and reduction of non-cultivated areas leads to the transformation of complex landscapes with a relatively high proportion of semi-natural habitats into simple in structure landscapes dominated by arable fields (Roschewitz et al., 2005). Landscape structure is a key factor in maintaining biodiversity and forming productive potential (Antrop, 2005; Zhukov et al., 2016).
Thus, modern ideas about the dynamics of agricultural landscapes' productive potential pay special attention to studying the dynamics of crop yields in space and time. Yield is considered a dynamic process that is a function of agrarian and economic, agrarian, technological, agrarian, and ecological factors. Determining their roles is the basis for creating effective measures to manage agricultural production and achieve food security.
This work aims to establish the spatial and temporal variability of corn yield for grain in the Volyn region during 1965-2017.

Methods

Information on corn yield for grain for the period 1965–2015 was obtained from the Main Department of Statistics in Volyn Region of the State Statistics Service of Ukraine (http://www.lutsk.ukrstat.gov.ua/). We used the information on yields from administrative districts. Calculations of descriptive yield statistics (average, standard error, minimum, maximum, coefficient of variation, asymmetry, and excess), and graphical display of histograms of the distribution of yield indicators, cluster analysis performed in Statistica 12.0 software. The database and visual display of the spatial arrangement of clusters established based on the dynamics of corn yield per grain were carried out in ArcGIS 10.0.

Results

During the period 1965–2015, the highest grain yields for grain within the Volyn region were observed for the southern districts - Horokhiv (average 43.6 ± 2.7 c/ha), Lutsk (52.2 ± 2.9 c/ha), and Ivanychiv (41.6 ± 3.0 c/ha), (Table 1). The lowest level of corn yield per grain was established for the northern districts: Starovyzhivsk (17.7 ± 1.0 c/ha), Lyubeshiv (19.8 ± 1.3 c/ha), and Ratniv (23.2 ± 1.3 c/ha). The corn yield level within the region can vary almost 2.9 times due to the heterogeneity of the region's soil and climatic conditions. The maximum yield of corn for grain was set for Lutsk district, 107.9 c/ha, and the minimum - for Manevychi district, which was 5.9 c/ha. The significant range of variation also indicates a specific temporal aspect of the variability of corn yield per grain within the study area. The variability in corn yield per grain is most significant at the boundaries between physical and geographical areas, and least at the northwest or southeast. Thus, the lowest value of the coefficient of variation was established for Shatsk (26.8%), Kivertsiv (28.0%), and Liuboml (31.6%) districts. The highest value of the coefficient of variation was found for Manevychi (70.9%), Volodymyr-Volynskyi (70.3%), and Kovel (52.9%) districts.
The yield indicators of corn for grain in all areas are characterized by a statistically significant positive asymmetry coefficient, which indicates an asymmetric distribution with a shift to the left (Fig. 1). The most considerable asymmetry in the distribution of corn yield on grain was established for Liuboml (1.26 ± 0.33) and Rozhysche (1.14 ± 0.33) districts, and the minor asymmetry was established for Kivertsiv (0.51 ± 0.33) and Manevychi districts (0.71 ± 0.33).
The presence of asymmetry indicates the heterogeneity of conditions and modes of the yield of corn for grain during the study period and the possibility of establishing qualitatively homogeneous time intervals, i.e., the periodization of the studied time in terms of yield of corn for grain.

Table 1. Descriptive statistics of corn yield for grain by administrative districts of Volyn region (period 1965–2015).

District	Average ± tolerance, c/ha	Min, c/ha	Max, c/ha	Variation rate, %	Asymmetry ± tolerance	Excess ± tolerance
Horokhiv	43.6±2.7	14.8	95.1	44.0	0.80±0.33	−0.27±0.66
Ivanychiv	41.6±3.0	16.0	96.6	51.3	0.91±0.33	−0.16±0.66
Kamin-Kashyrskyi	23.4±1.4	10.5	46.2	43.2	0.85±0.33	−0.53±0.66
Kivertsiv	31.3±1.2	18.0	52.7	28.0	0.51±0.33	−0.46±0.66
Kovel	33.5±2.5	8.7	78.8	52.9	0.99±0.33	−0.04±0.66
Liubeshiv	19.8±1.3	9.1	43.0	47.8	1.07±0.33	0.08±0.66
Liuboml	32.8±1.5	22.6	62.1	31.6	1.26±0.33	0.50±0.66
Lokachyn	39.4±2.9	15.2	87.3	52.8	0.92±0.33	−0.50±0.66
Lutsk	52.2±2.9	19.0	107.9	39.7	0.88±0.33	0.18±0.66
Manevytskyi	29.9±3.0	5.9	78.5	70.9	0.71±0.33	−0.89±0.66
Ratniv	23.2±1.3	11.4	47.0	39.7	0.94±0.33	−0.16±0.66
Rozhyshche	37.2±2.0	16.7	77.4	39.0	1.14±0.33	0.72±0.66
Shatskyi	25.2±0.9	14.5	43.0	26.8	0.83±0.33	−0.23±0.66
Starovyzhiv	17.7±1.0	9.1	34.3	38.9	0.89±0.33	−0.38±0.66
Turiiskyi	37.3±2.1	19.1	66.7	39.5	0.82±0.33	−0.89±0.66
Volodymyr-Volynskyi	35.5±3.5	9.3	97.3	70.3	0.97±0.33	−0.49±0.66

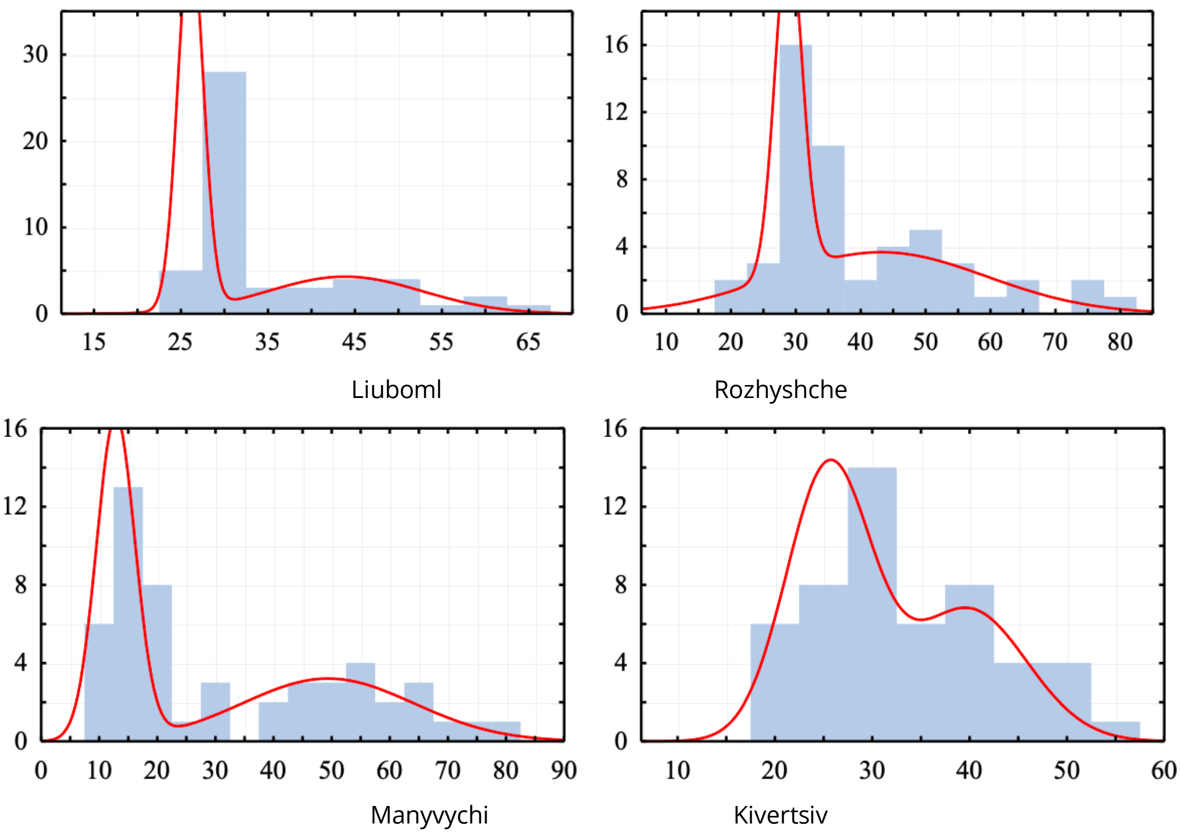


Fig. 1. Typical grain yield distributions on grain with the most considerable asymmetry (Liuboml and Rozhysche districts) and the minor asymmetry (Manevychi and Kivertsiv districts). The abscissa is a yield (c/ha), the ordinate is the relevant cases number

The excess yield distribution is not statistically significantly different from zero (13 districts). For Turiiskyi and Manevychi districts, the excess distribution is negative, and for Rozhysche - positive. Thus, the distribution's asymmetry is also accompanied by its two-vertex (there is a strong positive correlation between asymmetry and excess) $r = 0.72$, $p < 0.001$). These results emphasize heterogeneous periods in the time yield of corn for grain during the study period. We can also assume that these periods may manifest themselves differently in different geographical conditions of the region.

According to the peculiarities of the temporal dynamics of corn for grain yield, administrative districts can be classified (Fig. 2) to select spatially homogeneous formations (Fig. 3).

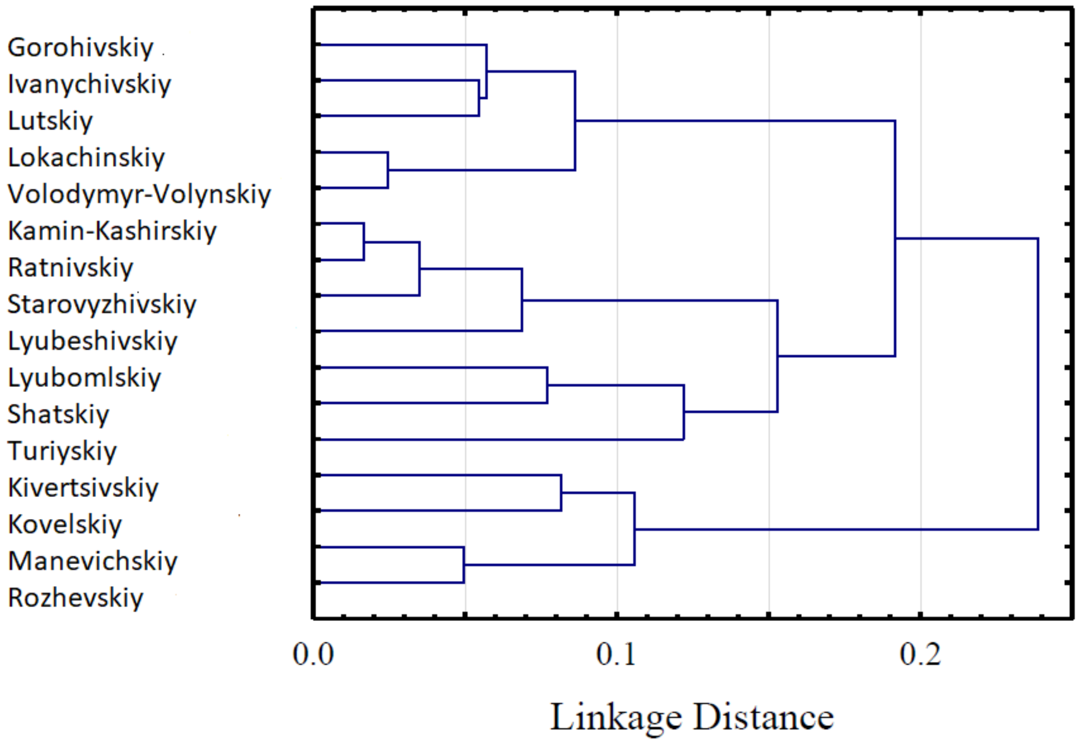


Fig. 2. Cluster analysis of administrative districts of Volyn region according to the yield dynamics of corn for grain (1965–2015) (cluster analysis according to the Ward method based on Pearson's metrics)

There are three such formations, or clusters, each occupying a particular area of the region. Cluster 2 corresponds most closely to the transition zone between Polissia and the Forest-Steppe within the region, cluster 1 occupies the Forest-Steppe landscapes of the region, and cluster 3 occupies the landscapes of Polissia. It should be noted that such a correspondence exists only in general form and is not entirely identical.

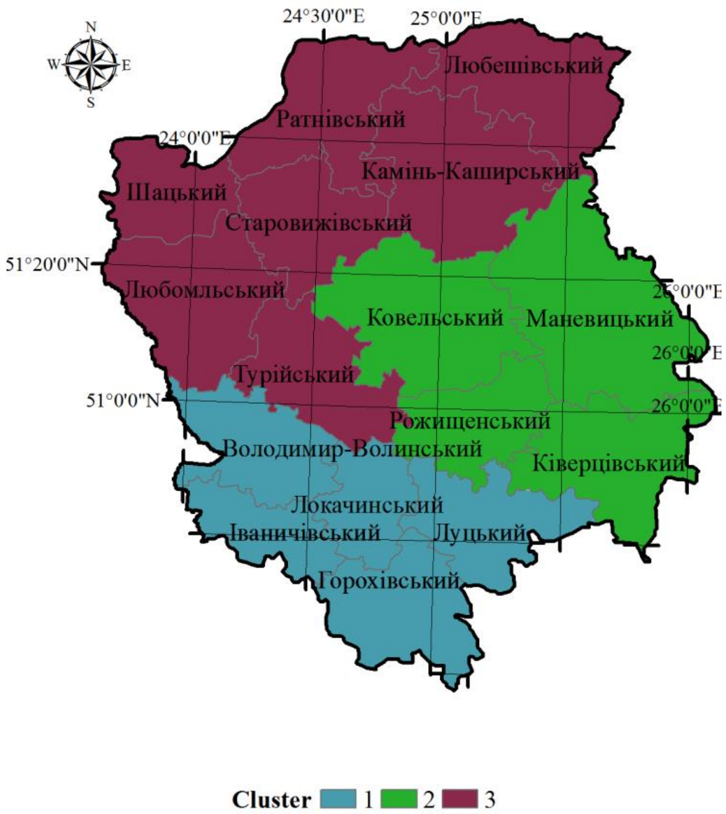


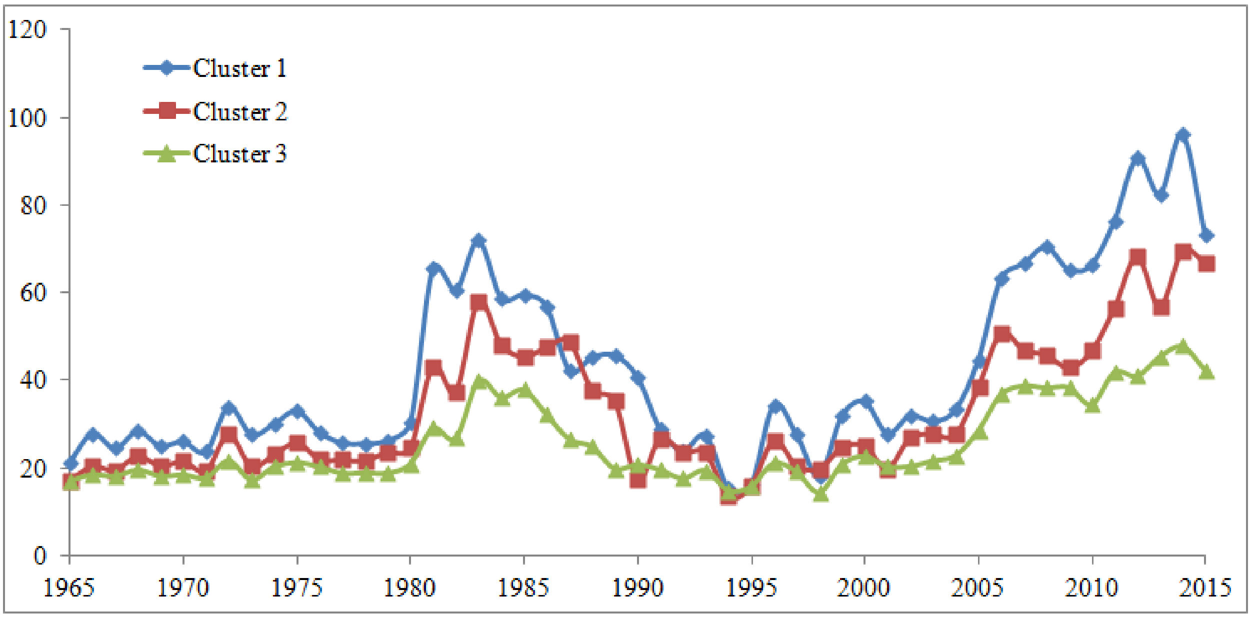
Fig. 3. The spatial arrangement of clusters, which are established based on the yield dynamics of corn for grain (1965–2015)

The geography of homogeneous clusters selected according to the dynamics of corn yield for grain, which corresponds to the region's physical and geographical zoning, is evidence of ecological conditionality of corn yield for grain regimes that correlate with physical and geographical factors heterogeneity of the region. Of the ecological and geographical factors, the most variable for the relevant period were climatic conditions. However, it is impossible to exclude from the factors of influence and changes in the trophic status of agricultural areas and the influence of a set of agrarian and economic and agrarian and technological factors.

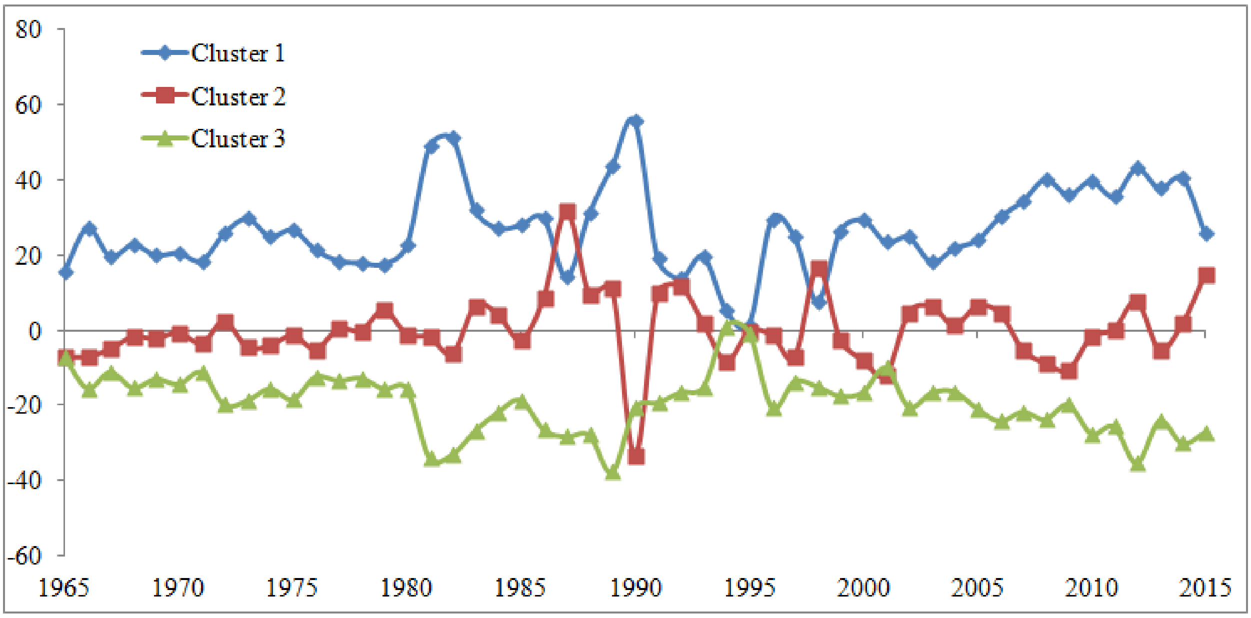
Specific time patterns of yield characterize spatial clusters during 1965–2015 (Figure 4, A). First of all, the peculiarity lies in the general yield level of corn for grain: it is the largest for cluster 1 (Forest-steppe zone) and the smallest for cluster 3 (Polissia) and, accordingly, has an intermediate level for the transition zone (cluster 3). In some years, the differences between clusters 2 and 3 may be insignificant, and the order may change slightly, which does not significantly affect the overall trend.

Differential representation of yield as a difference with the average yield level in the region (Figure 4, B) highlights specific clusters' dynamic features. We see that clusters 1 and 3 differ in antiphase dynamics, and cluster 2 shows an independent oscillatory pattern. Thus, favorable conditions for increasing yields in one physical-geographical zone are accompanied by inverse conditions for the adjacent zone and vice versa. The growth of the total yield in the region is due to yield growth in the Forest-Steppe zone. The specific yield in the transition zone is close to zero, emphasizing the transition zone's intermediate nature.

According to the peculiarities of corn yield for grain, the years were subjected to cluster analysis, the results of which identified two clusters, which represent the following sequences of years: cluster I - periods 1965-1980 and 1987-2005; cluster II - 1981–1986 and 2006–2015 (Figure 5).



A



B

Fig. 4. Yield dynamics of corn for grain within clusters. A. The yield, c/ha B. In % compared to the average yield in the region (OY axis)

Thus, during 1965–2015, we registered the qualitative transformations in the yield dynamics of corn for grain, which is the basis for the corresponding periodization.

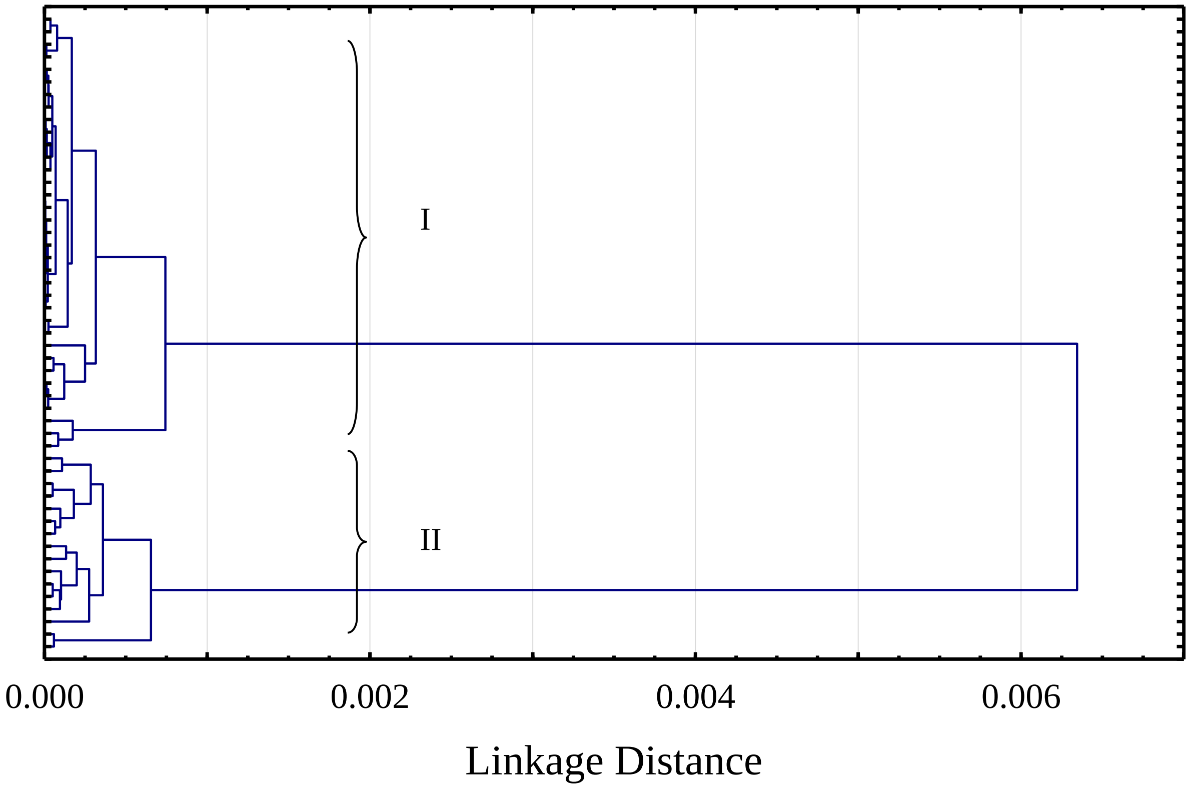


Fig. 5. Periodization by types of grain yield dynamics for grain (cluster analysis by the Ward method based on Pearson's metrics). I - periods 1965–1980 and 1987–2005; II - 1981–1986 and 2006–2015

Essential markers of the respective periods are the general level of yield and the general direction of the crop yield trend (Fig. 6). The yield of corn for grain showed cyclic dynamics, expressed in the repetition of clusters I and II in different periods. Cluster I marks the stage with reduced yields, which was observed twice during the study period. Cluster II, respectively, marks a stage with a high level of yield.

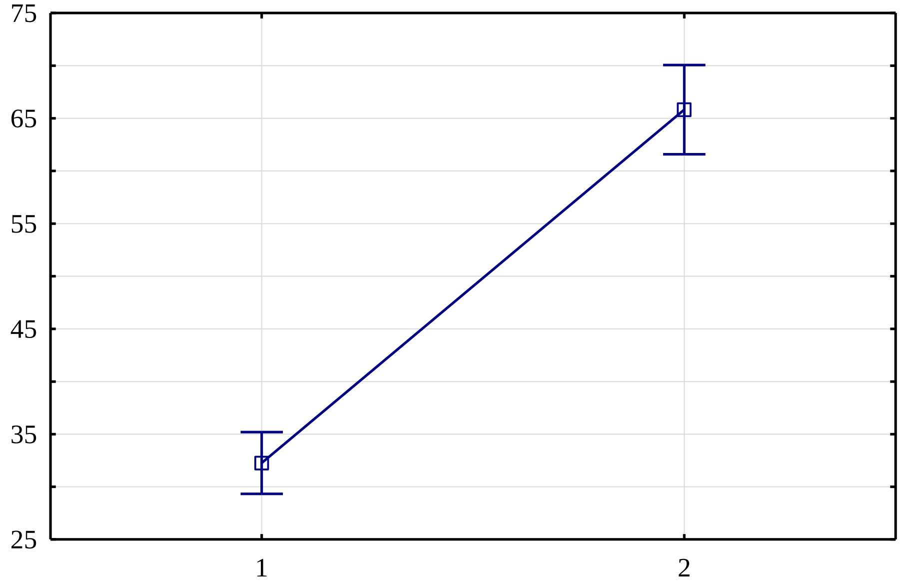


Fig. 6. Average yield level (c/ha, OY axis) in different periods of yield dynamics of corn for grain (OX axis). I - periods 1965–1980 and 1987–2005; II - 1981–1986 and 2006–2015

It is important to note that the trend to reduce the yield of corn for grain manifested itself in the tenth decade of the 20th century was laid in the previous period. The decline in yields in the 1990s can be attributed to the socio-economic crisis at that time. Nevertheless, it should be noted that it is most likely that the crisis has accelerated the processes that had an agroecological genesis.

Discussion

Volyn region demonstrates one of the highest corn yields in Ukraine - up to 7.8 tons/ha (Taran, 2019). Within the region, the highest level of yield is characterized by areas located in the forest-steppe zone. A slightly lower level of yield is set for the Transition Zone and the lowest for Polissia. The peculiarity of the region's territories, which essentially correspond to the physical and geographical zoning, is also the presence of specific time patterns of corn yield. This indicates the presence of specific natural regimes that affect crop yields and specific conditions in them. Thus, it was shown that agroecological processes' spatial and temporal variability could be decomposed into its spatial and temporal components (Hammond et al., 2014). Areas with different productivity potential can be established based on the study of soil cover and yield dynamics of cultivated plants (Basso et al., 2011; Fleming et al., 2004; Zhukov et al., 2015). Synchronicity and stability are essential components of the spatial and temporal dynamics of crop yields; when the yield of certain crops increases or decreases in the same year in each of the two places, the dynamics of culture in these places are synchronous.

On the other hand, stability is manifested because the average yield is different in two places or other spatial units (Li, 2015). Spatial patterns of yield variation can be used to reveal the hidden mechanisms of landscape systems' functioning. In such permanent mechanisms, long-term forecasts of the dynamics of agri-environmental processes in the future become possible. (Hammond et al., 2014). Thus, we have shown that the forest-steppe zone is characterized by the most significant sensitivity of corn to grain to environmental influences. This is manifested in the highest level of yield growth in favorable periods. Yield dynamics in the Transition Zone and Polissia repeats the dynamics in the Forest-Steppe Zone but with a much smaller amplitude of oscillating phenomena.

Using ascending regression models, yield trends can be classified into four categories: growth, stagnation, collapse, and lack of improvement (Chen, 2018). The lack of improvement is typical for areas within which there is no significant yield improvement over time. Yield stagnation can be identified in areas where yields have previously improved but are now stagnant or declining. Yield collapse corresponds to a situation where yields decreased or first increased and then decreased to baseline (Ray et al., 2012). Relatively simple polynomial dependence cannot describe the patterns of time variation of corn yield established by us, cannot be unambiguously identified. In fact, against the background of stagnant yields, we observed two local yields during the research period - in the 80s of the last century and from the second half of the zero years of the 21st century. This result indicates the need to address a range of issues related to selecting adequate tools to describe the production process and identify agri-environmental predictors that can fully explain the process's dynamics. As prospects for the study, we see the need to answer what environmental factors are associated with trends in the yield variation of corn for grain.

Conclusions

The highest yield of corn for grain within the Volyn region was observed for administrative districts located within the Forest-Steppe zone, and the lowest is typical for districts within Polissia. The yield level of corn for grain within the region can vary almost 2.9 times due to the heterogeneity of soil and climatic conditions of the region. The dynamics of the production process in the Forest-Steppe zone and Polissia are in antiphase: favorable conditions for increasing yields in one physical-geographical zone are accompanied by inverse conditions for the adjacent zone vice versa. Corn grain yield during 1965–2015 demonstrated cyclical dynamics, during which periods with two local maxima were separated: in the ninth decade of the 20th and the second half of the first decade of the 21st century.

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