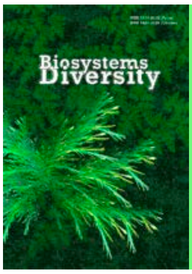

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Agroecological and agroeconomic aspects of the grain and grain legumes (pulses) yield dynamic within the Dnipropetrovsk region (period 1966–2016)

O. V. Zhukov*, T. O. Pelina*, O. M. Demchuk**, N. I. Demchuk***, S. O. Koberniuk***

**Oles Honchar Dnipro National University, Dnipro, Ukraine*
***Tavria State Agrotechnological Uneversity, Melitopol, Ukraine*
****Dnipro State Agrarian and Economic University, Dnipro, Ukraine*

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Oles Honchar Dnipro National University,
Gagarin av., 72, Dnipro,
49010, Ukraine.
E-mail:
zhukov_dnipro@ukr.net

Tavria State Agrotechnological Uneversity,
B. Khmelnytsky av., 18,
Melitopol, 72310, Ukraine.
E-mail:
olena.demchuk@tsatu.edu.ua

Dnipro State Agrarian and Economic University,
Sergey Yefremov st., 25,
Dnipro, 49600, Ukraine.
E-mail:
natademchyk@gmail.com

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This paper reveals the spatial and temporal patterns of grain and leguminous crops yield dynamics in Dnipropetrovsk region and evaluates the role of agro-environmental and agro-economic factors in their formation. Crop data were obtained from the State Statistics Service of Ukraine. The data of the grain and grain legumes (pulses) yield during 1966–2016 on average per year in the administrative districts of Dnipropetrovsk region was analysed. The obtained data indicate that average yields of cereals and leguminous crops within Dnipropetrovsk region varies from 24.3 to 33.4 CWT/ha. The smallest interannual variability in yield is typical for Vasylkivskyi district (CV = 9.9%), and the largest is typical for Yurivskyi district (CV = 27.7%). As a result of the principal component analysis of the cereals and leguminous crops yields variability, three principal components were extracted which together explain 81.2% of the overall yield variability. Principal component 1 explains 69.4% of the total variability. It indicates the total synchronous yields variation within the area investigated as all examined variables have high loading values on principal component 1. The administrative districts that form a belt located in the direction from the north east to the south west of the region have the most coordinated variance, which is reflected by principal component 1. Principal component 2 explains 6.8% of the yield variability. This principal component is sensitive to opposite yield dynamics of central and south-western districts on the one hand and the eastern and northern districts – on the other. Principal component 3 explains 4.9% of the yield variability. This principal component reveals the opposite dynamics of productivity of the central districts on the one hand and the northern and south-eastern districts on the other. The cluster analysis of administrative districts was conducted based on the dynamics of the yield of grain and leguminous as a result of which four clusters were identified. The clusters are geographically defined administrative districts, together forming spatially connected areas. The similar temporal yield dynamics of grain and leguminous crops as a result of interaction between endogenous and exogenous ecological factors is the main principle for revealling such ecologically homogeneous territories. Spatial distribution of principal components indicates a continual pattern, but their overlapping allows one to extract spatially discrete units, which we identified as agroecological zones. Each zone is characterized by a certain character and dynamics of production capacity and has an invariant pattern of response to varying climatic, environmental, and agroeconomic factors.

Keywords: agroecological factors; yield; grain; leguminous crops; spatial and temporal variability; principal components analysis

Introduction

Crop yield is a result of the interaction between plant genetic traits, soil properties, agro-technology and climatic regimes (Diacono et al., 2012). Ecological conditions such as soil properties are expected to result in spatially varying climate change impacts (Cai et al., 2013). The combined analysis of soil and crop-growth parameters can be effective in delineating areas of different yield potential (Taylor et al., 2003; Fleming et al., 2004; Basso et al., 2011). Interpretation the mutual relations between climate and crop yield provides useful information for enhancing resilience of agricultural production systems to global climate change (Leng & Huang, 2017). Although agricultural technologies continue to improve, previous researches have shown that temperature and precipitation variations have considerable effect on crop yields (Lobell et al., 2007; Almaraz et al., 2008; Schlenker & Roberts, 2009). The impacts of climate change also have many undesirable effects on the global food supply and crop yield (Li, 2015). The average Earth surface temperature is a key indicator of climate change. Solid evidence has shown that the global mean temperature has risen by 0.90 ± 0.05 °C (95% confidence) since the 1950s, and could be rising another 1 to 3 °C by the end of this century (Hansen et al., 2010; Rohde, 2013). The growth rate of atmospheric carbon dioxide (CO_2), the largest human contributor to human-induced climate change, is rising rapidly. In recent years, elements of the global carbon balance have transformed considerably with greatest increases in anthropogenic emissions (Raupach et al., 2007). There is a significant connection between global warming and the levels of greenhouse gas in the atmosphere (Canadell et al., 2007). Since plants require carbon dioxide to grow, if there are higher amounts in the air, plant growth can increase (Cleugh, 2011). Higher levels of carbon dioxide makes carbon more available, but plants also need other nutrients (like nitrogen, phosphorus, etc.) to grow and survive. Without increases in those nutrients as well, the nutritional quality of many plants will decrease (Taub et al., 2008; Li, 2015).

Climate change is expected to increase the mean global temperature, alter patterns of precipitation, and increase frequency and severity of extreme weather (Cai et al., 2014). Although water is necessary for plant growth, excessive precipitation events can dramatically reduce crop production (Rosenzweig et al., 2002). Concentrations of atmospheric

CO_2 and near surface ozone are expected to increase significantly through the next century. Ozone causes cellular damage inside leaves that adversely affects plant production, reduces photosynthetic intensity and requires increased resource transfer to detoxify and repair leaves (Ashmore, 2005). Exposure of plants to ozone inhibits photosynthesis and therefore reduces vegetation production and carbon sequestration (Felzer et al., 2005).

The warming is anticipated to be greater on land than the oceans, both in arid regions and regions towards the poles (Sitch et al., 2007). The rise in sea level due to global warming poses risk from flooding of agricultural land in coastal regions (Li, 2015). Changes in rainfall patterns is less certain, but it is generally predicted that wet areas will become wetter and dry areas will become drier (Dore, 2005; Li, 2015). Extreme weather events are likely to reduce crop yields, which can be partially addressed by using differences between mean daily maximum and minimum temperatures (Porter & Semenov, 2005). Corn yield response to climate change varies with crop spatial distribution pattern, with distinct impacts on the magnitude (Leng & Huang, 2017). Agriculture is intrinsically linked to climate variability and change. Climate change is expected to directly influence crop production. These impacts may vary between locations depending on the level of warming and the associated precipitation changes (Kamran & Asif, 2011). Spatially comprehensive assessments of climate impacts based on yield alone, without accounting for cropping intensity, are prone to systematic overestimation of climate impacts. The findings therefore suggest a need for greater attention to crop suitability and land use change when assessing the impacts of climate change (Challinor et al., 2015). Variation in climate has a great impact on fluctuations in crop yields. In some regions, climate variability was able to explain more than 60% of temporal yield variability in maize, rice, wheat and soybean (Ray et al., 2015).

Different aspects of climate variability (i. e. temperature and precipitation) may have different effects on crop growth and its resultant yields (Urban et al., 2012). Climatic variables such as temperature and precipitation for example are major factors in the spatial differences in yields (Ray et al., 2015). A reduction in yields with higher temperature has been found worldwide (Lobell, 2007; Lobell et al., 2008). In Eastern Europe (including Ukraine) 23–66% of the wheat yield variability was explained by climate variability and normal and extremes of temperature variability were an important factor (Ray et al., 2015). However, in analyzing observed crop yields over time, it was found that negative correlations between yield and temperature were only predominant for maize, while both positive and negative correlations were detected for rice and wheat (Tao et al., 2008). Elevated temperatures had negative impacts on yields of grain and seed producing crops across the different Europeans regions. Although food security in Europe is likely to be less dependent on climate due to technologically sophisticated agricultural practices (Brown & Funk, 2008), climate induced uncertainty (substantial fluctuations) in food production may result from elevated temperatures in the future (Peltonen-Sainio et al., 2010).

Differences in technological investments, as well as differing agricultural management such as crop protection, sowing and fertilizer use can also contribute to the differences in yield (Annicchiarico & Iannucci, 2008; Jensen et al., 2010; Flores et al., 2012). Spatiotemporal patterns are found across landscapes and play a major role in the ecological dynamics of agriculture (Turner, 1990). Spatiotemporal variation can be broken down into its spatial and temporal components (Hammond & Kolasa, 2014). Synchrony and persistence are important components of spatiotemporal variability. When the same crop increases or declines in the same year in each of two places, they are in synchrony. Persistence on the other hand refers to consistent differences in mean yield between two places or other spatial units (Li, 2015).

Spatial patterns are diagnostic when they are used to uncover hidden mechanisms in the landscape, and predictive when they indicate the likely future behaviour of a process (Hammond & Kolasa, 2014). Crop yields, like most ecological variables, exhibit variation in space as well as in time. Annual yield of a particular crop can vary between regions, representing spatial variability (Mueller et al., 2012). Crop yields within a particular region can also differ from year to year, representing temporal variability (Ray et al., 2015). The aim of our research is to reveal the spatial and temporal patterns of grain and leguminous crops yield dynamics in Dnipropetrovsk region and to evaluate the role of agro-environmental and agro-economic factors in their formation.

Materials and methods

Crop data were obtained from the State Statistics Service of Ukraine (www.ukrstat.gov.ua). The data of the grain and grain legumes (pulses) yield during 1966–2016 on average per year in the administrative districts of Dnipropetrovsk region was analysed.

The statistical analysis was performed by Statistica 10 software. Descriptive statistics included means, standard error, coefficient of variation, minimum, maximum, skewness and kurtosis. Data was previously log-transformed in order to approach a normal distribution and to use transformed data in subsequent statistical procedures. How data is suited for principal component analysis was estimated by Kaiser-Meyer-Olkin (KMO) test (Kaiser, 1974). Calculations were performed using library REdaS (Hatzinger et al., 2014) in environment for statistical computing R (R Core Team, 2017). Principal component analysis (PCA) is a statistical method widely used in exploratory data analysis (Pearson, 1901). This non-parametric method compresses the dimension of a dataset and thus can reveal some simplified structures hidden in the dataset (Liu et al., 2012). Principal component analysis was performed using library stats (R Core Team, 2017).

Cronbach & Gleser (1953) first showed that the similarity between the profiles defined by the following three elements: the form, i. e. descents and ascents to the broken line for all variables; scattering, i. e. the variance values of the variable for the object in all the variables relative to their middle; rising (or level shift), i. e. the average value for the object in all the variables. The Pearson correlation coefficient is sensitive only to form of the time series. In order to use the Pearson correlation coefficient as a distance measure for time series it is desirable to generate low distance values for positively correlated (and thus similar) series. The Pearson distance is therefore defined as: $1–r^2$, where r is Pearson correlation coefficient (Berthold & Hoppner, 2016).

A spatial database was created in ArcGIS 10.0. The spatial autocorrelation, I-Moran's statistics (Moran, 1950), was used to calculate the global coefficient. I-Moran's is a measure of autocorrelation similar to the Pearson correlation statistics, and both statistics range from +1.0 meaning strong positive spatial autocorrelation, to 0 meaning a random pattern, to –1.0 indicating strong negative spatial autocorrelation (Iqbal et al., 2005). The global Moran's statistics were calculated using Geoda095i (www.geoda.uiuc.edu) (Anselin et al., 2005).

Results

The obtained data indicate that average yields of cereals and leguminous within Dnipropetrovsk region varies from 24.32 CWT/ha (Sofiivskyi district) to 33.43 CWT/ha (Novomoskovskyi district) (Table 1). The minimum average annual yield was recorded in Vasylkivskyi district (30.88 CWT/ha), and the maximum yield was in Novomoskovskyi district (50.80 CWT/ha). The smallest interannual variability in yield is typical for Vasylkivskyi district (CV = 9.95%), and the largest is typical for Yurivskyi district (CV = 27.69%) (Fig. 1). The coefficient of skewness for most yield measurement distributions is statistically significantly not different from zero. Significant positive skewness indicates a distribution shift mostly toward lesser values and is characteristic of yields data for Petropavlivskyi, Petrykivskyi, Piatykhatskyi and Tomakivskyi districts (Fig. 2).

Kurtosis either is not statistically significantly different from zero or is negative. The negative kurtosis indicates a bimodal distribution. The largest negative kurtosis modulo is characteristic of Nikopolskyi, Pokrovskyi and Synelnykovskyi districts. Positive kurtosis indicates a gravity distribution to modal value. This distribution is characteristic of Piatykhatskyi district.

Analysis of the spatial variability of yield measurements indicates the presence of high-yielding zones of grain and leguminous crops, which combines Novomoskovskyi and Dniprovskyi districts. Also areas with low rates of productivity were revealed in the region. This area is located in the east of the region (Yurivskyi, Pavlohradskyi, Petropavlivskyi and Vasylkivskyi districts) and in the west and center of the region (Verkhnodniprovskyi and Petrykivskyi districts) and in the southwest of the region (Kryvorizkyi, Sofiivskyi and Apostolivskyi districts). Between the areas of maximum and minimum yield, the space was occupied by territories with transition yield rates of grain and leguminous crops. Week spatial dependence was found for spatial distribution of grain and pulses productivity (I-Moran is 0.10, P = 0.13).

Table 1
Descriptive statistics of grain and grain legumes (pulses) yield within Dnipropetrovsk region (period 1966–2016)

District	Mean ± st. error, c/ha	CV, %	Minimum, c/ha	Maximum, c/ha	Skewness ± st. error	Kurtosis ± st. error
Apostolivskyi	25.88 ± 0.44	12.22	19.10	34.10	0.19 ± 0.33	0.45 ± 0.66
Vasylkivskyi	26.17 ± 0.41	11.14	19.01	31.98	–0.20 ± 0.33	–0.18 ± 0.66
Verkhnodniprovskyi	26.54 ± 0.43	11.51	19.10	32.80	–0.15 ± 0.33	–0.03 ± 0.66
Dniprovskyi	32.14 ± 0.60	13.43	23.50	40.10	–0.07 ± 0.33	–0.87 ± 0.66
Kryvorizkyi	26.21 ± 0.66	18.10	17.90	35.60	0.06 ± 0.33	–0.85 ± 0.66
Krynychanskyi	28.65 ± 0.66	16.56	18.60	37.40	–0.26 ± 0.33	–0.17 ± 0.66
Mahdalynivskyi	30.29 ± 0.82	19.25	18.80	42.50	0.10 ± 0.33	–0.54 ± 0.66
Mezhivskyi	28.48 ± 0.69	17.26	16.50	40.26	–0.21 ± 0.33	–0.10 ± 0.66
Nikopolskyi	29.76 ± 0.99	23.69	15.31	42.30	–0.02 ± 0.33	–1.05 ± 0.66
Novomoskovskyi	33.43 ± 0.92	19.68	20.30	50.80	0.30 ± 0.33	–0.12 ± 0.66
Pavlohradskyi	26.08 ± 0.91	24.98	14.30	43.50	0.37 ± 0.33	–0.35 ± 0.66
Petrykivskyi	26.37 ± 0.76	20.55	16.27	40.08	0.47 ± 0.33	–0.12 ± 0.66
Petropavlivskyi	26.48 ± 0.98	26.50	15.40	46.70	0.67 ± 0.33	0.05 ± 0.66
Pokrovskyi	30.21 ± 1.01	23.99	15.50	43.80	0.00 ± 0.33	–0.84 ± 0.66
Piatykhatskyi	27.47 ± 0.89	23.14	15.00	46.50	0.59 ± 0.33	0.88 ± 0.66
Synelnykovskyi	27.70 ± 0.92	23.77	16.90	40.50	0.14 ± 0.33	–0.95 ± 0.66
Solonianskyi	27.46 ± 0.98	25.49	15.65	45.50	0.33 ± 0.33	–0.64 ± 0.66
Sofiivskyi	24.32 ± 0.88	25.88	10.08	37.10	0.09 ± 0.33	–0.57 ± 0.66
Tomakivskyi	27.67 ± 0.90	23.13	18.30	42.80	0.36 ± 0.33	–0.58 ± 0.66
Tsarychanskyi	27.78 ± 0.81	20.76	13.30	40.10	–0.10 ± 0.33	–0.15 ± 0.66
Shyrokivskyi	26.92 ± 0.70	18.53	13.65	37.37	–0.23 ± 0.33	0.28 ± 0.66
Yurivskyi	25.20 ± 0.98	27.69	12.80	42.63	0.28 ± 0.33	–0.74 ± 0.66

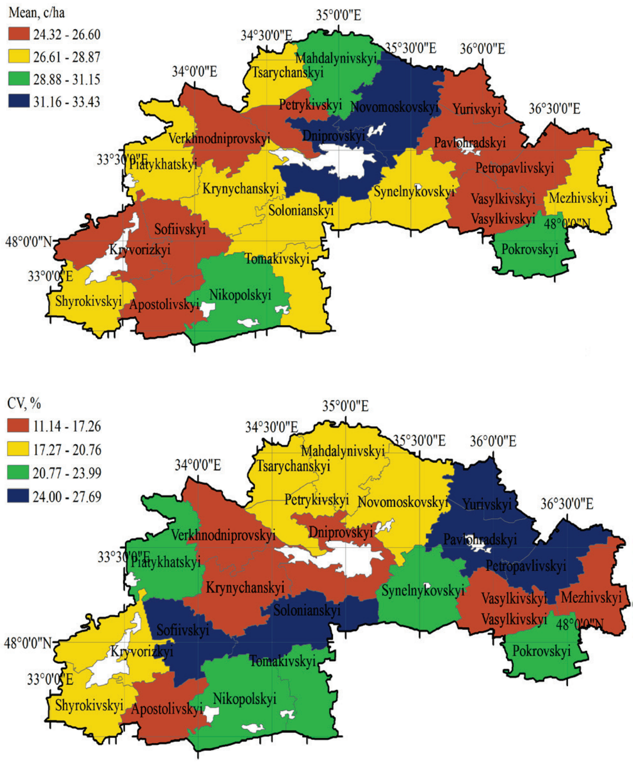

Fig. 1. Spatial pattern in the yield and yield coefficient of variation of grain and pulses within Dnipropetrovsk region (mean for the period 1966-2016)

The time dynamics features of the grain and leguminous crops yield indicate that zones of higher variability are surrounded by the most stable zones. As a result, the coefficient of variation exhibited negative spatial autocorrelation (I-Moran is –0.19, P = 0.17). Negative spatial autocorrelation refers to a geographic distribution of values, or a map pattern, in which the neighbours of locations with large values have small values, the neighbours of locations with intermediate values have intermediate values, and the neighbours of locations with small values have large values (Griffith & Arbia, 2010). In general, the territory of the region is divided into two parts by the horizontal belt of higher variability in time of cereals and leguminous yield. Zones of stable yields in time are specific to the north and the southwest districts.

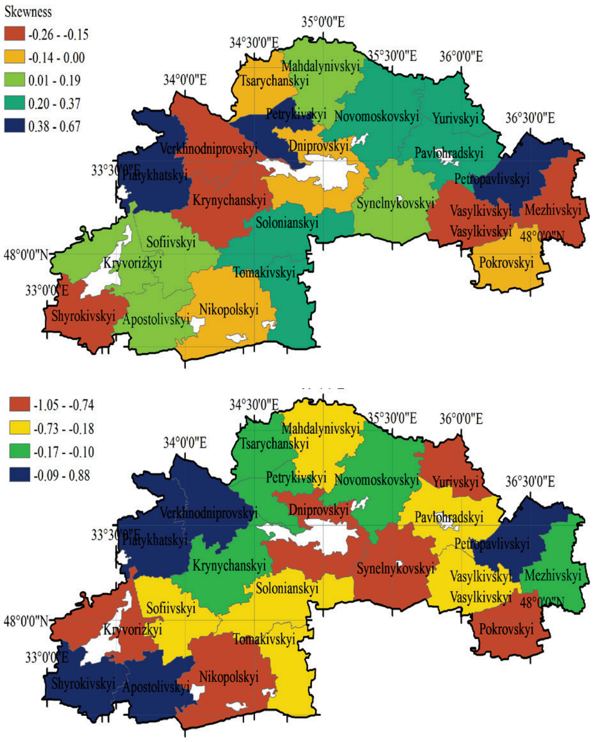

Fig. 2. Spatial pattern of the grain and pulses yield skewness and kurtosis within Dnipropetrovsk region (mean for the period 1966–2016)

The high level of spatial dependence was revealed for asymmetry of the yield distribution (I-Moran is –0.26, P = 0.05). The spatial dependence is the consequence of a negative spatial autocorrelation. It shows that territories with high level of asymmetry are surrounded by areas with a low (negative) asymmetry. In turn, the kurtosis spatial variation does not has spatial component of variation (I-Moran is 0.03, P = 0.27).

Thus, from the considered descriptive statistics of grain and leguminous crops yield variation in time the asymmetry of distribution has the highest level of spatial dependence. Asymmetry distribution is the result of regular directed factors intended to measure the investigated factors. A statistically significant negative asymmetry is established only for the yield distribution of Vasylkivskyi district. The shift of the distribution in a positive direction may be due to the presence of a certain number of years, when the crop yields studied was significantly (catastrophically) lower. A significant positive asymmetry is the consequence of limiting factors that prevented the achievement of large yields of grain and leguminous crops.

The Kaiser-Meyer-Olkin (KMO) criterion of adequacy for individual items is equal to 0.88, which according to a rule of thumb for those values is meritorious. The obtained result reveals that yield data may be properly processed by principal component analysis.

As a result of the principal component analysis of the yield variability of cereals and leguminous crops three principal components were extracted which together explain 81.16% of the overall yields' variability (Table 2). Principal component 1 explains 69.42% of the total variability. It indicates the total synchronous yield's variation within the area investigated as all examined variables have high loading values on principal component 1. The administrative districts that form a belt located in the direction from the north east to the south west of the region, have a most coordinated the variance, which is reflected by principal component 1

(Fig. 3). But Moran's index points to the lack of the spatial components of variation in this measure (I-Moran 0.006, P = 0.37). Obviously, the spatial variation of principal components 1 loadings consists of two parts: the area of naturally high values of loadings and zones with random changes in the space of these loads (Fig. 3). Variation in time of principal components 1 scores has a moderate linear trend (Fig. 4). The time dynamics of principal components 1 scores is a mixture of oscillatory processes with periods 3.0, 3.8, 4.5, 12.5 and 16.6 years whose relative strengths are most important for explaining the variation in the time series.

Principal component 2 explains 6.79% of the yield variability. This principal component is sensitive to yield opposite dynamics of central and south-western districts on the one hand and the eastern and northern districts – on the other (Fig. 3). This component has a high level of spatial variability (I-Moran 0.52, P = 0.001). Variation in time of principal components 2 has a very large period of oscillation, which is marked as a global trend, which can be described by polynomial function (Fig. 4). Other oscillation components have periods of 2.3, 3.8, 7.1, 16.0 and 25.0 years whose relative strengths are most important for explaining the variation in the time series.

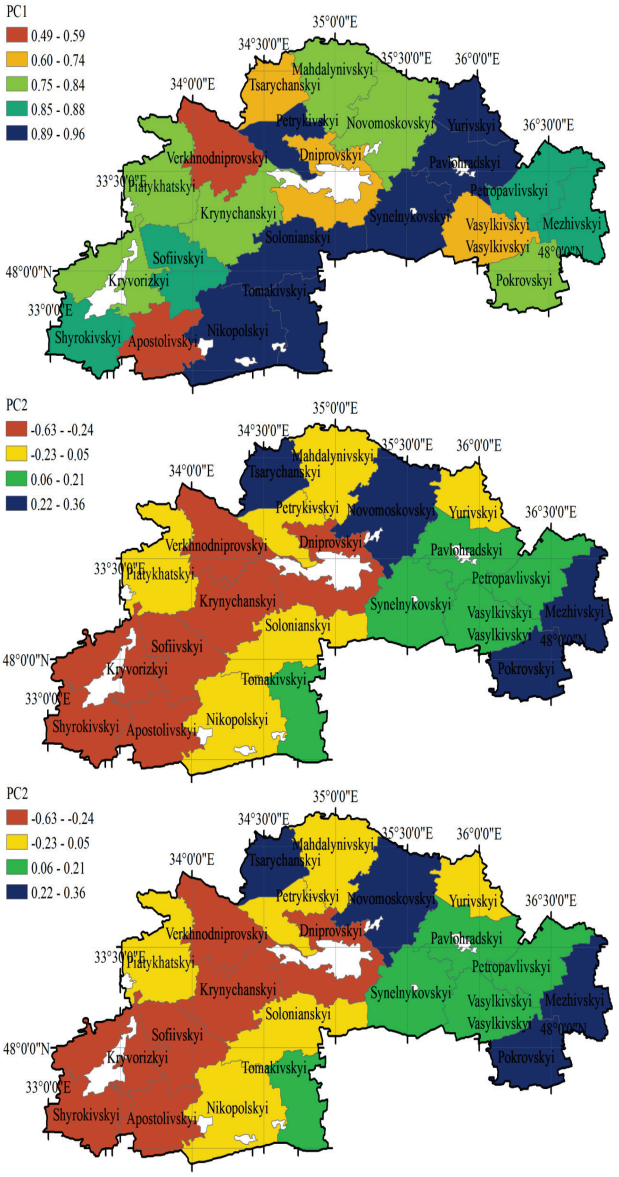

Fig. 3. Spatial variation of principal components 1–3

Principal component 3 explains 4.95% of the yield variability. This principal component reveals the opposite dynamics of productivity of the central districts on the one hand and the northern and south-eastern districts on the other (Fig. 3). Principal component 3 has not a high level of spatial variability (I-Moran 0.08, P = 0.17). Variation in time of principal components 3 has a very large period of oscillation, which is marked as a global trend, which can be described by polynomial function (Fig. 4). Other oscillation components have periods of 3.5, 4.5 and 16.6 years whose relative strengths are most important for explaining the variation in the time series.

Table 2

Principal component analysis of the yield of grain and pulses data within Dnipropetrovsk region

District	PC1	PC2	PC3
Apostolivskyi	0.56	–0.70	–
Vasylkivskyi	0.73	–	0.29
Verkhnodniprovskyi	0.50	–	0.51
Dniprovskyi	0.67	–	0.48
Kryvorizkyi	0.80	–0.48	–
Krynychanskyi	0.77	–	0.36
Mahdalynivskyi	0.78	–	–0.28
Mezhivskyi	0.85	–	–
Nikopolskyi	0.92	–	–
Novomoskovskyi	0.83	–	–
Pavlohradskyi	0.93	–	–
Petrykivskyi	0.93	–	–
Petropavlivskyi	0.89	–	–
Pokrovskyi	0.84	–	–
Piatykhatskyi	0.85	–	–
Synelnykovskyi	0.96	–	–
Solonianskyi	0.93	–	–
Sofiivskyi	0.88	–	–
Tomakivskyi	0.95	–	–
Tsarychanskyi	0.68	0.28	–
Shyrokivskyi	0.84	–0.33	–
Yurivskyi	0.96	–	–
Eigenvalue	15.27	1.49	1.09
% Total	69.42	6.79	4.95
Cumulative eigenvalue	15.27	16.77	17.85

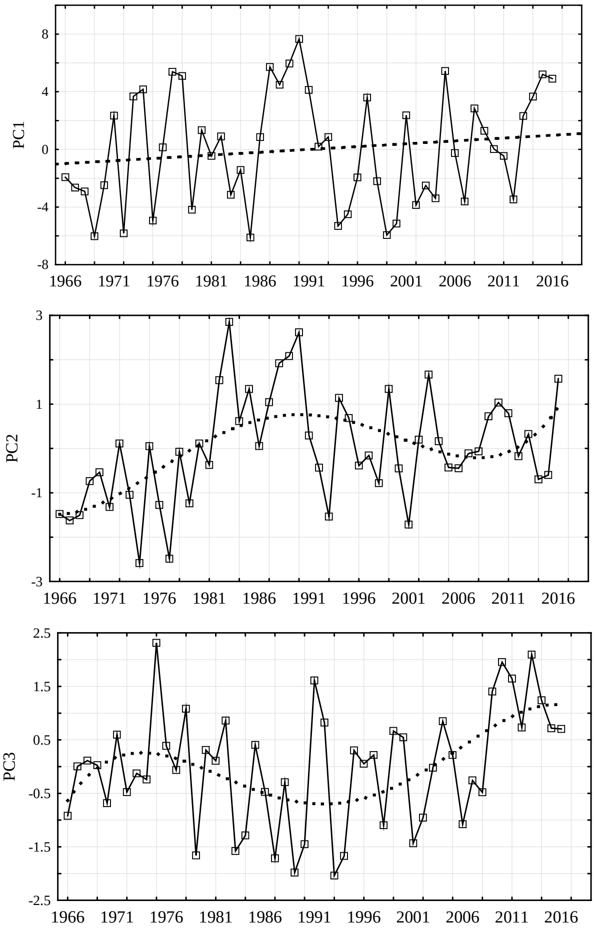

Fig. 4. Temporal variation of principal components 1–3 (dotted line is a linear trend for PC1 or a polynomial trend for PC2 and PC3)

The cluster analysis of administrative districts was conducted based on the dynamics of the yield of grain and leguminous crops as a result of which four clusters were identified (Fig. 5). The spatial distribution of clusters reveals that cluster 1 covers the south-western districts, cluster 2 covers the northern districts, cluster 4 is located in the southwest of the previous cluster, cluster 3 covers the rest of the territory of the region. Thus, the clusters are geographically defined administrative districts, together forming spatially connected areas. The similar temporal yield dynamics of grain and leguminous crops as a result of interaction between endogenous and exogenous ecological factors is the main principle for revealing such ecologically homogeneous territories.

ANOVA shows that the main aspect of the clusters differentiation is not the total level of productivity and the performance of synchronous dynamics of different spatial areas (Table 3). So, among the descriptive statistics statistically significant differences among clusters are observed only in terms of yield variation in time. The mean value, skewness and kurtosis are not different between clusters. In turn, clusters are clearly differentiated by principal components. I. e., the clusters form spatial structures within which occur natural patterns of the yield of cereal and leguminous crops time dynamics.

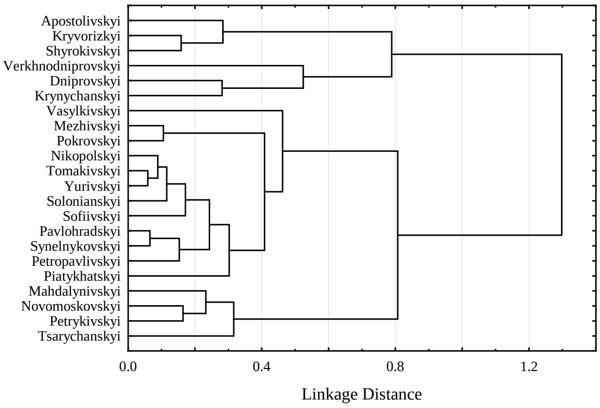

Fig. 5. Cluster analysis of the administrative districts of Dnipropetrovsk region according to yield of grain and pulses data (1966–2016): dotted line indicates cluster decision

Fig. 6. Clusters extracted from the yield of grain and pulses data within Dnipropetrovsk region (for the period 1966–2016)

Table 3
ANOVA assessment of cluster effect on yield of grain and pulses data descriptive statistic and principal components

Variable	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	*F*-ratio	*p*-level
Mean	26.27	3	8.76	78.28	18	4.35	2.01	0.15
CV	265.10	3	88.37	267.70	18	14.87	5.94	0.01
Skewness	0.37	3	0.12	1.18	18	0.07	1.89	0.17
Kurtosis	0.39	3	0.13	4.66	18	0.26	0.51	0.68
PC1	0.15	3	0.05	0.17	18	0.01	5.35	0.01
PC2	1.05	3	0.35	0.44	18	0.02	14.24	0.00
PC3	0.75	3	0.25	0.33	18	0.02	13.46	0.00

Notes: SS Effect – sums of squares based on the overall mean, MS Effect – variance due to the between-groups variability (Mean Square Effect), SS Error – within-group variability, MS Error – within-group variability (Mean Square Error), df – degrees of freedom.

Discussion

The indicators of productivity of agroecosystems are those most considered when studying dynamics of agricultural crop yields (Zhukov & Ponomarenko, 2017). Within our research we placed the emphasis on the evaluation of the correlative relationship between time series of the grain and grain legumes (pulses) yield within the administrative districts of Dnipropetrovsk region (period 1966–2016). The obtained results indicate that productivity as a result of functioning of agroecosystems has a complex nature and is affected by the influence of different factors. The impact of these factors can be identified through research on synchronous dynamics characteristics. The synchronous dynamics expresses itself through the forming of the correlation relationship. The correlation matrix is the basis for the principal component analysis and cluster analysis. Principal component analysis allows us to discover the main variability trends of agricultural crops' productivity. Cluster analysis led to the establishment of uniform ecological area.

Crop production per unit area (yield) is a fundamental parameter in agricultural and environmental research (Iizumi et al., 2014). The global demand for agricultural crops is expected to roughly double by 2050, driven by increases in population, meat and dairy consumption and biofuel use (Godfray et al., 2010; Tilman et al., 2011). However, between 1985 and 2005, the total global crop production increased by only 28% (through a ~2.5% net expansion of global cropland area, an ~7% increase in the frequency of harvesting, and an average ~20% increase in crop yields per hectare) (Foley et al., 2011). Yields for three key crops (maize, rice and wheat) which together produce ~57% of the world's agricultural calories may be stagnating or declining in some regions of the world (Tilman et al., 2011). Global yield trends were broadly divided into four types (Ray et al., 2012). The dynamic of the yield of grain and pulses in Dnipropetrovsk region over the course of the 1966–2016 years may be considered as occupying an intermediate position between types 'yields never improved' and 'yields still increasing'. This trend is reflected in the variation over time of principal component 1, which explains a significant part of the productivity dynamics in time (69.42%). It should be noted that a combination of linear trend and high frequency oscillatory processes is specific to principal component 1. This trend is global for the whole territory of the region. Spatial features characterise the intensity of the manifestation of this trend. Other less significant trends of the variability in yield have a local character with clearly defined spatial patterns. The principal components 2 and 3 describe these trends, which have an oscillating nature that combines high-frequency and low-frequency processes.

We associate with causes of a different nature with oscillatory processes of varying frequency. The linear trend increase in yields can be explained as the result of improving technology and causes of agroeconomic origin. The linear trend can be seen as an oscillatory process with a period that is approaching infinity. This position is confirmed by the fact that the countries that are in permanent or temporal socio-economic crisis belong to the category "productivity never increases" (Ray et al., 2012). The slow level of overall increase in yield of grain and legumes in Dnipropetrovsk region is also associated with the crisis of the Soviet Union and the formation of the new production relations in agriculture. The overall slow trend is caused by the presence of a crisis at the beginning of the 1990s, after which the recovery in efficiency of agriculture is proceeding quite slowly.

The oscillatory process with several years frequency (7, 16, 25 – larger periods are hypothetical due to relatively limited time series) may be a climatic origin. This assumption is confirmed by the spatial patterns of the principal components 2 and 3. The spatial variability of the principal components 2 can be associated with continental gradient, indicating a gradual change in environmental regimes in the latitudinal direction. The axis of symmetry of the spatial pattern of the principal components 3 is Dnipro river – at a distance from the river on both sides there are similar changes in time of the yield rhythm.

High frequency yield components may have the character of noise and may have environmental origins as a consequence of such phenomena as the impact of diseases and pests, or the impact of weather anomalies. Changes in the abundance of pests depends on the characteristics of landscape diversity (Zhukov et al., 2015; Kunah, & Papka, 2016a). Analysis of the yield of grain and leguminous crops in Poltava region showed that the trend of the temporal dynamics is associated with the effect of systematic factors of an agroeconomic and agrotechnological nature (Zhukov et al., 2017). The cyclical component is identified as having a predominantly agro-ecological origin (Kunah, & Papka, 2016b; Zhukov & Ponomarenko, 2017).

We did the agroecological zoning on the principle of uniformity of character dynamics of the production potential of agricultural areas. This approach is fundamentally different from that of zoning based on the total yield of crops (Lazarenko, 1995). Classification on the basis of yield is justified for systems that are in a state close to the steady state. In terms of global climate change and transformation of the environmental regimes, this approach is unacceptable. The agroecological zones proposed by us do not differ in the overall level of productivity of grain and leguminous crops during the study period. Features of these zones lie in the values of principal components, and reflect the nature of relationships between different spatial units. Spatial distribution of principal components indicates a continual pattern, but their overlapping allows us to extract spatially discrete units, which we identified as agroecological zones. Each zone is characterized by a certain character and dynamics of production capacity and has an invariant pattern of response to varying climatic, environmental, and agroeconomic factors.

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