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ECOLOGICAL DETERMINANTS OF THE STRUCTURE OF SOWN AREAS IN POLISSYA AND FOREST-STEPPE OF UKRAINE

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The article discusses the environmental, climatic and soil factors that determine the structure of sown areas in Polissya and Forest-Steppe of Ukraine. The study focuses on the impact of natural and climatic conditions on the choice of crops and the spatial organisation of agricultural production. The main attention is paid to the specifics of climatic conditions: average annual temperature, precipitation regime and duration of the growing season. Polissia is characterised by a predominance of acidic, low-fertility soils that require reclamation, as well as a moderately humid climate with cool summers. This favours the cultivation of crops such as rye, oats, potatoes and flax. The Forest-Steppe region is dominated by chernozem and grey forest soils, which provide high yields of grain (wheat, barley, corn), industrial crops (sunflower, sugar beet) and fodder grasses. The moderately continental climate with sufficient heat and precipitation creates favourable conditions for a wide range of crops. The study was conducted using discriminant analysis, which allowed us to interpret seven clusters of regions with a similar structure of sown areas. These clusters reflect the spatial organisation of agro-ecological zones and the change in dominant crops depending on moisture gradients, heat balance and soil characteristics. The analysis confirmed that the choice of crops is determined by adaptation to local conditions: heat-loving crops dominate in the Forest-Steppe, while in Polissya crops resistant to acidic soils and excessive moisture predominate. The results of the study are of practical importance for planning a rational structure of sown areas, optimising land use and increasing agricultural productivity in the context of climate change.

Key words: *climatic conditions, spatial patterns, moisture coefficient, landscape, precipitation, temperature regime.*

Никитюк Ю.А., Кравченко О.І. Екологічні детермінанти структури посівних площ у Поліссі та Лісостепу України

У статті розглядаються екологічні, кліматичні та ґрунтові фактори, що визначають структуру посівних площ у Поліссі та Лісостепу України. Дослідження зосереджено на впливі природно-кліматичних умов на вибір сільськогосподарських культур і просторову організацію аграрного виробництва. Основну увагу приділено специфіці кліматичних *умов: середньорічній температурі, режиму опадів та тривалості вегетаційного періоду. Полісся характеризується переважанням кислих, малородючих ґрунтів, що потребують меліорації, а також помірно вологим кліматом із прохолодним літом. Це сприяє вирощуванню таких культур, як жито, овес, картопля та льон. У Лісостепу переважають чорноземи та сірі лісові ґрунти, які забезпечують високу врожайність зернових (пшениця, ячмінь, кукурудза), технічних культур (соняшник, цукровий буряк) і кормових трав. Помірно континентальний клімат з достатньою кількістю тепла й опадів створює сприятливі умови для широкого спектра культур. Дослідження проведено з використанням дискримінантного аналізу, який дозволив інтерпретувати сім кластерів регіонів із подібною структурою посівних площ. Ці кластери відображають просторову організацію агроекологічних зон і зміну домінуючих культур залежно від градієнтів зволоження, теплового балансу та ґрунтових характеристик. Аналіз підтвердив, що вибір культур визначається адаптацією до місцевих умов: теплолюбні культури домінують у Лісостепу, тоді як у Поліссі переважають культури, стійкі до кислих ґрунтів і надмірного зволоження. Результати дослідження мають практичне значення для планування раціональної структури посівних площ, оптимізації землекористування та підвищення продуктивності сільського господарства в умовах зміни клімату.*

Ключові слова: *кліматичні умови, просторові патерни, коефіцієнт зволоження, ландшафт, опади, температурний режим.*

Problem definition. The environmental determinants of the structure of sown areas in Polissya and the Forest-Steppe of Ukraine are a complex problem that includes the influence of climatic, soil and socio-economic factors on the choice and specialisation of crops. In today's climate change, soil degradation and growing demand for environmentally friendly products, there is a need for in-depth analysis and consideration of natural constraints and the potential of agricultural areas for sustainable land use. In particular, the Polissia region is characterised by acidic, low-fertility soils and a moderately humid climate, which favours the cultivation of crops with low heat requirements. In contrast, the Forest-Steppe of Ukraine has chernozems and grey forest soils with high agricultural potential, which provide favourable conditions for heat-loving crops. At the same time, factors such as soil acidity, lack of organic and mineral fertilisers, the need for reclamation measures and fluctuations in moisture supply make it difficult to create an optimal structure of sown areas. Uncertainty in the distribution of climatic resources and an increase in the frequency of extreme weather events, such as droughts or excessive rainfall, limit the possibilities for using land resources. The lack of a systematic approach to managing sown areas in different agro-ecological zones can lead to inefficient land use, reduced yields and environmental risks. Therefore, the study of the environmental determinants of the structure of sown areas in these regions of Ukraine is relevant for ensuring sustainable development of the agricultural sector, increasing its productivity and preserving ecosystem services.

Analysis of recent research and publications. Natural, economic and social factors influence the specialisation of the region and the choice of crops and determine the structure of crops in Polissya and Forest-Steppe. In the region, 51.6% of crops are grown by households, which supply the market with products that are part of the consumer basket of ordinary citizens: root and tuberous vegetables, vegetables and melons. Enterprises that grow industrial, cereals and legumes are focused on exporting their products [1]. Climate is the leading factor that determines the range of crops grown in a particular region [2]. The climate conditions, in particular a temperate continental climate with cool summers and sufficient rainfall, favour the cultivation of crops requiring moderate temperatures and high humidity, such as potatoes, oats and flax [3]. Risk of frost limits the possibility of growing heat-loving crops such as corn [4]. The soil conditions of Polissya, represented mainly by sod-podzolic, peaty and sandy soils, which are poor in nutrients and have high acidity, influence the choice of crops resistant to these conditions [5]. Acidic soils are difficult to farm effectively without corrective measures. Increased annual precipitation, especially with rising temperatures, increases the acidification of unreclaimed soils. Acidic soils are soils in which, among other problems that determine the efficiency of their use for agricultural purposes, acidity prevails [6]. Sod-podzolic soils of light particle size distribution, characterised by an acidic reaction of the soil environment, a deficit of nutrients and organic matter, and low buffering capacity, are widespread in the Polissya region of Ukraine. They were formed in rather humid climatic conditions, mainly on sandy and sandy loam soils. In recent years, due to the dominance of short crop rotations (winter wheat, corn, rapeseed), a decrease in organic fertilisers and a lack of mineral fertilisers and calcium-containing ameliorants, the agro-ecological condition of sod-podzolic soils has deteriorated significantly. Acidification, leaching of absorbed bases and deterioration of buffer properties lead to rapid degradation of these soils. This is further exacerbated by climate change, with sharp temperature fluctuations and contrasting precipitation patterns, with long dry spells followed by continuous downpours [7]. The danger is that degradation processes in sod-podzolic soils develop very quickly due to their weak buffer, and traditional improvement measures (liming) are not able to effectively counteract degradation [8]. Significant waterlogging and flooding also make it difficult to cultivate many lands [9], therefore, in Polissya, preference is given to crops resistant to waterlogging [10]. The region's traditional specialisation in flax, potatoes and fodder grasses is based on historical, climatic and economic conditions. Socio-economic factors, such as the level of infrastructure development, demand for products, and government policy on subsidies and support for agriculture, also play an important role in shaping the crop mix. Environmental considerations, such as the need to preserve natural ecosystems and limit the ploughing of new land, encourage environmentally friendly farming. At the same time, climate change, such as warming and changing precipitation patterns, is gradually affecting the ability to grow heat-loving crops such as soybeans and corn. The structure of agricultural crops in Polissia is the result of the complex influence of natural and socio-economic factors that determine the specialisation of the region [11].

The climatic factors that determine the structure of sown areas in the Forest-Steppe are key to the formation of the region's specialisation in agriculture [12]. The Forest-Steppe zone is dominated by a moderately continental climate with sufficient heat and precipitation, which creates favourable conditions for growing a wide range of crops [13]. Precipitation patterns affect the spread of crops [14]. In the more humid areas of the Forest-Steppe, spring and winter crops and fodder grasses are grown [15, 16], and in drier areas, drought-tolerant crops such as sunflower and maize are favoured [17]. Periodic droughts, especially in the second half of summer, necessitate the use of moisture conservation technologies, such as minimal tillage [18]. Climate change, in particular warming, longer frost-free periods and changes in precipitation patterns, also affect the structure of sown areas in the Forest Steppe [19]. In recent years, the role of heat-loving crops, such as soybeans and corn, has been increasing, as they adapt to higher temperatures [21]. Climatic factors such as temperature, precipitation, length of the growing season and moisture regime are crucial for the structure of sown areas, determining the choice of crops and agricultural technologies that ensure maximum productivity in these conditions [20].

Task definition. The agro-ecological zoning of Polissya and Forest-Steppe is based on conditions and regimes that have been established over a significant period of time, but which do not reflect the current dynamics of climatic conditions and do not fully take into account the success of breeding when typical crop ranges are changing significantly. The structure of sown areas is a dynamic indicator that depends on both environmental factors and the state and level of agricultural technology. The undoubted advantage of this indicator is its relevance. Therefore, we aimed to test the hypothesis that the structure of sown areas is a sensitive indicator of agro-environmental conditions. As a criterion for testing this hypothesis, we consider the possibility of explaining the structure of sown areas with the help of agro-ecological indicators.

Methods of research. The important characteristics of climatic conditions for assessing their impact on the environment and agricultural production are indicators of the bioclimatic potential of the territory, such as the value of the solar radiation balance (R, MJ/m^2 year^{-1}), climate energy consumption for soil formation (Q, MJ/m^2 year^{-1}), total precipitation per year (mm/year), potential evaporation (mm/year), moisture coefficient (K_h) [21]. An empirical formula was used to calculate the solar radiation balance:

$R = a * T + b$,

where *R is the* value of the solar radiation balance (MJ/m^2 year^{-1}), *T* is the average annual temperature, °C, *a is* 133, *b* is 736.

The total value of climatic energy consumption for soil formation (Q) is determined by the annual radiation balance of the active surface and the amount of precipitation. After adjusting Volobuev's formula to reflect the need to use radiation balance values in the international system of accounting, the values of climate energy consumption for soil formation were calculated using the following formula:

$$Q = R * \exp\left(-1.23 * \frac{R^{0.73}}{P}\right),$$

where Q is the climatic energy consumption for soil formation (MJ/m^2 year^{-1}), *R is the* solar radiation balance (MJ/m^2 year^{-1}), and *P* is the total annual precipitation (mm/year).

The Vysotsky-Ivanov wetting coefficient is an important indicator used to assess the relationship between precipitation and evapotranspiration in a particular region, particularly in agroclimatic studies. The formula for its calculation is as follows:

$$K_h = \frac{P}{E},$$

where $_{Kh}$ is the humidification coefficient, *P* is the amount of precipitation per year (mm), and *E* is the potential evaporation for the same period (in mm). Excessive moisture zones ($_{Kh}$ > 1.3) are characterised by a significant excess of precipitation over evaporation. These zones are typified by highly humid forest areas. In such conditions, swampy soils are often formed, which are saturated with moisture for most of the year. Adequate moisture zones ($_{Kh}$ = 1.0-1.3) include temperate zones with a balance between precipitation and evaporation. These include mixed and deciduous forests. Moisture conditions are favourable for agriculture without the need for artificial irrigation. Areas of insufficient moisture ($_{Kh}$ = 0.6-1.0) are typical of the forest-steppe, where precipitation is no longer sufficient to fully meet the water balance. These zones are characterised by moderate aridity and require additional irrigation to grow heat-loving crops. Arid climate zones ($_{Kh}$ = 0.3-0.6) include steppes and semi-deserts. Precipitation in these areas is much lower than evaporation, leading to droughts and the need for intensive artificial irrigation to support agricultural activities.

Evapotranspiration was calculated by N. M. Ivanov:

$$E = 0.0018*(t + 25)^2*(100 - R),$$

where E is the evapotranspiration per year, mm, t is the average temperature for the period (°C/year), and R is the average relative humidity (%).

The average relative humidity was calculated based on monthly data on temperature and partial pressure of water vapour. The saturated vapour pressure over water is the vapour pressure of air at which the number of water molecules that condense is equal to the number of molecules that evaporate from a flat surface of water together with air and water at a certain temperature (T). The equation for the pressure of saturated vapour (P_s) above water at a temperature (T) is as follows:

$$P_s = 0.6108 * exp\left[\frac{17.27T}{T + 237.3}\right],$$

where P_s is the pressure of saturated vapour above water (KPa), T *is the* air temperature, °C.

The average mean relative humidity was calculated based on the observed data on water vapour pressure in the atmosphere and the saturated vapour pressure calculated based on the atmospheric temperature:

$$R = 100\% * \frac{P_e}{P_s},$$

where R is the average relative humidity (%), P_e is the observed water vapour pressure in the atmosphere (KPa), P_s is the saturated vapour pressure above water (KPa). Data on precipitation, temperature and water vapour pressure were obtained from https://www.worldclim.org/ [22].

Presentation of the main research findings. The analysis of the structure of sown areas in administrative districts allowed to identify seven relatively homogeneous clusters (Fig. 1). The structure of sown areas is specific to each cluster (Fig. 2). The discriminant analysis shows that the largest contribution to the differentiation of rayons by the structure of sown areas is made by the opposite dynamics of areas under sunflower on the one hand and areas under rye, potatoes, oats, corn and barley on the other (Table 1).

Along this differential gradient, the clusters are naturally located both in the space of discriminant functions (Fig. 1) and in the geographical space (Fig. 3). The highest values of discriminant function 1 correspond to cluster 5, which geographically covers the east and south of the region and is most typical of forest-steppe landscapes. Clusters 2 and 6 correspond to the transition zone between the Forest-Steppe and Polissya. However, it should be noted that according to the agro-ecological zoning, cluster 2 extends to the territory of left-bank Polissia. Cluster 3 is partially located in the left-bank Polissia, but its significant part covers the territory of central Polissia.

Cluster 6 is largely located in the Forest-Steppe on the North-Western Podillia Upland, but the right flank of the cluster is extended along the Forest-Steppe and Polissia to the east, serving as a transition zone on the right bank of the Dnipro. Cluster 4 covers the western Forest-Steppe, but continues northwards as a transition zone between western and central Polissya. Cluster 1 corresponds to western Polissya, and cluster 7 corresponds to the Precarpathian Upland. Discriminant function 2 contrasts cluster 1 and cluster 7. This discriminant function indicates the peculiarities of the cropping pattern of western Polissia compared to that of the Precarpathian Upland. The share of corn, peas, rye, and buckwheat was higher in the Precarpathian Upland, but the share of wheat, rapeseed, silage corn, and flax was higher in the agricultural lands of western Polissia. Discriminant function 3 distinguishes cluster 3 from clusters 1 and 7. The peculiarity of cluster 3 is the larger share of flax, beetroot, and corn, but the smaller share of such

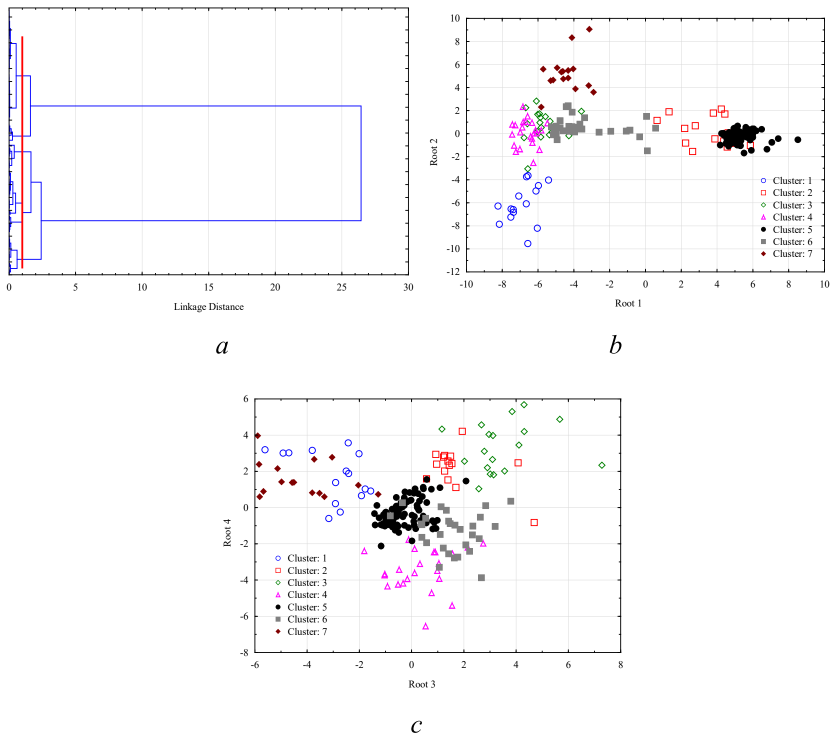

Fig. 1. Cluster analysis of the structure of sown areas with a factor solution consisting of seven clusters, shown by the red line (a), and the location of administrative districts in the space of discriminant functions 1 and 2 (b) and 3 and 4 (c)

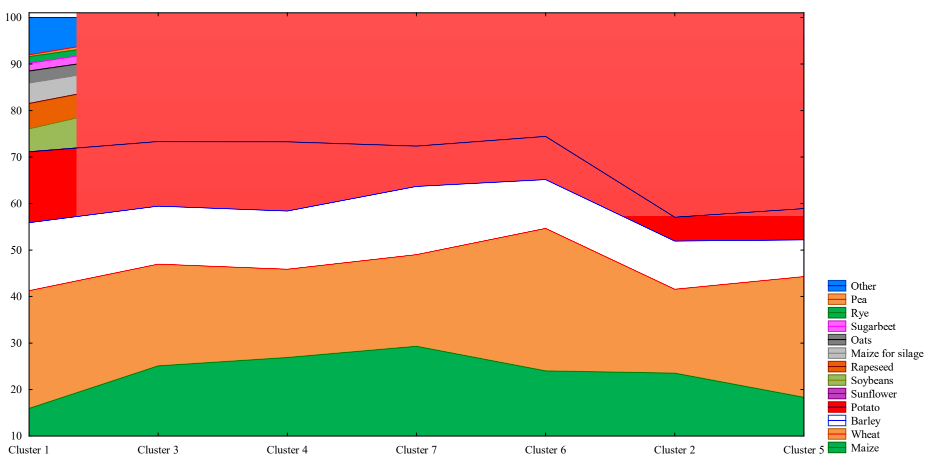

Fig. 2. Structure of sown areas in the main clusters of the region

crops as peas, potatoes, rape, and buckwheat. Feature 4 distinguishes cluster 3 from cluster 4. Cluster 4 is characterised by a predominant share of beans, cabbage, carrots, onions, potatoes, rapeseed, soybeans, but a smaller share of rye, oats, silage corn, flax, table beet and barley.

Table 1

Correlation of discriminant functions with indicators of crop area and environmental variables

Variable	Root 1	Root 2	Root 3	Root 4
Crop				
Barley	–0.37	–	–	0.38
Bean	–	–	–	–0.38
Cabbage	–	–	–	–0.12
Carrot	–	–	–	–0.12
Beetfor	–	–	0.21	0.13
Linseed	–	–0.24	0.60	0.17
Maize	–0.15	0.36	0.25	–
Maize for silage	–0.25	–0.13	–	0.28
Millet	–	–	–	–
Oats	–0.39	–	–	0.28
Onion	–	–	–	–0.13
Pea	–	0.40	–0.21	–
Potato	–0.38	–	–0.62	–0.18
Rapeseed	–	–0.13	–0.12	–0.19
Rye	–0.30	0.02	–	0.26
Soybeans	–	–	–	–0.63
Sugarbeet	–	–	–	–
Sunflower	0.84	–	–	–
Tomato	–	–	–	–
Wheat	–	–0.15	–	–0.27
Buckwheat	–	0.21	–0.23	–
Environmental variable				
Annual evaporation	0.55	–0.21	–	–0.29
K_h	–0.56	0.45	–0.16	0.22
Annual precopatation	–0.36	0.51	–0.28	–
Solar net balance	0.51	0.26	–	–
Energy consumption for soil formation	0.30	0.46	–0.16	–

Gradients in the structure of sown areas correlate with environmental factors. Discriminant function 1 was positively correlated with soil formation energy, annual moisture evaporation and solar radiation balance, but negatively correlated with moisture coefficient and annual precipitation. Discriminant function 2 was positively correlated with the moisture coefficient, annual precipitation, solar radiation balance and soil formation energy. The discriminant function was negatively correlated with soil formation energy, moisture coefficient and annual precipitation. The discriminant function 4 was positively correlated with the moisture coefficient and negatively correlated with annual evapotranspiration.

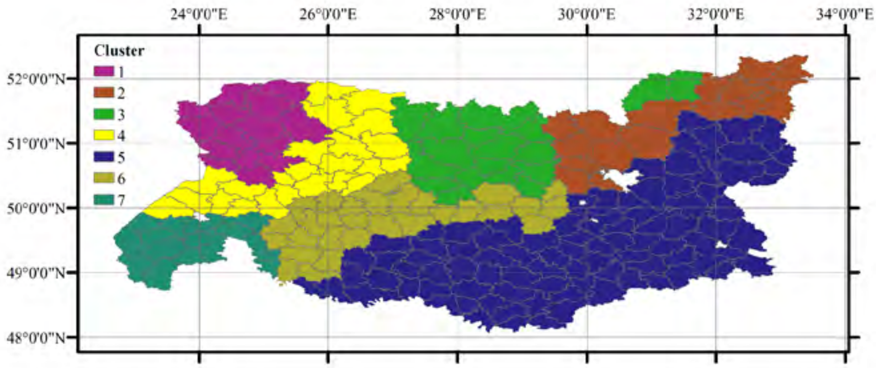

Fig. 3. Spatial distribution of clusters that are homogeneous in terms of the structure of sown areas

Discussion. Discriminant analysis plays an important role in agricultural science and the study of the structure of sown areas, providing the ability to analyse multidimensional data and classify objects according to specified criteria. This method allows us to identify the factors that influence the distribution of sown areas of different crops and determine their relationship with climatic, soil, socio-economic and technological conditions [23]. The application of discriminant analysis has made it possible to compare regions by crop structure, identify areas with the most favourable conditions for growing certain crops, and predict changes in agricultural production depending on external influences. In addition, discriminant analysis is used to evaluate the effectiveness of various agricultural technologies, study the dynamics of changes in sown areas under the influence of climate change or economic factors, and plan the optimal structure of crop rotations. It allows analysing large volumes of data arising in the process of monitoring agricultural production and helps to make informed management decisions. The application of discriminant analysis allowed us to interpret clusters that spatially largely coincide with traditional agro-ecological zoning categories [24]. Differences in the areas of the identified clusters and agroecological zones can be explained by the impact of global climate change on the structure of sown areas. It is reflected in a shift to the north of the traditional boundaries of physical and geographical zones. In addition, there is a restructuring between agro-ecological zones in the meridional aspect due to changes in continental regimes.

The forest-steppe is a homogeneous zone in terms of the structure of sown areas. The average annual air temperature in the Forest-Steppe ranges from +7°C to +9°C, and the sum of active temperatures above +10°C is 2500-2900°C, which allows growing cereals (wheat, barley, corn), industrial crops (sunflower, sugar beet) and legumes. A warm growing season lasting 190-210 days favours the growth of both early and late crops. The amount of precipitation in the Forest-Steppe region is 500-600 mm per year, of which 70% falls during the warm season. This provides sufficient moisture for the main crops, but in some years there is a deficit of soil moisture, especially in the southern part of the zone, which limits the productivity of crops with high moisture requirements. The Forest-Steppe is a homogeneous zone in terms of the structure of sown areas due to favourable natural and climatic conditions that create opportunities for growing a wide range of crops. This zone is characterised by fertile soils, mainly black earth and grey forest soils, a temperate climate with sufficient rainfall and optimal heat levels, which ensures high yields. The homogeneous structure of the sown areas in the Forest-Steppe is due to the versatility of its agro-ecological conditions, which are suitable for growing grain crops such as wheat, corn, barley and rye, as well as industrial crops, including sunflower, sugar beet and soybeans. In addition, a significant portion of the area is devoted to fodder crops, which supports the livestock industry. The homogeneity of this zone is also reinforced by the intensive use of modern agricultural technologies, which help to increase productivity and ensure the rational use of land resources. At the same time, although the Forest-Steppe is generally homogeneous, there are regional differences in the structure of sown areas depending on local soil conditions, water availability and the level of economic development of the territory. Thus, the Forest-Steppe zone is one of the key regions of Ukraine for agricultural production due to its homogeneous structure of sown areas and high agro-ecological potential.

The climatic factors that determine the structure of sown areas in Polissya play a crucial role in shaping the region's agricultural specialisation. Polissya is characterised by a moderately continental climate with cool summers and sufficiently humid conditions, which leads to the prevalence of certain crops. The average annual air temperature in the Polissya region is +6°C...+8°C, and the sum of active temperatures above +10°C is in the range of 2000-2400°C. This temperature regime makes it possible to grow crops with moderate heat requirements, including cereals (rye, oats), potatoes, flax, fodder crops, and some vegetables. Precipitation in Polissya varies from 550 to 700 mm per year, with the bulk of it falling in the warm season (May-August). This factor provides optimal conditions for growing crops with high moisture requirements, such as potatoes and flax. However, excessive moisture in some years can lead to waterlogging of the soil, which makes cultivation difficult and reduces yields. The growing season lasts about 180-200 days, which makes it possible to grow mainly early and mid-season varieties. At the same time, cool summers limit the spread of heat-loving crops such as corn and sunflower, which are grown only in small volumes in the southern part of the region. One of the most important climatic factors is the winter period, which is characterised by a stable snow cover that helps to accumulate moisture in the soil. This is key for the start of spring field work and ensuring high moisture for winter crops. Climate change in recent years, including an increase in average annual temperature and a decrease in precipitation stability, has affected the structure of sown areas in Polissya. This is leading to a gradual increase in the area under corn and soybeans, which were not previously typical for the region. Thus, the climatic conditions of Polissya, including temperature, precipitation, length of the growing season and moisture regime, determine the choice of crops that dominate the structure of sown areas and the adaptation of agricultural technologies to local conditions. Between 1995 and 2019, there were changes in the ratio of areas between different crops. In Polissya, the area under sugar beet, fruit and berry crops, cereals and pulses decreased, while the area under sunflower and vegetable crops increased. Only sugar beet and fruit and berry crops recorded an increase in yields and a slight decrease in gross harvest [1].

Soil factors play a key role in shaping the structure of sown areas in Polissya, as they influence the choice of crops that can provide high yields in this region. Polissya is characterised by sandy, sandy loam and peaty soils, which have their own characteristics that determine the agricultural use of the land. Sandy and sandy loam soils, which are common in large areas of Polissya, are characterised by low fertility due to their low humus content (1-2%) and organic matter. These soils have low water retention capacity, which makes them vulnerable to drought. At the same time, they are well-drained, which avoids water stagnation. These soils are best suited for growing unpretentious crops such as rye, oats and potatoes, which can grow even with low fertility. Peat soils, typical of the wetlands of Polissya, have a high organic matter content and potential fertility, but require reclamation measures, including drainage. Without proper management, these soils can suffer from excessive moisture, making it difficult to grow crops. Dried peatlands are actively used for growing fodder grasses, flax, potatoes and vegetables. Soil acidity is another important factor that affects the structure of crops. Most soils in Polissya have an acidic or slightly acidic reaction (pH 4.5-5.5), which limits the choice of crops and requires liming to improve growing conditions. Crops that are resistant to acidic soils, such as rye, buckwheat and potatoes, occupy a significant area in the region. Low nutrient content, particularly of nitrogen, phosphorus and potassium, also determines the agricultural use of Polissya soils. This necessitates the use of mineral and organic fertilisers to ensure adequate yields. At the same time, intensive fertilisation and liming of soils allows for a wider range of crops, including an increase in the area under grain, corn and industrial crops. The structure of sown areas in Polissya depends heavily on soil factors such as soil type, humus content, acidity, drainage and nutrient availability. Taking these characteristics into account is the basis for rational land use and increasing the efficiency of agricultural production in the region.

Soil factors play a decisive role in shaping the structure of sown areas in the Forest-Steppe, as they influence the choice of crops that provide optimal productivity in this region [25]. The forest-steppe of Ukraine is characterised by a significant diversity of soils, including chernozems, grey forest soils, dark grey podzolic and sod-carbonate soils [26]. The characteristics of these soils determine the agricultural potential of the region and the priorities for agricultural use. Chornozems are the most fertile soils in the region due to their high humus content, significant reserves of nutrients (nitrogen, phosphorus, potassium) and favourable physical and chemical properties [27]. They provide optimal conditions for growing grain crops (wheat, barley, corn), oilseeds (sunflower, rapeseed) and sugar beet [28]. The high water-holding capacity and deep humus horizon of chernozems contribute to stable yields even under conditions of slight moisture deficit [29]. Grey and dark grey forest soils are common in the more humid areas of the Forest Steppe [30]. They have a moderate level of fertility, lower humus content compared to black soils, and increased acidity, which can limit the cultivation of some crops [31]. To increase the productivity of these soils, liming and the application of mineral and organic fertilisers are used [32]. On grey and dark grey forest soils, cereals (rye, wheat), fodder grasses, vegetables and partially industrial crops are grown [33]. Sod-carbonate soils, which are found in elevated areas, have specific properties, including a high carbonate content, which makes it difficult to grow crops that are sensitive to calcareous environments. They are more commonly used for growing legumes, fodder grasses and some industrial crops [34]. An important factor affecting the structure of crops in the Forest-Steppe is the water-physical properties of soils, in particular their permeability and moisture capacity [35]. The region's soils generally retain water well, which favours crops with high water requirements, such as corn, sugar beet and soybeans. At the same time, areas with light soils can be prone to drought, requiring the introduction of irrigation systems [36]. The acidity of the Forest-Steppe soils, which on average ranges from neutral to slightly acidic, affects the choice of crops and agronomic practices. Liming is used to reduce acidity and improve fertility, allowing for a wider range of crops, including wheat, rapeseed and vegetables [37]. The structure of sown areas in the Forest-Steppe region depends on soil factors such as soil type, fertility, water and physical properties and acidity. Rational use of these soils, fertilisation and liming contribute to high yields and ensure efficient land use in the region.

Our results confirmed the high differential value of the moisture coefficient, which depends on a complex of environmental conditions. The moisture coefficient is an important indicator that affects the structure of sown areas in the Forest-Steppe and Polissya. In the Forest-Steppe, the moisture coefficient is usually close to one, which indicates a balance between precipitation and evaporation. This provides favourable conditions for growing both grain and industrial crops, making the Forest-Steppe one of the most productive regions of Ukraine. The structure of sown areas in the Forest-Steppe is shaped by climatic, soil and economic factors. Cereals such as wheat, corn, barley and oats are the main crops grown in the region. These crops have high yields in the area due to favourable soil moisture and fertility conditions, in particular black soil and grey forest soils. Technical crops, such as sunflower, sugar beet and rapeseed, also account for a significant portion of the area, as the climate and moisture conditions ensure their high productivity. In addition, fodder crops play an important role in the structure of sown areas, which contributes to the development of livestock production. The moisture content determines the distribution of sown areas between different crops. For example, in regions with a slightly lower moisture content, the share of sunflower may be higher due to its drought tolerance, while in areas with better moisture content, more areas are allocated to wheat and sugar beet. In the Forest-Steppe, the structure of sown areas is the result of the interaction of natural and climatic conditions, including the moisture coefficient, and economic needs, ensuring stability and high productivity of agricultural production.

The moisture content is a key factor that influences the structure of sown areas in Polissya. In this natural and climatic zone, the moisture coefficient exceeds one, which indicates an excess of precipitation compared to evaporation. This creates specific conditions for agricultural production that differ from other areas of Ukraine. Polissya's high moisture coefficient favours the cultivation of crops that require a significant amount of moisture. The majority of the area under crops is occupied by cereals, including rye, barley, oats and wheat. Rye is one of the leading crops due to its ability to grow on the less fertile sandy soils typical of Polissya. Technical crops such as flax and potatoes are also an important part of the crop mix. Flax is traditionally grown in the region due to the favourable climate and sufficient moisture, which ensures a high quality crop. Potatoes occupy a significant area as a food crop and also as a basis for fodder production. Due to the high level of moisture and low natural soil fertility (mainly sod-podzolic soils), various agronomic measures are used in Polissya to improve the structure of crops. Drainage reclamation is a common approach to manage excess moisture. Fodder crops, such as perennial grasses, occupy an important place in the cropping pattern, due to the development of livestock production in the region. In addition, significant areas remain under natural meadows and pastures, which also corresponds to high moisture conditions. The high moisture content in Polissya affects the choice of crops and necessitates the implementation of land reclamation measures to optimise agricultural production.

Conclusion. The structure of sown areas depends on environmental gradients and climatic factors. The main factors affecting the distribution of sown areas are the moisture coefficient, solar radiation balance, annual precipitation and evaporation. These factors determine territorial differences in the choice of crops. The discriminant analysis allowed us to interpret the cluster structure of the regions by crop type. Seven clusters were identified that demonstrate a natural distribution in geographical space, from Polissya to Forest-Steppe and Precarpathian region. Each cluster is characterised by a specific structure of crops that corresponds to the climatic and environmental conditions of the region. The distribution of sown areas reflects the adaptation of crops to environmental conditions. In the forest-steppe regions, heat-loving crops such as sunflower and corn dominate, while in Polissya the share of flax, potatoes and oats is much higher. This indicates that the choice of crops depends on moisture and heat balance.

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