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Proposed method for delimiting spatial structure on the example of agriculture types in Poland

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Abstract. This work presents the results of research on the identification of types of Polish agriculture. Polish gminas (the third-order administrative division of the country sometimes referred to as "communes" or "municipalities", until 2016 – according to Local Administrative Units – LAU level 2) have been divided into three types, characterised by low, medium or high levels of agricultural development, with 10 sub-types. A multi-stage typological procedure was used, employing two classification methods: k-mean cluster analysis and the random forest method. Twelve diagnostic attributes were used that comprehensively characterise Polish agriculture. The results show the diversity of this sector of the economy, which should be taken into account when planning its future development.

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1. Introduction

Environmental conditions and past geo-political partitions have made Poland's agricultural space extremely diverse and complex. It is important to recognise this diversity and explain the mechanisms of change when managing agricultural development, which should take into account local determinants and potential (Adamowicz, Zwolińska-Ligaj, 2009; Dixon et al., 2001; Mądry et al., 2011; Rudnicki, 2016ab; Wysocki, 2010).

In geography, this is achieved by research on the spatial structure of agriculture, in terms of the set of interrelated agricultural attributes, phenomena and processes in a given space (Falkowski, Kostrowicki, 2001). The most comprehensive method in geographical–agricultural research is the typology of agriculture (Bański, 2007), in which Polish geography has made significant achievements. The typology of agriculture developed by J. Kostrowicki's team at the Institute of Geography and Spatial Organization of the Polish Academy of Sciences [*Instytut Geografii i Przestrzennego Zagospodarowania Polskiej Akademii Nauk* – IGiPZ PAN] has been used in research conducted in, among others, the USA, the former USSR, Canada, Australia, Brazil, India and Serbia (Kulikowski, 2005). Polish socio-economic geographers have drawn up a number of typologies for the entire country (e.g. Kostrowicki, Szczęsny, 1978; Szczęsny, 1988), selected regions (e.g. Biegajło, 1973; Głębocki, 1973; Falkowski, 1977; Stola, 1970; Matusik, 1973) and other European countries (e.g. Stola, 1973, 1977; Szczęsny, 1977, 1982; Tyszkiewicz, 1977). The continuing popularity of the developed typological method can be demonstrated by its continued presence in publications (Alvarez et al., 2014; Report ... 2016) and in relation to various regions of the world (Chendrayudu et al., 2015).

The present research issue is related to the rich tradition of typological studies on agriculture in Poland, which, according to the literature review, has become less relevant in favour of more comprehensive research into rural areas (e.g. Stola, 1993; Bański, Stola, 2002; Bański, 2014; Rosner, Stanny, 2014). The latest studies to deal with the typology of agriculture (the first on the *gmina* scale since 1988) are the works of B. Głębocki's team (2018, 2019). Due to the scale of the research and the data used, the results of these typologies are the most important point of reference for the presented proposal.

As previously mentioned, due to its utilitarian and practical nature, typological research on agriculture is conducted in various parts of the world, both in developed EU countries (e.g. Álvarez-López et al., 2008; Velbuena et al., 2008; Andersen, 2010) where they are intended to help prepare optimal agricultural policy instruments, and in developing and less developed countries (Parthasarathy et al., 2014; Chopin et al., 2015; Chendrayudu et al., 2015; Torero, Maruyama, 2016), where they often support measures to reduce malnutrition or poverty.

The purpose of this work is to elaborate the conception of the typological studies which allow the spatial structure of Polish agriculture to be delimited. The results let us answer the following questions: What were the main types of agriculture in Poland? How were they spatially diversified at the local and regional level? What are the external determinants of agriculture development?

2. Research methods and materials

The main source of the data used in the study were 2010 results from the National Agricultural Census (PSR). The data were aggregated by the location of each farm's headquarters (the headquarters of the farm should be understood as the *gmina* in which the farm has its seat or headquarters. In the absence of a formal headquarters or seat, the headquarters was determined to be the *gmina* that hosts the largest part of the farm's area (Central Statistical Office website [3] accessed 5.07.2018)). It should be noted that, despite the passage of time, the data used are currently the most complete source of information on agriculture at the survey's adopted territorial level. The employed database contained 931 attributes, which, in light of the spatial extent of the research (2,478 *gminas*), yielded over 2.3 million numerical values in various units (items, hectares, square metres, cubic metres). A multi-stage typology procedure was developed, the essence of which is presented in Fig. 1.

The first step involved selecting the following 12 diagnostic attributes determining the level of agriculture (these attributes were selected based on

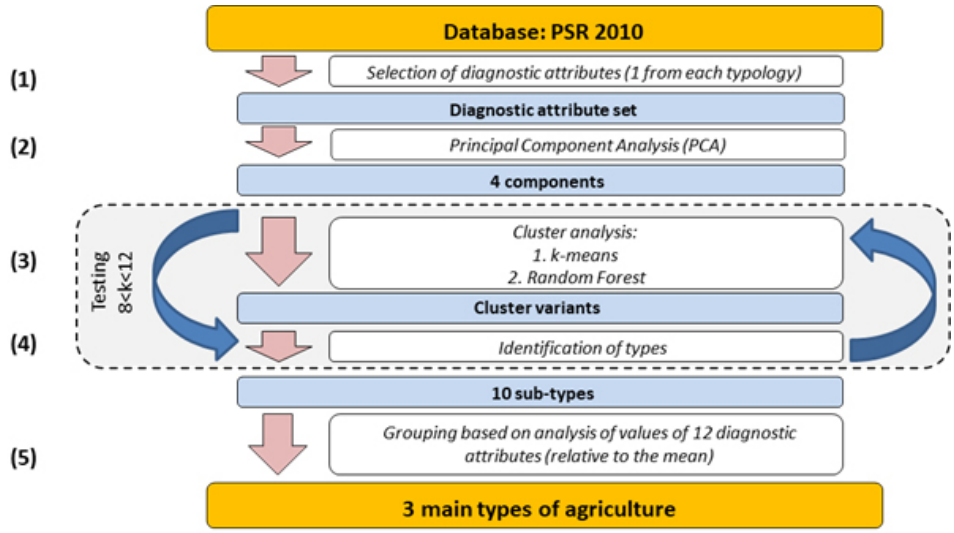

Fig. 1. Procedure for creating agricultural typology
Source: own study

their typogenic impact in 12 thematic typologies of agriculture made in previous research. The attributes were cleared of outliers. *Gminy* excluded on this basis, a total of 14, are indicated in Fig. 2. For a precise description of the methodology, see Wiśniewski, 2019):

(1) farms' extensive forms of land use (total area of permanent pasture, forest land and other land) as a proportion of the total area of farms (destimulant),

(2) average farm area (in ha of agricultural land),

(3) number of persons working in Annual Work Units (AWU) per 100 ha of agricultural land (destimulant),

(4) share of managers aged 44 or less in the total number of managers running farms,

(5) farm managers by general educational level – secondary, further/post-secondary, or higher – as a proportion of the total number of farm managers running a farming business,

(6) number of mechanised items per active farming business, the following point bonitation was used: combine harvester (5 pts); potato harvester (3 pts); beet harvester (5 pts); self-propelled forage harvester (5 pts); towed forage harvester (3 pts); fertiliser and lime spreader (1 pt); manure spreader (2 pts); towed mower (1 pt); front loader gripper (1 pt); potato digger (1 pt); potato planter (1 pt); collector trailer (2 pts); collecting press (3 pts); motorised plough (1 pt); multi-function plough (2 pts); towed field sprayer (2 pts); towed orchard sprayer (2 pts); bucket milking machine (1 pt); stanchion milking machine (2 pts); bucket milk cooler (1 pt); bulk tank milk cooler (1 pt). Author's bonitation based on assessment of technical complexity of machines and equipment,

(7) consumption of mineral fertilisers calculated on the pure ingredient in kg of NPK (nitrogen, phosphorus, potassium) per 1 ha of agricultural land,

(8) crop production intensity (in points, calculated using the B. Kopeć point method (1984)),

(9) intensity of animal production (in points) - Ibid,

(10) farms with non-agricultural income (combined categories of paid employment, non-agricultural income, pensions, non-employment and other income) constituting over 50% of income, as a proportion of the total number of active farms (destimulant),

(11) farming businesses consuming 25% or less of final agricultural production value of the business, as a proportion of the total number of active farms,

(12) total agricultural production per 1 ha of agricultural land (in PLN). Production was calculated by multiplying the area of individual crops and farm animal populations by SO "2010" coefficients. SO – Standard Output: the 5-year average of the annual production value of a given crop or

stock farm per ha or per animal in regionally average conditions (Bocian et al., 2014).

Then, by principal component method (Hotelling, 1933), these attributes were reduced to four meta-variables that explained over 78% of the variance of the original set of attributes. The variables were subjected to cluster analysis using the *k*-means algorithm (MacQueen, 1967). The final number and composition of clusters were determined based on the mutual relations between intra- and inter-class variance of objects, having considered various different population classification variants (classification was tested using *k*-parameter values from 8 to 12). The goal was to maximise differences between the centroids of individual clusters while minimising differences between individual objects within clusters.

Thus, a 10-group division was arrived at, which was then verified and corrected using a random forest algorithm (Breiman, 2001). This approach, put very simply, consists in building multiple classification trees from a series of randomly selected samples (*gminas* and attributes alike were random), with the set being divided into two subsets: a training set and a verification set. In the final stage, the trees "vote" on whether a given object (*gmina*) belongs to a class.

The method in question attempts to eliminate the shortcomings of classic binary classification trees, and its key strengths are: resistance to overtraining, estimation of incorrect-classification costs, resistance to disturbances associated with outliers or lack of data, and the ability to detect relationships between explanatory variables (Breiman, 2001; Hastie et al., 2013).

As a result of the random forest method, 390 *gminas* were re-designated. It should be remembered that the changes affected "extreme" *gminas*, i.e. those most difficult to group – with indicator values that in some sense "fit" two neighbouring types. The high classification quality is indicated by receiver operating characteristic (ROC) curve charts and classification convergence matrices (not included, due to publication length restrictions). A similar methodology – a two-stage division using *k*-mean cluster analysis and random forests – was used by R. Perdał in classifying *gminas* by degree of socio-economic development (2018).

To establish the identity of the types, a substantive formal identification was used that consisted in determining the name of the type (based on analysis of centroid locations in relation to the arithmetic mean of the diagnostic attributes adopted in the study). A significant difference between these values justified associating a type name with a given attribute. Substantive identification was carried out using cluster centres and the range of diagnostic attribute values (Wysocki, 2010).

Individual subtypes were grouped into three main classes characterised by a low, medium or high level of agricultural development. The criterion for this was the number of attributes above the national average (out of the original 12 attributes). It was arbitrarily agreed that in order to classify a given subtype as belonging to a highly developed type, at least half of the variables (six or more) should be high (above the national average). Fewer high-level attributes classified a given subtype as being of average (four or five attributes above average) or low (three or fewer attributes above average) level of agricultural development (see Table 1).

The resulting system was referenced against the spatial variation of external conditions for agricultural development. To this end, the *gminas* were divided into a number of groups representing their diversity of natural conditions, former historical and political divisions, and level of socio-economic development (see Table 1).

3. Results

The procedure discussed above allowed three main types of agriculture to be distinguished: highly developed, medium developed and low developed, with 10 sub-types. The average values of the 12 diagnostic attributes for individual types and subtypes are presented in Table 2.

Each of the subtypes brings together *gminas* in which the agriculture has similar values of diagnostic attributes (see Fig. 2). These types can be characterised as follows.

Table 1. External determinants of agricultural development

Type of determinants	Basis for delimitation and method	Classifications
Environmental	value of the agricultural production space quality index* / Jenks natural breaks method (1967)	1 – unfavourable (up to 91.3 points; 979 *gminas*) 2 – medium-favourable (91.4–117.6 points; 1,052 *gminas*) 3 – favourable (over 117.7 points; 447 *gminas*)
Historical and political	political borders, 1815–1914 and 1918–39 (Kozłowski, Rudnicki, 2003)	1 – lands in the former Austrian partition and interwar Poland (351 *gminas*) 2 – lands in the former Russian partition and interwar Poland (1,118 *gminas*) 3 – lands in the former Prussian partition and interwar Germany (634 *gminas*) 4 – lands in the former Prussian partition and interwar Poland (375 *gminas*)
Level of socio-economic development	11 diagnostic attributes** / zeroed unitarisation (Kukuła, 1999) / Jenks natural breaks method (1967)	1 – low (848 *gminas*) 2 – medium (1,149 *gminas*) 3 – high (481 *gminas*)

* from the agricultural production space quality index used by the Institute of Soil Science and Plant Cultivation in Puławy in constructing a comprehensive environmental index of the ecological production utility of areas (Stuczyński et al., 2007).
** from data of the Local Data Bank of the Central Statistical Office used to characterise a given territorial unit in demographic, infrastructure, financial and economic terms.

Table 2. Description of types and sub-types of Polish agriculture

Breakdown of types and subtypes		Diagnostic attributes											
		1*	**2**	**3***	**4**	**5**	**6**	**7**	**8**	**9**	**10***	**11**	**12**
Poland		**36.7**	**6.9**	**13.6**	**37.3**	**41.8**	**4.3**	**114.6**	**120.5**	**165.6**	**71.7**	**48.4**	**6,260.0**
I. Highly developed		**27.7**	**12.7**	**12.6**	**40.8**	**41.8**	**6.5**	**138.2**	**132.4**	**188.0**	**54.6**	**65.0**	**7,287.8**
I.1.	Diversely developed	18.6	14.6	10.6	42.0	38.9	8.6	170.3	138.8	272.9	43.6	67.5	8,089.8
I.2.	Areally extensive	21.4	19.0	6.4	37.8	47.0	5.6	154.1	128.7	72.6	60.3	67.2	4,791.9
I.3.	Crop farm	21.4	5.5	23.2	39.3	45.6	4.9	120.7	178.6	101.3	63.3	64.7	8,855.0
I.4.	Stock farm	44.0	10.3	12.9	43.6	36.8	6.9	111.0	103.3	241.3	52.7	61.7	6,749.7
I.5.	Industrial farm	36.2	6.5	20.8	34.6	46.4	4.3	94.2	117.9	691.9	66.8	54.8	25,767.8
II. Medium developed		**35.0**	**7.3**	**12.9**	**31.6**	**54.8**	**2.8**	**95.2**	**116.8**	**135.5**	**80.6**	**58.4**	**6,814.4**
II.1.	Transitional	33.7	8.2	10.3	30.4	58.3	2.4	89.2	118.5	58.1	81.7	60.2	4,797.8
II.2.	Semi-industrial	37.0	5.9	17.0	33.6	49.2	3.4	104.9	113.9	261.2	78.7	55.6	10,064.7
III. Low developed		**58.4**	**4.6**	**22.8**	**33.4**	**41.9**	**2.5**	**51.3**	**98.7**	**102.3**	**84.3**	**35.5**	**4,735.4**
III.1.	Special	70.8	5.2	13.3	28.2	50.7	1.6	23.3	82.4	59.4	88.6	40.7	3,502.8
III.2.	Traditional	42.7	6.4	16.2	38.6	39.4	4.0	81.4	107.0	132.7	74.8	46.4	5,182.6
III.3.	Problematic	66.5	2.1	38.0	31.6	37.6	1.6	38.8	102.2	101.3	91.9	18.7	5,197.6

Note: Diagnostic attributes ordered as above; values above national average are show in grey; * destimulants; Source: own study based on data from PSR 2010

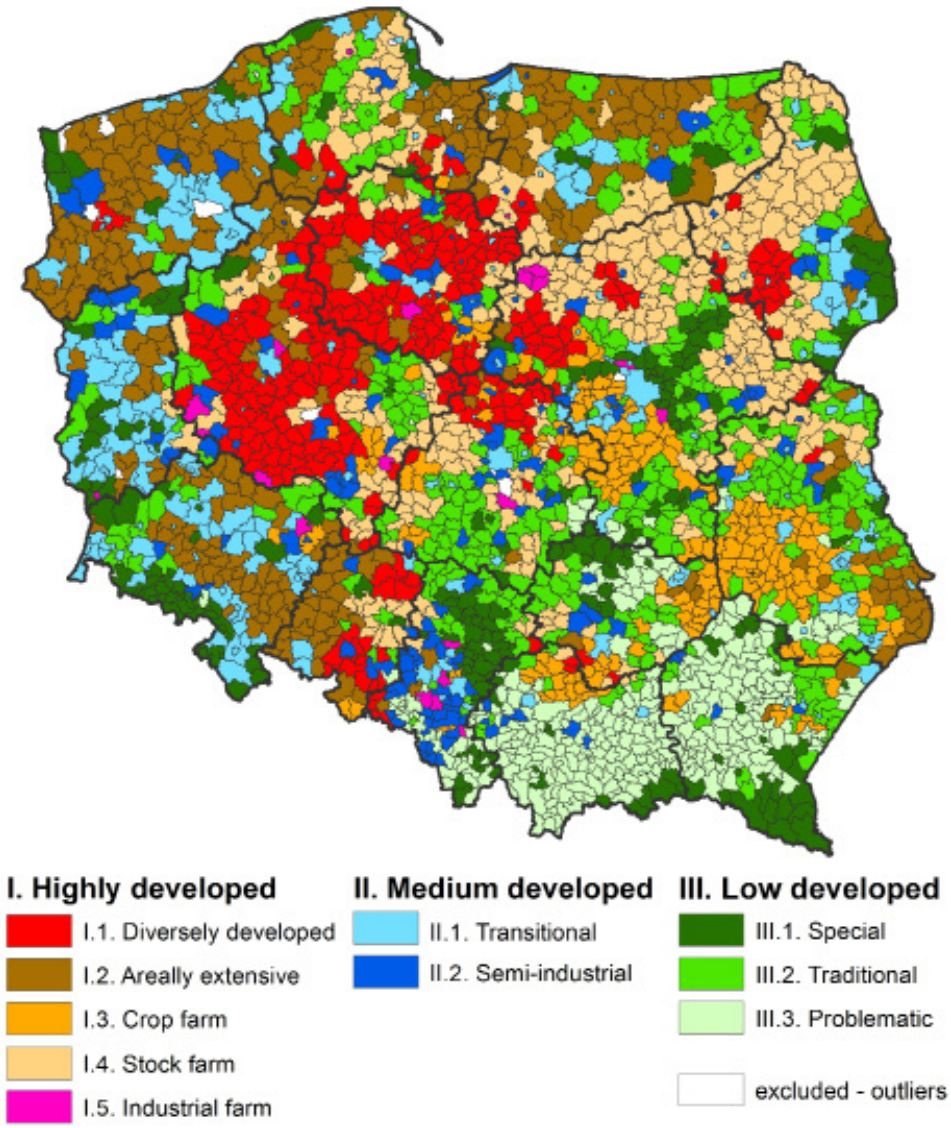

Fig. 2. Types of Polish agriculture in 2010
Source: own study based on data from PSR 2010

3.1. Type I. Highly developed agriculture

This type is represented by 1,155 *gminas* (46.6%). By the criterion of similarity of diagnostic attributes, five subtypes were distinguished:

- highly developed crop and animal production (diversely developed; 281 *gminas* – 11.3%),
- highly developed agriculture focused on large-scale crop production (areally extensive; 303 – 12.2%),
- high level of agricultural development focused on specialist crop production, mainly fruit and vegetables (crop farms; 207 – 8.4%),
- highly developed agriculture focused on animal production (stock farms; 343 – 13.8%),
- highly developed agriculture characterised by industrial animal farming (industrial farms; 21 – 0.8%) (see Table 2).

Gminas of this type are considered to be strategic areas of agricultural production (Bański, Kulikowski, 2009) of fundamental significance to the Polish food economy. They are characterised by a highly developed farming culture and production specialisation, and are relatively large compared to the rest of the country (see Table 2). Support for this type of area should be directed at further improving competitiveness (modernising fixed assets), transfer-

ring modern technologies (for precision, energy and ecological farming), stimulating collaborations (e.g. producer groups), and further diversifying farm activities in order to strengthen both their surrounding areas (e.g. agri-food processing, services) and the multifunctional development of rural areas. Further changes should be made in a spirit of sustainable development, so as not to miss the opportunity to create a model of environmentally friendly agriculture. In this regard, particular attention should be paid to both the negative and positive effects of maintaining animal production and mineral fertilisation at optimal levels.

3.2. Type II. Medium developed agriculture

This type of agriculture (400 *gminas* – 16.1%) consists of two subtypes (see Table 2):

- medium level of agricultural development (transitional; 248 – 10.0%),
- medium level of agricultural development focused on raising stock (semi-industrial; 152 – 6.1%).

Medium-level agriculture is determined as areas where agriculture has to choose an appropriate development path. The first, preferred path is development and evolution towards highly developed agriculture. This could lead to success by exploiting, on the one hand, the development potential already available to the farms of such areas (as confirmed by the relatively large size, low workload and good technical equipment) and, on the other, interventionism (both national and regional) aimed at planning development according to the principles of sustainable agricultural and rural development (Roszkowska-Mądra, 2014). The second path of change is towards low-developed agriculture.

3.3. Type III. Low-developed agriculture

This type comprises 923 municipalities (37.2%) and consists of three subtypes:

- low level of agricultural development determined by specific environmental conditions (special; 250 – 10.1%),
- low level of agricultural development determined by the subsistence nature of production (traditional; 362 – 14.6%)
- low level of agricultural development determined by agrarian overpopulation and fragmentation (problematic; 311 – 12.6%).

Areas of the low-level agricultural development type are associated with problem areas in Polish agriculture (Bański, 1999; Czapiewski, 2010). This is confirmed by the low-developed agriculture type overlapping with the delimitation of agricultural areas that lag behind in development (as designated for both 1996 and 2002). It is impossible to assess changes in this system for methodological reasons, while the distribution of the main "hotspots" indicates that the socio-economics of these areas is relatively persistent in Poland.

3.4. Agricultural sub-types and external determinants of agricultural development

The spatial arrangement of selected sub-types (see Fig. 2) is related to external determinants of agricultural development. These relationships were determined by what percentage of *gminas* of a given agricultural sub-type was characterised by each political and historical determinant type, by each environmental determinant type, and by each socio-economic level determinant type (see Table 3).

It has been shown that the impact of natural determinants is spatially diverse. *Gminas* with unfavourable environmental conditions predominate in areas with both low-developed agriculture (mainly subtype III.1) and highly developed agriculture (subtypes I.4 and I.5). It has been shown that, for subtypes I.1 and I.2, *gminas* with average environmental conditions constitute the numerically largest share. This attests to agricultural culture strongly influencing agricultural production results.

Meanwhile, the spatial arrangement of types of Polish agriculture was heavily determined by historical and political factors. This is mainly due to

Table 3. Assessment of the spatial diversity of agricultural development types and subtypes, according to the share of *gminas* of a given subtype within three categories of external determinants of agricultural development

Type/Sub-type Conditions		I					II		III		
		I.1	I.2	I.3	I.4	I.5	II.1	II.2	III.1	III.2	III.3
Environmental	1	11	11.2	8.7	64.1	61.9	35.1	38.2	76.8	58	37.3
	2	64.1	51.5	38.2	33.5	33.3	47.6	47.4	20.8	35.4	46.6
	3	24.9	37.3	53.1	2.3	4.8	17.3	14.5	2.4	6.6	16.1
Historical	1	0	1.3	4.8	0.6	4.8	2.4	11.8	17.2	7.2	77.8
	2	37.4	11.6	88.9	71.4	33.3	31	36.2	44.4	68.5	16.1
	3	8.2	78.5	2.4	10.8	14.3	56.9	25.7	35.2	16	1.6
	4	54.4	8.6	3.9	17.2	47.6	9.7	26.3	3.2	8.3	4.5
Development level	1	32.7	24.4	45.9	55.7	14.3	10.1	11.8	20	44.5	44.7
	2	56.6	61.1	42.5	41.1	61.9	33.1	44.1	42.8	48.6	42.1
	3	10.7	14.5	11.6	3.2	23.8	56.9	44.1	37.2	6.9	13.2

Note: Predominating values (over 50.0%) within a given group of determinants are show in grey; Explanations of types and determinants as in Table 1 and 2; Source: own study

the fact that in the 19th century – the period of transition from a feudal to capitalist economy – the territory of Poland was occupied by three partitioning powers, each of which differed in its pace and level of socio-economic development. The analysis focusing on this aspect showed that among low-developed agriculture, the numerical majority of *gminas* of sub-type III.1 (problematic) was found in the area of the former Austrian partition. Areas within the borders of the former Russian partition were associated with a significant share of type I *gminas*, including sub-types I.3 and I.4. Within this partition, the majority of *gminas* were of the low-developed agriculture type, including subtype III.2. Attributes were of a relatively higher level in the *gminas* of the former Prussian partition within the interwar borders of both Germany (type I.2) and Poland (type I.1).

The diversified territorial types were also referenced against level of socio-economic development. It was found that a group of *gminas* of low-level socio-economic development had a majority of highly developed agriculture subtypes – I.4. Elsewhere, *gminas* of medium socio-economic development level predominated in three highly-developed agricultural sub-types (I.1, I.2, I.5), while only sub-type II.1 had a majority of *gminas* of high socio-economic development.

4. Conclusions

The issues raised relate to a rich tradition of agricultural typological research that, after almost three decades of diminished popularity, is attracting renewed interest among researchers (Rudnicki, 2016ab; Głębocki et al., 2018, 2019; Wiśniewski, 2019). The presented method for delimiting the spatial structure of agriculture uses results from PSR 2010 developed according to the Eurostat methodology. It may be of particular interest to revisit and continue similar studies in other EU countries using data from further agricultural censuses. It should be remembered that an agricultural typological method should allow "the agricultures of all countries and times to be objectively compared against one another" (Kostrowicki, 1983, p. 607).

The results of the typology showed that the most devolped agriculture was in the Kujawsko-Pomorskie, Wielkopolskie and Opolskie voivodeships. By contrast, the lowest developed type dominated in the Małopolskie and Podkarpackie voivodeships. The spatial structure of the selected types and subtypes is connected with external determinants of agriculture development.

The obtained results may constitute an important and useful source of data for further analyses, especially those aiming to determine the directions of agricultural and rural development policy. In this

regard, the scale of the research appears to be an important advantage, as it allows local diversity to be determined, in contrast to regional approaches, which do not. The developed proposal for a comprehensive approach to the spatial structure of agriculture synthesises information that traditional portrayals presented using a range of individual indicators. The advantage – in terms of the practical usability of the results – is their readability and ease of interpretation, which results from the relatively small number of types and their names, which clearly indicate the nature of the classification.

According to the authors, the research results display high utility, and the random forest method (not previously used in Polish agricultural geography) proved an effective classification tool that improved the quality of the division obtained by traditional methods (*k*-means).

The research has shown that Polish agriculture constitutes a very complex system. It is a proving ground of sorts, on which diametrically opposed types of agriculture function alongside one another. The harmonious development of such a complex system requires specialised knowledge and in-depth analyses, including spatial ones. Therefore, the continuation of this type of research should be considered an important task for geographers.

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