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Management of nutrients from mineral fertilizers in the Polish agriculture – selected issues

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Abstract. The paper presents the issue of nutrient management, such ingredients as N, P, K and Ca, in mineral and lime fertilization in the Polish agriculture. The analysis covered changes in the number and share of farms using mineral fertilization and the level of consumption of individual ingredients in mineral fertilizers. The comparative analysis was based on individual farm data with 2007 and 2016 years. Spatial analysis was carried out at the level of voivodships (NUTS-2). The results indicated regional diversification in the management of mineral fertilisers. This differentiation is progressing, which was evidenced by the different pace of changes in the share of farms using mineral fertilization among voivodships. Nitrogen fertilizers are the most common type of mineral fertilizers, that was indicated by the number of farms applying this type of fertilizers. At the same time, lime fertilizers are very rarely used on individual farms. In this scope, there is also a wide, increasing regional diversity. According to the carried out analyses, the level of consumption of mineral fertilizers, especially nitrogen fertilizers in Poland, is mainly related to the intensity of crop production. The average fertilizer rates for Poland do not reflect the actual situation and changes in particular voivodships. The consumption of mineral fertilizers is mainly dependent on the diversity of the area structure and the organizational and economic level of agricultural holdings. The intensity of fertilization with fertilizing components increases simultaneously with the size of agricultural holdings. This dependency is described by the second-degree polynomial equation. The highest doses of macronutrients in mineral fertilizers have been used for many years in south-western and western Poland, and the smallest, with a few exceptions, in the east of the country. The results of the studies indicate that organizational factors (related to the farms` area) are an equally strong determinant of the consumption of fertilizing components as well as the location of the farms (geographical, administrative).

Key words: fertilizers management, regional differentiation, mineral fertilizers, NPK and Ca

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INTRODUCTION

The participation of agricultural producers in the various instruments of the Common Agricultural Policy (CAP) should, by their very intention, facilitate the achievement of the priority and, at the same time, varied objectives of sustainable agricultural development (Bułkowska, 2011; Chmurzyńska, 2011; Poczta, 2010). From the sustainable agricultural development view, the essential issue is to maintain the soil production potential (its fertility), while at the same time to achieve production and economic effects (Zegar, 2013). These are the premises to take a view different than before of the problems for fertilizer management in the broad sense of the word, including in particular nitrogen and phosphorus management in agriculture. The new approach to fertiliser management forces looking for environmentally friendly solutions, ensuring optimisation of the production and economic effects of the agricultural producer. However, the achievement of the above objectives at the farm or entire sector level is challenging, due to the frequent occurrence of competition between them (Wrzaszcz, 2012).

The concern for rational mineral, organic, and natural fertilizer management arises from significant interference of agricultural activity, mainly through intensified production, into the natural nutrient cycle (Kopiński, 2018). The need for fertilizers results from the demand to maintain and restore the essential nutrient resources in the soil, both for production, in order to ensure optimal conditions for plant growth and development (Czuba, Mazury, 1988) and environmental reasons (Jadczyszyn, Kopiński, 2013; Kopiński, Jurga, 2016). The negative environmental consequences of nitrogen and phosphorus fertilization, resulting from wasteful and incompetent management, often manifest themselves in the form of deterioration in groundwater, surface water and air quality and animal and human health (Fotyma et al. 2009; Kopiński, 2017; Pastuszak et al., 2014; Prandecki, 2015).

Unbalanced fertilization has environmental and economic consequences. On the one hand, too low a level of fertilizer rates in terms of the nutritional needs of arable crops leads to both depletion of soil resources with non-renewable macronutrients and deterioration of production effects (plant productivity). On the other hand, excessive rates of fertilizers generate pressure on environmental individual components and unjustified, high direct costs of agricultural production, due to the parabolic curve of plant productivity in relation to fertilizer inputs. Such relationships underline the need for a quantitative and qualitative approach to fertilizer management, guaranteeing both the appropriate amount of macronutrients (adjusted to the crops grown) and product quality. The right relationship of ingredients in terms of their optimal use by cultivated plants, taking into account the Liebig's minimum law is also worth mentioning and remembering (Fotyma et al., 2009).

The main macronutrients are nitrogen, phosphorus, potassium, and calcium. According to Filipek (2002), rational fertilizer management must take into account three aspects, i.e. acquisition (production) of fertilizers, flows in the process of plant production, but also more broadly agricultural production, as well as care for the natural environment. Natural fertilizer resources should also be taken into account, which, after mineral fertilization, are the main source of inflows of fertilizer (nutrient) components in the agricultural production cycle (Kopiński, 2017).

The consumption of mineral fertilizers in Poland, including nitrogen fertilizers, is significantly affected by changes in the economic situation of agriculture and the national economy (Fotyma et al., 2009; Matyka, 2013). Also, the changes in the economic situation, influenced by internal and external factors (Kopiński, 2020) that shape the prices of energy carriers in raw material markets have a significant impact on fertilizer production costs (Zalewski, Igras, 2012). In a sense, fertilizer management, taking into consideration also the specific regional diversity of Polish agriculture (Krasowicz, 2009, Matyka et al., 2013, Wrzaszcz 2018), fits in with the issue of food security, especially under the pressure of regional (EU) and global determinants (Michalczyk, 2013; Mikuła, 2012). It is also important to note the strong impact of climate change, adversely affecting the possibility of using the production (genetic) potential of plants and food production (Kopiński, 2018).

The aim of the paper was to assess mainly organizational changes in the management of mineral-origin macronutrients in Polish agriculture, in the context of their production functions and potential environmental impacts.

MATERIALS AND METHODS

The source material adopted in the study was mass statistics data published by the Central Statistical Office (GUS, 2003-2019a; 2003-2019b; 2001-2020; 2014-2019), the National Centre for Balancing and Management of Emissions (Poland's..., 2016) and unpublished data aggregated by the Statistical Office in Olsztyn, collected as part of the Farm Structure Survey (FSS) in 2007 and 2016, as well as the results of the IUNG-PIB and IERiGŻ-PIB own research (Kopiński, 2017; Wrzaszcz, Kopiński, 2019). The research was concerned with individual farms with an area of at least 1 ha of agricultural land maintained in good agricultural condition (AL in gac).

The studies included three basic macroelements – nitrogen (N), phosphorus (P_2O_5), potassium (K_2O) and calcium (CaO). The analysis covered changes in the number and share of farms using mineral fertilisers and the level of consumption of individual components in mineral fertilisers. The analysis concerned the size of applied doses of macroelements in the fertilizers. The collected data were subjected to comparative analysis of changes in the management of macroelements in Poland, for the years 2007 and 2016. Spatial analysis of regional differentiation was carried out at the national (NUTS-0) and provincial (NUTS-2) levels[1]. The indicators for individual voivodeships were compared to the average values for Poland. The material was presented in tabular and graphic form.

RESULTS AND DISCUSSION

The number of farms with mineral fertilization

In 2016, there were 1.4 million individual farms with at least 1 ha of UAA in Poland. In the analyzed period, the number of individual farms decreased by more than 1/5 (Figure 1). Such results indirectly indicate that a significant proportion of farmers have taken up other business activities or retired while selling or leasing their land to active agricultural producers. In Poland, between 2007 and 2016, the number of farms using mineral fertilizers decreased by as much as 28%. However, the above decrease should not necessarily be associated with the process of moving away from the intensification of plant production and its 'greening'. The main reason is the general trend in the reduction of the number of farms. Such process has affected small-scale farms the most, due to the phenomenon of land concentration and agricultural production of larger farms (Kopiński 2019, Wrzaszcz 2018). Therefore, a large decrease in the number of farms using mineral fertilizers was observed in Małopolskie, Podkarpackie, Świętokrzyskie and Śląskie voivodships (within 33–45%). In Lubuskie voivodeship their number decreased the most (Wrzaszcz, Kopiński 2019).

In the assessment of the intensification of plant production, the indicator of the share of farms using mineral and/

[1]NUTS – Nomenclature of Territorial Units for Statistics

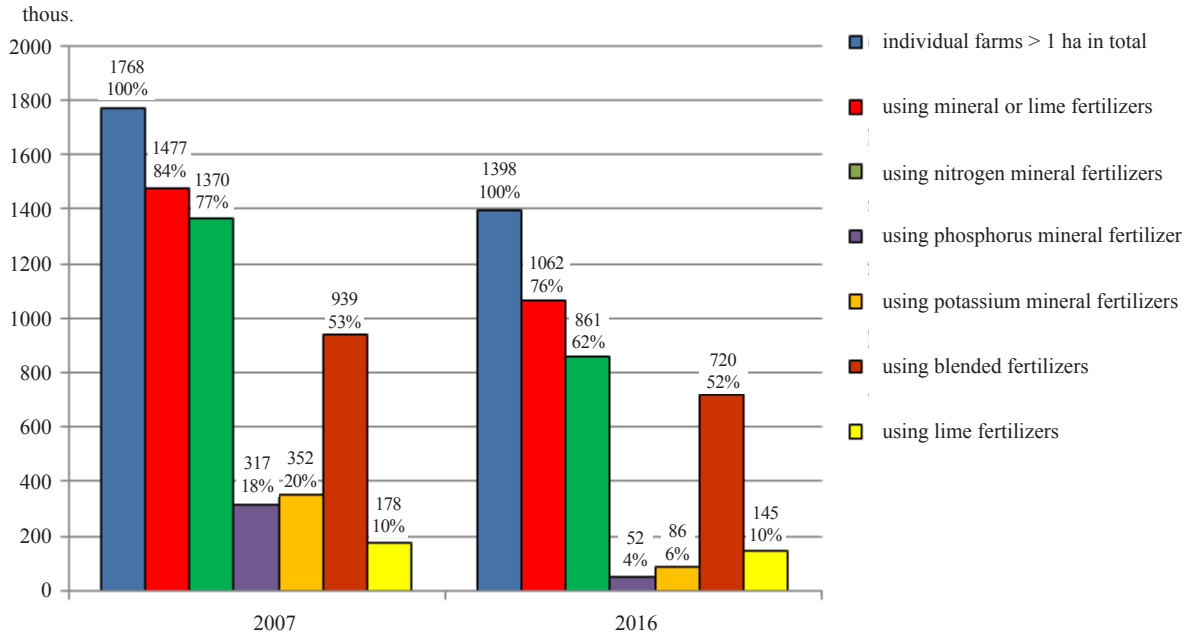

Figure 1. The number and percentage of individual farms in total and using mineral and/or lime fertilizers in 2007 and 2016 (in thous., % of total farms in analysed year).
Source: authors' research, based on FSS 2007 and 2016 data, prepared by Statistical Office in Olsztyn

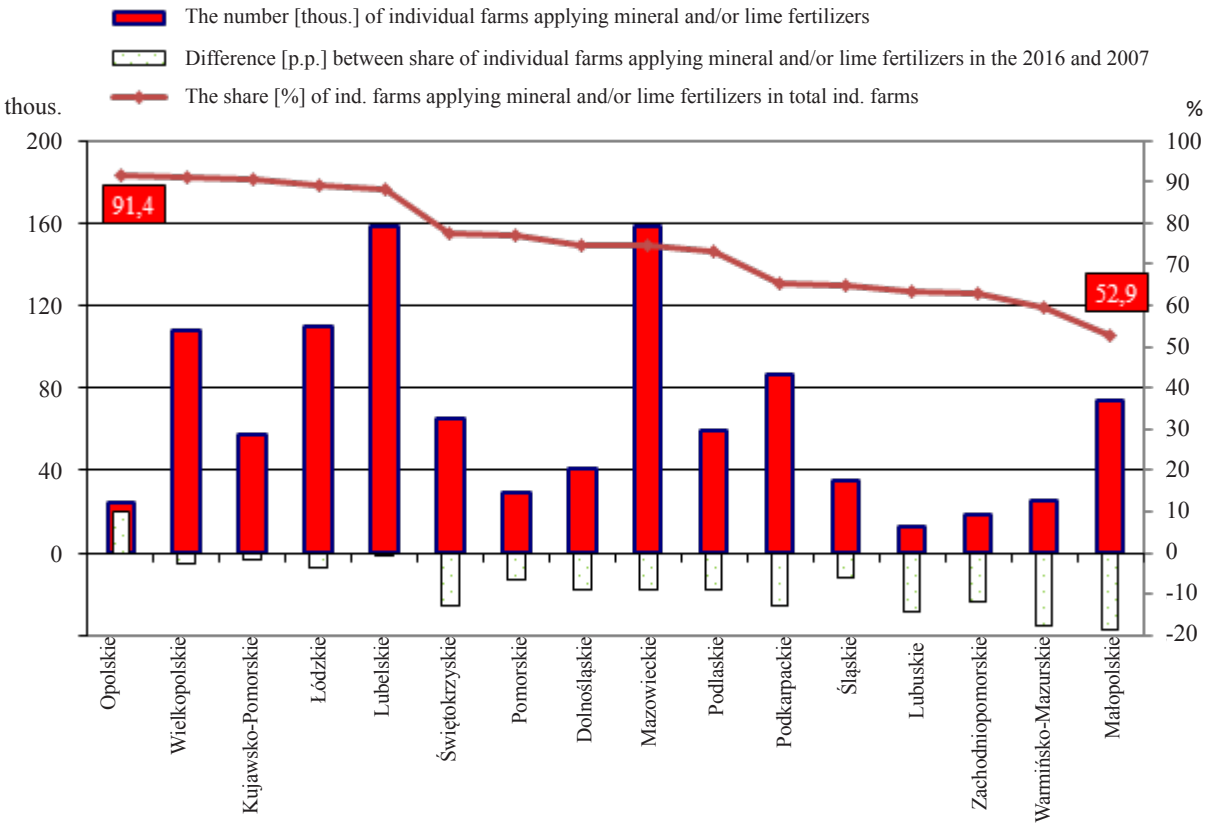

Figure 2. Territorial differentiation of the number (in thous.) and percentage (%) of individual farms applying mineral and/or lime fertilizers in 2016 and changes in this scope between 2007–2016.
Source: authors' research, based on FSS 2007 and 2016 data, prepared by Statistical Office in Olsztyn

or calcium fertilizers is quite reliable. Generally in Poland in 2016 76% of farms used mineral or calcium fertilizers. The share of these farms decreased by 8% in 2007 (Fig. 1). In voivodships with areas of so-called intensive agriculture, the dominant part of farms (over 90%) used mineral fertilizers in 2016 (Fig. 2). The relatively smallest share of such farms was in Małopolskie voivodeship, but also in Warmińsko-Mazurskie, Zachodniopomorskie, and Lubuskie. The above voivodships were also distinguished by the highest percentage of farms resigning from intensifying production by using mineral fertilizers. Only in the Opolskie voivodeship did the share of farms using mineral fertilizers increase.

In the majority of voivodships, the proportion of farms using mineral fertilizers has decreased, although these figures were only a few percentage points. However, in the case of Małopolskie and Warmińsko-Mazurskie voivodeships, significant changes in the use of fertilizers were visible, which may be one of the reasons to conclude that the intensity of plant production in these areas is falling. The above-mentioned phenomenon may result from certified or uncertified greening of agricultural production which is confirmed by the analysis concerning the paths of development of various plant production systems in Poland (Kopiński, 2019). The presented results indicate regional differentiation in terms of mineral fertilizer management. The differentiation is progressing, confirmed by the different pace of changes in the share of farms using mineral fertilizers in individual voivodships.

In Poland, individual farms apply mainly nitrogen fertilizers, followed by compound fertilizers (62% and 52% respectively in 2016, Figure 1). A worrying fact is that only 4% of farms use phosphate fertilizers. Also, a small proportion of farms use potassium mineral fertilizers (only 6%). Compared to 2007, the share of farms using nitrogen, phosphorus, and potassium fertilizers has decreased significantly, which is certainly important for the abundance of these macronutrients in the soil. However, the attention of farmers in multi-component fertilizers is at a similar level, as every second farmer applies them on their farm.

In Poland, in 2016, relatively the largest number of farms, about 80%, applied nitrogen fertilizers in the following provinces: Kujawsko-Pomorskie, Opolskie, Wielkopolskie, and Łódzkie (Fig. 3). In Małopolskie, Podkarpackie, and Zachodniopomorskie voivodeships the fertilizers were applied less frequently than in every second

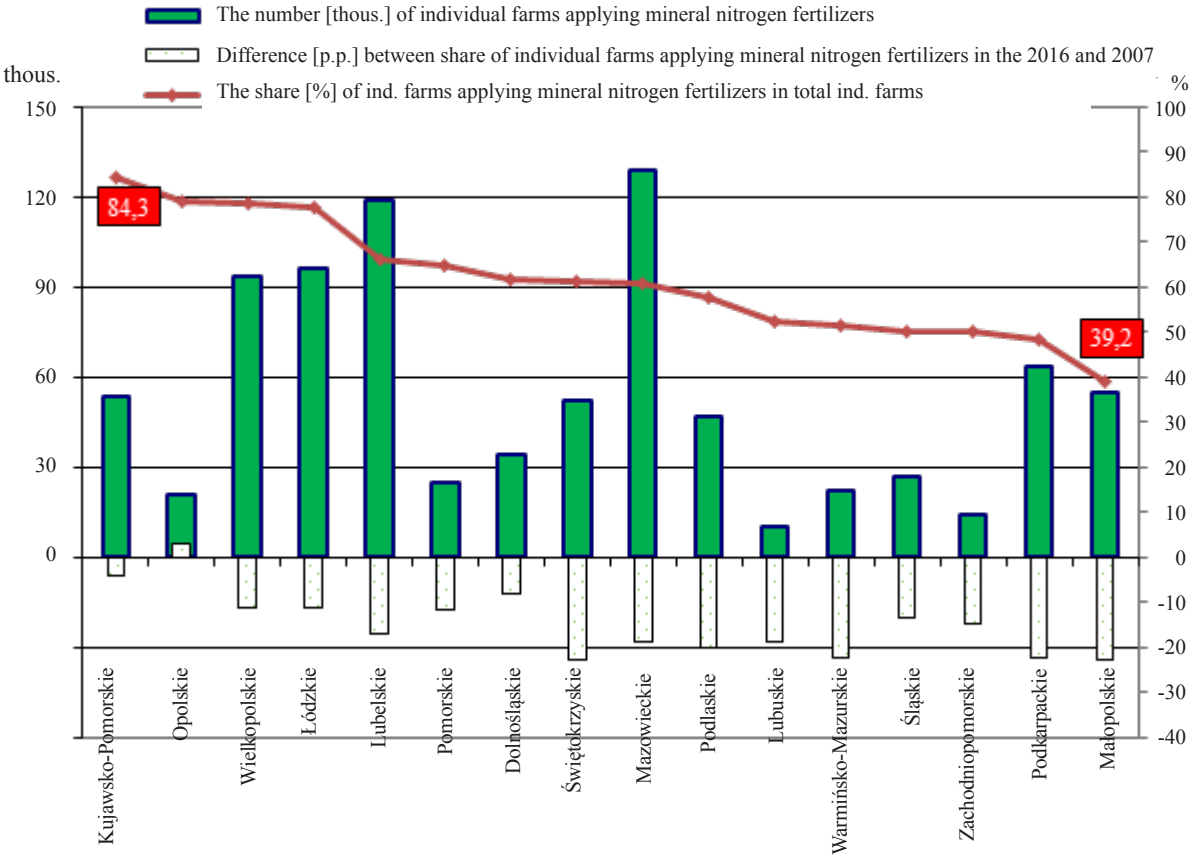

Figure 3. Territorial differentiation of the number [thous.] and percentage [%] of individual farms applying mineral nitrogen fertilizers in 2016 and changes in this scope between 2007–2016.

Source: authors' research, based on FSS 2007 and 2016 data, prepared by Statistical Office in Olsztyn

farm. Thus, mineral nitrogen fertilizers are much less frequently chosen by farmers with larger areas of permanent grassland. Taking into account the changes in the application of nitrogen fertilizers in 2007–2016, it can be concluded that apart from the Opolskie voivodeship, the percentage of farms using nitrogen fertilizers has decreased. However, the pace of change has varied. Major decreases were observed in Podkarpackie and Małopolskie voivodeships, as well as Świętokrzyskie, i.e. regions with a relatively low share of farms using such fertilizers. Simultaneously, the shifts were small in the case of regions where the majority of farms use mineral nitrogen fertilizers, which is confirmed by the progressing regional diversification and polarisation of farms in terms of nitrogen management.

The data presented in Figure 4 show that most mineral nitrogen fertilizers are used in farms with an area of 25–49.99 ha of UAA (83% of total farms in particular area group). Much less frequently (by 8.5%) such mineral fertilizers were used in farms with an area of 5–24.99 ha. On the other hand, in every second farm, mineral nitrogen fertilizers were applied the least frequently (1–4.99 ha), which indicates a much lower intensity of agricultural production in the farms.

Most soils in Poland are by nature strongly or moderately acidic, with low water and nutrient retention capacity as well as low organic matter content. Such unfavorable conditions of agricultural production also deepen the processes of anthropogenic acidification (Filipek, Skowrońska 2013). The environmental effect of soil acidification is a spatial reduction of the root system, leading to plant dysfunction in the entire soil profile. As a consequence, increased leaching of nitrates, chlorides, sulfates, and difficult uptake of cations, mainly calcium and magnesium, occurs (Grzebisz et al., 2013). This is particularly dangerous in conditions of unfavorable proportions between nitrogen, phosphorus, and potassium used in mineral fertilizers to the detriment of phosphorus and potassium (Kopiński, 2017).

Given the high proportion of acidic and very acidic soils as well as the high effect of soil pH on the effectiveness of essential nutrients consumption, the low interest in lime fertilization in Poland (Ochal, Kopiński, 2017) is particularly worrying. Although the percentage of farms using calcium fertilizers is stable and in 2007 and 2016 amounted to 10% (Fig. 1), the current state raises concerns in confrontation with the actual demand for regulation of soil pH and the nutritional needs of cultivated plants. The satisfactory plant supply with nutrients creates optimal conditions for their growth and development.

The regional variation in the use of calcium fertilizers is very high, from 20% in the Opolskie voivodship to about 3% of farms in the Podkarpackie and Małopolskie voivodships (Fig. 5). A much higher percentage of such farms is observed in the voivodships of western Poland, as opposed to the south of the country. It is worth emphasizing the fact that in most voivodships there has been an increase in the share of farms with calcium fertilization applied in 2007–2016. Such an observation was particularly true of the Opolskie and Wielkopolskie voivodships, while in the Dolnośląskie and Lubuskie voivodships this indicator decreased the most. The regional differentiation has also deepened in this respect. The presented data for particular area groups of farms indicate that with the increase in the area of agricultural land the interest of farmers in calcium fertilization also increases (Fig. 6). The aforementioned results indirectly demonstrate the importance of the economic (cost) and social factor, since farmers managing larger farms have greater possibilities undertaking such activities.

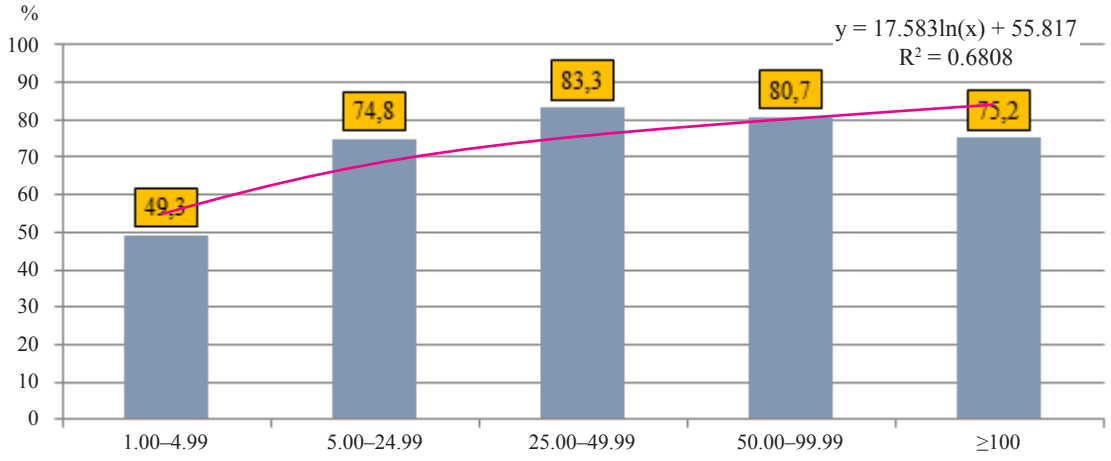

Figure 4. Share of farms applying nitrogen mineral fertilization in relation to the total farms in particular area groups of farm (in ha of UAA) in Poland in 2016.

Source: authors' research, based on based on FSS 2007 and 2016 data, prepared by of Statistical Office in Olsztyn

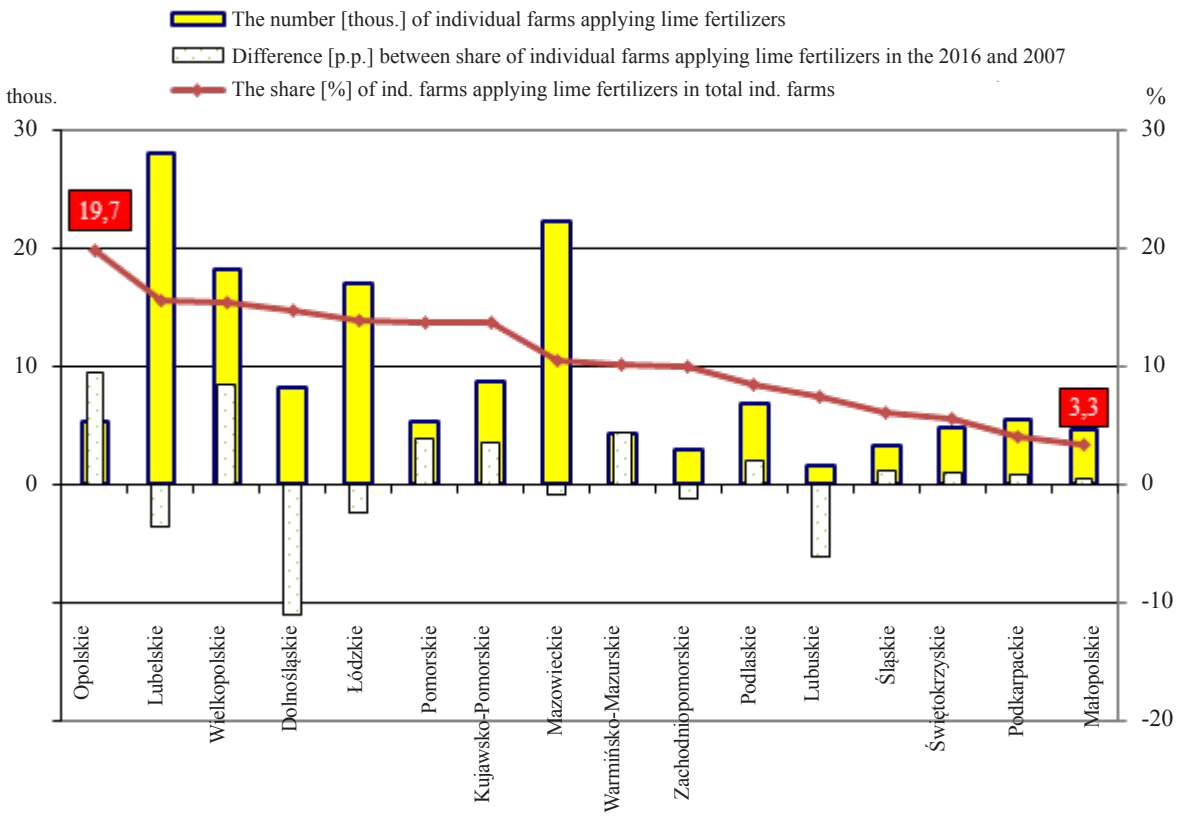

Figure 5. Territorial differentiation of the number (in thous.) and percentage (%) of individual farms applying mineral lime fertilizers in 2016 and changes in this scope between 2007–2016.
Source: authors' research, based on FSS 2007 and 2016 data, prepared by Statistical Office in Olsztyn

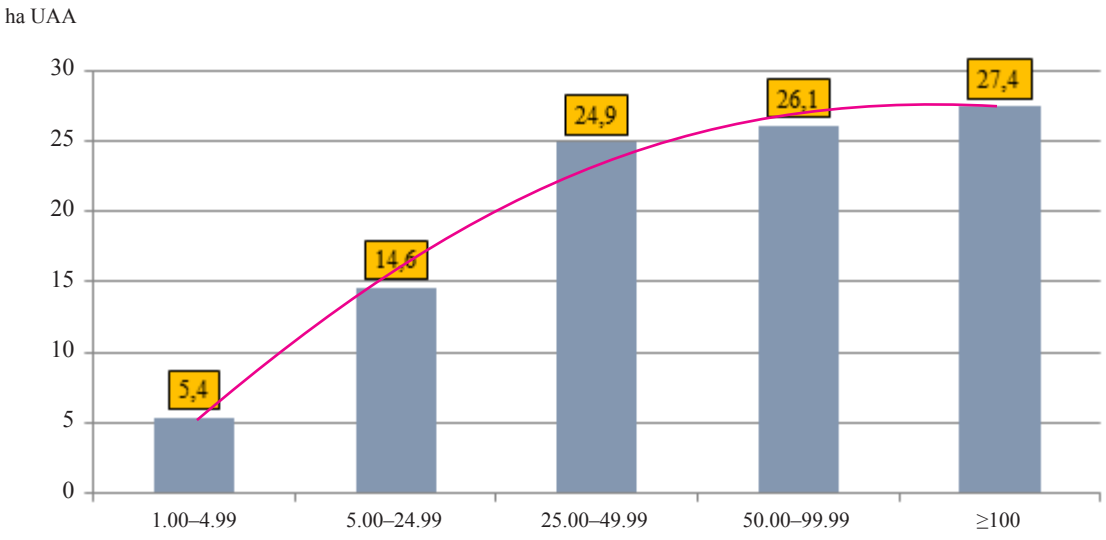

Figure 6. Share of farms applying lime mineral fertilization in relation to the total farms in particular area groups of farm (in ha of UAA) in Poland in 2016.
Source: authors' research, based on FSS 2007 and 2016 data, prepared by Statistical Office in Olsztyn

The level of nutrient consumption in mineral fertilizers

The level of consumption of mineral fertilizers, especially nitrogen fertilizers in Poland, which is mainly related to the intensity of agricultural production, is very diversified regionally. Therefore, it is often considered as a measure of farming intensity, e.g. for making comparisons between production technologies, farms, or administrative units, e.g. voivodships (NUTS-2). Average fertilizer indicators for a country do not reflect the actual situation and changes taking place in different parts of the country. While across Poland's agriculture the average unit nitrogen consumption was 76 kg N ha^{-1} UAA in 2016–2019, the differences between the voivodships are even almost threefold (Fig. 7).

In recent years, as a result of intensified processes of specialization, concentration and polarization of production, the existing differences between Poland's regions have further deepened. The amount of mineral fertilizer consumption is to a large extent determined by the diversity of area structure and organizational and economic level of farms in Poland. Within a dozen or so years following the period 2002–2004, i.e. before Poland acceded to the European Community (EC) structures there was an increase in nitrogen consumption by 24 kg N ha^{-1} UAA, i.e. by about 46%. According to other analyses (Wrzaszcz, Kopiński, 2019), such a strongly upward trend was slightly inhibited in 2008 as a consequence of the global financial crisis, and in 2009–2017, after a reduction in the use of nitrogen fertilizers, there was a return to a high level of their application.

The data presented in Figure 7 show that in 2016–2019, the highest intensity of plant production, measured by the level of nitrogen consumption in mineral fertilizers, was observed in the Dolnośląskie, Kujawsko-Pomorskie i Opolskie voivodeships (over 95 kg ha^{-1} UAA). During the period, the lowest rates were applied in the Małopolskie and Podkarpackie voivodeships (up to 45 kg ha^{-1} UAA). The level of nitrogen consumption in mineral fertilizers increased, although at a different pace in all voivodeships.

The average nitrogen consumption in individual farms in 2016 was about 6 kg lower than in total Polish agriculture (Fig. 7). In 2007, the highest increase in nitrogen consumption in mineral fertilizers was observed in individual farms in the Dolnośląskie (by 38) and Opolskie voivodeship (by 75%). During the period, there was a decrease in nitrogen consumption in mineral fertilizers (relative and absolute) in several voivodeships and this concerned individual farms in the following voivodships: Warmińsko-

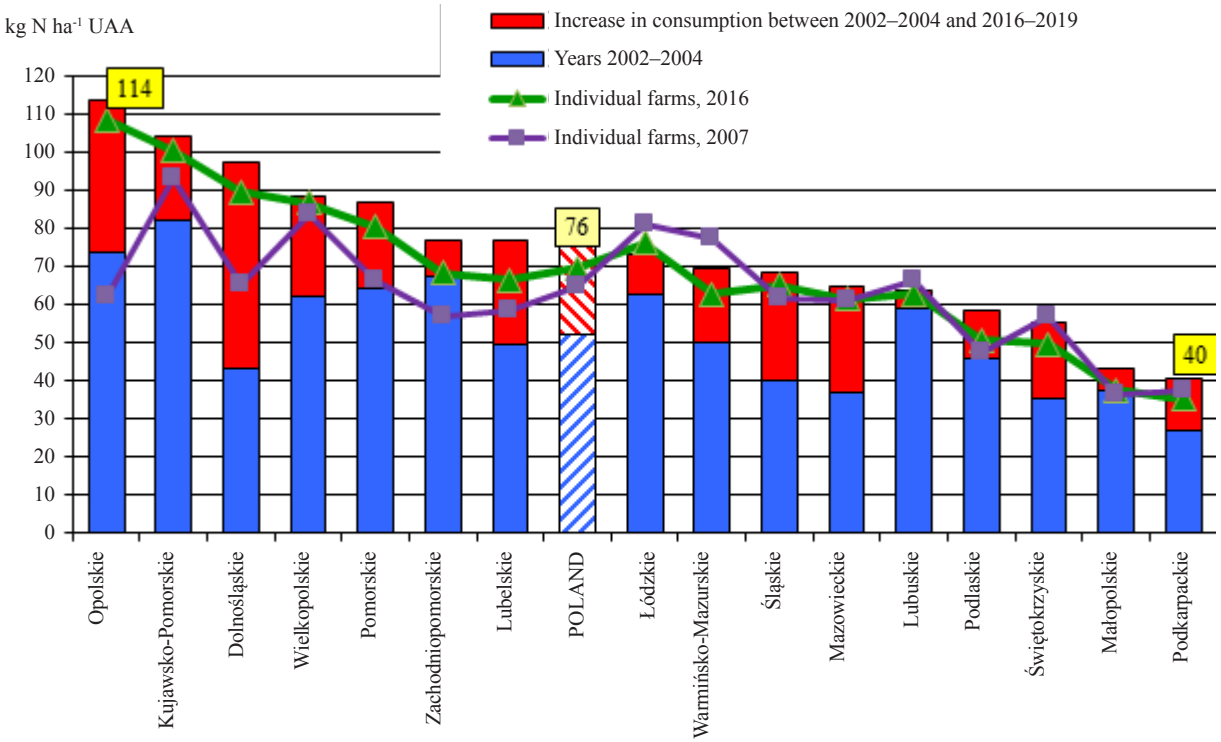

Figure 7. The level of nitrogen N consumption in total mineral fertilizers in Polish agriculture between 2002-2004 and 2016-2019 and on individual farms in 2007 and 2016.

Source: authors' research, based on FSS 2007 and 2016 data, prepared by Statistical Office in Olsztyn

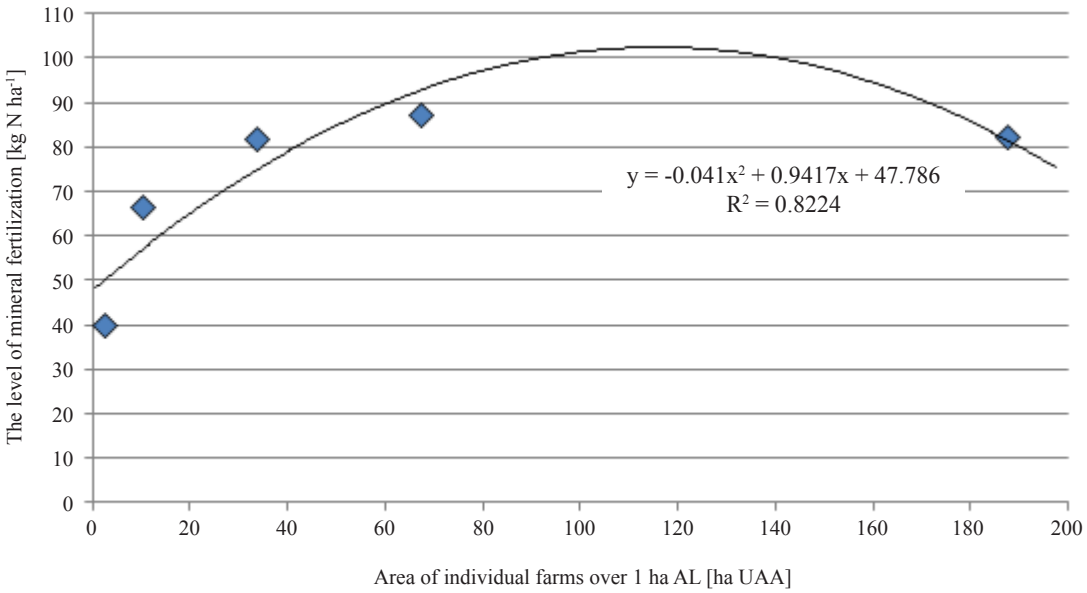

Figure 8. Polynomial regression 2º between the area of the farm and the level of mineral fertilization with nitrogen in Poland, data for individual farms in 2016.
Source: authors' research, based on data of GUS and data of Statistical Office in Olsztyn

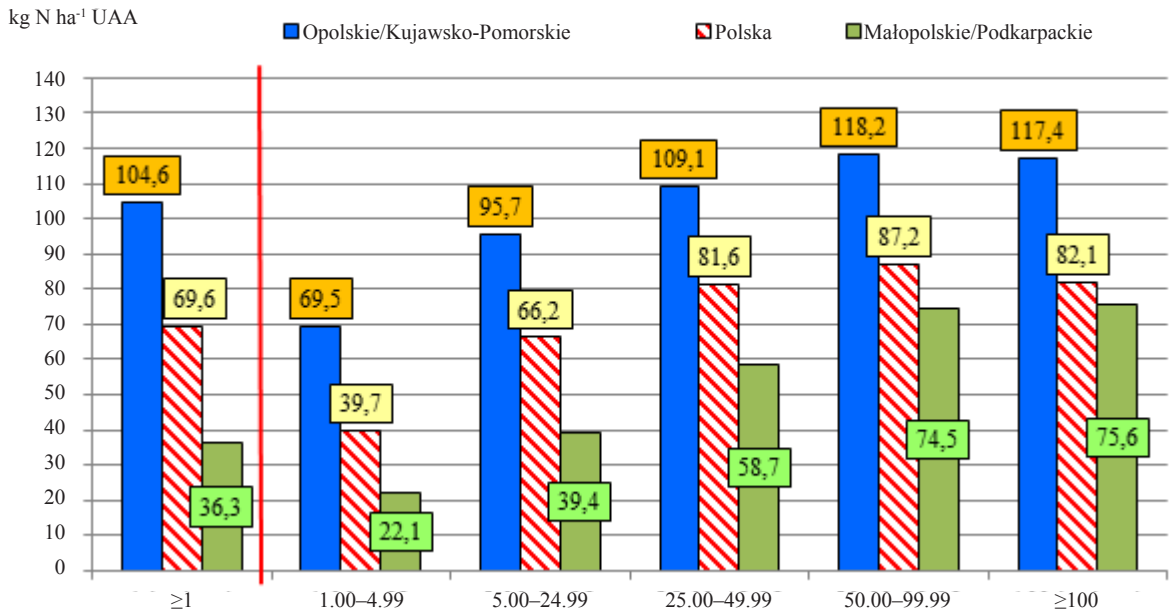

Figure 9. Nitrogen consumption (N) in mineral fertilizers in particular area groups of farms (in ha of UAA) in Poland and selected groups of voivodships in 2016.
Source: author's research, based on data of GUS and data of Statistical Office in Olsztyn

Mazurskie, Świętokrzyskie, as well as Podkarpackie, Łódzkie, and Lubuskie. The observed phenomenon is a confirmation of the deepening polarization in Polish agriculture in terms of plant production intensity (Kopiński, 2013, Kopiński, 2019).

The level of nitrogen consumption in mineral fertilizers in Poland is increasing along with the increase in the agricultural holding area structure. The growth is suppressed in farms with 100 or more hectares of UAA (Fig. 8). Although differences in the level of nitrogen fertilization intensity between individual voivodships were found, the above regularity applies to all voivodships. A large variation between farms of the same size from different regions of Poland is also observed. The above diversity diminishes with the increase in the area of farms. Furthermore, the relation between consumption, e.g. in the group of Opolskie and Kujawsko-Pomorskie voivodships and Małopolskie and Podkarpackie voivodships varies from 3.1 in the farm area range of 1–4.99 ha to 1.55 in farms with an area of 100 ha UAA and more (Fig. 9).

Similar trends, although weaker than for nitrogen, are also visible concerning phosphorus consumption in mineral fertilizers (the second biogen after nitrogen). In 2016–2019, the average consumption of phosphorus in Poland was 23 kg P_2O_5 ha^{-1} UAA, after an increase of 4 kg compared to the level in 2002–2004 (Fig. 10). The use of phosphorus fertilizers in Poland is characterized by a slightly upward trend, with low variability, and the annual increase not exceeding 0.5 kg P_2O_5 ha^{-1} UAA.

The highest rates of phosphorus in mineral fertilizers have been applied for many years in south-western and western Poland, while the lowest ones, except for the Lubuskie voivodeship, in the east (Fig. 10). The differences between the leading Opolskie voivodeship 33 kg P_2O_5 ha^{-1} UAA) and Lubuskie and Warmińsko-Mazurskie (15–16 kg P_2O_5 ha^{-1} UAA) are over twofold. The Lubuskie voivodship, next to the Pomorskie voivodship, has experienced the biggest decrease in phosphorus consumption in mineral fertilizers over the last several years. Thus, Małopolskie and Podkarpackie voivodships, considered to be extensive in terms of plant production intensity, are classified higher in terms of phosphorus consumption than Lubuskie and Kujawsko-Pomorskie voivodships.

The national trend in phosphorus application was not confirmed by data concerning phosphorus consumption in mineral fertilizers in individual farms (Fig. 10). Between 2007 and 2016, an average decrease by 15%, i.e. by 4 kg P_2O_5 ha^{-1} UAA in the level of mineral phosphorus fertilization was recorded. Such a tendency was visible in farms in most voivodships. The highest reduction in mineral phosphorus fertilizers application in individual farms, as well as in agriculture in general, was observed in Lubuskie and

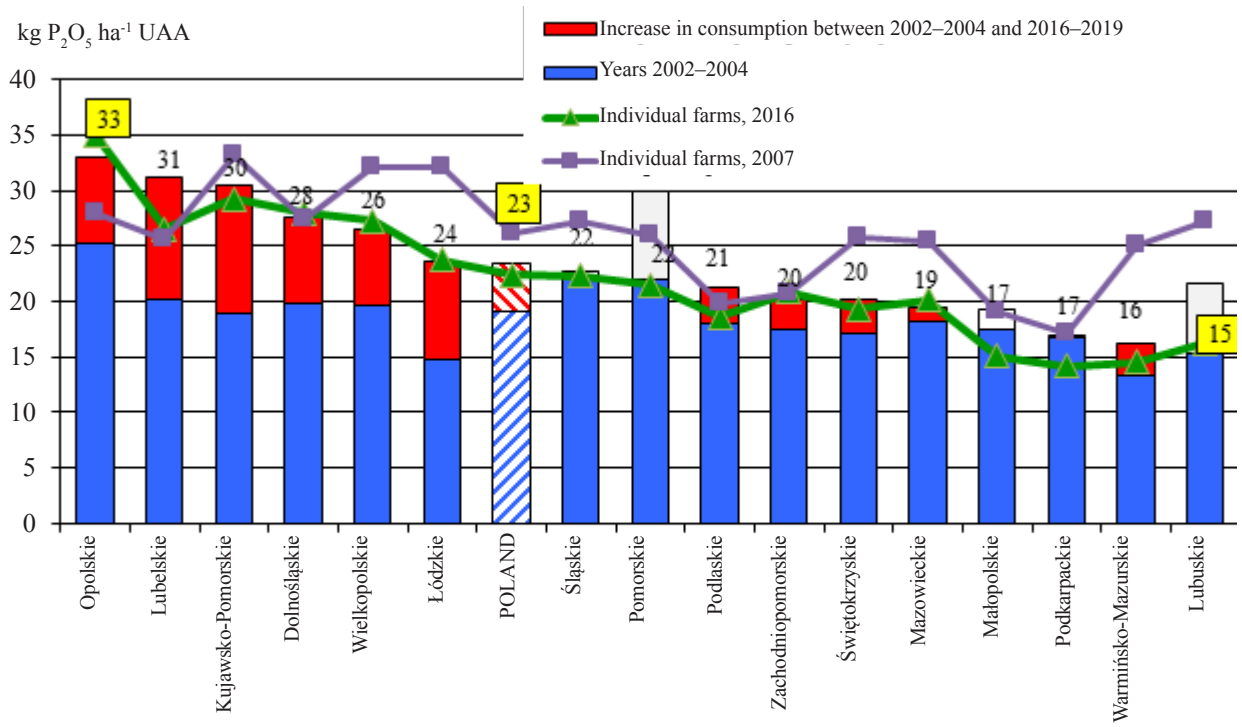

Figure 10. The level of phosphorus P_2O_5 consumption in total mineral fertilizers in Polish agriculture between 2002-2004 and 2016-2019 and on individual farms in 2007 and 2016.
Source: author's research, based on data of GUS and data of Statistical Office in Olsztyn

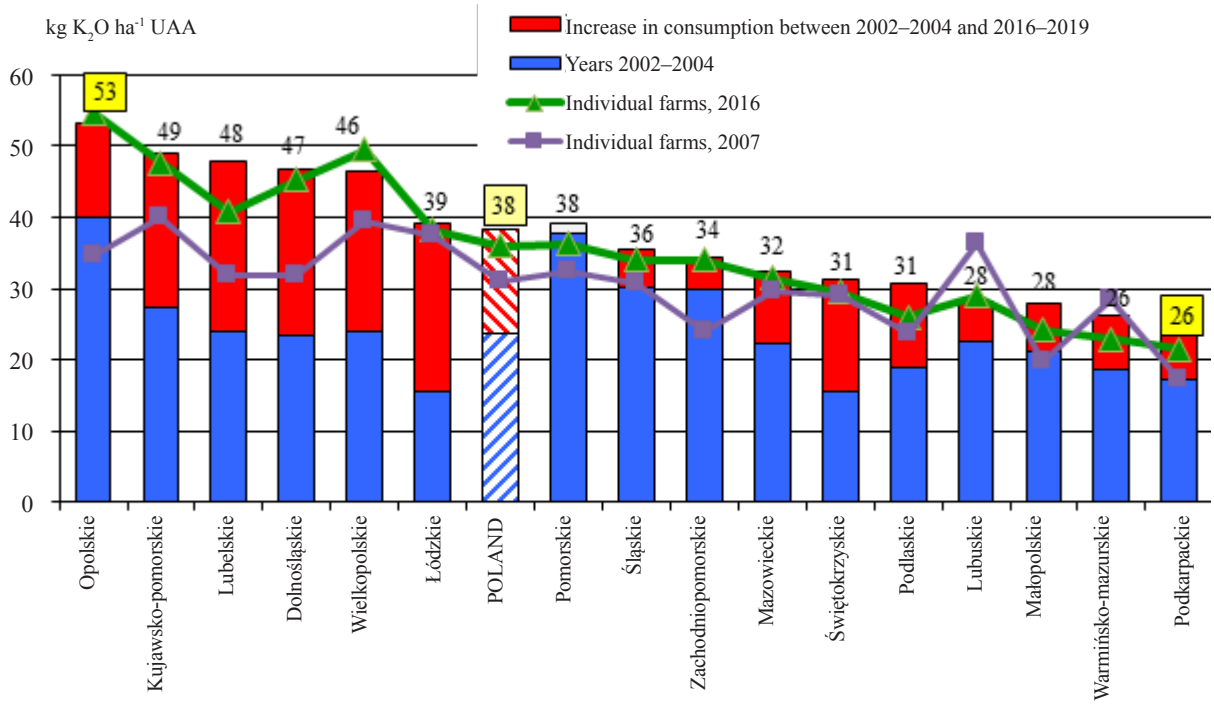

Figure 11. The level of potassium K_2O consumption in total mineral fertilizers in Polish agriculture between 2002–2004 and 2016–2019 and on individual farms in 2007 and 2016.
Source: author's research, based on data of GUS and data of Statistical Office in Olsztyn

Warmińsko-Mazurskie voivodships. The unit phosphorus consumption in individual farms in 2016 was at a similar level to the average use in 2016–2019 in Polish agriculture in general, 22 and 23 P_2O_5 ha^{-1} UAA, respectively.

The observed low level of phosphorus consumption in mineral fertilizers, below 20 kg P_2O_5 ha^{-1} UAA in farms of several voivodeships, may be alarming, considering the fact that the most soils in above voivodeships are with very low and low phosphorus content (Jadczyszyn, Kopiński, 2013; Kopiński, 2016).

The current unit potassium consumption (2016–2019) amounts to 38 kg K_2O ha^{-1} UAA (Figure 11). Previous (Kopiński, Ochal, 2013), as well as current data, show that the annual growth of potassium fertilizer consumption in Poland is about 1 kg K_2O ha^{-1} UAA. Between the years 2002–2004 and 2016–2019, an increase in the level of applied potassium rates in mineral fertilizers was recorded in most voivodeships, except Pomorskie. Such a trend was also observed in the case of individual farms between 2007 and 2016. In the farms of most voivodeships an increase in the applied rates of potassium was noted, except for Lubuskie and Warmińsko-Mazurskie voivodeships. These two regions, apart from Małopolskie and Podkarpackie, are characterized by the lowest domestic potassium consumption in mineral fertilizers, not exceeding 20 kg K_2O ha^{-1} UAA (Fig. 11). Definitely, the highest rates of potassium in mineral fertilizers are applied in agriculture in general, including individual farms, in the Opolskie, Kujawsko-Pomorskie, Lubelskie, Dolnośląskie, and Wielkopolskie voivodeships. Apart from Lubelskie, these voivodeships belong to the FADN "Wielkopolska i Śląsk" macroregion, which stands out in terms of the high intensity of plant production. (Skarżyńska et al., 2005). Increased potassium consumption in most Polish voivodeships should be considered a positive phenomenon, especially in conditions of increasingly frequent droughts in Poland (Piniewski et al., 2020).

The soil reaction, greatly conditioned by the liming treatment, is a very important element of a balanced fertilization system. Soil acidification in Poland is largely natural, yet it is also caused by anthropogenic factors. Many soils in Poland, due to the type of parent rock, exhibit an acidic and very acidic reaction. Soil pH is the easiest measurable indicator of soil quality. The pH_{KCl} values below 4.5 indicate the risk of soil environment degradation (Fotyma, Zięba 1988; Filipek, 2001; Grzebisz et al. 2006; Ochal, 2012; Rutkowska 2018). Lime fertilization is a fundamental treatment against acidification and its negative effects on the environment, as it has a multifaceted impact on the physical, physicochemical, and biological properties of soil. Besides, it promotes an increase in the microbiological activity of the soil environment, activating mineralization processes, increasing the availability and efficiency of some mineral components (Ochal, Kopiński, 2017).

The accession of Poland into the EC and the inclusion of agriculture in the Common Agricultural Policy (CAP) resulted in the abandonment of subsidizing calcium fertilizers, which resulted in a significant reduction in their consumption. The level of lime consumption decreased from 94 kg CaO ha^{-1} UAA in 2002–2004 to 59 kg CaO ha^{-1} UAA in 2016–2019, i.e. by 37% (Fig. 12). The lime fertilizer consumption is therefore lower than the nitrogen consumption in mineral fertilizers. The reduction of lime application has intensified especially strongly since 2007. However, from 2013, its consumption is slowly increasing (Kopiński, 2018). Over the last dozen or so years, concerning 2002–2004, the level of lime consumption has decreased in all voivodeships, except for Wielkopolskie, Mazowieckie, and Lubuskie.

Over the voivodeships, farm to farm differences in the level of lime consumption (in kg CaO ha^{-1} ha UAA) are much higher than in the case of other fertilizer components. Such differentiation is somewhat indicative of the level of agricultural culture and the nature of plant production, including the environmental context. Among individual Polish farms, the highest CaO rates in calcium fertilizers, amounting to 225 kg CaO ha^{-1} ha UAA, are applied in the Wielkopolskie voivodeship (Fig. 12). The rates are nearly two times higher than in the Opolskie voivodeship and almost three times higher than in the Dolnośląskie and Kujawsko-Pomorskie. The distribution of CaO rates is irregular in Poland. The lowest CaO rates were applied in Podlaskie, Małopolskie, Podkarpackie, and Świętokrzyskie voivodeships (below 23 kg ha^{-1} UAA). The calcium consumption in 2016 was significantly higher than in 2007 in individual farms in all voivodeships. The size of the farm area using lime fertilizers has a significant impact on the above process. Since 2007 in Poland, there has been an increase in the area of land subjected to liming is and in 2016 it amounted to 2511 thousand ha UAA (Wrzaszcz, Kopiński, 2019).

In farms applying liming, nearly 350 kg of CaO were used per 1 ha of UAA in 2016 in Poland (Fig. 13). Considering 2007, the dose increased by 86%. A slight decrease in the level of CaO consumption was observed only in farms from the Warmińsko-Mazurskie voivodeship. It should be mentioned that liming is often applied to new land that has been, acquired by purchase or lease (Wrzaszcz, Kopiński, 2019). To some extent, this applies to individual farms in the Wielkopolskie voivodeship, where the average level of CaO fertilization per 1 ha of UAA increased, between 2007 and 2016, by almost 270%, reaching the level of about 880 kg per ha of used area.

A widely observed phenomenon was the application of lime fertilizers in voivodeships with intensive plant production, i.e. Wielkopolskie, Kujawsko-Pomorskie, and

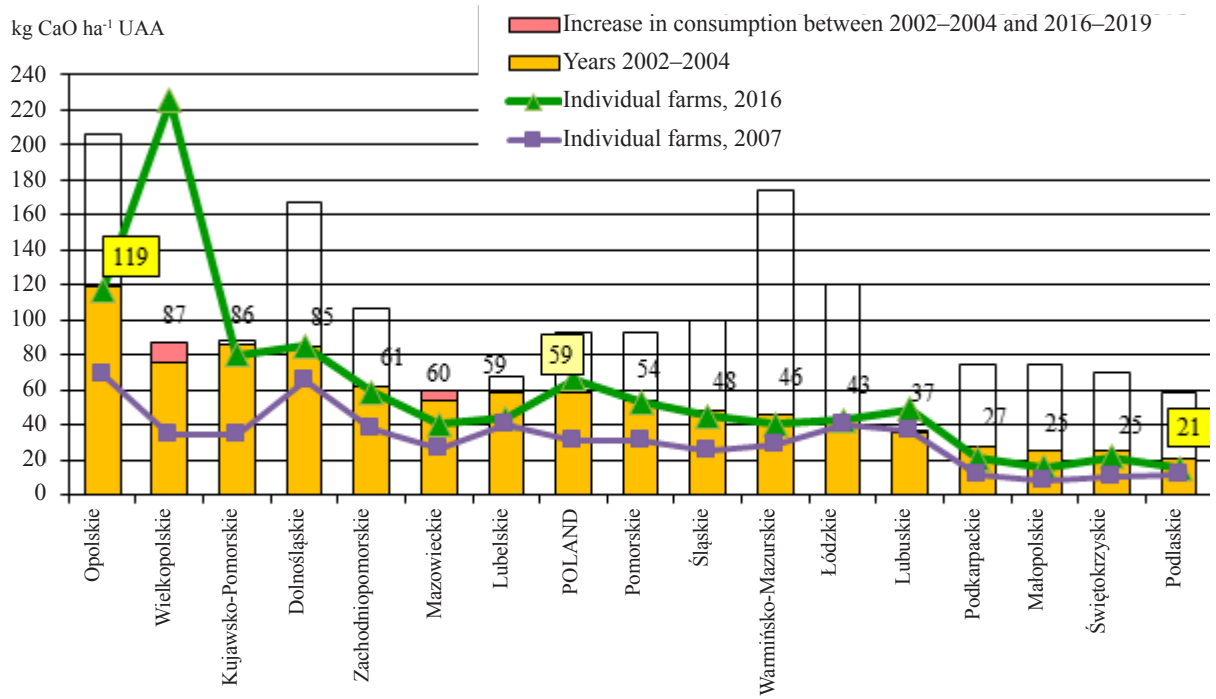

Figure 12. The level of lime consumption (CaO) in total mineral fertilizers in Polish agriculture between 2002–2004 and 2016–2019 and on individual farms in 2007 and 2016 (colorless bars indicate a decrease).
Source: author's research, based on data of GUS and data of Statistical Office in Olsztyn

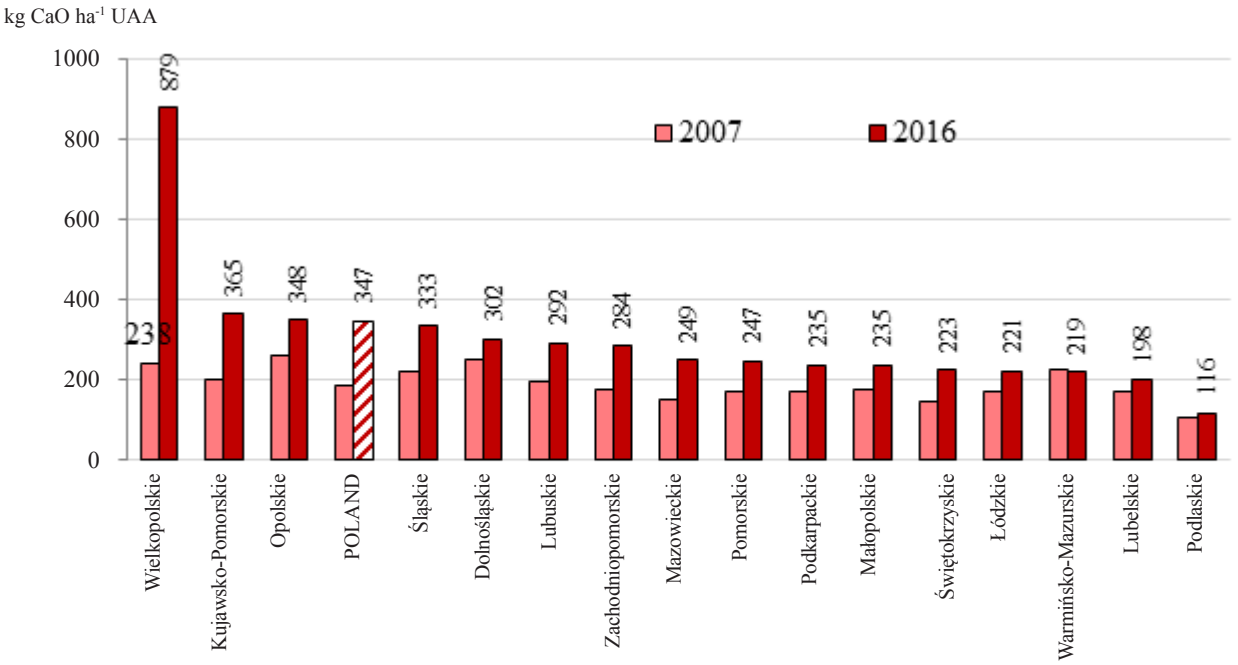

Figure 13. The average level of lime consumption (kg CaO·ha^{-1} UAA) in total mineral fertilizers in Polish agriculture between 2002–2004 and 2016–2019 and on individual farms in 2007 and 2016.
Source: author's research, based on data of GUS and data of Statistical Office in Olsztyn

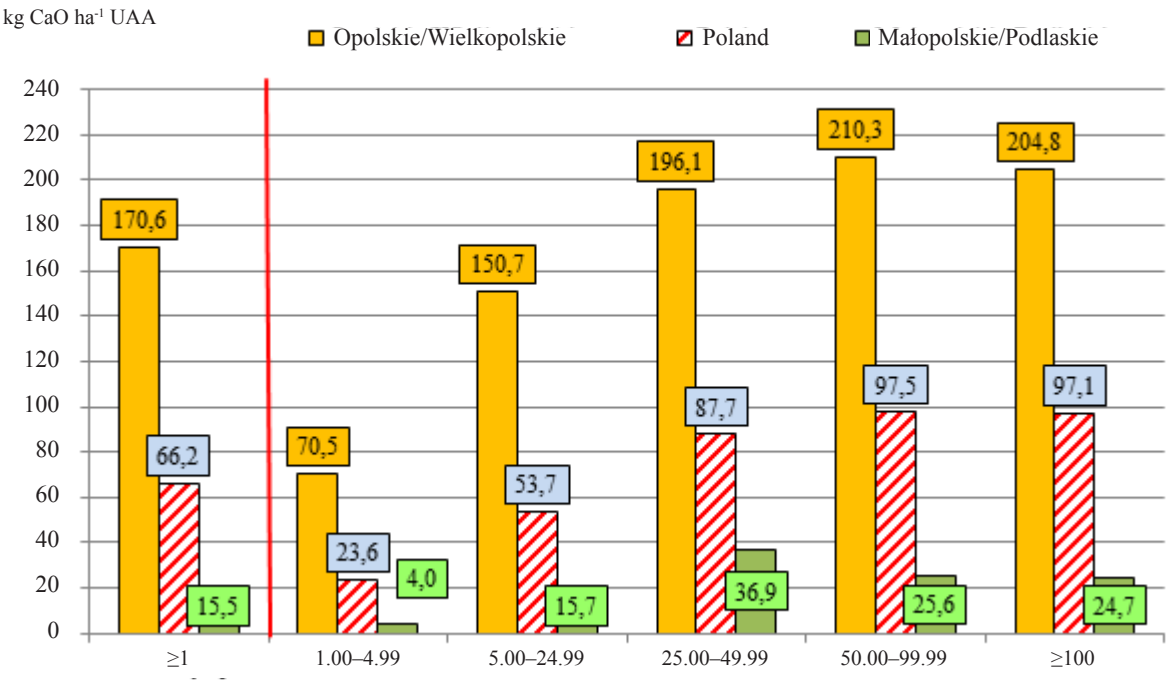

Figure 14. Lime consumption (CaO) in mineral fertilizers in particular area groups of farm sizes (in ha of UAA) in Poland and selected groups of voivodships in 2016.
Source: author's research, based on data of GUS and data of Statistical Office in Olsztyn

Opolskie. Therefore, every initiative that is addressed to farms with an area of up to 75 ha of UAA (NFOŚiGW, 2020) including the "Programme of environmental regeneration of soils by liming", is so important.

The data in Figure 14 show that the level of fertilizer lime consumption increases with the size of the area of an individual farm, up to 100 ha of UAA. However, according to the indicator, the differences in the level of CaO consumption intensity are also visible. In the group of individual farms with an average and larger area, i.e. with 50 and more hectares of UAA, from the Wielkopolskie and Opolskie voivodeships, the applied rates are 8 times higher than in farms of the same size from the Podlaskie and Małopolskie voivodhips (Figure 14). In small-sized farms up to 5 ha of AL from Podlaskie and Małopolskie voivodeships, the average rate of fertilizer lime amounts only to 4 kg CaO ha^{-1} UAA. The data analysis reveals that organizational parameters (related to the area of the farm) are an equally strong determinants of fertilizer lime consumption as the location ones (geographical, spatial, administrative). The results of the analyses confirmed previous beliefs about significant regional differentiation of Polish agriculture in terms of agricultural production intensity (Krasowicz, 2009; Kopiński, 2013).

SUMMARY

Accurate fertilizer management is one of the most important indicators of sustainable farming. On the one hand, it should result in satisfactory crop productivity, deriving from the production and economic output of the agricultural producer, while on the other hand, it should not generate environmental pressure. Such fertilizer management is undoubtedly a challenge not only to farmers but also to other stakeholders. Therefore, research in the area of fertilizer disposal is becoming increasingly important, both from the perspective of farmers (being guided by the economic criterion, which depends on the productivity of agriculture and its cost) and of the decision-makers responsible for shaping agricultural policy, which, with each successive financial perspective, increasingly stresses the need for rational management in the natural environment. An essential role in fertilizer economy is played by mineral fertilizers, as evidenced by their dominant share in the fertilization structure of cultivated plants.

The results revealed regional differentiation in the management of mineral and calcium fertilizers. The fact is also evidenced by the different pace of changes in the share of farms using mineral and calcium fertilizers in particular voivodeships. On a national scale, in 2016, 76% of farms applied any mineral or calcium fertilization, and their share decreased by several percentages in relation to 2007. The generic structure of applied mineral fertilizers changed under study.

Over the estimated 10 years, nitrogen fertilizers remain the dominant mineral fertilizers, and farmers have been phasing out phosphate and potassium fertilization. This is evidenced by the decreasing percentage of farms using such mineral fertilizers. At the same time, the presented results indicate that the interest of farmers in multicomponent fertilizers has been maintained. The decreasing variety of mineral fertilizers used is also evident.

Nitrogen fertilizers are among the most popular mineral fertilizers used by individual farmers. Nitrogen is the main, but not the only, yield-forming component. The highest percentage of farms where mineral nitrogen fertilizers are applied is in voivodeships with intensive plant production (Kujawsko-Pomorskie, Opolskie, Wielkopolskie), as opposed to the south of Poland. The pace of changes also indicates a deepening regional diversification in nitrogen fertilizer management.

Taking into account the state of soil acidification in Poland, calcium fertilizers are of great economic and environmental importance. Their properties in neutralizing soil acidification determine their multilateral significance. In Poland, calcium fertilizers are relatively rarely used on farms (only 10% of farms). This is mainly due to economic (cost) reasons, as well as awareness-raising, as statistics on the pH-ratio indicate an urgent need to popularize such practices. Financial support for various environmental measures should encourage farmers to lime their soils, which will bring both considerable benefits for the farmer and the soil environment.

The level of mineral fertilizers consumption, especially nitrogen fertilizers in Poland, is mainly related to the intensity of agricultural production and is very diversified regionally. Average domestic fertilizer indicators do not reflect the actual situation and changes taking place in its parts. While in the whole Polish agriculture, the average level of nitrogen consumption in mineral fertilizers was 76 kg ha^{-1} UAA in 2016–2019, the differences between the voivodeships are almost threefold. The amount of mineral fertilizer consumption is to a large extent determined by the diversity of farm area size structure and the farm organizational and economic level in Poland. A general phenomenon, which relates not only to nitrogen, is the tendency to rise in fertilization together with the increase of the farm area size.

Concerning the period preceding Poland's accession to the European Community (EC) structures, over the next dozen or so years the increase in nitrogen consumption in mineral fertilizers by 24 kg N ha^{-1} UAA, i.e. by about 46% was noted. Such increase in production intensity resulted to some extent also from the shrinkage of land resources (area of agricultural land), constituting the production potential of agriculture (Kopiński, 2017; 2019). Different directions of trends in mineral nitrogen consumption by individual farms in different voivodeships since 2007 confirm

the deepening polarization of plant production intensity in Poland.

Similar trends, although weaker than for nitrogen, concern phosphorus consumption. The consumption of P component in Poland in the years 2002–2019 is characterized by a slightly increasing trend, with low variability, and the annual increase does not exceed 0.5 kg P_2O_5 ha^{-1} UAA. The highest phosphorus rates in mineral fertilizers have been applied for many years in south-western and western Poland, and the lowest rates, except for the Lublin voivodeship, in the east of the country. The observed low level of phosphorus consumption in mineral fertilizers, below 20 kg P_2O_5 ha^{-1} UAA in individual farms of several voivodships, is disturbing in conditions of very low and low soil phosphorus content.

In Poland, an upward trend in the level of applied rates of potassium in mineral fertilizers has been observed over a dozen years. An average annual increase in the consumption of K component in mineral fertilizers in Poland is about 1 kg K_2O ha^{-1} UAA. The highest rates of potassium are applied in the Opolskie, Kujawsko-Pomorskie, Lubelskie, Dolnośląskie, and Wielkopolskie voivodships. Increasing potassium consumption in growing drought conditions should be regarded as a positive trend.

Poland's accession to the EC and the agriculture inclusion into the Common Agricultural Policy (CAP) resulted in a significant reduction in the use of calcium fertilizers. The average level of lime consumption decreased from 94 to 59 kg CaO ha^{-1} UAA in 2016–2019. Such a trend concerns the majority of Polish voivodeships, except for Wielkopolskie, Mazowieckie, and Lubuskie. Differences in the level of fertilizer lime consumption in individual farms between voivodships are much greater than in the case of other fertilizer components. The above confirms the level of agricultural culture and the nature of plant production.

The level of CaO consumption is irregular in Poland. On average, it is lowest in Podlaskie, Małopolskie, Podkarpackie, and Świętokrzyskie voivodships. Less differentiated CaO rates are found in the group of farms that perform liming. In such farms, an average of 350 kg of CaO per ha of UAA is applied. Wielkopolskie Voivodeship stands out for liming rate in the country, where the CaO consumption regulating the soil reaction amounts to 879 kg CaO ha^{-1} UAA. According to the carried out research, the liming (rate level) increases with the size of farms. On all farms small in area (up to 5 ha UAA), in Podlaskie and Małopolskie voivodships among others, the average level of applied lime fertilizer is slight (only 4 kg CaO ha^{-1} UAA).

In consideration of the presented research results, organizational factors (related to the area of the farm) are as strong determinants of fertilizer consumption as those related to location (geographical, administrative).

REFERENCES

Bułkowska M., 2011. Efekty WPR w odniesieniu do rolnictwa. pp. 56-80. In: Analiza efektów realizacji polityki rolnej wobec rolnictwa i obszarów wiejskich; Wigier M., IERiGŻ-PIB (PW 2011-2014), Warszawa, 26.

Chmurzyńska K., 2011. Efekty WPR w odniesieniu do obszarów wiejskich. pp. 37-55. In: Analiza efektów realizacji polityki rolnej wobec rolnictwa i obszarów wiejskich; Wigier M., IERiGŻ-PIB (PW 2011-2014), Warszawa, 26.

Czuba R., Mazur T., 1988. Wpływ nawożenia na jakość plonów. PWN, Warszawa.

Filipek T., 2001. Natural and anthropogenic causes and effects of soil acidification. Nawozy i Nawożenie, 8: 5-26. (in Polish + summary in English)

Filipek T., 2002. Management of phosphorus resources in agricultural environment. Nawozy i Nawożenie, 4(13): 245-258. (in Polish + summary in English)

Filipek T., Skowrońska M., 2013. Current dominant causes and effects of acidification of soils under agricultural use in Poland Aktualnie dominujące przyczyny oraz skutki zakwaszenia gleb użytkowanych rolniczo w Polsce. Acta Agrophysica, 20(2): 283-294. (in Polish + summary in English)

Fotyma M., Igras J., Kopiński J., 2009. Produkcyjne i środowiskowe uwarunkowania gospodarki nawozowej w Polsce. Studia i Raporty IUNG-PIB, Puławy, 14: 187-206.

Fotyma M., Zięba S., 1988. Przyrodnicze i gospodarcze podstawy wapnowania gleb. Wyd. PWRiL, Warszawa, 250 pp.

GUS, 2003-2019a. Rocznik Statystyczny Rolnictwa, GUS, Warszawa [Statistical Yearbook of Agriculture, Statistics Poland].

GUS, 2001-2020. Środki produkcji w rolnictwie w roku gospodarczym 2002…2018/2019. GUS, Warszawa [Means of production in agriculture, Statistics Poland].

GUS, 2003-2019b. Użytkowanie gruntów, powierzchnia zasiewów i pogłowie zwierząt gospodarskich w 2002 … 2018 roku. GUS, Warszawa [Land use, Sown area, Farm animals; Statistics Poland].

GUS, 2014-2019. Zwierzęta gospodarskie w 2015 … 2018 roku. GUS, Warszawa [Farm animals, Statistics Poland].

Grzebisz W., Diatta J.B., Szczepaniak W., 2006. Productive and ecological backgrounds of arable soil liming. Nawozy i Nawożenie, 27: 69-85. (in Polish + summary in English)

Grzebisz W., Diatta J.B., Szczepaniak W., 2013. Produkcyjne i ekologiczne uwarunkowania wapnowania gleb gruntów ornych. Studia i Raporty IUNG-PIB, 34(8): 19-26.

Jadczyszyn T., Kopiński J., 2013. Nawożenie azotem w Polsce – aspekt produkcyjny i środowiskowy. Studia i Raporty IUNG-PIB, 34(8): 125-143.

Kopiński J., 2017. Gross nitrogen balances – agri-environmental indicator of the impact of agriculture on the environment. Description of methodology and discussion at the results of balance on the level NUTS-0 (Poland) and NUTS-2 (voivodeships). Wyd. IUNG-PIB, Monografie i Rozprawy Naukowe, Puławy, 55, 116 pp. (in Polish + summary in English)

Kopiński J., 2020. Kierunki rozwoju produkcji zwierzęcej w Polsce w aspekcie gospodarki nawozowej. In: Uwarunkowania i perspektywy rozwoju produkcji rolniczej w różnych regionach Polski. Studia i Raporty IUNG-PIB, 62(16): 71-101, doi: 10.26114/sir.iung.2020.62.03.

Kopiński J., 2019. Kierunki rozwoju różnych systemów produkcji roślinnej w Polsce. Studia i Raporty IUNG-PIB, 60(14): 103-128.

Kopiński J., 2016. The assessment of phosphorus management in the agricultural production process at the NUTS-0, NUTS-2 levels. Roczniki Naukowe SERiA, 18(1): 131-137. (in Polish + summary in English)

Kopiński J., 2018. Stan aktualny oraz prognoza zmian różnych kierunków produkcji rolniczej w Polsce. Studia i Raporty IUNG-PIB, 55(9): 47-75.

Kopiński J., 2013. Grade of polarization of intensity and efficiency of agricultural production in Poland in the last ten years. Roczniki Naukowe SERiA, 15(1): 97-103. (in Polish + summary in English)

Kopiński J., 2017. Evaluation of changes in the efficiency of nitrogen utilization in agricultural production of Poland. Roczniki Naukowe SERiA, 19(1): 88-94. (in Polish + summary in English)

Kopiński J., 2018. Diversity of nitrogen management in Polish agriculture. Polish Journal of Agronomy, 32: 3-16. (in Polish + summary in English), doi: 10.26114/pja.iung.351.2018.32.01.

Kopiński J., Jurga B., 2016. Managing phosphorus in Polish agriculture - production and environmental aspects. Polish Journal of Environmental Studies, 6(25): 2451-2458.

Kopiński J., Ochal P., 2013. Gospodarowanie potasem w warunkach zróżnicowanej zasobności gleb. Studia i Raporty IUNG-PIB, 34(8): 31-46.

Krasowicz S., 2009. Regionalne zróżnicowanie zmian w rolnictwie polskim. Studia i Raporty IUNG-PIB, 15: 9-36.

Matyka M., 2013. Trends in consumption of mineral fertilizers in Poland against the background of the European Union. Roczniki Naukowe SERiA, 15(3): 237-241. (in Polish + summary in English)

Matyka M., Krasowicz S., Kopiński J., Kuś J., 2013. Regionalne zróżnicowanie zmian produkcji rolniczej w Polsce. Studia i Raporty IUNG-PIB, 32(6): 143-165.

Michalczyk J., 2013. Main determinants of Poland's food security and an attempt of its measuring. Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu, 315: 577-591. (in Polish + summary in English)

Mikuła A., 2012. Food security in Poland. Roczniki Ekonomiki Rolnictwa i Rozwoju Obszarów Wiejskich, 99(4): 39-48. (in Polish + summary in English)

NFOŚiGW, 2020. http://nfosigw.gov.pl/oferta-finansowania/srodki-krajowe/programy-priorytetowe/ogolnopolski-program-regeneracji-gleb/

Ochal P., 2012. Regeneracyjne wapnowanie gleb w Polsce. Instrukcja upowszechnieniowa nr 198, IUNG-PIB, Puławy.

Ochal P., Kopiński J., 2017. Wpływ zakwaszenia gleb na środowisko i produkcję roślinną. Studia i Raporty IUNG-PIB, 53(7): 9-23.

Pastuszak M., Kowalkowski T., Kopiński J., Stalenga J., Panasiuk D., 2014. Impact of forecasted changes in Polish economy (2015 and 2020) on nutrient emission into the river basins. Science of the Total Environment, 493: 32-43

Piniewski M., Marcinkowski P., O'Keeffe J., Szcześniak M., Nieróbca A., Kozyra J., Kundzewicz Z.W., Okruszko T., 2020. Model-based reconstruction and projections of soil moisture anomalies and crop losses in Poland. Theoretical and Applied Climatology, 140: 691-708.

Poczta W., 2010. Przemiany w rolnictwie. pp. 9-43. In: Polska wieś 2010. Raport o stanie wsi; Wilkin J., Nurzyńska I., Wyd. Scholar, Warszawa.

Poland's National Inventory Reports. Greenhouse Gas Inventory for 1988-2014. IOŚ, KOBiZE, Warszawa, 2016, 417 pp.

Prandecki K., 2015. Zagrożenia środowiskowe pochodzenia rolniczego jako skutek efektów zewnętrznych. pp. 68-89. Efekty zewnętrzne i dobra wspólne w rolnictwie- identyfikacja problemu; Prandecki K. Monografie PW IERiGŻ-PIB, Warszawa.

Rutkowska A., 2018. Ocena przestrzennego zróżnicowania odczynu gleb w Polsce w latach 2008-2016. Studia i Raporty IUNG-PIB, 56(10): 9-20.

Skarżyńska A., Goraj L., Ziętek I., 2005. Metodologia SGM „2002" dla typologii gospodarstw rolnych w Polsce. IERiGŻ-PIB, 4.

Wrzaszcz W., 2012. Poziom zrównoważenia indywidualnych gospodarstw rolnych w Polsce (na podstawie danych FADN). Studia i monografie, IERiGŻ-PIB, 155, 252 pp.

Wrzaszcz W., 2018. Agriculture production potential and farms' environmental sustainability – regional convergence or divergence? pp. 54-86. In: From the research on socially-sustainable agriculture (48), IERiGŻ-PIB, Warszawa.

Wrzaszcz W., Kopiński J., 2019. Gospodarka nawozowa w Polsce w kontekście zrównoważonego rozwoju rolnictwa. Studia i monografie, IERiGŻ-PIB, 178, 145 pp.

Zalewski A., Igras J., 2012. Światowy rynek nawozów mineralnych z uwzględnieniem zmian cen bezpośrednich nośników energii oraz surowców (2). Wyd. IERiGŻ-PIB (PW 2011-2014), 37, 102 pp.

Zegar J. St., 2013. Konkurencyjność celów ekologicznych i ekonomicznych w rolnictwie. PW 2011-2014 IERiGŻ-PIB, Warszawa, 93: 28-46.

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