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# Management of nutrients derived from natural fertilizers (manures) in the Polish agriculture – selected issues

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**Abstract.** The paper presents selected issues of managing nutrients from natural fertilizers used in Polish agriculture. The analysis covered changes in the livestock population and stocking density, the number and share of farms using natural fertilization, fertilized area and the level of consumption of particular nutrients from manures. Spatial analysis was carried out at the level of voivodeships (NUTS-2) and concerned the determination of the amount of nutrient from natural fertilizers in 2017–2020. The presented results indicate that the level of stocking density has the greatest impact on regional differences in the management of natural fertilizers. This diversity is also manifested in the share of farms using natural fertilization in individual voivodeships. Natural fertilizers in Poland, mainly manure, are used on 27% of UAA in good agricultural and environmental condition (UAA in GAEC). The share of four voivodeships, ie Podlaskie, Wielkopolskie, Łódzkie and Mazowieckie, covers 55% of the total area fertilized with manures in the country. In the years 2017–2020, the average consumption of solid manure in the country was 44.3 million t, poultry manure 0.9 million t, liquid manure 8.0 million $m^3$ and slurry 14.6 million $m^3$. The highest intensity of natural fertilization was found in the Podlaskie voivodeship, the average consumption was 11.4 t $ha^{-1}$ of all agricultural land, while in Poland the average consumption was estimated at 4.6 t $ha^{-1}$ of UAA in GAEC. The highest doses per fertilized area were applied in the Podlaskie, Warmińsko-Mazurskie, Lubelskie, Lubuskie and Pomorskie voivodeships and it was directly related with the level of consumption of NPK from natural fertilizers in these voivodeships. In the analyzed period, the average doses of nitrogen, phosphorus and potassium applied to the manures' fertilized area in Poland were 87 kg N $ha^{-1}$, 29 kg $P_2O_5$ $ha^{-1}$, 113 kg $K_2O$ $ha^{-1}$, respectively. The highest nutrient consumption in natural fertilizers was observed in Podlaskie voivodeship. Based on the analyses, it can be concluded that the Podlaskie voivodeship is a leader in the intensity of natural fertilizer management in Poland.

**Keywords:** fertilizers management, natural fertilizers, nutrients, regional differentiation, livestock density

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## INTRODUCTION

In Poland, livestock production is the dominant branch of commodity agricultural production and an essential element of the system guaranteeing the country's food security (Kopiński, 2018). The proper management of natural fertilizers is of great importance not only for production purposes but also for environmental and climatic reasons, especially in the context of maintaining the productive potential of soils (Wrzaszcz, Kopiński, 2019; Kopiński, Wrzaszcz, 2020). Fertilizers are also secondary raw materials used for the bioeconomy (Chyłek, 2017), although they are often treated as a by-product of livestock production. The fertilizer components contained therein are an essential element in conducting correct, rational fertilizer management, as they should be the first to be considered in meeting the nutritional needs of plants. A significant reduction in the use of natural fertilizers leads to a violation of the ionic balance in the soil environment and consequently to a decrease in soil fertility and productivity due to insufficient reproduction of soil organic matter (Kopiński, Kuś, 2011; Kopiński, 2017; Kopiński, Witorożec-Piechnik, 2022).

It should be emphasized that the main advantage of natural fertilizers justifying their widespread use is the fact that, unlike mineral fertilizers, they contain all the nutrients necessary for proper plant growth and development, despite the proportions of these components that are not always appropriate from the point of view of plant nutrition. Moreover, unlike mineral fertilizers, they have a longer and slower action, so the effects of their use also become apparent in subsequent years after their application (Gonet, 2006).

In addition, they affect the soil physical properties, such as the crumb structure of soil or water holding capacity, chemical properties – increase the content of macro- and micro-nutrients, and microbiological properties – enzymatic activity (Pikuła, 2014; Kazberuk et al., 2021; Siebielec et al., 2021). Against the background of recent years (high prices of mineral fertilizers), it should be stressed

that they are, as a secondary raw material, a cheaper source of fertilizer inputs than mineral fertilizers.

Natural fertilizers include solid manure (also poultry manure), liquid manure and slurry. Considering the productive, economic, and environmental effects, correctly including the different types of natural fertilizers in the fertilization system requires knowledge of their chemical composition (Walczak et al., 2012; Wrzaszcz, Kopiński, 2019). At the farm level, the quality of fertilizers is determined by the direction of animal use, the way they are fed and maintained, as well as the conditions of storage and application of natural fertilizers, and the amount of available macronutrients in natural fertilizers, depends on the size and structure of the animal population (Kopiński, Witorożec, 2021).

The changes and deepening regional differences in the structure and intensity of livestock production in Poland (Kopiński, Krasowicz, 2022) indicate a decreasing number of farms engaged in livestock production and a smaller animal population, and thus a smaller area fertilized with natural fertilizers (Wrzaszcz, Kopiński, 2019; Wrzaszcz, 2021). This reduction in the close links between crop and livestock production at the farm level also impinges on shifts in the crop production structure and the overall performance of the agricultural output.

This study aimed to assess the amount of available resources of the macronutrients (NPK) in different types of natural fertilizers in Poland, considering their regional variability.

## MATERIALS AND METHOD

The research and analysis were carried out on an intimate basis. The primary source of information was the statistical data of the Central Statistical Office (2019–2022) and in-house research results (Kopiński, Wrzaszcz, 2020; Kopiński, Witorożec, 2021). The volume of macronutrient fertilizer resources was determined for 2017–2020.

The amounts of NPK fertilizer consumption were calculated based on their average content in different types of natural fertilizers, following the data contained in the national nitrate programme (MRiRW, 2020), as well as from the database of natural fertilizers prepared according to the analysis of Regional Chemical-Agricultural Station (Baza danych..., 2021) and the results of the work of Walczak et al. (2014), considering the structure of animal stock in large livestock units (LU) (MRiRW, 2014, 2020).

The study covered three essential macronutrients – nitrogen (N), phosphorus ($P_2O_5$), and potassium ($K_2O$). The analysis considered changes in the number and proportion of farms applying natural fertilizers and the area fertilized with them. The research was carried out on the total amounts of macronutrients used in the form of natural fertilizers, per area fertilized, and the size of farmland maintained in good agricultural and environmental condition (UAA in GAEC). Spatial analysis of regional differentiation was performed at the level of voivodeships (NUTS-2). Indicators for individual voivodeships were compared to average values for Poland (NUTS-0), taking them as a reference system.

Table 1. Average content of nutrients fertilizers NPK in various form of natural fertilizers.

| Manure type | N | $P_2O_5$ | $K_2O$ |
|---|---|---|---|
| | kg $t^{-1}$ fresh matter | | |
| Solid manure: | | | |
| cattle | 3.16 | 1.12 | 8.2 |
| pigs | 3.52 | 1.48 | 7.6 |
| sheeps and goats | 7.52 | 3.67 | 11.9 |
| poultry | 25.58 | 6.41 | 13.6 |
| horses | 2.70 | 0.99 | 9.0 |
| Poultry manure | 22.42 | 6.61 | 13.6 |
| Liquid manure: | | | |
| cattle | 3.14 | 1.17 | 2.5 |
| pigs | 3.53 | 1.54 | 1.2 |
| Slurry: | | | |
| cattle | 3.79 | 1.35 | 2.1 |
| pigs | 3.87 | 1.70 | 1.9 |

Source: author's research, based on national nitrate programme (MRiRW, 2020); natural fertilizer database (Baza danych..., 2021), and Walczak at al. (2014)

## STOCKING DENSITY IN POLAND

Fertilizer production is determined by the size and species structure of livestock populations in different regions of Poland. Figure 1 shows the regional variation of livestock density in Poland in 2017–2020 expressed in large livestock units (LU/100 ha). The paper by Kopiński (2020) reveals that about 45% of the livestock population in Poland is located on farms in the Mazowieckie, Wielkopolskie and Podlaskie voivodeships.

However, the intensity of the livestock production carried out is mainly evidenced by the stocking density to the area of farmland. Also, in this respect, the three voivodeships mentioned above stand out, as well as the Warmińsko-Mazurskie voivodeship. This is due to the high concentration of cattle and pig rearing. The average stocking rate in Poland in 2016–2020 was about 50 LU/100 ha of UAA in GAEC. The stocking rate in the leading voivodeships, i.e. Podlaskie and Wielkopolskie, was 4 times higher than in the Zachodniopomorskie, Podkarpackie and Dolnośląskie voivodeships, where it was at the level of about 20 LU/100 ha of UAA in GAEC.

During Poland's membership in the European Community, an unfavourable downward trend in the animal stocking was outlined (Kopiński, 2020). It mainly concerned such species as pigs, sheep, goats, and horses. Despite this, the average stocking density did not significantly

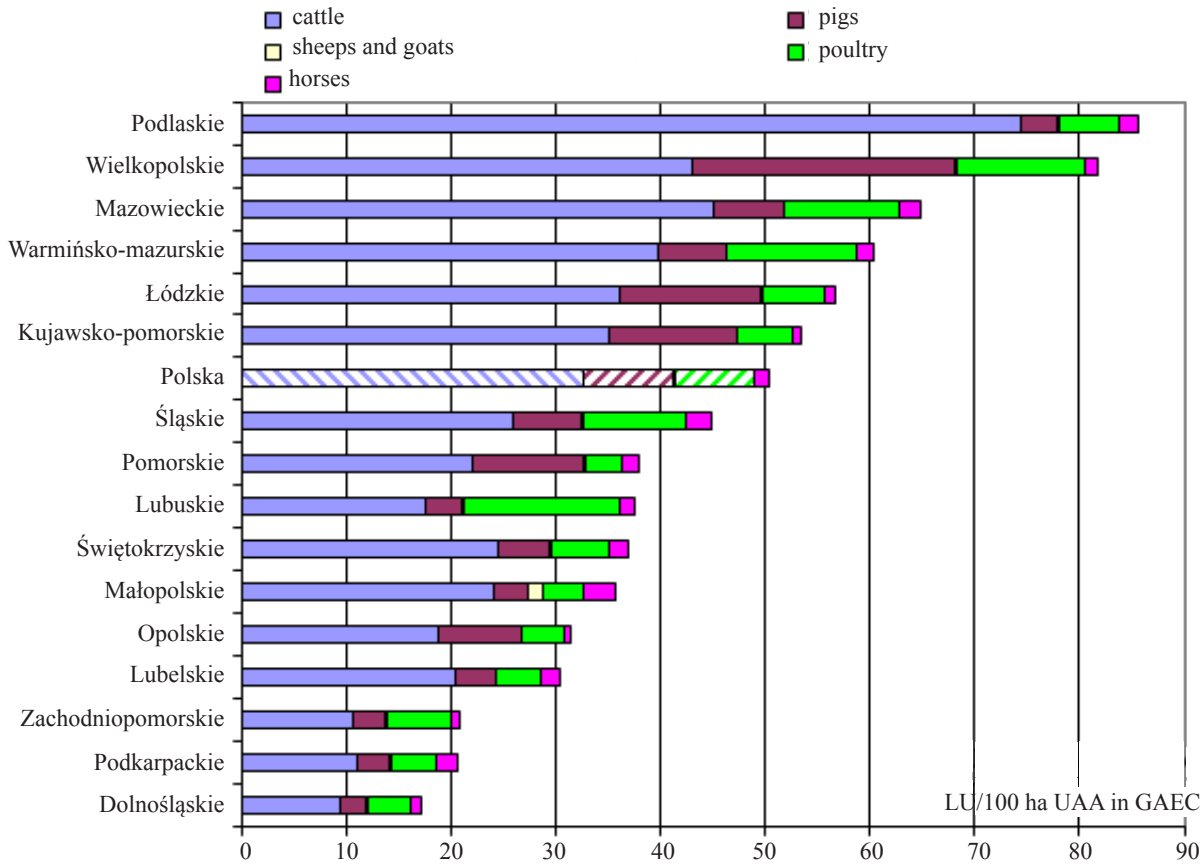


Figure 1. Stocking density in Polish voivodeships, on average in 2017–2020.
Source: authors' research, based on GUS (2018-2022c)

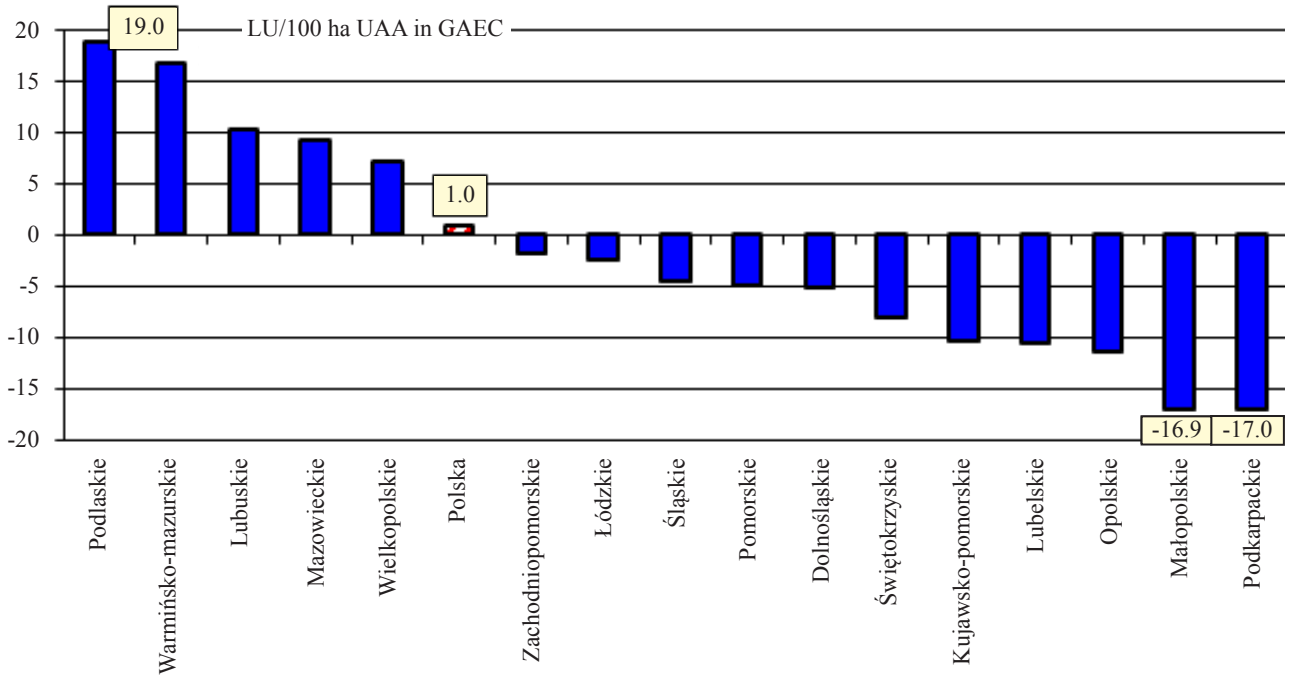


Figure 2. Changes in stocking density in LU/100 ha UAA in GAEC, between 2002–2004 and 2017–2020.
Source: authors' research, based on GUS (2018-2022c)

change. However, significant differences are observed in this regard in individual voivodeships of Poland (Figure 2). One can speak of a deepening polarization of animal production. As Kopiński and Krasowicz (2022) point out, in voivodeships where farms specialize in commodity animal production (milk, meat, poultry) or combine it harmoniously with commodity crop production, the stocking density was higher. The low stocking density, and therefore the low production of manure in such voivodeships as Małopolskie, Podkarpackie, Lubelskie, Dolnośląskie, Zachodniopomorskie and Opolskie, is cause for concern. The ratio of livestock density in LU/100 ha of UAA in 2017–2020 to the average of 2002–2004 indirectly indicates the tendencies of increasing or decreasing the production of natural fertilizers in individual voivodeships and, consequently, the amount of nutrients introduced to agricultural land.

## NUMBER OF FARMS APPLYING NATURAL FERTILIZERS

In 2020, there were 1.3 million individual farms with an area of UAA of at least 1 hectare. Compared to 2016, the number of individual farms decreased by more than 100 thousand (Figure 3). In 2020, only 570 thousand individual farms applied natural fertilizers. Between 2016 and 2020, their number decreased from 48 to 44%, and this reduction should not necessarily be associated with moving away from the intensification of crop production and its "greening". The overall trend of decreasing farm number, and less interest in keeping animals, caused by various reasons, should be identified as the main reason. This assessment applies to most voivodeships of Poland. In Zachodniopomorskie voivodeship, where the share of farms using natural fertilizers is one of the smallest, its increase of about 4 percentage points was noted (Figure 4).

The current situation and the lines of development in livestock production result from natural conditions but also dynamically changing and increasingly influential organizational and economic conditions (Kopiński, 2020). Significant reductions in the number of farms using natural fertilizers occurred in Lubelskie, Małopolskie, Mazowieckie and Łódzkie voivodeships.

Figure 4 illustrates that only in Podlaskie and Wielkopolskie voivodeships the share of individual farms applying natural fertilizers exceeds 50%. By contrast, in the Zachodniopomorskie or Dolnośląskie voivodeships, these fertilizers are used by only one in five farms.

## AREA FERTILIZED WITH NATURAL FERTILIZERS

In 2017–2020, the farmland on which natural fertilizers were applied amounted to about 4 million hectares and accounted for 27% of the total area of UAA in GAEC in

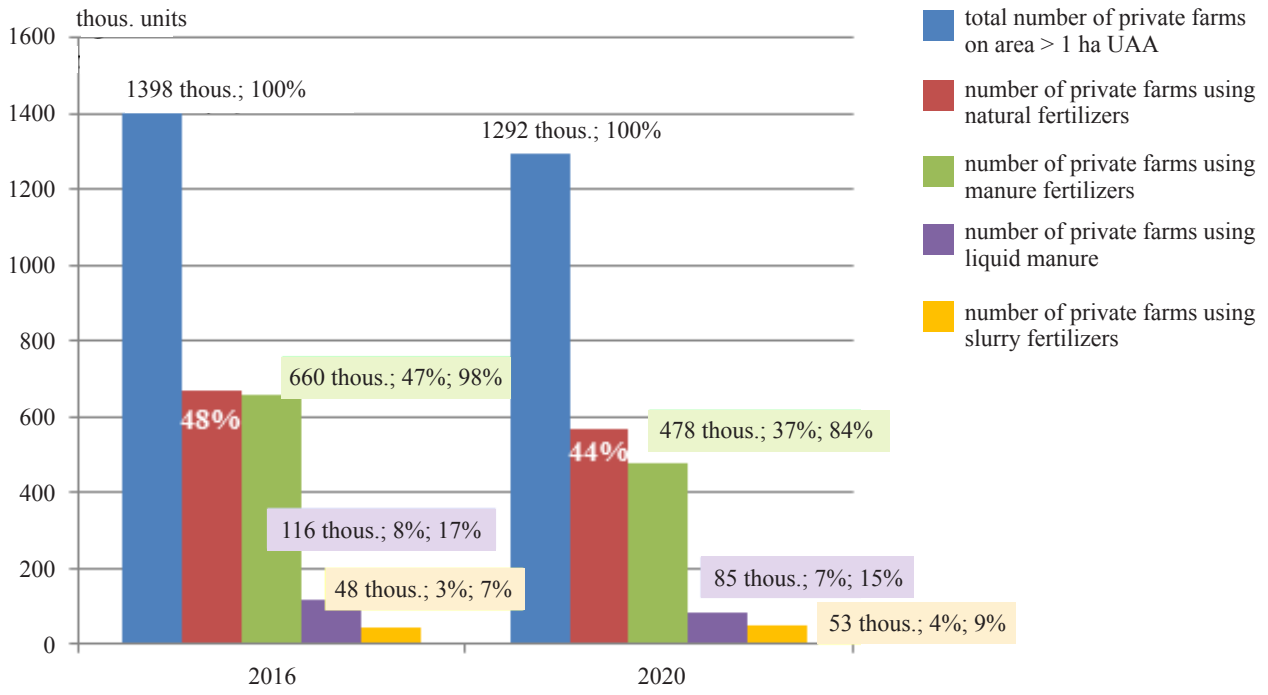


Figure 3. The number and percentage of individual farms in total and using of different various natural fertilizers in 2016 and 2020 (in thous., % of total farms in analysed year).
Source: authors' research, based on GUS (2017-2022, 2018-2022 a,b)

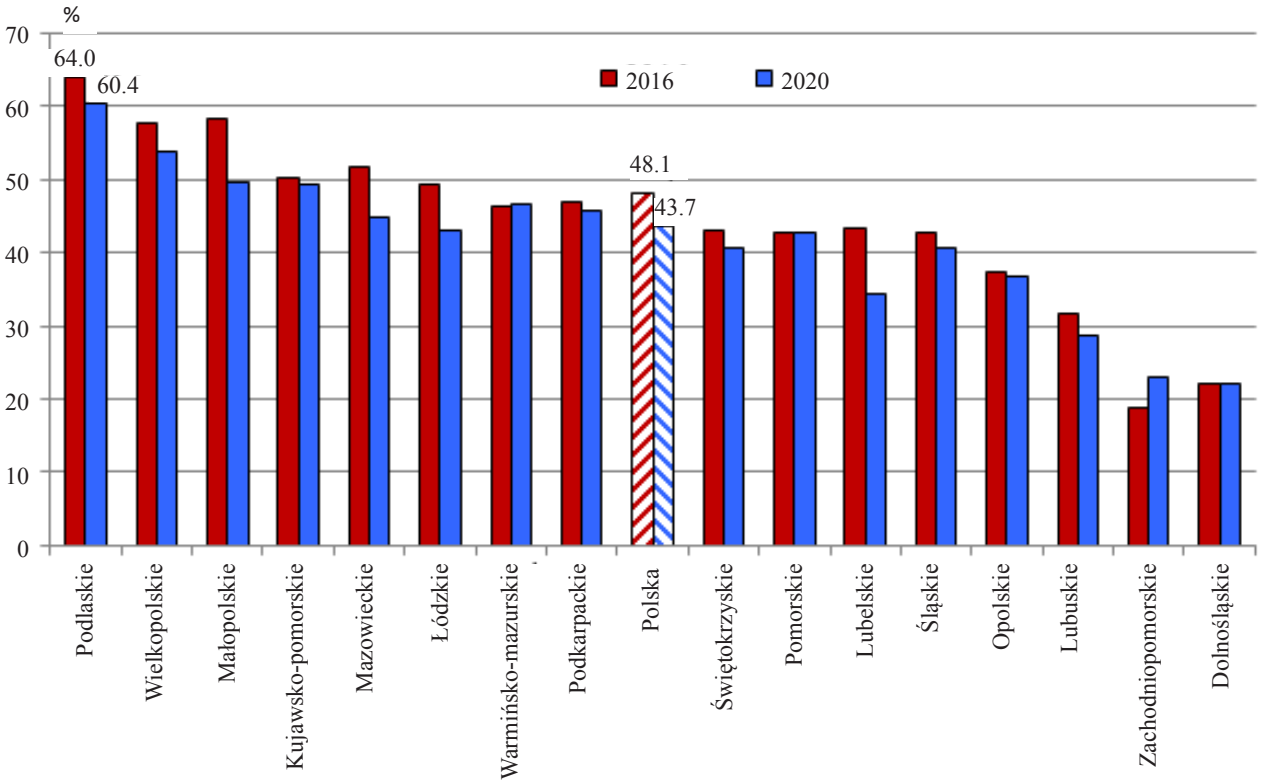


Figure 4. Share of farms using natural fertilizers in voivodeships of Poland – in 2016 and 2020.
Source: authors' research, based on GUS (2017-2022, 2018-2022 a,b)

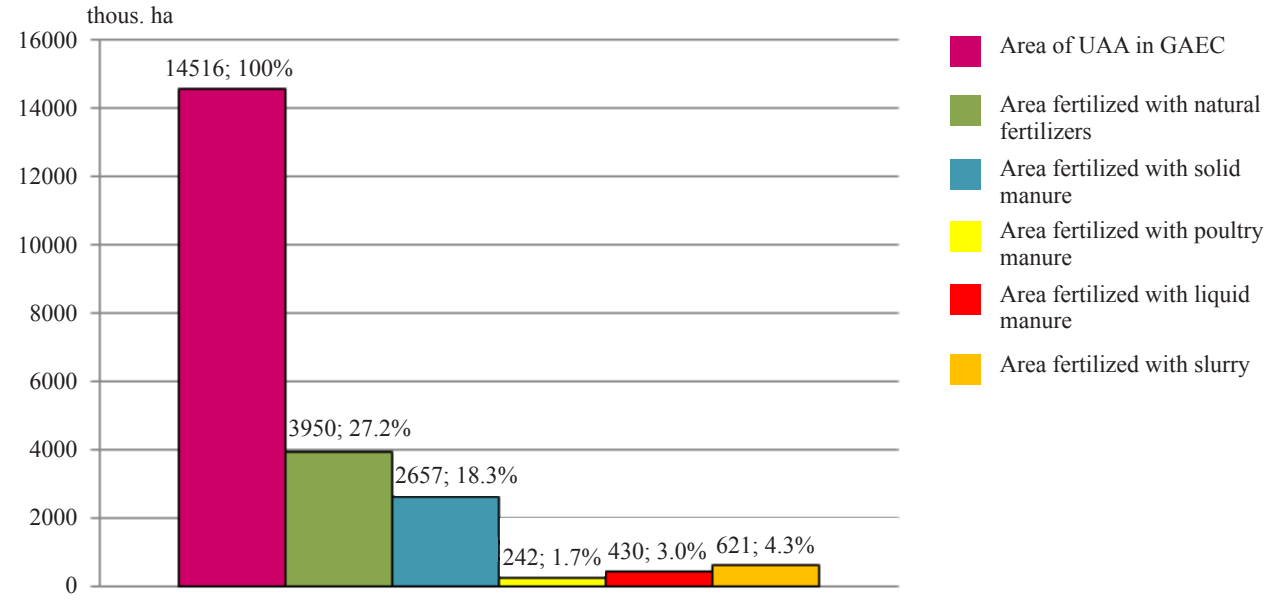


Figure 5. Area fertilized with natural fertilizers in Poland in 2017–2020.
Source: authors' research, based on GUS (2017-2022, 2018-2022 a,b)

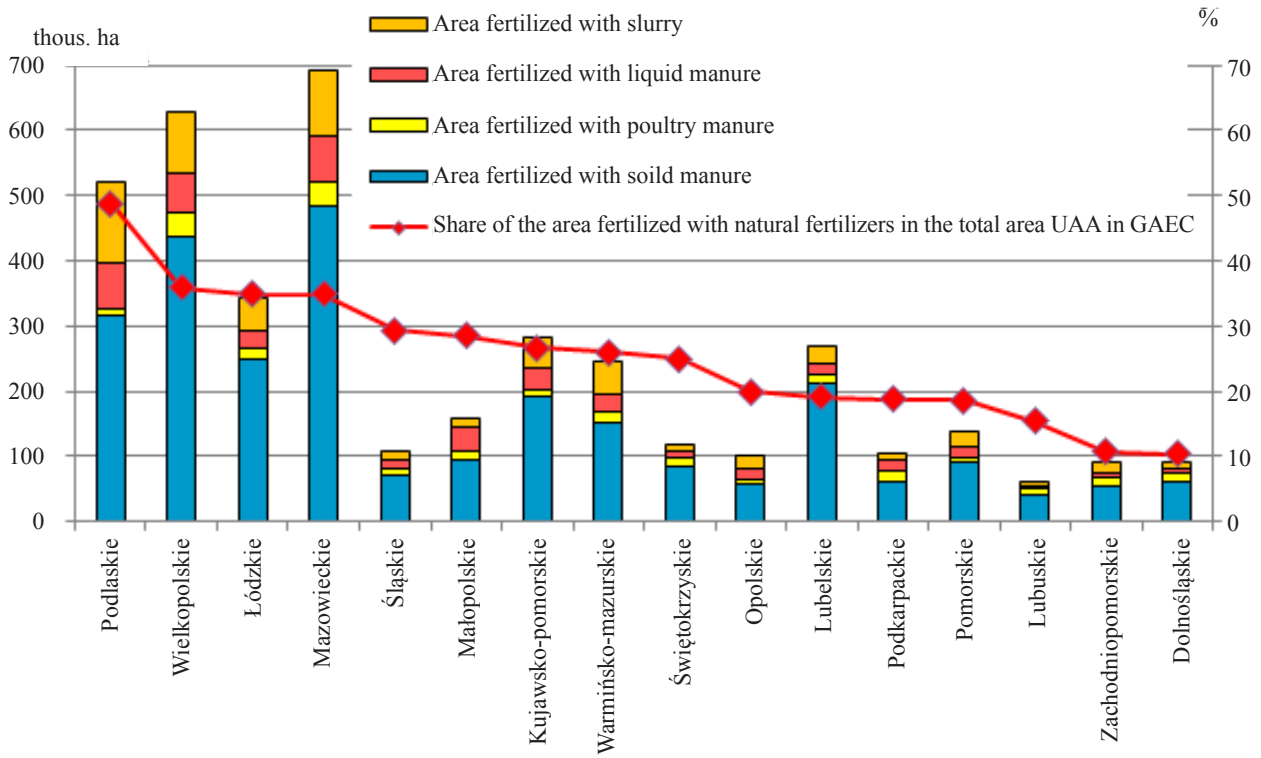


Figure 6. Territorial differentiation of the area fertilized with various types of natural fertilizers in Polish voivodeships in 2017–2020. Source: authors' research, based on GUS (2017-2022, 2018-2022b, 2022)

Poland (Figure 5). The area fertilized with manure in the period under review was 2,657 thousand hectares, while only 7.3% of UAA in GAEC was fertilized with liquid natural fertilizers in the form of liquid manure and slurry. The poultry manure fertilization was applied to 242 thousand hectares, and its share in the total area of UAA in GAEC did not exceed 2%. The presented data confirm the need, already apparent in the first years of the 21st century, to take measures on a significant area of agricultural acreage in Poland, primarily arable land, to counteract the depletion of soils in soil organic matter (Kopiński, Kuś, 2011).

Fertilizer management is spatially differentiated (evident even at the voivodeship level). Considering the regional dimension, the Podlaskie, Wielkopolskie, Łódzkie, and Mazowieckie voivodeships have the relatively largest area of agricultural land fertilized with natural fertilizers (Figure 6). The total area fertilized with natural fertilizers in mentioned four voivodeships accounts for 55% of the total fertilized area in the country. However, in the other regions, soil surface fertilized with solid manure, poultry manure, liquid manure and/or slurry does not exceed 30% of the voivodeships' agriculturally used area. On the other hand, in the Dolnośląskie or Zachodniopomorskie voivodeships, only 10–11% of the agricultural area is subject to natural fertilization (Figure 6).

## CONSUMPTION OF NATURAL FERTILIZERS

In Poland, in 2017–2020, the average consumption of solid manure was 44.3 million tons, poultry manure 0.9 million tons, liquid manure 8.0 million $m^3$ and 14.6 million $m^3$ slurry (Table 2). The ratios of consumption of different natural fertilizers are as follows: solid manure 65%, poultry manure 1.3%, liquid manure 11.8%, and slurry 21.6%. The consumption of natural fertilizers in Poland is strongly regionally differentiated. The discrepancies are directly due to differences in the size of livestock populations and housing systems of individual animal species and indirectly due to differences in the area size of voivodeships. Half of the available natural fertilizers in Poland are used in three voivodeships: Podlaskie (18.1% of total consumption), Wielkopolskie (17.2% of total consumption) and Mazowieckie (14.8% of total consumption). Simultaneously, the first two voivodeships have the highest livestock density, at more than 80 LU/100 ha UAA in GAEC.

A complete picture of the assessment of the variation in the intensity of natural fertilizer use can be obtained by comparing the applied doses of these fertilizers (their types) with a unit of a total agricultural area or with the area fertilized with them. For example, in 2017–2020, the Podlaskie voivodeship stood out by far the highest level of natural

Table 2. Consumption of natural fertilizers and stocking density in Poland in 2017–2020 years.

| Voivodeships | solid manure | poultry manure | liquid manure | slurry | Stocking density |
|---|---|---|---|---|---|
| | thous. t, thous. m$^3$ | | | | LU/100 ha UAA in GAEC |
| Dolnośląskie | 776 | 50 | 93 | 248 | 17.3 |
| Kujawsko-pomorskie | 3416 | 54 | 571 | 1069 | 53.3 |
| Lubelskie | 4400 | 57 | 381 | 654 | 30.5 |
| Lubuskie | 663 | 37 | 61 | 236 | 40.3 |
| Łódzkie | 3975 | 53 | 454 | 1184 | 56.3 |
| Małopolskie | 1244 | 32 | 496 | 214 | 35.1 |
| Mazowieckie | 6324 | 159 | 1306 | 2257 | 64.9 |
| Opolskie | 815 | 25 | 284 | 405 | 31.0 |
| Podkarpackie | 835 | 45 | 184 | 99 | 20.3 |
| Podlaskie | 7239 | 37 | 1550 | 3437 | 85.2 |
| Pomorskie | 1438 | 27 | 305 | 585 | 37.5 |
| Śląskie | 850 | 29 | 201 | 262 | 44.0 |
| Świętokrzyskie | 1105 | 24 | 153 | 165 | 36.4 |
| Warmińsko-mazurskie | 2596 | 58 | 538 | 1208 | 63.5 |
| Wielkopolskie | 7920 | 155 | 1234 | 2305 | 82.3 |
| Zachodniopomorskie | 617 | 31 | 149 | 281 | 20.3 |
| **Poland** | **44213**<br>**65.3%** | **875**<br>**1.3%** | **7961**<br>**11.8%** | **14608**<br>**21.6%** | **50.2** |

Source: authors' research, based on GUS (2022, 2017-2022, 2018-2022a)

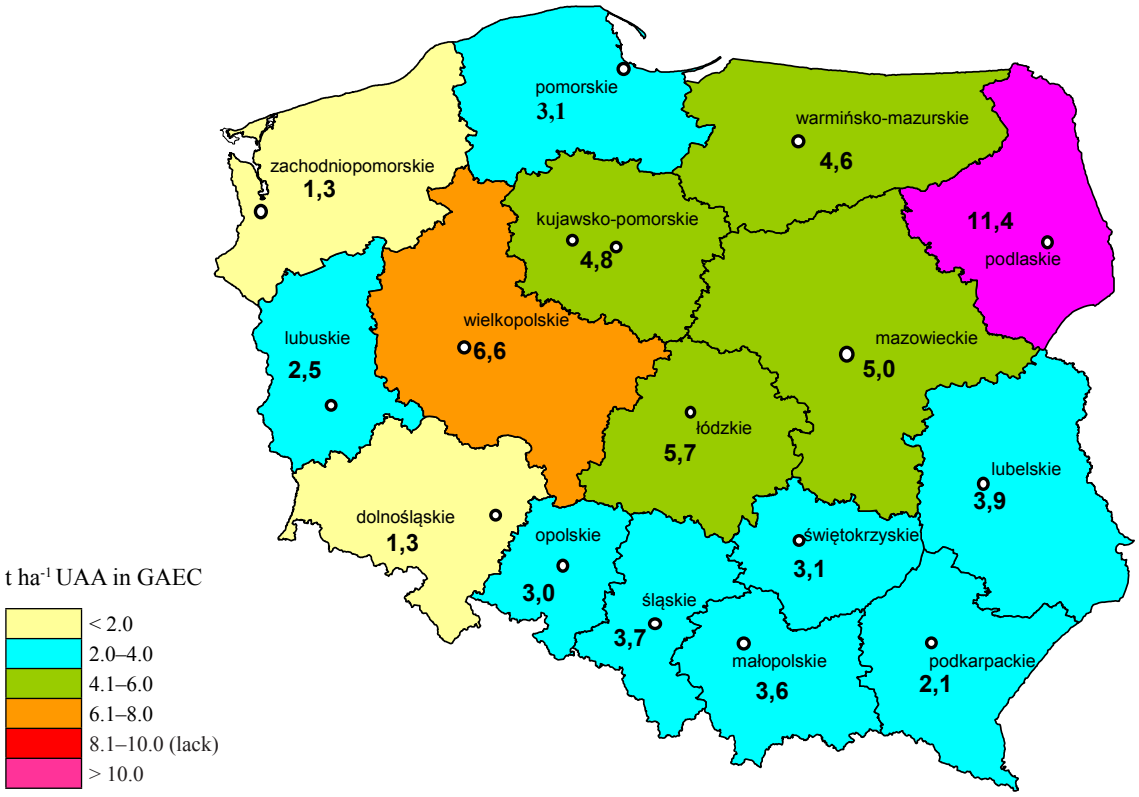


Figure 7. The level of consumption of natural fertilizers by voivodeships of Poland in 2017–2020.
Source: authors' research, based on GUS (2022, 2017-2022, 2018-2022a)

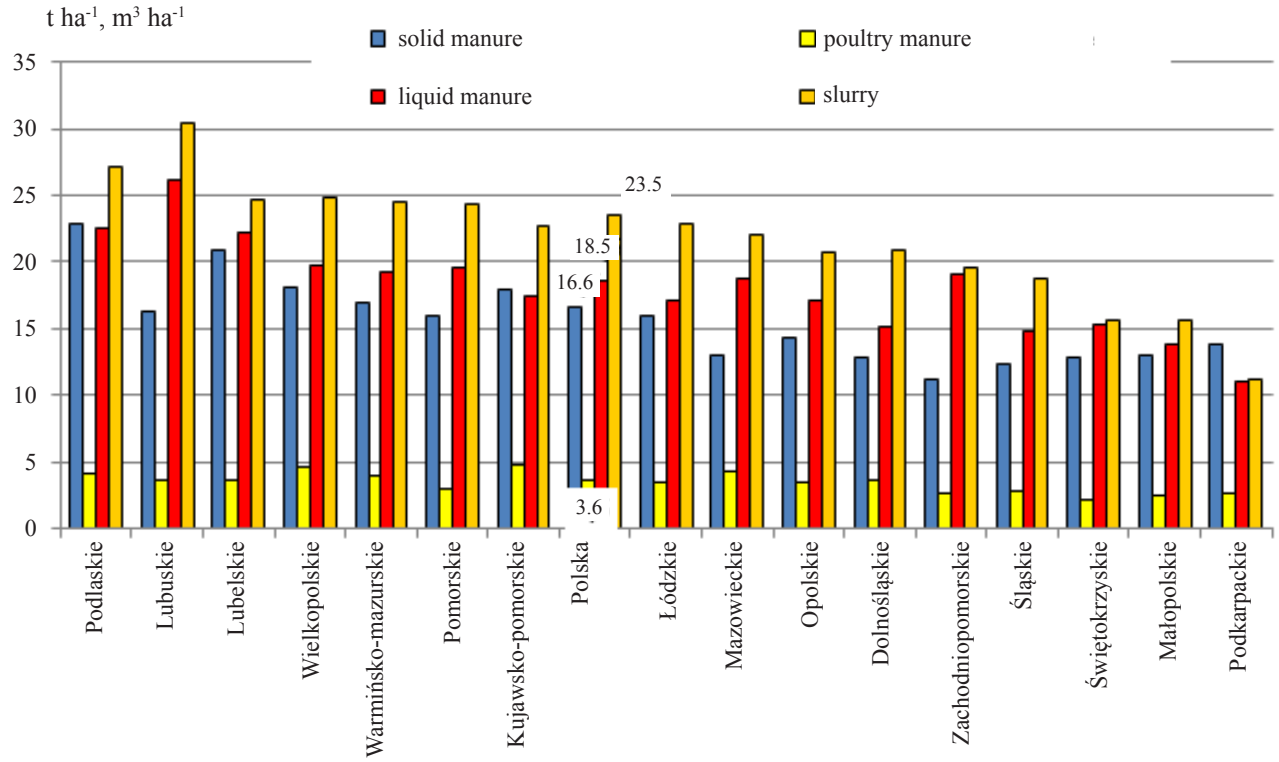


Figure 8. The level of doses of various types of natural fertilizers (on the fertilized area) in Polish voivodeships in 2017–2020. Source: authors' research, based on GUS (2022, 2017-2022, 2018-2022a)

fertilizer intensity, with an average use of 11.4 t of natural fertilizers per 1 ha of UAA in GAEC, while the consumption level in Poland was 4.6 t ha$^{-1}$ of UAA in GAEC (Figure 7). The level of consumption of individual types of natural fertilizers in Poland concerning ha of UAA in GAEC was 3.03 t of solid manure, 0.06 t of poultry manure, 0.55 m$^3$ of liquid manure and 1.00 m$^3$ of slurry (Kopiński, Wach, 2022). Higher or equal to the national average fertilizer intensity also occurred in the voivodeships of Wielkopolskie, Łódzkie, Mazowieckie, Kujawsko-Pomorskie and Warmińsko-Mazurskie. In the remaining voivodeships, the consumption of all types of natural fertilizers did not reach 4 t ha$^{-1}$ UAA in GAEC. The main reason for this is the very high proportion of livestock-free farms and the low stocking density of livestock in these regions.

An adequate measure is to relate the consumption of each type of fertilizer to the area in which it is applied (Kopiński, Wrzaszcz, 2020). The average rates used in Poland are 17 t ha$^{-1}$ of solid manure, 3.6 t ha$^{-1}$ of poultry manure, 19 m$^3$ ha$^{-1}$ of liquid manure and 24 m$^3$ ha$^{-1}$ of slurry. The highest doses of solid manure are practiced in Podlaskie voivodeship, i.e. 23 t ha$^{-1}$. On the other hand, the highest doses of slurry and liquid manure are applied in Lubuskie voivodeship, 30 m$^3$ ha$^{-1}$, 26 m$^3$ ha$^{-1}$, respectively, and poultry manure in Kujawsko-Pomorskie voivodeship, 4.8 t ha$^{-1}$ (Figure 8). In general, much higher fertilizer application rates than the national average are used in Podlaskie, Kujawsko-Pomorskie, Lubuskie, as well as Warmińsko-Mazurskie, Lubelskie, Pomorskie and Wielkopolskie voivodeships. The smallest doses of solid manure (11–12 t ha$^{-1}$) are applied in the Zachodniopomorskie and Śląskie voivodeships. The Podkarpackie voivodeship, in turn, stands out in terms of the lowest doses of applied liquid manure and slurry (about 11 m$^3$ ha$^{-1}$ each) (Figure 8). As far as the intensity of manure management is concerned, the leading voivodeship remains Podlaskie, confirming its dominant role in animal production in Poland.

## CONSUMPTION OF MACRONUTRIENTS (NPK) IN NATURAL FERTILIZERS

According to Kopiński and Wach's (2022) calculations, the average annual nitrogen consumption in Poland in 2017–2020 was as follows: 234.2 thousand tons in farmyard (solid) manure, 19.6 thousand tons in poultry manure, 25.6 thousand tons in liquid manure and 55.6 thousand tons in slurry. Of the natural fertilizers, most nitrogen (about 70%) was delivered as farmyard manure. Meanwhile, the amount of nitrogen supplied in the form of slurry was more than 2 times higher than in the applied liquid manure. Nitrogen from poultry manure accounted for about 6% of the nitrogen used in all kinds of natural fertilizers.

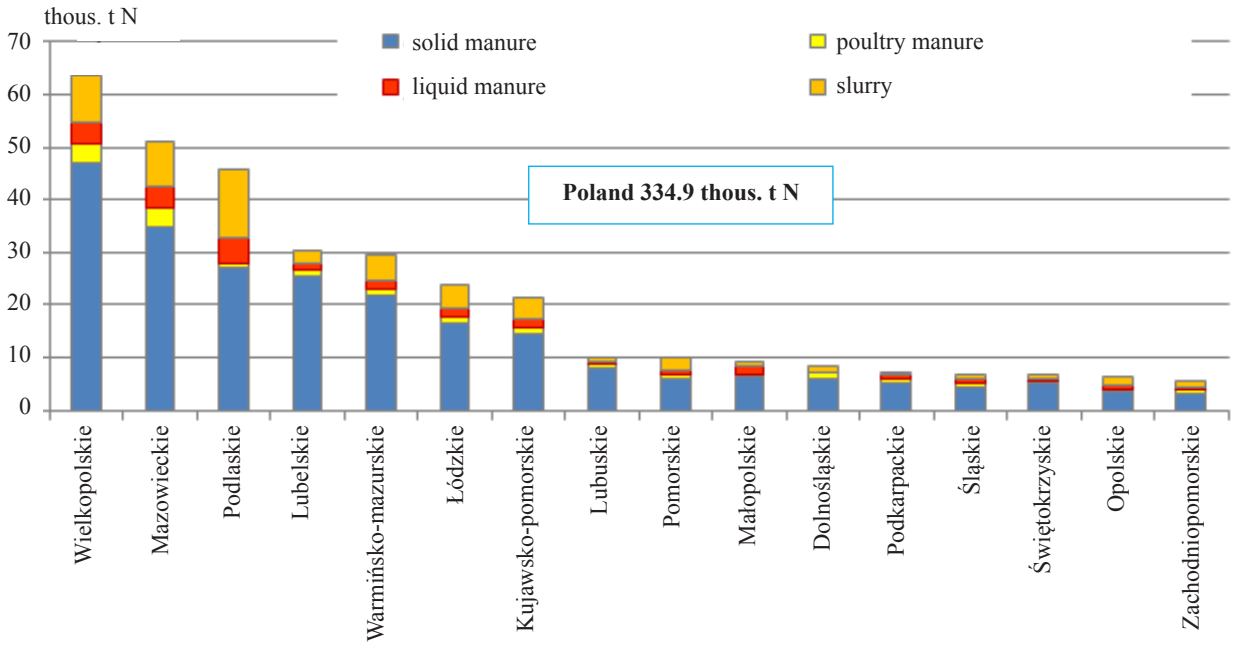


Figure 9. The consumption of nitrogen (N) in various types of natural fertilizers in voivodeships in 2017–2020.
Source: calculation on authors' research, based on GUS (2022, 2017-2022), national nitrate programme (MRiRW, 2020), natural fertilizer database (Baza danych..., 2021) and Walczak at al. (2014)

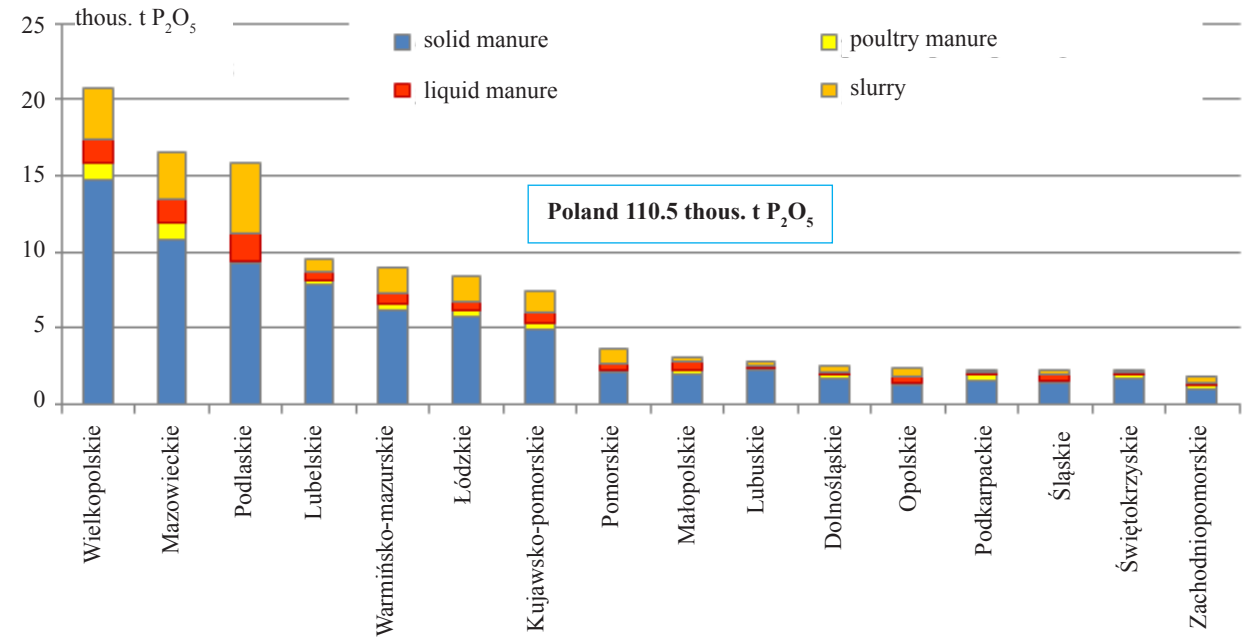


Figure 10. The consumption of phosphorus ($P_2O_5$) in various types of natural fertilizers in voivodeships in 2017–2020.
Source: calculation on author's research, based on GUS (2022, 2017-2022), national nitrate programme (MRiRW, 2020), natural fertilizer database (Baza danych..., 2021) and Walczak at al. (2014)

The highest amount of nitrogen (in all kinds of natural fertilizers) was applied in the Wielkopolskie, Mazowieckie and Podlaskie voivodeships, 63, 51 and 46 thousand tons of N, respectively. In contrast, the lowest consumption was in the Zachodniopomorskie, Opolskie, Świętokrzyskie and Śląskie voivodeships – less than 7 thousand tons of N (Figure 9).

Analogous to nitrogen, all provinces also recorded a significantly higher level of fertilization with phosphorus and potassium in the form of solid manure than in

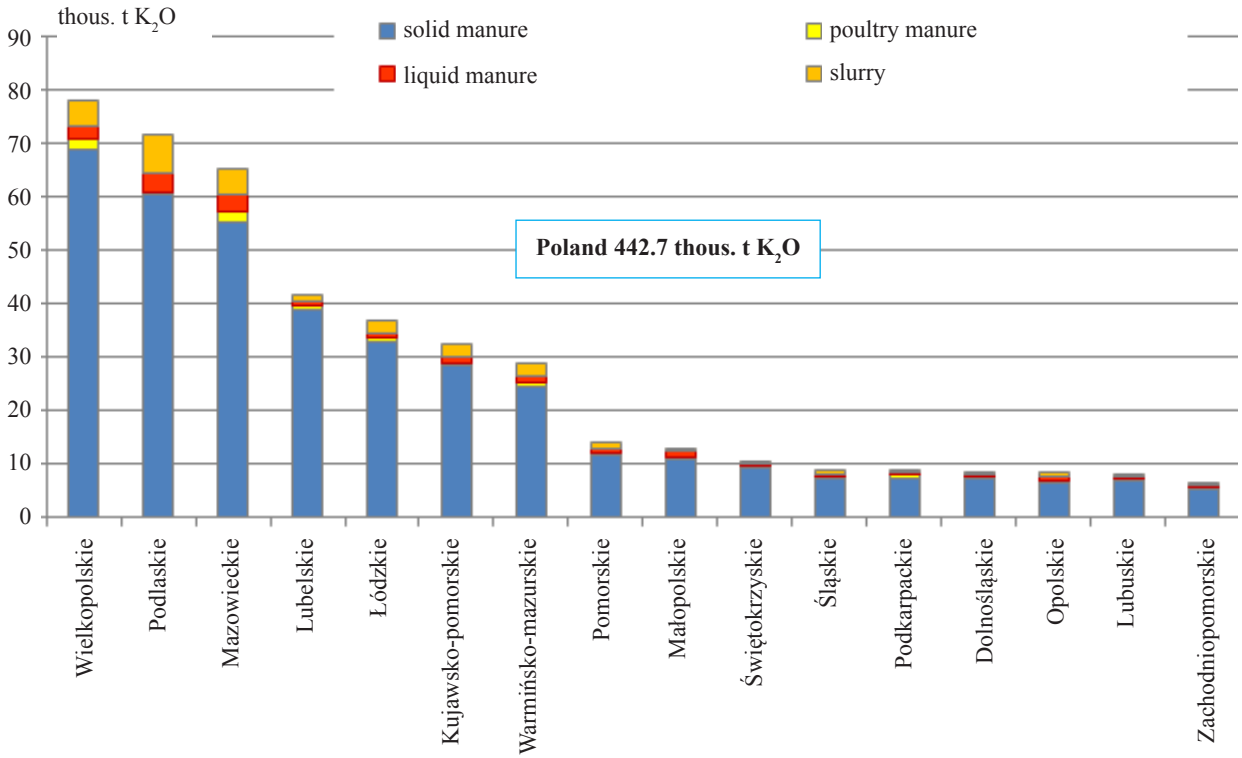


Figure 11. The consumption of potassium ($K_2O$) in various types of natural fertilizers in voivodeships in 2017–2020.
Source: calculation on author's research, based on GUS (2022, 2017-2022), national nitrate programme (MRiRW, 2020), natural fertilizer database (Baza danych..., 2021) and Walczak at al. (2014)

the applied liquid manure and slurry or poultry manure. The leaders in terms of phosphorus and potassium consumption in manures remained the Wielkopolskie, Mazowieckie and Podlaskie voivodeships. Analysis of the data in Figures 9–11 shows that the amounts of potassium in natural fertilizers in Poland (442.7 thousand tons of $K_2O$) is higher than the amounts of nitrogen consumed (334.9 thousand tons of N). The comparatively lowest resource among these macronutrients is phosphorus in mineral fertilizers (110.5 thousand t $P_2O_5$).

The level of intensity of the use of natural fertilizers directly affects the level of nutrient consumption contained in fertilizers. In Poland, the average macroelement consumption level in natural fertilizers, concerning the area of UAA maintained in good culture in 2017–2020, was 23.6 kg N $ha^{-1}$, 7.7 kg $P_2O_5$ $ha^{-1}$ and 30.5 kg $K_2O$ $ha^{-1}$. The total use of NPK components in natural fertilizers was calculated at 61.8 kg NPK $ha^{-1}$ UAA in GAEC (Figure 12), which is twice as low as the consumption of these components in mineral fertilizers (Wrzaszcz, Kopiński, 2019). The level of nutrient consumption in natural fertilizers directly correlates with the level of livestock density. Considering both indicators, on a national scale, two voivodeships stand out clearly: Podlaskie (124 kg NPK $ha^{-1}$ UAA in GAEC) and Wielkopolskie (93 kg NPK $ha^{-1}$ UAA in GAEC). The lowest level of consumption of NPK macronutrients in natural fertilizers was characterized by the Zachodniopomorskie and Dolnośląskie voivodeships, in which this consumption did not exceed the level of 25 kg NPK $ha^{-1}$ UAA in GAEC. It should be noted that a relatively high level of NPK fertilizer components to animal density was consumed in the Lubelskie voivodeship. The reverse situation, however, occurred in the case of agriculture in the Mazowieckie voivodeship (Figure 12).

The level of applied doses, particularly concerning the area fertilized, is more likely to indicate the strength of the pressure of these current assets exerted on the environment. In Poland, in 2017–2020, the highest doses of NPK components in natural fertilizers were applied in Lubuskie, Warmińsko-Mazurskie and Lubelskie voivodeships, as well as in Podlaskie and Wielkopolskie voivodeships (Figure 13). In such voivodeships, the average doses of applied nitrogen, phosphorus and potassium were higher than the national averages of 87 kg N $ha^{-1}$, 29 kg $P_2O_5$ $ha^{-1}$, and 113 kg $K_2O$ $ha^{-1}$, respectively. However, in none of the voivodeships did the average dose of applied nitrogen in natural fertilizers pass the permissible level of 170 kg N $ha^{-1}$ set by the Nitrate Directive (91/676/EEC) (Zwykła..., 2003).

The lowest doses of macronutrients from natural fertilizers, not exceeding a total of 170 kg NPK $ha^{-1}$, were

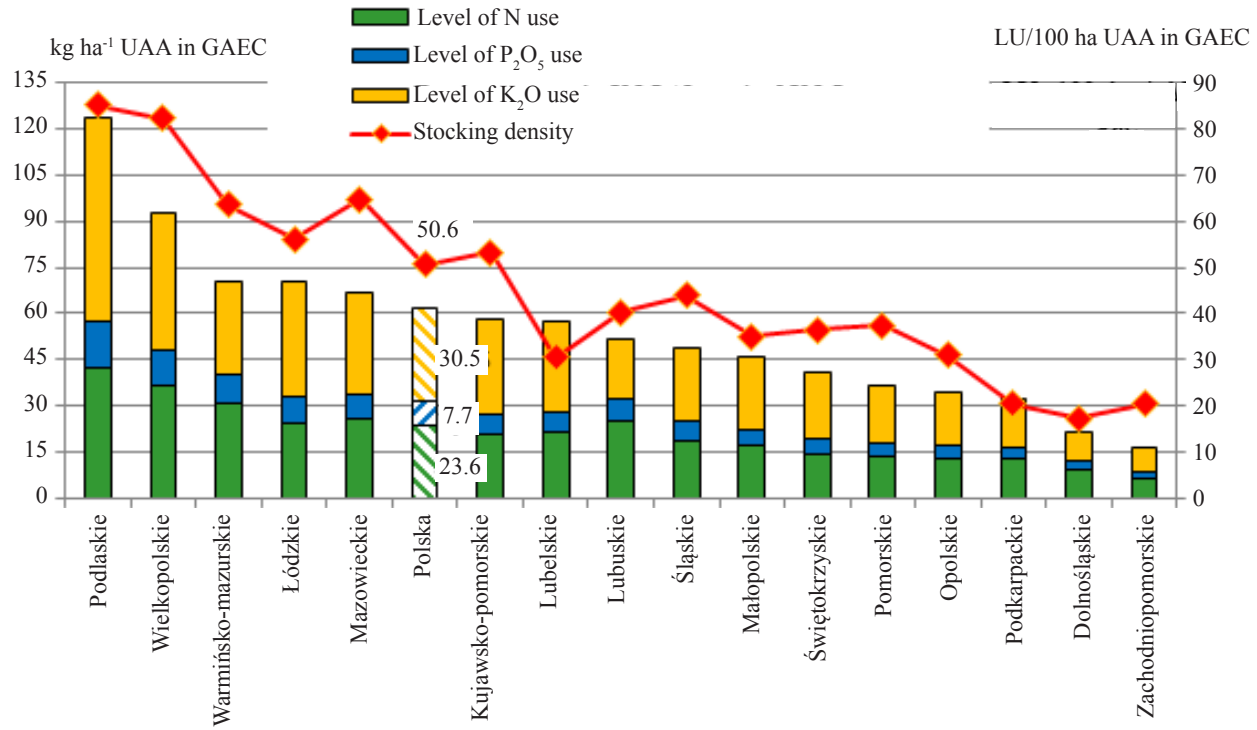


Figure 12. Territorial differentiation of the intensity of consumption of macronutrients (NPK) in natural fertilizers and stocking density in Polish voivodeships in 2017–2020.
Source: calculation on author's research, based on GUS (2022, 2017-2022, 2018-2022b), national nitrate programme (MRiRW, 2020), natural fertilizer database (Baza danych..., 2021) and Walczak at al. (2014)

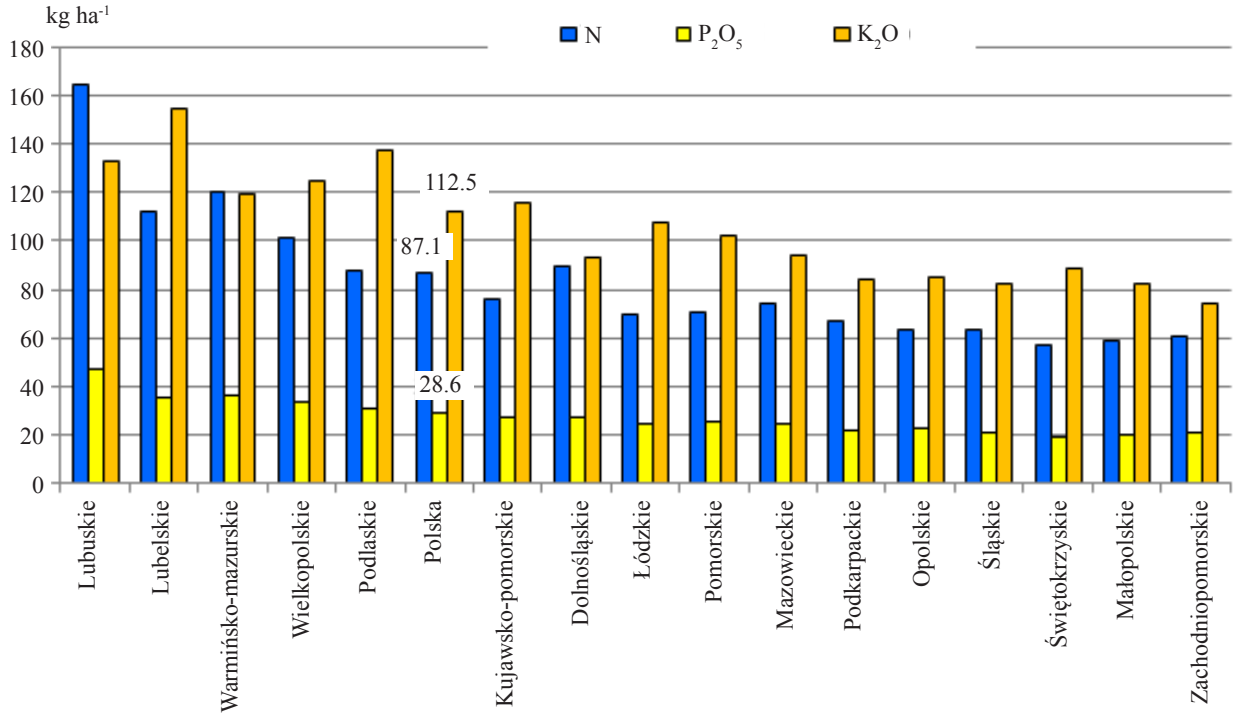


Figure 13. The level of doses of macronutrients (NPK) in natural fertilizers (on the fertilized area) in Polish voivodeships in 2017–2020.
Source: calculation on author's research, based on GUS (2022, 2017-2022, 2018-2022b), national nitrate programme (MRiRW, 2020), natural fertilizer database (Baza danych..., 2021) and Walczak at al. (2014)

applied in the Małopolskie, Śląskie, Świętokrzyskie and Zachodniopomorskie voivodeships (Figure 13). If we relate such an indicator to the extent of impact (the scale of applied natural fertilization in individual voivodeships) (Kopiński, Wrzaszcz, 2020), the leading voivodeships in Poland, in terms of organization and intensity of fertilization with macronutrients of natural fertilizers, are Podlaskie and Wielkopolskie voivodeships. Thus, these voivodeships may potentially use some of the natural fertilizers like a substrate for biogas plants or for processing into a form of mineral fertilizers, the so-called RENURE fertilizers (Chojnacka et al., 2020).

## SUMMARY

One of the most important determinants of sustainable management in agriculture is proper fertilizer management, including natural fertilizers. The advantage of these products is that they contain all the nutrients necessary for regular plant growth and development, providing an often underestimated source of their supply in the agricultural production system. In general, the availability of macronutrients from natural fertilizers is determined by the size and structure of the livestock.

In Poland, the average stocking rate has remained the same in recent years. Nevertheless, quite significant differences can be observed between the various voivodeships of Poland in this regard, indicating the deepening polarization of animal production. Highet stocking density is found in voivodeships where farms specialize in commodity animal production (milk, meat, poultry) or combine it harmoniously with commodity crop production. A significant reduction in stock density in such voivodeships as Małopolskie, Podkarpackie, Lubelskie, Dolnośląskie and Opolskie is a matter of concern. The directions of changes in animal stocking rates over the past several years indirectly suggest trends of increasing or decreasing manure production in individual voivodeships and, consequently, the amount of nutrients applied to farmland.

An analysis of spatial variations in the organization and intensity of manure management indicates a successive decrease in the number and share of farms using this form of fertilization, enriching the soil with organic matter. Currently, natural fertilizers, mainly solid manure, are used by only 570,000 individual farms, i.e. 44% of the total number of farms in Poland. This is also the pattern of changes in the area fertilized with natural fertilizers. In 2017–2020, solid manure was used on only 18% of the area used for agriculture, and the area fertilized with poultry manure accounted for 2%. Liquid natural fertilizers (in the form of liquid manure and slurry) were applied to 7% of the UAA area in Poland. Considering the regional perspective, it should be pointed out that the total area fertilized with natural fertilizers in four voivodeships, i.e. Podlaskie, Wielkopolskie, Łódzkie and Mazowieckie, accounts for 55% of the total area fertilized in the country.

In Poland, in 2017–2020, the average consumption of solid manure was 44.3 million tons, 0.9 million tons of poultry manure, 8.0 million $m^3$ of liquid manure and 14.6 million $m^3$ of slurry. Half of the available manure was consumed in three voivodeships: Podlaskie (18.1% of total consumption), Wielkopolskie (17.2% of total consumption) and Mazowieckie (14.8% of total consumption). At the same time, the first two voivodeships are characterized by the highest stocking density of livestock, amounting to more than 80 LU/100 ha UAA in GAEC.

Definitely, the highest intensity of natural fertilization is featured by Podlaskie voivodeship, where the average consumption is 11.4 t $ha^{-1}$ of total UAA in GAEC, while in Poland, the average consumption can be estimated at 4.6 t $ha^{-1}$ of UAA in GAEC. Regarding the fertilized area, the leading voivodeships, in terms of applied rates, are Podlaskie, Warmińsko-Mazurskie, Lubelskie, Lubuskie and Pomorskie. The fertilizer application rates used in these voivodeships are higher than the national average, which amounted to 17 t $ha^{-1}$, 22 $m^3$ $ha^{-1}$, and 26 $m^3$ $ha^{-1}$ for solid manure, liquid manure and slurry, respectively.

In Poland, in 2017–2020, the highest doses of NPK components in natural fertilizers were applied in Lubuskie, Warmińsko-Mazurskie and Lubelskie voivodeships, as well as in Podlaskie and Wielkopolskie voivodeships. In these voivodeships, the average doses of applied nitrogen, phosphorus and potassium (on fertilized area) were higher than the average for the country, 87 kg N $ha^{-1}$, 29 kg $P_2O_5$ $ha^{-1}$, 113 kg $K_2O$ $ha^{-1}$. In none of the voivodeships did the average dose of applied nitrogen in natural fertilizers exceed the permissible level of 170 kg N $ha^{-1}$ specified by the Nitrate Directive. However, concerning the area of agricultural land, the total consumption of NPK in natural fertilizers in Poland can be estimated at a level of about 62 kg NPK per ha UAA in GAEC, which is twice as low as the consumption of these components in mineral fertilizers.

An analysis of the proportion of individual macronutrients in the natural fertilizers used shows that the amounts of potassium in natural fertilizers in Poland (442.7 thousand tons of $K_2O$) are higher than the amounts of nitrogen consumed (334.9 thousand tons of N). The relatively lowest resource among these macronutrients is phosphorus contained in natural fertilizers (110.5 thousand t $P_2O_5$). The lowest level of consumption of NPK macronutrients is distinguished by the Zachodniopomorskie and Dolnośląskie voivodeships, respectively 17 and 22 kg NPK $ha^{-1}$ UAA in GAEC. The Wielkopolskie voivodeship used about 93 kg NPK per $ha^{-1}$ UAA in GAEC. The highest level of consumption of macronutrients in natural fertilizers was shown in the Podlaskie voivodeship (124 kg NPK $ha^{-1}$ UAA in GAEC).

Considering the scale of regional differentiation in the organization and intensity of natural fertilizer management, it can be confirmed that in this regard, the leading regions in Poland are Podlaskie and Wielkopolskie voivodeships. This indicates potential opportunities to process surpluses

of these fertilizers as RENURE, thus increasing the possibility of their use in the country's deficit area. This is because the scale of trading in natural fertilizers in Poland is insignificant at present, and their distribution does not solve the problem of national fertilizer management.

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