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DEPENDENCE OF THE VOLUME OF NATURAL FERTILIZER CONSUMPTION IN RELATION TO THE LEVEL OF LIVESTOCK DENSITY IN POLAND[2]

Key words: animal livestock, animal stocking rate, natural fertilizers, manure, poultry manure, liquid manure, slurry, breeding intensity

ABSTRACT. The article presents the results of an analysis of the dependence of the volume of consumption of various types of natural fertilizers in Poland, on the intensity of animal husbandry. As a measure of the intensity of animal husbandry, the level of animal stocking rate was adopted. The scope of the analysis covered the years 2017-2020. The amount of natural fertilizer consumption was determined at the level of voivodeships. The study showed that the size of animal stocking rates in Poland is determined by the share of cattle, followed by pig and poultry stocking rates. Analysis of basic statistical indicators, confirmed spatial inequality with regard to the location of animal husbandry in Poland at the regional level. The intensity of manure application is a reflection of the level of livestock stocking, and this relationship is explained by a 2° polynomial regression, where $R^2 = 0.7326$. The highest intensity of livestock and natural fertilization in Poland was the Podlaskie Voivodeship, where the average level of natural fertilizer use in recent years was 11.48 t/ha UAA, and the stocking rate was 85.2 LU/100 ha UAA, while the average level of use for Poland is 4.64 t/ha UAA. The amount of each type of manure applied per large animal unit (LU) is relatively constant, and in Poland in recent years has been: 6.0 t of manure, 0.8 t of poultry manure, 1.3 m^3 of liquid manure and 2.4 m^3 of slurry.

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INTRODUCTION

A very important element in the process of maintaining soil fertility is the use of optimal levels of fertilization with natural fertilizers, by enriching the soil with organic matter and fertilizer components necessary to meet the nutritional needs of plants. Natural fertilizers, despite being a by-product of livestock production, are also an important link in the bioeconomy [Chyłek 2017], indirectly projecting the productivity and economic efficiency of agricultural production [Wrzaszcz, Kopiński 2019].

It should be noted that, unlike mineral fertilizers, they have a longer-lasting effect, and therefore also slower effects, which are revealed in subsequent years after their application. Their main advantage is that they contain all the nutrients necessary for proper plant growth and development [Gonet 2006]. The quality of natural fertilizers and their effectiveness, in addition to their form depends on the timing and method of application, but, above all, on determining the optimal dose that takes into account the nutritional needs of plants and the abundance of soils in basic macronutrients [Kopiński, Wrzaszcz 2020, Kopiński, Witorożec 2021].

The level of consumption of natural fertilizers, is obviously related to changes in the size of livestock populations and stocking rates of the various livestock groups and their housing systems [Kopiński 2020]. This relationship is also influenced by changes in livestock production including: new developments in animal feeding and housing systems, as well as ways of storing and applying fertilizers themselves [Walczak et al. 2012, Skowron et al. 2019, Wrzaszcz, Kopiński 2019, Maćkowiak, Żebrowski 2000].

Over the past several years, there has been a trend toward a reduction in both the number of farms engaged in livestock production and the number of animals (mainly pigs). This results in major organizational and structural changes in commodity livestock production and affects the level of natural fertilizer resources. The existing, in this regard, very large regional differences are being exacerbated [Kopinski 2020, Kopinski, Krasowicz 2022].

The purpose of this study was to determine the current relationships occurring between the size of livestock and stocking rates and the level of natural fertilizer fertilization in Poland.

MATERIAL AND METHODOLOGY OF THE STUDY

The main sources of information were the statistical data of the Central Statistical Office [GUS 2018-2020, 2018-2021a, 2018-2021b, 2023] and the results of our own research [Kopiński, Witorożec 2021, Kopiński, Krasowicz 2022]. Determination of the volume of the natural fertilizer types in the voivodeships of Poland included data for 2017-2020.

The amount of consumption of individual types of natural fertilizers (manure, poultry manure, liquid manure and slurry) was calculated taking into account the structure of animal population in large animal units (LU)[3]. For total consumption volumes, it was assumed that 1 t is equivalent to 1 m^3 (the equivalent is 1).

Spatial comparative analysis was conducted at the level of voivodeships (NUTS-2), where the reference point was the average figures for Poland. The analysis included the amount of consumption of various types of natural fertilizers and in relation to the number of animals and the area of agricultural land maintained in good condition (UAA), as a measure of the intensity of animal breeding. Relationships for the variables (n = 64, i.e., 4 years and 16 voivodeships) were evaluated using regression analysis, applying basic methods (indicators) of descriptive statistics, i.e.: arithmetic mean, median, minimum value (min), maximum value (max) and coefficient of variation of correlation.

RESEARCH RESULTS

Conducting livestock production on a farm does not determine the use of natural fertilizers, on the other hand, some of the farms with livestock production do not necessarily have the agricultural land necessary to carry it out [Wrzaszcz, Kopiński 2020]. Such a direct link generally applies to the rearing of ruminants, for which it is necessary to provide roughage. In general, surplus manures produced are disposed of by farms with large-scale animal production, but the scale of their turnover between regions is rather small. In 2017-2020, the average consumption in Poland was 44.2 million tons of manure, 0.9 million tons of poultry manure, 8.0 million m^3 of liquid manure and 14.6 million m^3 of slurry (Table 2). The share of consumption of each type of manure was as follows: manure 65.0%, poultry manure 1.3%, liquid manure 11.8%, slurry 21.6%. The volumes of natural fertilizer consumption varied strongly regionally, but this can only partly be explained by differences in the acreage of agricultural land of the voivodeships. In general, these discrepancies are a direct result of differences in the size and structure of livestock populations and differences in the housing systems of individual animal species. In Poland, 50% of natural fertilizers were used in three voivodeships (Table 1). These included the voivodeships of: Podlaskie (12.2 million t), Wielkopolskie (11.6 million t) and Mazowieckie (10.0 million t). In these voivodeships, livestock populations exceeded or were close to 10 million livestock units (LUs), and in the first two, the stocking rate exceeded 80 LU/100 ha UAA (Table 2).

[3] LU – a large conversion unit according to the Ministry of Agriculture and Rural Development, used on the basis of the Annex to the Regulation of the Council of Ministers of November 9, 2004 [Journal of Laws 2004, No. 257, item 2573] and on the basis of the Annex "Program of measures to reduce water pollution by nitrates from agricultural sources and to prevent further pollution" to the Regulation of the Council of Ministers of February 12, 2020 [Journal of Laws 2020, item 243].

Table 1. Average consumption of natural fertilizers and area of agricultural land in the Polish voivodeships in 2017-2020

Voivodships	Consumption of natural fertilizers					Area of agricultural land in good agricultural condition (UAA)
	manure	poultry manure	liquid manure	slurry	total	
	thousand t		thousand m^3		thousand t	thousand ha
Dolnośląskie	776	50	93	248	1,168	889.3
Kujawsko-pomorskie	3,416	54	571	1,069	5,112	1,056.1
Lubelskie	4,400	57	381	654	5,492	1,412.0
Lubuskie	663	37	61	236	997	397.0
Łódzkie	3,975	53	454	1,184	5,666	984.9
Małopolskie	1,244	32	496	214	1,986	552.2
Mazowieckie	6,324	159	1,306	2,257	10,045	1,987.7
Opolskie	815	25	284	405	1,529	503.8
Podkarpackie	835	45	184	99	1,162	552.0
Podlaskie	7,239	37	1,550	3,437	12,264	1,068.7
Pomorskie	1,438	27	305	585	2,354	746.3
Śląskie	850	29	201	262	1,343	366.7
Świętokrzyskie	1,105	24	153	165	1,446	472.5
Warmińsko-mazurskie	2,596	58	538	1,208	4,400	943.9
Wielkopolskie	7,920	155	1,234	2,305	11,614	1,749.0
Zachodnio-pomorskie	617	31	149	281	1078	833.6
Poland	44,213	875	7,961	14,608	67,658	14,515.5

Source: own study based on SP data [GUS 2018-2020, 2018-2021b, 2023]

The optimal indicator for assessing the level of intensity of animal husbandry is precisely the stocking rate. It takes into account both the size and structure of animal stocking in relation to the unit of AU area being compared. An analysis of Table 2 shows that, in general, the size of the stocking rate was determined by the share of cattle, followed by the share of pigs and poultry. It should be noted, that in 11 v hips the average stocking rate of poultry, expressed in LU/100 ha AU in UAA, was higher than the average stocking rate of pigs, which indicates the significant structural changes that have occurred in livestock production in Poland in the last several years [Kopiński 2020, Kopiński, Krasowicz

Table 2. Livestock and average load animals in the Polish voivodeships in 2017-2020

Voivodships	Livestock of animals [thousand LU]						Load of livestock [LU/100 ha UAA]					
	cattle	pigs	sheep and goats	poultry	horses	total	cattle	pigs	sheep and goats	poultry	horses	total
Dolnośląskie	84.0	21.1	1.2	39.6	8.1	154.0	9.4	2.4	0.1	4.2	1.1	17.3
Kujawsko-pomorskie	370.7	129.0	0.8	55.3	7.2	563.1	35.1	12.2	0.1	5.3	0.8	53.3
Lubelskie	287.2	55.1	1.8	67.2	20.0	431.2	20.3	3.9	0.1	4.3	1.7	30.5
Lubuskie	69.5	14.1	0.6	71.2	4.7	160.1	17.5	3.5	0.2	14.8	1.4	40.3
Łódzkie	355.6	132.7	1.3	56.9	7.8	554.3	36.1	13.4	0.1	6.0	1.0	56.3
Małopolskie	132.8	18.1	7.3	21.7	13.9	193.9	24.1	3.3	1.3	4.0	3.0	35.1
Mazowieckie	895.8	134.8	0.9	226.8	31.6	1,289.9	45.1	6.8	0.0	11.0	1.9	64.9
Opolskie	94.2	40.2	0.3	19.0	2.4	156.1	18.7	8.0	0.1	4.0	0.6	31.0
Podkarpackie	60.8	16.5	1.9	23.5	9.3	112.0	11.0	3.0	0.4	4.3	2.0	20.3
Podlaskie	795.9	36.3	2.1	60.8	15.7	910.8	74.5	3.4	0.2	5.8	1.8	85.2
Pomorskie	164.4	79.0	1.3	26.0	9.2	280.0	22.0	10.5	0.2	3.6	1.5	37.5
Śląskie	95.1	23.5	1.2	34.3	7.3	161.5	25.9	6.4	0.3	9.7	2.4	44.0
Świętokrzyskie	115.7	23.1	0.7	25.1	7.5	172.1	24.5	4.9	0.1	5.5	1.9	36.4
Warmińsko-mazurskie	376.1	60.8	1.2	149.2	12.4	599.7	39.8	6.3	0.1	12.5	1.6	63.5
Wielkopolskie	751.7	441.0	2.4	228.1	16.6	1439.8	43.0	25.2	0.1	12.3	1.1	82.3
Zachodnio-pomorskie	88.1	26.9	0.8	48.4	5.1	169.3	10.6	3.2	0.1	6.1	0.7	20.3
Poland	4,737.6	1,252.3	25.8	1,153.0	178.9	7,347.7	32.6	8.6	0.2	7.5	1.5	50.6
Median (n = 64)	-	-	-	-	-	-	24.3	5.6	0.1	5.4	1.3	37.6
Minimum (n = 64)	-	-	-	-	-	-	8.9	2.1	0.0	3.2	0.4	14.7
Maximum (n = 64)	-	-	-	-	-	-	74.5	26.1	1.4	22.2	2.6	86.2
Coefficient of variation (n = 64)	-	-	-	-	-	-	57.0	79.1	133.4	60.9	43.7	46.4

Source: own study based on SP data [GIS 2018-2020, 2018-2021a, 2023]

2022]. A comparison of the average stocking rates for Poland and the median (n = 64) stocking rates in the voivodeships confirmed the spatial unevenness of the distribution of animal husbandry in Poland. This is also evidenced by high coefficients of variation, and especially in terms of intensity of sheep and goat rearing (Table 2). The occurrence of area specialization (regional in Poland) in animal husbandry is evidenced by higher coefficients of variation for individual groups of animal species than the coefficient for total animals.

The intensity of the use of manure, determined by the level of consumption of these fertilizers (their types), is a reflection (derivative) of the level of livestock density. In Poland, the highest intensity of manure application was distinguished by the Podlaskie Voivodeship, where the average level of consumption in recent years was 11.48 t/ha UAA, while in the second highest voivodeship – Wielkopolskie, the level of consumption was 6.64 t/ha UAA, with the average level of consumption for Poland calculated at 4.64 t/ha UAA (Table 3). In addition to these two voivodeships, the Kujawsko-Pomorskie, Łódzkie, Mazowieckie and Warmińsko-Mazurskie voivodeships had higher fertilizer intensity than the national average. A comparison of the minimum and maximum indices and coefficients of variation of consumption of different types of natural fertilizers confirmed the existence, high in this respect, of regional polarization. It should be noted that the consumption of natural fertilizers in the voivodeships in the West and South of Poland is very low, in relation to the total agricultural land maintained in good culture.

In 2017-2020, the average consumption of manure in Poland was 3.03 t/ha UAA, poultry manure 0.06 t/ha UAA, liquid manure 0.55 m^3/ha UAA, and slurry 1.00 m^3/ha UAA (Table 3). Higher coefficients of variation for the consumption of manure and slurry than for liquid manure indicate greater regional differences in terms of how animals are kept in a barnless or shallow litter system than in a full barn system.

The average amount of consumption of each type of manure in relation to a large animal unit (LU) is relatively constant, and in Poland in recent years has been: 6.0 t of manure, 0.8 t of poultry manure, 1.3 m^3 of liquid manure and 2.4 m^3 of slurry (Table 3). Nevertheless, there are differences in the level of unit consumption of natural fertilizers between different regions of the country. The reasons for these differences include different disposal and storage systems for these fertilizers, as well as possible, but unspecified, interregional flows. In 2017-2020, a very high, relative to the national average, manure consumption was observed in the Lubelskie Voivodship (10.2 t/LU). On the other hand, in the Małopolskie and Podkarpackie voivodeships, the unit consumption of manure was relatively higher than in the other voivodeships, and in the Opolskie and Podlaskie voivodeships – slurry. These calculated indicators can be very important in estimating the amount of fertilizer consumption potential in different regions of Poland on the basis of the state of animals per LU.

Table 3. Average units of consumption of types natural fertilizers in the Polish voivodeships in 2017-2020

Voivodships	Consumption of natural fertilizers [t/ha UAA]					Consumption of natural fertilizers [t/LU]				
	manure	poultry manure	liquid manure	slurry	total	manure	poultry manure	liquid manure	slurry	total
Dolnośląskie	0.87	0.06	0.10	0.28	1.31	5.0	1.3	0.9	2.4	7.6
Kujawsko-pomorskie	3.23	0.05	0.54	1.01	4.84	6.1	1.0	1.1	2.1	9.1
Lubelskie	3.11	0.04	0.27	0.46	3.89	10.2	0.8	1.1	1.9	12.7
Lubuskie	1.65	0.09	0.15	0.59	2.51	4.1	0.5	0.7	2.8	6.2
Łódzkie	4.03	0.05	0.46	1.20	5.75	7.2	0.9	0.9	2.4	10.2
Małopolskie	2.24	0.06	0.90	0.39	3.60	6.4	1.5	3.3	1.4	10.2
Mazowieckie	3.17	0.08	0.66	1.13	5.05	4.9	0.7	1.3	2.2	7.8
Opolskie	1.62	0.05	0.56	0.80	3.04	5.2	1.3	2.1	3.0	9.8
Podkarpackie	1.50	0.08	0.33	0.18	2.10	7.5	1.9	2.4	1.3	10.4
Podlaskie	6.73	0.03	1.44	3.19	11.48	7.9	0.6	1.9	4.1	13.5
Pomorskie	1.92	0.04	0.41	0.78	3.16	5.1	1.0	1.3	2.4	8.4
Śląskie	2.31	0.08	0.55	0.71	3.66	5.3	0.8	1.7	2.2	8.3
Świętokrzyskie	2.33	0.05	0.32	0.35	3.06	6.4	1.0	1.1	1.2	8.4
Warmińsko-mazurskie	2.71	0.06	0.56	1.26	4.66	4.3	0.4	1.2	2.8	7.3
Wielkopolskie	4.52	0.09	0.70	1.31	6.64	5.5	0.7	1.0	1.9	8.1
Zachodnio-pomorskie	0.73	0.04	0.18	0.33	1.29	3.6	0.6	1.3	2.4	6.4
Poland	3.03	0.06	0.56	1.00	4.64	6.0	0.8	1.3	2.4	9.2
Median (n = 64)	2.36	0.06	0.43	0.70	3.57	5.5	0.9	1.1	1.7	8.8
Minimum (n = 64)	0.50	0.03	0.05	0.12	0.81	2.4	0.3	0.2	0.7	3.9
Maximum (n = 64)	7.78	0.11	1.63	3.55	12.90	15.4	2.1	3.2	4.2	19.0
Coefficient of variation (n = 64)	58.1	34.0	67.6	83.5	60.3	34.4	41.9	52.6	43.7	28.3

Source: own study based on SP data [GUS 2018-2020, 2018-2021a, 2018-2021b, 2023]

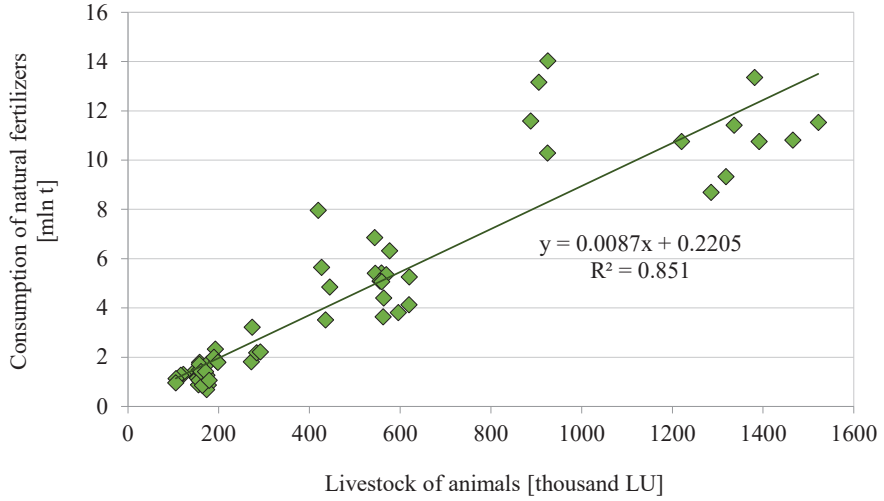

Figure 1. Linear regression showing the relationship* between consumption of natural fertilizers in the Polish voivodeships and livestock of animals in 2017-2020 (n = 64)
* statistically significant level at $\alpha > \alpha_{0,05} = 0.25$

Source: own study and calculation based on SP data [GUS 2018-2021a, 2018-2023]

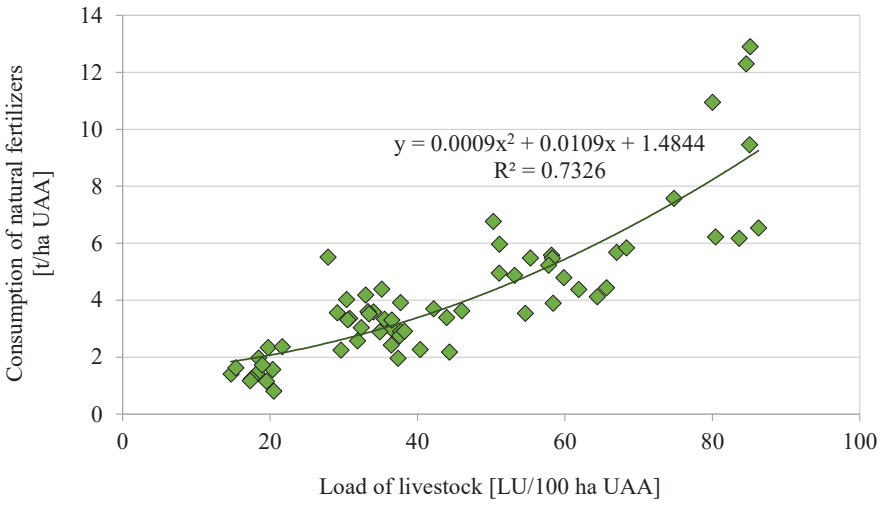

Figure 2. Regression (polynomial) showing the relationship* between consumption of natural fertilizers in the Polish voivodeships and load of livestock in 2017-2020 (n = 64)
* statistically significant level at $\alpha > \alpha_{0,05} = 0.25$

Source: own study and calculation based on SP data [GUS 2018-2020, 2018-2021a, 2018-2021b, 2023]

The strength of the relationship between the amount of natural fertilizer consumption and animal stock is explained by the correlation coefficient r = 0.922, at a significance level of 0.25 (Figure 1). Statistical analysis shows that, on average in Poland, each increase in animal population by 1 LU results in an increase in the consumption (total of all) natural fertilizers by 8.7 tons. The relationship between natural fertilizer intensity and animal stocking intensity is best explained by a 2° polynomial, where $R^2 = 0.7326$ (Figure 2). An animal stocking rate of 1 LU/ha UAA means a consumption of 11.57 t/ha UAA. Of course, at the regional or individual farm level, these rates can vary, as evidenced by the coefficients of variation and standard deviation presented in Tables 2 and 3.

SUMMARY

Analysis of the average consumption of different types of natural fertilizers and the size of livestock and livestock stocking rates in a spatial arrangement made it possible to assess the scale of regional differences. The reasons for these discrepancies can be attributed to differences in the average size and average structure of livestock populations, as well as the use of different systems of keeping individual animal species in livestock buildings and storage of natural fertilizers. In 2017-2020 the average consumption in Poland was 44.2 million tons of manure, 0.9 million tons of poultry manure, 8.0 million m^3 of liquid manure and 14.6 million m^3 of slurry. Relationships of consumption of different types of natural fertilizers were as follows: manure 65.0%, poultry manure 1.3%, liquid manure 11.8%, slurry 21.6%. Half of the natural fertilizers in Poland were consumed in three voivodeships: Podlaskie (12.2 million t), Wielkopolskie (11.6 million t) and Mazowieckie (10.0 million t).

In general, livestock stocking rates in Poland are determined by the share of cattle, followed by pig and poultry stock. In recent years, in as many as eleven voivodeships, poultry stocking rates (expressed in LU/100 ha UAA) have been higher than pig stocking rates, indicating structural changes taking place.

Analysis of basic statistical indicators confirmed the spatial unevenness of the distribution of animal husbandry in Poland at the regional level, indicating at the same time the occurring area specialization of animal production.

The intensity of the use of manure is a reflection (derivative) of the level of livestock density, and this relationship is explained by a 2° polynomial regression, where $R^2 = 0.7326$. Podlaskie Voivodeship definitely stood out from the rest in terms of the level of intensity of natural fertilization, where the average level of consumption in recent years was 11.48 t/ha UAA, while in the second highest Wielkopolska Voivodeship, the level of consumption was 6.64 t/ha UAA, and the average level of consumption for Poland can be estimated at 4.64 t/ha UAA. In 2017-2020, the average consumption of manure in Poland

was 3.03 t/ha UAA, poultry manure 0.06 t/ha UAA, liquid manure 0.55 m^3/ha UAA, and slurry 1.00 m^3/ha UAA.

The amount of consumption of individual types of natural fertilizers in relation to LU is relatively constant, and in Poland in recent years has been: 6.0 t of manure, 0.8 t of poultry manure, 1.3 m^3 of liquid manure and 2.4 m^3 of slurry, with differences between different regions of the country. The strength of the relationship between the amount of manure consumption and animal population is explained by the correlation coefficient r = 0.922 (at a significance level of 0.25).

The indicators calculated on the basis of the analysis can be very important in estimating the amount of potential for fertilizer use in different regions of Poland based on the state of animals per LU. The occurrence of regional differences in terms of the intensity of animal husbandry can be a premise for in-depth analysis of fertilizer management and rationalization of total fertilization (from different sources of fertilizer inputs).

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ZALEŻNOŚĆ WIELKOŚCI ZUŻYCIA NAWOZÓW NATURALNYCH W ODNIESIENIU DO POZIOMU OBSADY ZWIERZĄT INWENTARSKICH W POLSCE

Słowa kluczowe: pogłowie zwierząt, obsada zwierząt, nawozy naturalne, obornik, pomiot, gnojówka, gnojowica, intensywność chowu

ABSTRAKT. W opracowaniu przedstawiono wyniki analizy zależności wielkości zużycia poszczególnych rodzajów nawozów naturalnych w Polsce od intensywności chowu zwierząt. Jako miarę intensywności chowu przyjęto poziom obsady zwierząt. Zakres analizy obejmował lata 2017-2020. Wielkość zużycia nawozów naturalnych określono na poziomie województw. W badaniach wykazano, że o wielkości obsady zwierząt w Polsce decyduje udział pogłowia bydła, a w dalszej kolejności – pogłowia trzody chlewnej i drobiu. Analiza podstawowych wskaźników statystycznych potwierdziła nierównomierność przestrzenną w odniesieniu do lokalizacji chowu zwierząt w Polsce na poziomie regionalnym. Intensywność stosowania nawożenia naturalnego jest odzwierciedleniem poziomu obsady zwierząt inwentarskich, a zależność tę objaśnia regresja wielomianu 2°, gdzie $R^2 = 0,7326$. Najwyższą intensywnością chowu i nawożenia naturalnego w Polsce wyróżniało się województwo podlaskie, w którym przeciętny poziom zużycia nawozów naturalnych w ostatnich latach wynosił 11,48 t/ha UR w dkr, a obsada 85,2 DJP/100 ha UR w dkr, podczas gdy przeciętny poziom zużycia dla Polski wynosił 4,64 t/ha UR w dkr. Wielkość zużycia poszczególnych rodzajów nawozów naturalnych w odniesieniu do dużej jednostki przeliczeniowej (DJP) zwierząt jest względnie stała i w Polsce w ostatnich latach wynosiła: 6,0 t obornika, 0,8 t pomiotu ptasiego, 1,3 m^3 gnojówki i 2,4 m^3 gnojowicy.

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