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FERTILIZER MANAGEMENT IN POLAND IN LIGHT OF EUROPEAN GREEN DEAL OBJECTIVES

Key words: fertilizer management, mineral fertilizers, NPK, European Green Deal, Farm to Fork strategy, fertilizer balance

ABSTRACT. The aim of the paper is to outline the problem areas of fertilizer management in Poland, taking the need to achieve European Green Deal (EGD) objectives into account. Fertilizer management is one of the key elements of future agricultural policy, to which the European Green Deal refers, and is closer to the Farm to Fork strategy. The emphasis on the need to promote rational fertilizer management in European documents stemmed from the pressures of this economic activity on the natural environment. The paper focuses on the main determinants of fertilizer management, including the costs and quantities of mineral fertilizers used and the results of the NPK fertilizer balance, using the gross balance and indicator method. The study used Statistics Poland data 2007 and 2016 from the Farm Structure Survey and agricultural accountancy FADN 2014-2019. It was found that, at the level of the agricultural sector, the results of fertilizer balances do not create surpluses and problematic issues concern a significant share of farms with an understated balance of main NPK macroelements. The expected reduction in the level of fertilization under the EGD may result in a reduction in production and economic performance from a farm and negatively affect the state of the natural environment. The fertilizer balance and nutrient efficiency level should be used as measurable indicators for setting reduction targets.

INTRODUCTION

At the end of 2019, the European Commission (EC) published the EU's European Green Deal (EGD) strategy, which outlined policy objectives for 2050 [EC 2019]. It updates the EC's commitment to address climate and environmental issues, which have been identified as priority purposes for European society. The strategy's aim is to build a modern, resource-efficient, and competitive economy that will achieve net-zero greenhouse gas emissions in 2050 and separate economic growth from the use of natural resources. It identifies

the need for reduction measures in every sector of the economy, including agriculture. The EC has outlined specific objectives for European agriculture in the Farm to Fork strategy that reinforces the need to "green" the common agricultural policy [EC 2020].

The Farm to Fork strategy identifies four main targets for agricultural activity that should be achieved by 2030. These objectives concern the use of pesticides and antibiotics, the development of organic farming and the fertilizer economy. The first points to the need of reducing the number of chemical pesticides used by 50%, paying attention to the more dangerous ones. The second outlines the need to reduce the sale of antimicrobials for farmed and aquaculture animals by 50%. Another considers the popularization of organic farming up to 25% of agricultural area, through an increase in the area of organic cultivation. While in the area of fertilizer management, the strategic objective was to reduce nutrient losses by at least 50%, while preventing soil fertility from deteriorating, and reduce the use of fertilizers by at least 20% [EC 2020, Wrzaszcz, Prandecki 2020, Matyka 2021].

Although the EU's Farm to Fork strategy objectives seem to be clear, many questions arise in the scientific community as well as in public administration: how will they be enforced at a member state level, what indicators will be used to monitor progress in the measures taken, what year will be the starting point when assessing changes, will each country be treated uniformly when imposing specific reduction targets in the field of agriculture, and what will the productive and economic effects in agricultural production and society be, etc. A separate and very important issue is the adaptation of farms to the new requirements related to the implementation of the European Green Deal strategy, which will pose a significant challenge in the perspective of 2030. This paper focuses on the issue of fertilizer management, using important measures, established based on public statistics and agricultural accounting data.

The aim of the paper was to outline the problem areas of fertilizer management in Poland, taking the need to achieve the objectives of the European Green Deal into account.

MATERIAL AND METHODS

Research covered the population of individual farms in Poland with at least 1 ha of agricultural land maintained in good agricultural condition. The research was conducted at a country and voivodeship level. Data collected as part of the Farm Structure Survey (FSS), carried out by Statistics Poland (GUS) in 2007 and 2016, and the agricultural accounting data of the Polish FADN on commodity agriculture for the period 2014-2019 were used in the research. The fertilizer balance was established based on the farm-level balance method as the difference in the quantities of macroelements to and from the soil [OECD 2006], adapting it to available public statistics. The results of the balance were

Table 1. Range of optimal balances of nitrogen (N), phosphorus (P) and potassium (K) in Poland (kg of pure component per ha of UAA)

Lp.	Voivodship	Fertilization [kg/ha AL]					
		N		P		K	
		from	to	from	to	from	to
1	Dolnośląskie	23	38	0.0	3.0	2.3	6.3
2	Kujawsko-pomorskie	37	52	-2.9	0.1	7.7	11.7
3	Lubelskie	32	47	-0.2	2.8	8.5	12.5
4	Lubuskie	33	48	-1.4	1.6	3.6	7.6
5	Łódzkie	42	57	-0.4	2.6	13.7	17.7
6	Małopolskie	50	65	3.5	6.5	14.0	18.0
7	Mazowieckie	49	64	-0.6	2.4	15.9	19.9
8	Opolskie	43	58	-0.5	2.5	4.2	8.2
9	Podkarpackie	45	60	2.2	5.2	8.1	12.1
10	Podlaskie	64	79	2.3	5.3	20.1	24.1
11	Pomorskie	27	42	-0.5	2.5	7.5	11.5
12	Śląskie	47	62	-0.1	2.9	8.4	12.4
13	Świętokrzyskie	32	47	1.0	4.0	8.2	12.2
14	Warmińsko-mazurskie	42	57	0.2	3.2	3.1	7.1
15	Wielkopolskie	61	76	-3.5	0.3	6.4	10.5
16	Zachodniopomorskie	20	34	0.0	30	5.1	9.1
17	Poland	42	57	-0.4	2.6	7.3	11.3

Source: [Wrzaszcz, Kopiński 2019]

assessed based on estimated norms for voivodeships (Table 1). Long-term deviation from the optimal state (resulting from the nutritional needs of plants and local soil conditions) indicates an adverse impact of agricultural activities on the state of the natural environment, as well as economic performance [Wrzaszcz, Kopiński 2019].

RESEARCH RESULTS AND DISCUSSION

Fertilizers are one of the main means of agricultural production. They can have different forms (liquid and solid) and origin (natural, synthetic/mineral and organic). However, without these products, plant productivity and further agricultural productivity would be significantly lower [Matyka 2021]. In addition to production and economic issues, the used fertilizers affect the state of the natural environment due to the violation of the

natural circulation of macronutrients in the soil and, consequently, by being able to move to waters, through the emission of gases into the air [Kopiński 2006a]. Thus, fertilizer management is one of the basic determinants of agricultural sustainability [Kopiński, Ochal 2013, Kopiński 2017, Wrzaszcz, Kopiński 2019]. Based on substantive considerations [Ochal, Kopiński 2017, Pastuszak et al. 2018], fertilizer management should be carried out in a rational manner, in other words, adapted to local conditions (mainly soil condition), plant nutrient needs or recommendations of a specific farming system in agriculture. This adjustment should take both the quantity and type of used fertilizers into account, ensuring the nutritional needs of the cultivated crops, but at the same time not creating excessive excess NPK in the environment. A useful measure for monitoring rational fertilizer management is the NPK fertilizer balance, which depends on the quantity of supplied and taken macronutrients by crops in agricultural production [Fotyma et al. 2000].

One of the objectives of the Farm to Fork strategy is to reduce the use of fertilizers by at least 20% by 2030 and reduce nutrient losses by at least 50% without allowing soil fertility to deteriorate. To establish the legitimacy of the enforcement of reduction practices, an important point of reference is to identify the current direction of changes in the level of fertilizer and the outcome of the fertilizer balance. Research results concerning the individual farm population show that over a period of 10 years, the fertilizer management of individual farms has changed significantly, with changes in the level of mineral and natural fertilization, balance performance and efficiency in the use of individual macronutrients (Table 2).

During the considered period, there was a slight increase in the quantity of mineral fertilizers supplied. However, relations in mineral fertilizing between different fertilizing components have changed, mainly due to a reduction in phosphorus fertilizer. The unfavourable relationship has been exacerbated by the so-called Liebig barrel rule, according to which the so-called minimum component limits plant productivity, further translating into the deterioration of efficiency of nitrogen use leading to an increase in environmental risks [Pastuszak et al. 2018]. The reasons can be found in the high and increasing costs of these means of production (Figure 1), which are a key element among the direct costs of farming [Skarżyńska 2019] and determine the economic decisions of the farmer aimed at purchasing the main ingredient that is nitrogen. Nevertheless, the deficit of even one nutrient contributes to the under-utilization of other macro- and micronutrients, soil productivity, plant production potential and relatively lower yields, reduced efficiency, which can consequently lead to a decrease in soil fertility and, over time, to its degradation [Wrzaszcz, Kopiński 2019].

In the case of natural fertilizers, there was a decrease in NPK components supplied, which was a result of changes observed in the livestock population. Consequently, the absence of natural fertilizers can lead to a decrease in soil fertility and productivity, which translates into the economic dimension of agricultural activity. Therefore, to ensure the nutritional needs of cultivated plants (taking soil content into account) and the level of

Table 2. Basic characteristics of the NPK fertilizer economy in Poland

Specification	2007	2016	Change in:	
			units	%
N quantity (mineral fertilizers) [kg/ha]	64.9	69.9	5.0	7.7
P_2O_5 quantity (mineral fertilizers) [kg/ha]	26.2	22.4	-3.8	-14.5
K_2O quantity (mineral fertilizers) [kg/ha]	30.9	36.0	5.1	16.5
Sum of N, P_2O_5 K_2O quantity (mineral fertilizers) [kg/ha]	122.0	128.3	6.3	5.2
N quantity (natural fertilizers) [kg/ha]	40.8	35.6	-5.2	-12.7
P quantity (natural fertilizers) [kg/ha]	8.1	6.6	-1.5	-18.5
K quantity (natural fertilizers) [kg/ha]	35.5	30.6	-4.9	-13.8
Sum of NPK quantity (natural fertilizers) [kg/ha]	84.4	72.8	-11.6	-13.7
Amount of N (total soil application) [kg/ha] *	119.2	121.6	2.4	2.0
Amount of P (total soil application) [kg/ha] *	19.8	16.7	-3.1	-15.5
Amount of K (total soil application) [kg/ha] *	61.2	60.5	-0.7	-1.1
N balance [kg/ha]	43.8	33.0	-10.8	-24.7
P balance [kg/ha]	5.7	-0.4	-6.1	x
K balance [kg/ha]	8.2	-0.5	-8.7	x
N balance in relation to optimal values **	in the range	below	x	x
P balance in relation to optimal values **	above	in the range	x	x
K balance in relation to optimal values **	in the range	below	x	x
Farms with understated N balance [%]	64.0	74.0	10.0	x
Farms with overstated N balance [%]	27.4	20.5	-6.9	x
Farms with understated P balance [%]	49.5	70.9	21.4	x
Farms with overstated P balance [%]	40.8	22.0	-18.8	x
Farms with understated K balance [%]	66.2	71.9	5.7	x
Farms with overstated K balance [%]	30.1	25.6	-4.5	x
Effectiveness of N use [%]	63.3	72.9	9.6	x
Effectiveness of P use [%]	71.0	102.2	31.2	x
Effectiveness of K use [%]	86.5	100.7	14.2	x

* The application includes mineral fertilizers; natural fertilizers; symbiotic nitrogen, nitrogen and phosphorus in atmosphere fallout

** Ranges of optimal balances for Poland determined on the basis of plant food needs, soil conditions and potential environmental pressures: N in kg/ha [4257]; P in kg/ha [-0.4; 2.6]; K in kg/ha [7.3; 11.3] [Wrzaszcz, Kopiński 2019]

Source: own study based on FSS Statistics Poland 2007 and 2016 unpublished data

production, these components should be substituted for an increased consumption of fertilizers, mainly mineral [Wrzaszcz, Kopiński 2020]. As a result of improving plant productivity, the removal of fertilizer components in the form of main and by-products of field plants has increased [Wrzaszcz, Kopiński 2019, Matyka 2021]. The harvests obtained from arable and permanent crops are a result of the interaction of fertilization, biological (breeding) progress and careful agrotechnics [Matyka 2014].

The summary effect of the fertilizer management evaluation is the balance and efficiency of the use of NPK by cultivated plants, which facilitate the assessment of the potential environmental burden of these components [Kopiński 2006b]. Nitrogen and phosphorus compounds from the agricultural sector are considered to be the most serious risks due

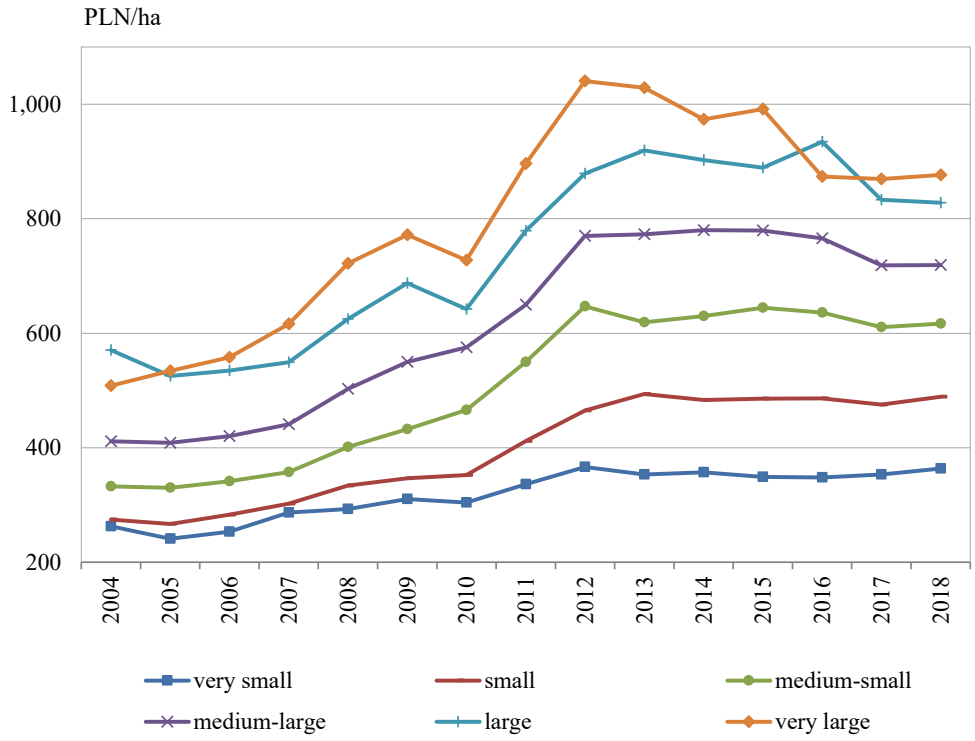

Figure 1. Unit cost of mineral fertilizers in economic size groups* of individual farms

* According to the FADN, the grouping of farms by economic size was based on the standard gross margin for the period 2004-2009, and according to standard production in EUR for the years 2010-2018 (very small: 2-8 thousand, small 8-25: thousand, medium-small 25-50: thousand, medium-large: 50-100 thousand, large 100-500: thousand, very large: from 500 thousand). Closed left compartments were used

Source: own study based on FADN 2004-2018 time series statements [www.fadn.pl]

to their movement into water and the atmosphere, in the case of nitrogen also into the air [OECD 2006]. The results showed (Table 2) that the balance performances decreased significantly, while P and K had taken negative values, with effectiveness indicators exceeding 100%. Given the low level of soil content in Poland in these two components, the results obtained should be considered unfavourable not only in economic terms, but also in the environmental dimension [OECD 2006]. In the case of nitrogen, the balance performance decreased during the analysed period, which was essentially an effect of an increased amount of N taken in agricultural production. Effective use of N also improved.

In the context of the objectives adopted in the Farm to Fork strategy, it is important to establish the distribution of agricultural holdings in terms of balance performance. The average result for the sector is the effect of averaging performances from entities distinguished by extensive, optimal or intensive fertilizer management. It was found that, on the one hand, the population of individual holdings is dominated by farms with understated NPK balances (more than 70%, Table 2), indicating the unused production potential of plants and the depletion of soil-accumulated ingredients. On the other hand, around 20-25% of farms practice too intensively in this scope, creating balance surpluses. Based on FADN data for different economic groups of farms, it can be concluded, that agricultural holdings with a size of more than € 25,000 (average, large and very large) have an input on fertilizers above average value, and the dynamics of changes in production costs significantly higher compared to smaller units (Figure 1). Public statistics for 2016 also confirmed the positive impact of farm economic size on the fertilizer balance (for extreme groups of farms, i.e., very small, an overstated performance of N balance was found in 12% of units, while in the case of the largest ones in 53% of farms. The relationship between the groups was similar in the case of P and K). These results confirmed the significance of farm economic size in balancing fertilization results and the evaluation of fertilization.

The issue of regional diversity, including plant productivity and NPK balance results, has been presented in numerous studies [Kopiński, Ochal 2013, Matyka 2014, Ochal, Kopiński 2017, Wrzaszcz, Kopiński 2019]. Data for individual farm populations also confirm these findings (Table 3). Regional disparities arise from a different level of agricultural production intensity, which is based both in environmental conditions (soil condition, climate) and at the technical and organizational level of agriculture in Poland [Wrzaszcz, Kopiński 2020]. The high variability of NPK balances and the efficiency of the use of fertilizing components, at a regional level, prejudge the need for a prudent approach to quantified reduction targets (Table 3).

The effectiveness of fertilizer component use and their potential losses are largely determined by the pH reaction of soil. According to research of the Institute of Soil Science and Plant Cultivation State Research Institute, about 80% of agricultural land in Poland is acidic, with very acidic soils representing 29%, acidic soils 28% and slightly acidic soils 24%. Most cultivated plants require soils with a reaction from slightly acidic

Table 3. Total macronutrient balance and efficiency of NPK utilization

Specification	N		P		K	
	kg/ha	E [%]	kg/ha	E [%]	kg/ha	E [%]
Dolnośląskie	21.7	81	-4.0	128	2.2	95
Kujawsko-pomorskie	56.3	63	0.5	98	4.1	94
Lubelskie	20.2	81	-1.0	106	-0.7	101
Lubuskie	24.2	77	-2.6	120	-4.6	111
Łódzkie	53.0	61	2.2	88	6.2	91
Małopolskie	-2.7	103	-4.6	138	-16.0	134
Mazowieckie	37.9	70	0.8	95	-3.9	106
Opolskie	35.1	76	-2.9	114	11.1	83
Podkarpackie	2.7	96	-2.4	123	-8.6	125
Podlaskie	18.6	85	-0.7	104	-9.6	113
Pomorskie	39.2	68	-0.5	103	2.7	95
Śląskie	21.7	81	-1.5	110	-0.3	101
Świętokrzyskie	28.9	69	-0.3	102	-3.9	108
Warmińsko-mazurskie	28.5	76	-1.6	111	-9.7	119
Wielkopolskie	60.5	62	3.6	85	17.3	80
Zachodniopomorskie	26.0	75	-1.7	114	-6.4	117
Poland	33.0	73	-0.4	102	-0.5	101
Coefficient of variation [%]	59.1	15	206.4	13	672.0	14

Source: own study based on FSS Statistics Poland 2016 unpublished data

to neutral, which determines the need for liming practices [Krasowicz et al. 2011]. Data on individual farm populations show that only 10% of farms have undertaken lime fertilization practices, both in 2007 and 2016. Positive changes in the percentage of farms that use lime were particularly noticeable in the Wielkopolskie and Opolskie voivodeship (Figure 2). On farms using liming practices, the average CaO consumption per 1 ha of agricultural land was around 190 kg in 2007 and 350 kg in 2016. During these years, the amount of lime fertilizers used in the individual farm population increased from 431,000 to 827,000 tonnes CaO, while the area of agricultural land in farms using this fertilizer changed slightly from 2.3 million ha to 2.5 million ha. By compiling these data, it can be argued that a twofold increase in the consumption of lime fertilizers during the analysis period was a result of an increase in fertilization on farms that had undertaken these practices in

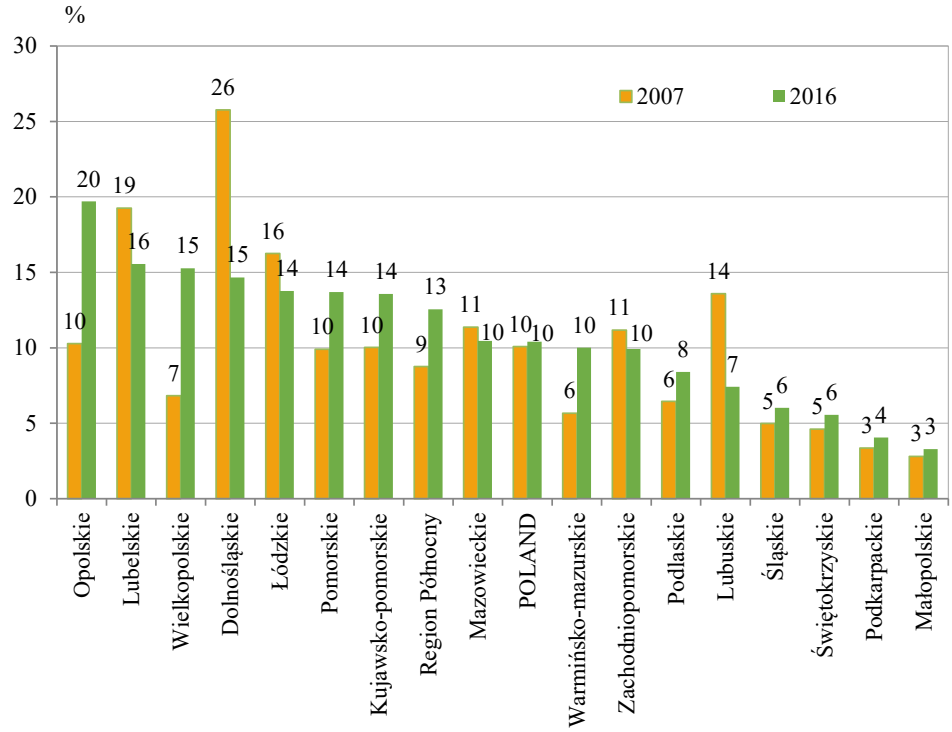

Figure 2. Farms using lime fertilizers (% of total individual farms with agricultural land)
Source: own study based on FSS Statistics Poland 2007 and 2016 unpublished data

previous years. The continuation of such agricultural practices may have resulted from perceived production benefits as a result of lime fertilization. However, significant regional differences in the management of lime fertilizers should be considered.

Considering the significant share of acidic soils (including very acidic soils), as well as the high impact of soil reaction on the efficiency of nutrient use [Ochal, Kopiński 2017], the results indicate the appropriateness of taking measures to regulate soil reaction and ensure optimal conditions for the growth and development of cultivated plants. Current fertilizer practices do not meet production and environmental needs, although a positive trend is recognized. Insufficient awareness among farmers of the importance of lime fertilizers for plant production and their use of other macronutrients in acidic soil environments, as well as rare soil analysis are the reasons for inappropriate lime fertilization [Wrzaszcz, Kopiński 2019]. An important factor limiting the actions of farmers in this area is certainly the rising prices of lime fertilizers [GUS 2015, 2021].

CONCLUSIONS

Rational fertilizer management is one of the determinants of sustainable agriculture and a key element of the Europe's Farm to Fork strategy, which is based on the need to reduce agricultural pressure on the environment. Rational fertilizer management not only involves the amount of fertilizers used, including mineral fertilizers, but also the quality of the practices performed, corresponding to local soil conditions. Its main determinant is the balance of the NPK balance, i.e., the final result of nutrient management. It is not only derived from the amount of ingredients brought and taken into/out of the soil, but also by its pH and state.

It has been established that, at the level of the agricultural sector, the results of fertilizer balances do not create dangerous surpluses to the environment. A significant share of farms with understated NPK balances, thus demonstrating the unused production potential of crops and the environmental pressure resulting from the reduction of natural macroelement stocks from the soil, was identified as a problem. At the same time, some farms are showing an overly high balance performance, prompting the introduction of reduction practices. Regional diversity in this area is significant. These results justify the introduction of a skilful system for reducing farm fertilization according to current intensity and specificity of production and regional location.

Given the increasing cost of fertilizers, the decreasing amount of natural fertilizers used, as well as the low soil richness in macronutrients and the dominance of acidic soils, it seems important to pay more attention to the quality of agricultural practices and the balance performance of fertilizing, rather than just the used amount of fertilizers (mineral). Basic practices for reducing the loss of fertilizing ingredients in agriculture are the following: ensuring an adequate pH soil reaction, ensuring an appropriate proportion of NPK in fertilization, ensuring organic and natural fertilization, adapting fertilization to soil conditions and plant needs, and providing an infrastructure to store fertilizers and reduce NPK losses.

The fertilizer balance and level of nutrient efficiency should be used as measurable indicators for setting reduction targets, especially in the case of intensively organized farms, i.e., generally larger in area or in terms of economic size. The reduction in fertilization assumed under the European Green Deal may result in a decrease in production and economic performance from the farm and negatively affect the natural environment due to the depletion of accumulated resources in the soil. It seems appropriate to promote tools to facilitate the calculation of the fertilizer balance and NPK effectiveness, taking the pH and soil content into account. Both environmental and economic considerations (the importance of fertilization for plant production and its significant cost) are important prerequisites for increasing farmer interest in such practices.

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GOSPODARKA NAWOZOWA W POLSCE W ŚWIETLE CELÓW EUROPEJSKIEGO ZIELONEGO ŁADU

Słowa kluczowe: gospodarka nawozowa, nawozy mineralne, NPK, Europejski Zielony Ład, strategia "Od pola do stołu", saldo bilansu nawozowego

ABSTRAKT

Celem artykułu jest nakreślenie obszarów problemowych gospodarki nawozowej w Polsce, biorąc pod uwagę potrzebę realizacji celów Europejskiego Zielonego Ładu (EZŁ). Gospodarka nawozowa to jeden z kluczowych elementów przyszłej polityki rolnej, do której nawiązuje EZŁ, a bliżej strategia „Od pola do stołu". Podkreślenie potrzeby prowadzenia racjonalnej gospodarki nawozowej w dokumentach europejskich wynikało z presji wywieranej przez tę działalność gospodarczą na stan środowiska przyrodniczego. Skupiono się na głównych wyznacznikach gospodarki nawozowej, w tym kosztach i ilości stosowanych nawozów mineralnych oraz wynikach bilansu nawozowego NPK, stosując metody liczenia bilansu brutto oraz wskaźnikową. Do badań wykorzystano dane zebrane przez GUS w latach 2007 i 2016 w ramach badania struktury gospodarstw rolnych oraz dane rachunkowości rolnej Polskiego FADN, dotyczące rolnictwa towarowego za lata 2014-2019. Ustalono, że na poziomie sektora rolnego wyniki bilansów nawozowych nie tworzą nadwyżek, a kwestią problematyczną jest znaczący udział gospodarstw o zaniżonym wyniku bilansu głównych makroskładników NPK. Zakładana redukcja poziomu nawożenia w ramach EZŁ może skutkować obniżeniem wyników produkcyjno-ekonomicznych w gospodarstwach rolnych oraz negatywnie wpłynąć na stan środowiska przyrodniczego. Bilans nawozowy oraz poziom efektywności wykorzystania składników pokarmowych powinien służyć jako wymierny wskaźnik do ustalania celów redukcyjnych.

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