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Nitrogen gross balance in farms specialised in plant production in selected regions of Poland

Bilans nawozowy azotu w gospodarstwach wyspecjalizowanych w produkcji roślinnej wybranych regionów Polski

Summary. The aim of the performed investigations was to evaluate nitrogen management in farms specialising in plant production situated in the following voivodeships: Wielkopolskie, Dolnośląskie, Opolskie and Mazowieckie. The analysed data were derived from 31 individual farms specialising in plant production situated in various regions and covered the period of 2004–2006. Farms from Wielkopolska and Dolny Śląsk were situated in nitrate vulnerable zones (NVZ's). The nitrogen balance in farms located in NVZ's, on average, amounted to 12.5 kg N ha^{-1} of agricultural land (AL). In the case of farms situated in Opolskie voivodeship, a significant deficit of this element was observed amounting to -63.3 kg N ha^{-1} of AL. Farmers from Raszyn commune in Mazowieckie voivodeship posed a potential hazard to the environment managing nitrogen resources in an irrational way. The nitrogen balance there exceeded the Code of Good Agricultural Practice (COGAP) recommended standard of 30 kg N ha^{-1} of AL reaching the level of about 50 kg N ha^{-1} of AL.

Key words: gross balance, nitrogen, nitrogen balance, plant production

INTRODUCTION

Agricultural activities are carried out all over the world on very large areas. In the case of the European Union, the agricultural land covers more than 60% of the area of Member States and, therefore, exerts a considerable influence on the condition of environment. In Poland, agricultural land constitutes 59.6% of the area of the country [Michalczyk 2004]. Monitoring carried out in West European countries for many years has revealed contamination of surface waters with nitrates. Standards specified in the directives referring to the quality of waters used for supplies of human populations [Dyrektywa 75/440/EEC, 79/869/ EEC and 80/778/ EEC] have been exceeded considerably. In addition, thresholds limiting the effect of nitrates on the intensification and course of the eutrophication process in inland surface and sea waters have also been exceeded. In some regions, agricultural production was indicated as the main source of nitrogen in waters [Informacje... 2003].

Utilisation in agriculture of such means of production as fertilizers or industrial feeds is essential to maintain stability and proper functioning of farms. However, their irrational application, without taking into consideration specificities of a given area, may pose a serious hazard to the environment. In order to limit negative effects of agriculture on surface and underground waters, on December, 12th 1991, countries of the European Union introduced the Nitrate Directive [Dyrektywa 91/676/EEC] dealing with the protection of waters against contaminations caused by nitrates of agricultural origin. The Directive, among many of its clauses, places an obligation on all member states to control and monitor the nitrogen cycle in agricultural farms. The main tool of the control of the nutrient circulation is the balance.

The surveys were a part of research project of Ministry of Science and Higher Education (MNiSW) nr 2 P04G 048 30 in 2006–2007 y. The aim of the paper was to assess nitrogen management in farms specialising only in plant production in Wielkopolskie, Dolnośląskie, Opolskie and Mazowieckie voivodeships.

MATERIAL AND METHODS

Investigations were conducted in years 2004–2006 selecting 31 individual farms specialising in plant production varying with regard to their structure and area under crops as well as levels of fertilization (Tab. 1–3). Part of the farms included extensive and double-occupational farms with the main income coming from outside farming. The performed surveys covered the area of 15 communes from 4 voivodeships: Wielkopolska, Dolny Śląsk, Opole and Mazowsze (Fig. 1 and 2). Eight farms were located on nitrate vulnerable zone's (NVZ's) determined in accordance with the recommendations of the EU Nitrate Directive [Dyrektywa 91/676/EEC], (Fig. 1).

The basic source of data included specially elaborated questionnaires as well as additional information obtained directly in analysed farms. Some data were acquired from documentation stored in commune offices as well as Agriculture Advisory Centres from the registry of farms included in the special Program of activities prepared for every nitrate vulnerable zone (NVZ) in Poland. Data from the questionnaires comprised basic parameters characterising a given farm, i.e. areas under crops, harvested crops, utilisation of mineral fertilizers and

manures. In the case of farms from Opolskie voivodeship, data were obtained from the Voivodeship Agriculture Advisory Centre in Opole, branch in Łosiów.

The calculation of the nitrogen balance was carried out using the „gross balance" method employed in many European countries [Kupiec 2008, Kopiński 2010, Fotyma *et al*. 2008]. In this type of balance, also known as fertilizer balance, the following parameters were taken into account:

– on the income side: used mineral fertilizers and manures,

– on the expenditure side: crop plants removed from the field.

Individual balance positions were calculated on the basis of data acquired from questionnaire surveys as well as from the available indices of constituent contents in different products (according to data provided by the producer and from tables of chemical concentrations).

CHARACTERISATION OF AGRICULTURAL FARMS

The average area of 8 farms situated in the nitrate vulnerable zone's (NVZ's) amounted to 30.7 ha. The structure of sown area of the analysed farms in this region was dominated by cereals which occupied 70.8% of the arable land area (root plants – 18%, industrial – 5.5%, papilionaceous – 0.1%, others – 5.6%). Farms of the Wielkopolska (6) and Dolny Śląsk (2) were characterised by a more diversified structure in comparison with the farms from the remaining regions. Mineral fertilizer consumption in comparison with the remaining farms was the lowest and amounted to 145.9 kg N ha^{-1} AL (Tab. 1). The ratio of N:P:K constituents derived from mineral fertilizers used on fields amounted to 1:0.34:0.52 (Fig. 3).

Farmers from Opolskie voivodeship farmed considerably larger areas than farmers from other regions. The mean size of the 7 examined farms from that region amounted to 113.1 ha. The structure of sown area in the examined farms from Opole region was poorly diversified with cereals taking up the largest area (cereals – 71.9%, industrial plants – 15.8%, root plants – 12.3%). Farmers from this region purchased slightly more mineral fertilizers than their counterparts from Wielkopolska and Dolny Śląsk regions and their consumption was at the level of 144.0 kg N ha^{-1} AL (Tab. 2). The mean ratio of used N:P:K macroelements from mineral fertilizers in this group of farms was: 1:0.47:0.62 (Fig. 4).

The smallest among the examined farms were found to occur in Raszyn commune. The mean area of agricultural land of 16 farms from this region amounted to 8.5 ha. The proportion of individual crop plants in the structure of sown area differed from the remaining examined farms with vegetables taking up the largest area in the cropping system structure and cereals – the smallest proportion of cultivations (vegetables – 42.4%, root plants – 37.3%, cereals – 20.2%). The consumption of mineral fertilizers was the highest among all the examined farms amounting to 138.4 kg N ha^{-1} AL (Tab. 3). The N:P:K consumption ratio was 1:0.59:0.80 (Fig. 5).

RESULTS AND DISCUSSION

The gross nitrogen balance in the 8 farms from Wielkopolskie and Dolnośląskie voivodeships was at the level of -12.5 kg N ha^{-1} AL (Fig. 3). The mean ratio of income to expenditure was close to balance and amounted to 0.9. Nitrogen utilization in the majority of farms was considerably higher than the amount of this element introduced into the field indicating its increased uptake from the soil. The mean utilization of this constituent for the group of farms from this region amounted to 159.5% (Tab. 1).

Table 1. Characteristic of private farms of Wielkopolskie and Dolnośląskie voivodships and the balance indexes
Tabela 1. Charakterystyka gospodarstw indywidualnych woj. wielkopolskiego i dolnośląskiego oraz wskaźniki bilansu azotu

Farm nr Nr gosp.	AL area (ha) Pow. UR	Commune Voivodship Gmina Województwo	Nitrate Vulnerable Zone (NVZ) Obszar szczególnie narażony (OSN)	Specialization Specjalizacja	Nitrogen from mineral fertilizers Azot z nawozów mineralnych	Nitrogen from manures Azot z nawozów naturalnych	Uptake with crops Pobranie z plonem	Balance Saldo
					kg N ha^{-1} UR / AL			
1	13.0	Poznań Wielkopolskie	Kopel	cereals zboża	26.9	0.6	131.0	-103.6
2	29.1	Kórnik Wielkopolskie	Kopel	cereals, root plants zboża, okopowe	208.9	24.7	204.4	29.3
3	19.5	Kórnik Wielkopolskie	Kopel	cereals zboża	270.8	0.6	187.4	84.1
4	35.6	Wąsosz Dolnośląskie	Orla	cereals zboża	117.8	0.0	123.1	-5.2
5	83.9	Rawicz Wielkopolskie	Orla	cereals zboża	138.7	3.3	162.3	-20.2
6	18.6	Góra Dolnośląskie	Rów Polski	cereals zboża	110.8	0.2	128.0	-17.0
7	29.5	Buk Wielkopolskie	Samica Stęszewska	cereals, root plants zboża, okopowe	87.7	0.0	204.1	-116.4
8	16.0	Stęszew Wielkopolskie	Samica Stęszewska	cereals zboża	205.6	0.0	156.8	48.8

Fig. 1. Localization of nitrogen vulnerable zones (NVZ's) in Wielkopolskie and Dolnośląskie voivodeships where were localized 8 of 31 investigated farms (1 – Kopel, 2 – Samica Stęszewska and Mogilnica, 3 – Rów Polski, 4 – Orla)
Rys. 1. Lokalizacja obszarów szczególnie narażonych (OSN) na obszarze woj. wielkopolskiego i dolnośląskiego, w których umiejscowione było 8 z 31 badanych gospodarstw (1 – obszar rzeki Kopli, 2 – obszar rzeki Samicy Stęszewskiej i Mogilnicy, 3 – obszar rzeki Rowu Polskiego, 4 – obszar rzeki Orli)

The nitrogen balance for the 7 farms of the Opolskie voivodeship calculated using the „gross balance" method exhibited a significantly higher deficit of this constituent in comparison with the farms specialising in plant production in Wielkopolska and Dolny Śląsk. The result of the balance was at the level of -63.3 kg N ha^{-1} AL (Fig. 4). The ratio of income to expenditure in the group of the examined farms amounted to 0.7, whereas the utilization of the constituent was at the level of 145.3% (Tab. 2).

Nitrogen management in farms situated in Raszyn commune was less efficient. A very high nitrogen deficit amounting to nearly -170 kg N ha^{-1} AL was observed only in one farm, while in the remaining cases nitrogen balance was positive (on average, 44.9 kg N ha^{-1} AL, Fig. 5). Ten farmers from this region exceeded, sometimes quite significantly, the value of 30 kg N ha^{-1} AL recommended by the Code of Good Agricultural Practice. The income to expenditure ratio in the examined farms of Raszyn commune amounted to 1.8, hence the lower utilization of the constituent – at the level of 68.5% (Tab. 3). The reason of results differences based on uptake of nitrogen by particular crops. Cereals remove from fields much more quantities of nitrogen in comparison with vegetables [Czarnik *et al*. 1986, Sady 2000]. By nearly the same nitrogen fertilization in analysing farms the results of balance were quite different in surveyed types of farms. Variety of specializations in agricultural production can be effect of a wide scale of results.

Table 2. Characteristic of private farms of Opolskie voivodship and the balance indexes
Tabela 2. Charakterystyka gospodarstw indywidualnych woj. opolskiego oraz wskaźniki bilansu azotu

Farm nr Nr gosp.	AL[1] area (ha) Pow. UR	Commune Administrative district Gmina Powiat	Specialization Specjalizacja	Nitrogen from mineral fertilizers Azot z nawozów mineralnych	Nitrogen from manures Azot z nawozów naturalnych	Uptake with crops Pobranie z plonem	Balance Saldo
				kg N ha^{-1} UR / AL[1]			
1	53.3	Namysłów Namysłowski	cereals zboża	137.0	0.0	246.1	-109.1
2	90.0	Nysa Nyski	cereals zboża	185.0	0.0	178.5	6.5
3	103.1	Otmuchów Nyski	cereals zboża	169.0	0.0	276.2	-107.2
4	87.3	Kluczbork Kluczborski	cereals, industrial plants zboża, przemysłowe	150.0	0.0	137.8	12.2
5	244.2	Dąbrowa Opolski	cereals zboża	132.0	12.0	207.6	-63.6
6	154.0	Głubczyce Głubczycki	cereals zboża	132.0	12.0	272.7	-128.7
7	59.9	Lubsza Brzeski	cereals zboża	103.0	0.0	156.5	-53.5

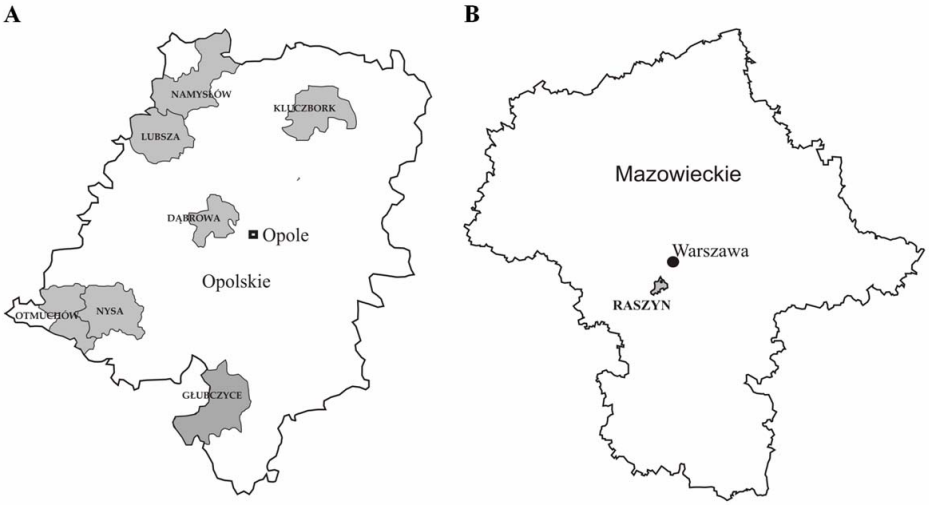

Fig. 2. Localization of regions in Wielkopolskie (A) and Mazowieckie (B) voivodships where were localized 7 of 31 investigated farms
Rys. 2. Lokalizacja gmin na obszarze woj. opolskiego (A) i woj. mazowieckiego (B), w których umiejscowione było 7 z 31 badanych gospodarstw

Table 3. Characteristic of private farms of Mazowieckie voivodship and the balance indexes
Tabela 3. Charakterystyka gospodarstw indywidualnych woj. mazowieckiego oraz wskaźniki bilansu azotu

Farm nr Nr gosp.	AL area (ha) Pow. UR	Commune Administrative district Gmina Powiat	Specialization Specjalizacja	Nitrogen from mineral fertilizers Azot z nawozów mineralnych	Uptake with crops Pobranie z plonem	Balance Saldo
				kg N ha^{-1} UR / AL		
1	9.0	Raszyn Pruszkowski	cereals zboża	150.6	60.0	90.6
2	4.5		root plants okopowe	118.4	66.5	52.0
3	7.3		vegetables – warzywa	126.8	64.7	62.1
4	4.0		vegetables – warzywa	160.4	52.7	107.7
5	4.0		vegetables– warzywa	216.0	187.5	28.5
6	3.4		vegetables – warzywa	175.9	67.2	108.7
7	5.0		cereals zboża	116.8	52.8	64.0
8	4.0		cereals zboża	133.8	52.4	81.4
9	6.0		vegetables – warzywa	129.8	61.3	68.6
10	5.0		root plants – okopowe	193.2	95.4	97.8
11	12.0		vegetables – warzywa	107.7	91.3	16.4
12	11.5		vegetables – warzywa	100.3	77.7	22.6
13	12.5		vegetables – warzywa	119.1	82.6	36.5
14	12.0		vegetables – warzywa	137.5	307.3	-169.8
15	19.0		vegetables – warzywa	123.3	94.7	28.6
16	17.0		vegetables – warzywa	104.8	82.2	22.5

The nitrogen balance calculated with the assistance of the „gross balance" method for countries of the European Union for years 1990–1991 revealed considerable regional differences. The balance of this constituent for individual member states of the Union ranged from 14.2 to 385.0 kg N ha^{-1} AL [Pawlik-Dobrowolski 1998]. Poland was characterized by the lowest balance among European countries which could have been due to system transformations in our country as well as high prices of mineral fertilizers in this period [Zbierska *et al*. 2002]. The highest surplus occurred in the Netherlands (385.0 kg N ha^{-1} AL) and Belgium (218.2 kg N ha^{-1} AL). In this study, the nitrogen balance calculated with the assistance of the „gross balance" recommended by Shleef and Kleinhanss [1994] for farms of Wielkopolska and Dolny Śląsk as well as Opole regions yielded a much lower result than that reported for Poland by Pawlik-Dobrowolski [1998]. The lower balance could have been affected, primarily, by a considerably more effective fertilization which was based on plant nutritional and fertilization requirements, especially in the case of farms situated in Wielkopolska and Dolny Śląsk. Farmers from the above regions removed considerably more of the constituent in primary crops than

farmers whose farms were situated in Raszyn commune. The highest quantities of the constituent were removed from soil with the primary crop plants in farms situated in Opolskie voivodeship, which increased the deficit of this element. In the case of farms situated in Mazowsze region, a positive balance was achieved which was by 31 kg higher in comparison with the all-country average given by Pawlik-Dobrowolski [1998].

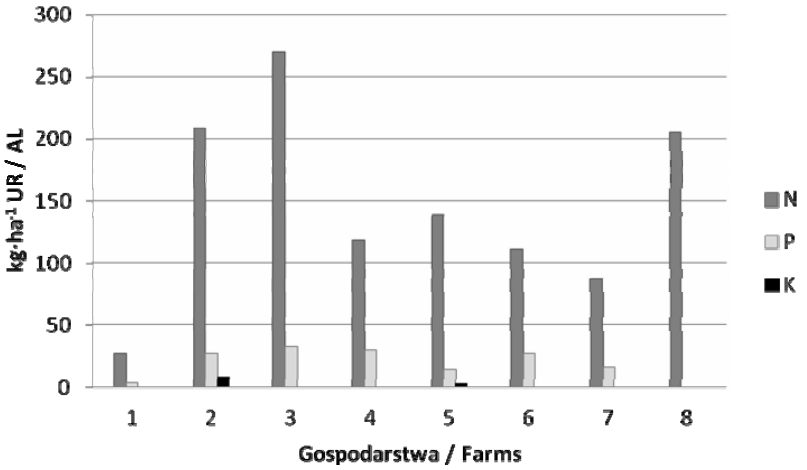

Fig. 3. Consumption of nutrients from mineral fertilizers in investigated farms of Wielkopolskie and Dolnośląskie voivodships
Rys. 3. Zużycie składników z nawozów mineralnych w badanych gospodarstwach woj. wielkopolskiego i dolnośląskiego

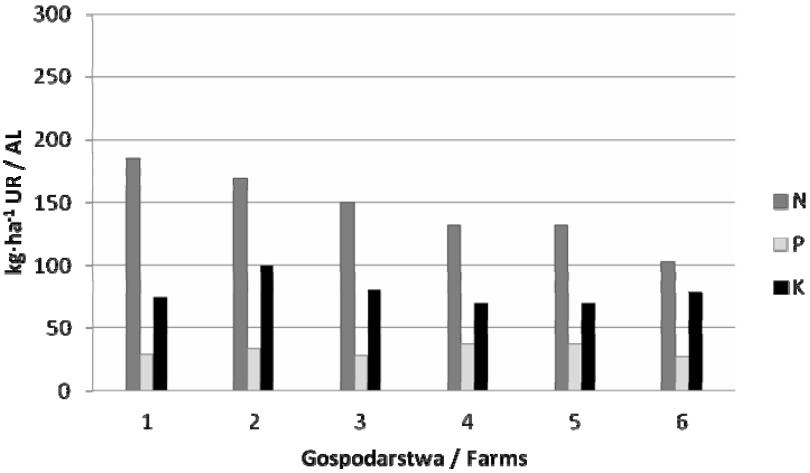

Fig. 4. Consumption of nutrients from mineral fertilizers in investigated farms of Opolskie voivodship
Rys. 4. Zużycie składników z nawozów mineralnych w badanych gospodarstwach woj. opolskiego

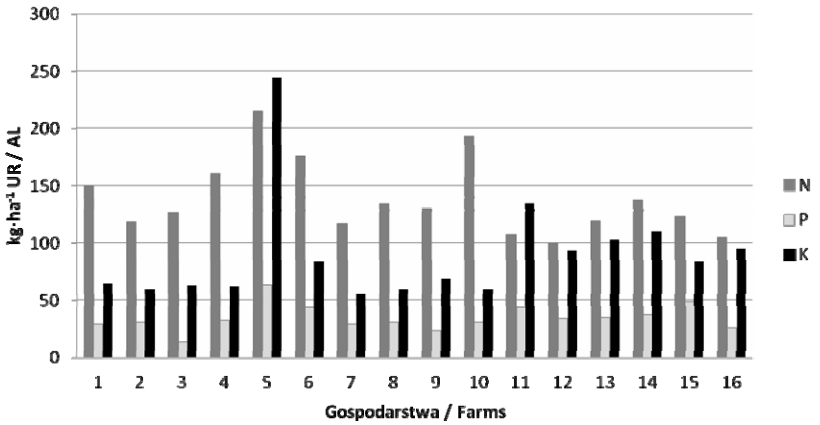

Fig. 5. Consumption of nutrients from mineral fertilizers in investigated farms of Mazowieckie voivodship
Rys. 5. Zużycie składników z nawozów mineralnych w badanych gospodarstwach woj. mazowieckiego

The „gross balance" balance exposed dangers associated with plant production in the analysed farms. One of the important problems observed in the course of the performed investigations was a low input of constituents contained in the purchased manures which did not exceed 2.5%. Natural fertilizers in those farmsteads were replaced by mineral fertilizers, which according to Mazur *et al*. [1993] can result in enhanced degradation of organic matter and, consequently, accelerate loss of organic matter from the soil. Manures, which provide substrate for soil microorganisms as well as a valuable source of organic matter, increase the effectiveness of mineral fertilization and therefore prevent excessive utilization of mineral constituents from the substrate contributing to the maintenance of appropriate ionic balance in the soil [Fotyma and Mercik 1992].

Sapek and Sapek [2005] maintain that among important targets to be reached is to achieve a certain level of nitrogen utilization effectiveness in agricultural production by 2015. Bearing in mind limited possibilities of 100% nitrogen utilization, the above-mentioned scientists suggest 30% utilization for farms specializing in animal production and 70% utilization for farms specializing in plant production. Nitrogen utilization in the examined farms was considerably higher in comparison with farms in the Netherlands (35%) and Sweden (24%) [Ondersteijn 2000, Swensson 2002]. Nevertheless, a significantly higher proportion of the constituent was uptaken by plants from the soil than was supplied by farmers. Barszczewski [2005] demonstrated, in a long-term balance (1994–2004) calculated for the Experimental Station in Falenty, nitrogen utilization for this farm ranging from 23.2 to 35.0%. However, it should be emphasized that this Experimental Station also carried out animal production and, therefore, the utilization of this constituent was at the appropriate level determined by Sapek and Sapek [2005].

Gross nitrogen balance calculated by Kopiński [2010] for farms in Poland showed surpluses in particular provinces (22.4–85.8 kg N ha^{-1} AL). Differences between results accounted by Kopiński [2010] and in this paper are significant. According the author balance for Wielkopolska was up to 85.8 kg N ha^{-1} AL, the highest in Poland. Average

gross balance for farms localized in Mazowsze and Opole regions trends to 54.7 and 48.1 kg N ha^{-1} AL Dolny Śląsk characterized lower value of balance on level 36.6 kg N ha^{-1} AL. However, the results of this paper were similar to values of Mazowsze region obtained by Kopiński [2010] (Tab. 3). In the other cases the differences probably arise from specialization of farms. Kopiński [2010] analysed every farms in the regions, not only with plant production. The level of mineral fertilization according the author was lower for surveyed regions (from 58.7 to 84.5 kg N ha^{-1} AL) but quantities of nitrogen from manures are considerably higher (Wielkopolska – 58.1, Mazowsze – 40.9, Opole – 26.6, Dolny Śląsk – 15.3 kg N ha^{-1} AL) in comparison with farms in present work.

Utilization of mineral fertilizers in all the examined farms was found to be at similar levels ranging from: 145.9 kg N ha^{-1} AL for Wielkopolska and Dolny Śląsk regions to 144.0 kg N ha^{-1} AL for Opole and 138.4 kg N ha^{-1} AL for Mazowsze regions. These doses exceeded significantly mean doses for entire Poland and individual regions. From 1995 to 2004, a nitrogen dose calculated per agricultural land in individual agricultural farms fluctuated from 46.1 to 50.5 kg N ha^{-1} AL [Rocznik… 2005]. Ilnicki [2004] claims that the application of fertilizers causes intensification in soil of some processes of organic matter and nitrogen compounds conversion intensifying emissions of, among others, nitrogen oxides and ammonia. Farmers from the examined regions applied high mineral fertilization in comparison with EU countries (so called, „old fifteen"). According to Sapek [2000], in the majority of these countries, nitrogen utilisation in 1997 was much higher than average N utilisation in Poland. The highest levels of nitrogen mineral fertilizers converted into pure nutrient were recorded in the Netherlands (168.2 kg N ha^{-1} AL), Belgium and Luxemburg (114.7 kg N ha^{-1} AL), Denmark (102.9 kg N ha^{-1} AL) and Germany (97.7 kg N ha^{-1} AL). Poland occupied only the 11^{th} position on this list with the application of 51.5 kg N ha^{-1} AL nitrogen fertilizers used under crop plants. According to Sapek [2000], only Portugal (41.7 kg N ha^{-1} AL), Greece (38.0 kg N ha^{-1} AL), Spain (37.8 kg N ha^{-1} AL) and Austria (32.2 kg N ha^{-1} AL) used less nitrogen than Poland.

Similar investigations regarding quantities of nutrients used in agriculture production in integrated farms in Opolskie voivodeship in years 1993–1999 which developed fertilization plans on the basis of NAW-2 software were carried out by Szoszkiewicz *et al*. [2000]. Average nitrogen utilization from mineral fertilizers during this period based on soil and plant chemical analysis amounted to 98.1 kg N ha^{-1} AL, i.e. it was considerably lower than in farms analysed in this study. These differences may have been caused by different production specialization.

CONCLUSIONS

1. From among the examined farms, nitrogen was utilized most effectively by farms situated in Wielkopolskie and Dolnośląskie voivodeships for which the mean balance result was nearly sustainable.

2. A considerable nitrogen deficit developed in farms situated in Opolskie voivodeship, which could have caused a higher uptake of the nutrient from soil. In long-term perspective, such situation may lead to a shortage of this nutrient in soil.

3. Farms located in Raszyn commune of Mazowieckie voivodeship posed a hazard to the environment caused by accumulating nitrogen surpluses. The mean balance for those farms exceeded 30 kg N ha^{-1} AL recommended by the COGAP.

4. In farms specializing in plant production, due to small quantities of the applied manures, there is a real hazard of losses of organic matter from soil leading to nutrient leaching from soil.

5. Completely different uptake of nitrogen by particular crops have significant impact for balance. The vegetable farms characterized higher results of nitrogen balance in comparison with the cereal farms in spite similar level of fertilization.

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Streszczenie. Celem badań była ocena gospodarowania azotem w gospodarstwach specjalizujących się w produkcji roślinnej, zlokalizowanych w woj. wielkopolskim, dolnośląskim, opolskim oraz mazowieckim. W pracy wykorzystano dane z okresu 2004–2006, z 31 konwencjonalnych gospodarstw indywidualnych, zlokalizowanych na obszarze 15 gmin. Gospodarstwa woj. wielkopolskiego i dolnośląskiego usytuowane były na obszarach szczególnie narażonych na zanieczyszczenia związkami azotu ze źródeł rolniczych (OSN). Saldo azotu w gospodarstwach zlokalizowanych na OSN wyniosło średnio -12,5 kg N · ha^{-1} UR. W gospodarstwach Opolszczyzny uwidocznił się znaczny deficyt tego składnika kształtujący się na poziomie -63,3 kg N · ha^{-1} UR. Rolnicy gminy Raszyn w woj. mazowieckim stwarzali potencjalne zagrożenie dla środowiska, gospodarując w sposób nieracjonalny azotem. Saldo przekraczało tam ustaloną przez Kodeks Dobrej Praktyki Rolniczej wartość 30 kg N · ha^{-1} UR i wyniosło ok. 50 kg N · ha^{-1} UR.

Słowa kluczowe: azot, bilans azotu, bilans nawozowy, produkcja roślinna