

CRITERION TO DETERMINE OPTIMUM SURPLUSES OF GROSS NITROGEN BALANCE ON THE LEVEL NUTS-0, NUTS-2

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Abstract. This paper presents a methodical attempt to determine criteria for the optimum surpluses of gross nitrogen balance, with regard to the conditions of agricultural production in recent years in Poland. To determine those criteria, factors such as active nitrogen and its gaseous compound emissions as well as atmospheric rainfall deposition were taken into account on the input side of the balance. Nitrogen that can be possibly taken with the yield, under optimal weather conditions is the main factor on the output side of the balance. The optimal permissible nitrogen balances, due to the calculated methodological assumptions, are in the range of 30.8 to 75.9 kg·ha⁻¹ UAA. The average permissible gross nitrogen balance, based on the data from the years 2011-2013, should be approx. 50 kg·ha⁻¹ UAA. Currently, it is higher than the determined optimal balance only by 2.5 kg·ha⁻¹ UAA.

Key words: environmental indicators, GNB, regional differentiation, surplus of nitrogen

INTRODUCTION

Accession of Poland to the European Union has posed new challenges to environmental protection on rural areas concerning appropriate management of production operations [Oszmiańska and Mielcarek 2006]. This results from a higher importance of the functions of public utility in contemporary post-industrial agriculture. They reflect relations occurring between the value of the environment as a public good and the value of agricultural production carried out in this environment [Duer 2000]. Therefore, as it is stated by Zegar [2014], orientation towards sustainable agricultural development is an opportunity to reconcile increase in agricultural production (taking into consideration increasing requirement for food and non-food raw materials) without increasing pressure on the environment, and towards preserving cultural heritage and vitality of rural areas. The goals concerning reduction of environmental threats caused

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by agriculture while highlighting its function as public utility [Zegar 2014], are also reflected in regulations and legal acts, which directly do not reduce intensification of production, but require taking into consideration protection of natural resources.

Environmental effects of an intensive agricultural production reveal in a measurable way in the change in indicators of soil fertility and in the composition of ground waters or in the air quality [Fotyma *et al.* 2009a]. To evaluate the effect of agriculture on the environment, various methods and models are used depending on the level of utilization and on needs of addressees. At the farm level, among other things, model RISE (*Response-Inducing Sustainability Evaluation*) should be mentioned [Häni *et al.* 2003, Boller *et al.* 2004], while in a global approach, mainly in the economic one, partial equilibrium model for agricultural sector CAPRI (*Common Agricultural Policy Regionalised Impact*) [Britz and Witzke 2012].

In Poland, for many years, one of the methods used to evaluate potential level of threat to environment, as an effect of agricultural activity, are balances of fertilizer components including nitrogen and phosphorus as main biogens [Kopiński 2006, Kopiński and Tujaka 2009, Pastuszak *et al.* 2014]. They are one of the many agri-environmental indicators used and required among other things by Eurostat and OECD (*Organisation for Economic Cooperation and Development*), which above all emphasize a possible effect of indicated surpluses of mineral components on the soil, ground water and air [Hansen 2000, Faber 2001, OECD 2006]. At the same time they enable monitoring the flow in the environment of the components generated in the process of agricultural production [Oenema 1999, Leip *et al.* 2011].

The use of the method of gross nitrogen balance, also defined since 2011 as gross nitrogen budget [Kremer 2013], enables evaluation of the appropriateness of managing this component on various management levels. Theoretically, balance of fertilizer components should be sustainable, however, nitrogen balance on the level of „0” is impossible in practice, since as it is stated by Fotyma *et al.* [2001] agriculture would not be able to realize its basic production and economic goals. From the overview of various studies and papers concerning evaluation of gross nitrogen balance [Fotyma *et al.* 2002, 2009b] it follows that balance of this indicator should be within the range of 30-70 kg·ha⁻¹ UR. Determination of the highest permissible limit of optimal N balance, however, arouses some doubts, as strict and rigorous adoption of proper criteria of its evaluation is hindered, among other things with regard to different methods of balancing (or their modifications: complete and reduced), and also by a limited access to data, and a significant variation caused by weather conditions or the agro-chemical condition of the soil (acidity) [Kopiński *et al.* 2013]. Therefore, the determined maximum should also include (reflect) significant regional variation in the functioning of Polish agriculture [Poczta and Bartkowiak 2012, Matyka *et al.* 2013].

This paper has made a methodical attempt to determine optimal criteria of gross nitrogen balances on the national level (NUTS-0) and voivodship level (NUTS-2), taking into account conditions of agricultural production in recent years.

MATERIAL AND METHODS

The studies and analysis had a conceptual and specifying character. Gross nitrogen balance should be taken as a difference between the input from all sources and the output in plant products harvested from the field. In the area of agricultural production,

nitrogen is applied into the soil in the form of molecular bonds in natural fertilizers [Zwierzęta... 2011-2014], plant material (seeds and planting material) and fixed biologically by symbiotic microorganisms. External nitrogen sources for agriculture are mineral fertilizers [Środki... 2012-2014], as well as to a lesser degree industrial and municipal sludges [Ochrona... 2014], and nitrogen in the atmospheric deposition [GIOŚ 2014]. The output of gross balance, however, includes the amount of components in the yield of main plants harvested from plough lands and grasslands, and in the yields of residues crops and catch crops that are possible to be determined [Produkcja upraw... 2008-2014]. Below you can see an equation for calculating gross nitrogen balance, whose detailed methodology has been described by Kremer [2013].

GNB	Gross nitrogen balance (N) $SNB = S_{min} + S_{org} + N_{sym} + N_{atm} + S_{msi} - S_{wrt} - S_{wtp} - S_{zup}$
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Abbreviations:

GNB – gross nitrogen balance,

S_{min} – nitrogen in inorganic fertilisers and in sewage sludge,

S_{org} – nitrogen in livestock excretion at stable,

N_{sym} – nitrogen from biological fixation of leguminous crops and grass mixtures, and on grasslands,

N_{atm} – atmospheric deposition of nitrogen on utilized agricultural area (UAA),

S_{msi} – nitrogen in seeds and planting materials,

S_{wrt} – nitrogen outputs of arable harvested crops,

S_{wtp} – nitrogen outputs of fodder crops and pasture,

S_{zup} – nitrogen outputs of crops residues.

To evaluate the effect of weather on the yield of main crops in Poland, the so-called weather indices were used (IP) for the following crop plants: rye, winter and spring wheat, barley, oats, triticale, maize for grain, rapeseed, potato and sugar beet, for the years 2006-2011. Indices determined for the conducted analysis with the use of an agrometeorological application „Modele IPO” [Górski *et al.* 1996, Nieróbca *et al.* 2012] enabled determination of the yield quantities potentially possible to obtain under optimal weather conditions (GPR_{pmp}). This methodology was described in detail in the paper of Kosiński *et al.* [2013].

While determining the optimum (maximum) of gross nitrogen balance, no spatial variation in quality (bonitation) of soil was taken into account, or its agrochemical condition.

RESULTS AND DISCUSSION

The starting point of the analysis, which was supposed to determine optimum of an appropriate gross nitrogen balance, was making an assumption formulated earlier by Fotyma *et al.* [2001], that its output quantity from the field in plant harvests should reflect the amount of N coming from all sources, calculated as the so-called reactive nitrogen. The amount of acting nitrogen (N_{cdz}) was determined by multiplying the total nitrogen amount from a given source by nitrogen fertilizer equivalent ($Rn \leq 1$) [Fotyma *et al.* 2001]. As we are discussing here gross balance, therefore theoretically the desired

zero balance „0” should be increased by the resulting quantity of nitrogen emission in gaseous compounds (N_{em}), which is unavoidable in the process of agricultural production [Poland’s... 2014], as well as the quantity of atmospheric deposition independent of agricultural production itself (N_{atm}). Additionally, the hypothetical balance should also include surplus, which would also include unfavourable weather conditions (also the ones independent of us) ($GPR_{pmp} - GPR_{rz}$). Then, we may be talking about optimal (maximum) balance criterion. Each additional surplus over the estimated ‘optimum’ will be load, which unless it is absorbed in the soil, may pose potential threat to the environment (water and air) [Hansen 2000, Kopiński and Tujaka 2009]. As it follows from the studies conducted by Fotyma *et al.* [2005], any increase in the supplies of mineral nitrogen in the soil in the profile up to 90 cm, causes increase in its potential losses as a result of leaching in the autumn-winter season.

While making the above assumptions, criterion for optimal nitrogen balance was determined in particular voivodships in Poland in the form of the following equation:

OGNB	Criterion – for optimal of surpluses gross nitrogen balance (N), $kg \cdot ha^{-1}$ UAA $OGNB = S_{wyn} \cdot (N_{cwn} \cdot N_{cdz}^{-1} - 1) + N_{em} \cdot C_{kem} + N_{atm} + S_{wyn} \cdot (GPR_{pmp} \cdot GPR_{rz}^{-1} - 1)$
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Abbreviations:

- OGNB – criterion surpluses of gross nitrogen balance, $kg \cdot ha^{-1}$ UAA,
- S_{wyn} – total nitrogen outputs ($= S_{wrt} + S_{wrt} + S_{zup}$), $kg \cdot ha^{-1}$ UAA,
- N_{cwn} – total nitrogen inputs ($= S_{min} + S_{org} + N_{sym} + N_{atm} + S_{msi}$), $kg \cdot ha^{-1}$ UAA,
- N_{cdz} – total nitrogen inputs based on the acting nitrogen, $kg \cdot ha^{-1}$ UAA,
- N_{em} – total nitrogen emissions from soils, $kg \cdot ha^{-1}$ UAA,
- C_{kem} – the correction coefficient of the quantity of nitrogen compound emission
($= S_{wyn} \cdot (GPR_{pmp}/GPR_{rz})/N_{cdz}$),
- N_{atm} – total atmospheric deposition of nitrogen, $kg \cdot ha^{-1}$ UAA,
- GPR_{pmp} – potentially possible total crop production under optimum (neutral) weather conditions, cereal units $\cdot ha^{-1}$ UAA,
- GPR_{rz} – actual total crop production under typical (unfavourable) weather conditions, cereal units $\cdot ha^{-1}$ UAA.

When comparing the calculated optimal permissible surpluses in gross nitrogen balance with the current balances, it should be stated that in particular voivodships, as well as for the country, they often oscillate on completely different levels. Based on the data from the years 2011-2013, on average for Poland, gross nitrogen balance was $52.4 kg \cdot ha^{-1}$ UAA, and was higher only by 2.5 kg N than the calculated hypothetical permissible balance (Table 1).

Table 1. The optimum surpluses of gross nitrogen balance in Poland (NUTS-0) and 16 voivodships (NUTS-2), kg·ha⁻¹ UAA (mean from 2011-2013)
 Tabela 1. Optimum salda bilansu azotu brutto dla Polski (NUTS-0) i 16 województw (NUTS-2), kg·ha⁻¹ UR (średnia z lat 2011-2013)

Voivodships Województwo	Value of elements of gross nitrogen balance Wartość elementów bilansu azotu brutto										Coefficient – Wskaźnik				OENB
	S _{wyn}	N _{ewn}	N _{cz}	SgNB	N _{em}	N _{ann}	N _{ewt} /N _{cz}	GPR _{pmp} /GPR _{cz}	C _{chem}	10(2-9/4)					
1	2	3	4	5(3-2)	6	7	8(3/4)	9	10	11	12	13	14	15	
Dolnośląskie	85.7	125.6	113.5	39.9	12.2	11.8	1.11	1.03	0.78					32.7	
Kujawsko-pomorskie	88.8	166.8	136.0	78.0	20.8	9.3	1.23	1.01	0.66					44.2	
Lubelskie	69.4	108.8	89.5	39.4	13.0	10.5	1.22	1.02	0.79					37.1	
Lubuskie	66.9	113.7	96.2	46.8	12.4	11.2	1.18	1.14	0.79					42.6	
Łódzkie	74.2	139.8	107.0	65.5	19.7	9.8	1.31	1.03	0.71					48.8	
Małopolskie	75.2	88.5	63.6	13.3	12.8	11.5	1.39	1.12	1.33					67.4	
Mazowieckie	74.3	122.3	88.7	47.9	18.2	11.3	1.38	1.02	0.85					56.4	
Opolskie	107.9	163.3	142.7	55.4	18.3	11.2	1.14	1.08	0.82					50.7	
Podkarpackie	64.8	77.0	59.4	12.1	9.5	11.5	1.30	1.09	1.19					54.0	
Podlaskie	89.2	132.4	88.6	43.2	22.2	9.9	1.49	1.00	1.00					75.9	
Pomorskie	77.7	134.4	112.1	56.8	16.0	9.4	1.20	1.02	0.70					37.3	
Śląskie	78.1	127.7	99.3	49.6	17.4	10.7	1.29	1.06	0.84					52.6	
Świętokrzyskie	65.3	106.6	82.9	41.3	13.9	10.2	1.28	1.02	0.80					41.3	
Warmińsko-mazurskie	84.8	131.7	101.5	47.0	18.5	9.7	1.30	0.99	0.83					49.8	
Wielkopolskie	87.0	173.2	128.7	86.1	25.9	12.6	1.35	1.06	0.72					67.0	
Zachodnio-pomorskie	77.3	132.4	119.5	55.1	12.3	11.7	1.11	1.03	0.67					30.8	
POLAND – POLSKA	79.7	132.0	103.6	52.4	17.6	10.9	1.27	1.04	0.80					49.8	

Source – źródło: own study – opracowanie własne

In the analysed years, gross nitrogen balance equal to the permissible one occurred only in Świętokrzyskie Voivodship. Very high nitrogen surpluses were noted in the central-west region, and especially in the following voivodships: Wielkopolska, Kujawsko-pomorskie and Lodz (over $65 \text{ kg}\cdot\text{ha}^{-1}$ UAA). In these voivodships, their current balances significantly, by over a dozen kg N, exceed the optima determined according to the suggested optimum methodology (Table 1). Significant nitrogen amounts are applied there into crop fields, both in mineral and natural fertilizers (derivative of high industrial feed supply), which despite high intensity of plant production, for various reasons: poor soil, acidity, weather conditions, are not sufficiently utilized [Jadczyzyn and Kopiński 2013]. Moreover, it should be highlighted that western Poland has a great proportion of light soils with a lower water capacity, which are more liable to leaching processes. However, in southern Poland, there prevail compact soils, though there occurs a higher than the average for Poland prevalence of rainfall over evapotranspiration [Fotyma *et al.* 2005]. Therefore, accurate determination of threats from the unused nitrogenous compounds (based on the balances) is quite hindered, and thus we may be talking here only about its potential losses and possible environmental effects, while the balance itself is just one of many agri-environmental indicators.

In case of 6 voivodships, we may be talking of a certain 'deficit' in gross nitrogen balance (compared with the determined optimum). From the conducted calculations it follows that a very economical nitrogen management is conducted mainly in the following voivodships: Malopolskie, Podkarpackie and Podlaskie. Agriculture in these voivodships still has significant reserves of its production potential through increased nitrogen fertilization. In case of Malopolskie and Podkarpackie voivodships, the currently indicated nitrogen balances (N) do not exceed $15 \text{ kg}\cdot\text{ha}^{-1}$ UAA, and are lower than the amount of nitrogen in the atmospheric deposition. Maintaining them on such a low level does not enable obtaining higher yields in given habitat conditions, and in the long-term it may lead to soil depletion of this nutrient and to a decrease in fertility, and consequently to its degradation (Table 1).

CONCLUSIONS

Determination of a permissible surplus of gross nitrogen balance depends on the effective utilization of this nutrient, structure of the input-output balance, natural and climatic management conditions, and above all on organizational factors such as: farmers' knowledge, method of using and storing organic fertilizers, agrochemical soil condition etc. One of the factors which strongly reduce utilization of the yield-forming potential of plants is acidic reaction of soils. In Poland in the years 2009-2012 up to 38% of soils required liming [Ochrona Środowiska 2014].

Based on the data from the years 2011-2013, from the conducted calculations it follows that in Poland, nitrogen balances (N) within the range from $30.8 \text{ kg}\cdot\text{ha}^{-1}$ UAA in Zachodniopomorskie Voivodship to $75.9 \text{ kg}\cdot\text{ha}^{-1}$ UAA in Podlaskie Voivodship were justifiable in terms of production and environment. On average for Poland, surplus in the nitrogen balance should not exceed the level of $50 \text{ kg}\cdot\text{ha}^{-1}$ UAA.

From the conducted analysis it follows that taking on strict and rigorous permissible criteria of evaluation surpluses of gross nitrogen balances is quite hindered, among other things due to various methods of balancing (or their modifications: complete and reduced), availability of data and because of a significant variation in space and time.

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OKREŚLENIE KRYTERIUM OPTIMUM SALD BILANSU AZOTU BRUTTO NA POZIOMIE NUTS-0, NUTS-2

Streszczenie. Saldo bilansu azotu jest jednym z najważniejszych wskaźników agrośrodowiskowych stosowanych m.in. przez Eurostat i OECD. Jego wielkość dostarcza informacji o sile oddziaływania produkcji rolniczej na środowisko. W pracy podjęto metodyczną próbę określenia kryteriów optymalnych sald bilansowych azotu brutto w Polsce, z uwzględnieniem uwarunkowań produkcji rolniczej ostatnich lat. W ich określeniu uwzględniono w przychodowej stronie bilansu brutto tzw. azot działający i emisję jego związków gazowych oraz depozyt w opadzie atmosferycznym, a po stronie rozchodowej – wynoszenie w zbiorach potencjalnie możliwych w optymalnych warunkach pogodowych. Z wyliczeń wynika, że uzasadnione założeniami metodologicznymi optima dopuszczalnych sald azotu (N) mieszczą się w granicach od 30.8 do 75.9 kg·ha⁻¹ UR. Średnio dla Polski, na podstawie danych z lat 2011-2013, saldo azotu brutto powinno wynosić około 50 kg·ha⁻¹ UR. Obecnie jest ono większe od określanego jako optymalne tylko o 2.5 kg·ha⁻¹ UR.

Słowa kluczowe: GNB, nadwyżka azotu, wskaźnik agrośrodowiskowy, zróżnicowanie regionalne

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