Original Research

Comparison of Results Obtained from Different Types of Nitrogen Balance in the Scale of a Field and a Farm

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Abstract

This article presents a comparison of nitrogen balances obtained on the basis of different methodologies applied in Poland and other countries to estimate N loss potential from agricultural sources. In the study, data from 130 agricultural farms situated in four regions, Wielkopolska, Lubuskie, Dolny Śląsk, and Opole, were used. Some of the analyzed farms were situated in nitrate vulnerable zones (NVZs). Seven types of 'field surface' and four types of 'farmgate' balances were selected. The comparison of the selected balances revealed considerable discrepancies in the results reaching 50 kg N·ha^{-1} in the case of field surface balances. With regard to 'farmgate' balances, differences in individual groups of farms sometimes exceeded 50 kg N·ha^{-1}.

Keywords: nitrogen, non-pointed pollution, farmgate balance, field surface balance

Introduction

Nutrient balance is one of the control tools of the nutrient turnover employed in agriculture to help estimate nutrient losses derived from non-pointed sources. Moreover, it is also used for the assessment of the state of environmental hazard, especially from the point of view of agricultural impact on the quality of surface and ground water. It also allows evaluation of the level of potential nutrient losses in agricultural production. More than 45 different nutrient balances are applied in Europe, making it difficult to compare them [1, 2]. Absence of a standardization method and assessment of the hierarchy, as well as degree of importance of individual elements taken into consideration, both considering input and output causes that the obtained results cannot be compared and are not fully reliable for wide purposes. Incorrect diagnosis can result in disturbed economic profitability of production and degradation of natural environment. In countries belonging to the European Union, it is obligatory to control and monitor nitrogen turnover in agricultural farms on the basis of balance resulting from the Nitrogen Directive [Directive 91/676/EU]. In Poland, a regulation was implemented by the Ministry of Environment in 2002 [J. Law No. 4, Item 44] which introduced the field surface balance method as obligatory. It is legally binding in the 19 Nitrate Vulnerable Zones (NVZs) established in Poland covering an area of 4,623.14 km^2. As a member state of the OECD, since 1996 Poland has been obliged to prepare annual nitrogen balances and, since 2002, also phosphorus balance [3]. Increased concentration of nitrogen from agricultural sources in freshwater and eutrophication was observed in other catchment areas in Poland, too [4]. The problem of nitrogen migration toward surface waters has been observed not only on the European continent but also in North America, specifically in Canada, where so-called 'Atlantic Canadian aquifers at risk of nitrate contamination' were delineated [5]. In these areas the 'whole balance' is recommended.

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Material and Methods

A total of 130 farms was selected for detailed investigations. Data were obtained either from direct interviews or were acquired from local administrative and local agricultural advisory centers. Ninety-one farms were situated on NVZs in Wielkopolska, Lubuskie, and Dolny Śląsk voivodships, of which 65 farms were mid-sized and 24 large-area farms (Fig. 1). The remaining 39 units were mid-sized farms located in Opole Voivodship outside NVZs. All farmsteads selected for investigations were characterized by different size, kinds of management and production system. Production on the experimental farms was carried out traditionally. The performed investigation extended from 2002 to 2006 and focused on two full vegetation seasons for each farm.

On the basis of available literature data, 13 balances most commonly employed in different European countries were chosen for analyses (7 'field surface' and 4 'farmgate' balances, Table 1) [6-13].

The aim of the performed investigations was to analyze nitrogen balances in agricultural production obtained on the basis of different methodologies applied both in Poland and abroad for needs of water quality monitoring.

Balance Calculations

The content of nutrient in bought and applied mineral fertilizers was estimated with information given by producers. The production of manures and nitrogen contained in

Fig. 1. Locations of survey Nitrate Vulnerable Zones (NVZs) in catchment areas: 1 – Kopel, 2 – Samica Stęszewska and Mogilnica, 3 – Rów Racocki, 4 – Olszynka, 5 – Pogona and Dąbrówka, 6 – Rów Polski, 7 – Orla.

purchased and sold manures was calculated in accordance with the coefficients and directives of The Regulation of the Council of Ministers as of May 18, 2006 [14]. The manures were calculated based on estimated average-annual animal state. The amount of nitrogen in purchased and applied organic fertilizers as compost, used vegetable soil, or peat was counted in accordance with the coefficients of Gorlach and Mazur [15]. Nitrogen content in fodders and industrial feeds was adopted after information of the manufacturer or our own analyses. Average content of the nutrient in various industrial feeds amounted to 4.3% of N.

Sowing material, which was purchased and used on fields analyzed according to information obtained from literature data, tables of food chemical composition, and recommendations for practice [16, 17], or our own analyses.

Biological N_2 fixation by various species of *Rhizobium* bacteria living in symbiosis with leguminous plants was calculated on the basis of symbiotic nitrogen binding coefficients by leguminous plants obtained from literature data [15]. The amount of nitrogen bound by free-living microorganisms in the soil was assumed at the level of 10 kg $N \cdot ha^{-1}$ AL (Agricultural Land) [18]. The size of atmospheric nitrogen deposition for the examined regions was adopted on the basis of total nitrogen fallout (oxidized and reduced) [5, 19-22].

Nitrogen in crop residues remaining in plowed fields, was calculated according to Gorlach and Mazur [15] and Fotyma and Mercik [18].

The content of nitrogen in animal products (milk, slaughter animals, wool, eggs) as well as in the main crops, by-products, and catch crops, as well as excess of fodders, was adopted from information obtained on farms, literature data, tables of food chemical composition, and recommendations for practice [16, 17] or our own analyses. The quantity of nitrogen in animal bodies (purchased, sold, and dead) was calculated on the basis of coefficients given by German research and recommended by German agricultural advisory services [23] and according to Elmadfa and Muskat [24].

Calculations of ammonia emission in animal production were carried out on the basis of recommendations for Poland on the basis of RAINS model (the regional air pollution information and simulation) [25]. Losses of NH_3 were calculated depending on animal species and technology of their rearing, taking into consideration emissions in animal housing facilities, during storage, and agricultural utilization of manures, as well as on pastures and cattle yards. N_2O emissions following denitrification as well as NH_3 release from mineral fertilizers was calculated using coefficients elaborated upon by Polish researchers [18, 26]. The level of the nutrient losses as a result of leaching from the soil was calculated according to Roszyk and Spiak [27], as well as Fotyma and Mercik [18].

The other products that were purchased and used as forage (e.g. distillery grains or pulp) or fertilizers (e.g. waste soil after mushrooms, sewage sludge) were calculated by Furgał-Dzierżuk et al. [16], Gorlach and Mazur [15], and Fotyma and Mercik [18].

Table 1. Nitrogen balance components under national and international methodology, used in present analyses (according to various sources).

	Balance components	Balances at field scale							Balances at farm scale			
		'net balance'	'gross balance'	extended 'net balance'	modified 'on field surface' OECD balance	classical 'on field surface'	according to Mazur et al.	MacroBil	OSPARCOM 'farmgate balance'	OECD 'farmgate balance'	classical 'farmgate balance'	'mixed'
	Input											
A	mineral fertilizers	X	X	X	X	X	X	X	X	X	X	X
B	manures	X	X	X	X	X	X	X		X*	X	X
C	organic fertilizers				X	X	X	X			X	X
D	fodders and industrial feeds										X	X
E	sowing material				X	X	X			X	X	
F	deposition from atmosphere	X		X	X	X	X	X	X	X		X
G	N$_2$ fixation by papilionaceous plants	X		X	X	X	X	X	X	X		X
H	N$_2$ fixation by free-living microorganisms	X		X			X		X	X		X
I	animals for breeding									X	X	X
J	sewage sludge					X			X	X		
K	crop residues						X	X				
L	other¹					X					X	X
	Output											
M	plant products (main crop and by-product)	X	X	X	X	X	X	X	X	X	X	X
N	excess of fodder									X	X	X
O	animals								X		X	X
P	animal products								X		X	X
R	excess of manure										X	X
S	dead animals										X	
T	ammonia emission from manures			X		X	X					
U	ammonia emission from fertilizers						X					
W	denitrification from fertilizers						X					
X	nitrogen leaching from soil						X					X

¹industrial wastes used as fodder or compost, horticultural substratum, ash; *content of nitrogen is corrected by ammonia emission

All input and output components for every kind of nitrogen balance were calculated in the same way.

Results and Discussion

Characterization of Farms

Large-sized farms were situated in 33 local communes. Twenty-six farms were located on 7 NVZs in Wielkopolska, Lubuskie, and Dolny Śląsk voivodships. The area of 26 large-area farms selected for investigations was in the interval from 209.0-11,391.5 ha (on average – 1,680.3 ha). The proportion of arable land in the total area of agricultural land (AL) amounted to 86.5%.

Levels of mineral fertilization in the examined large-area farms were high. On average, these farms applied 110.2 kg N per hectare of AL, with differences ranging from 0 to 169.1 kg N·ha⁻¹ agricultural land [28]. This is considerably more than in the entire country and in individual regions, where fertilization averages to 54.8 N·ha⁻¹ in the country and 66.9 kg N·ha⁻¹ in Wielkopolska. Nitrogen constituted more than half of the purchased mineral fertilizers. Cattle were reared in all the examined large-area farms and its proportion in the species livestock structure amounted to even 81.4%. The number of livestock units (1 LSU = one head of milking cow or group of animal with mass of 500 kg) in individual farms fluctuated from 0.25 to 1.23 LSU·ha⁻¹ of AL (on average 1.23 LSU·ha⁻¹ AL).

The group of 65 mid-sized farms administratively belonged to 22 local communes, of which 21 partially or completely were situated in 6 NVZs. The agricultural land of the selected mid-sized farms ranged from 10.5 to 115.0 ha (24.7 ha on average). Arable land dominated (87.4%) in the agricultural land structure of this group of farms.

The average mineral fertilizer application in the examined mid-sized farms was considerably higher than domestic and regional averages [28]. The average amount of mineral fertilizers used under crop cultivation was 106.5 kg N·ha⁻¹ of AL with fluctuation from 0 to 340.4 kg N·ha⁻¹ AL. In the group of 65 examined farms, 53.8% specialized in dairy cattle rearing and 43.9% in pig production. Part of the farms in this group specialized in plant production.

The number of animals in farms specializing in dairy cattle ranged from 0.5 to 3.1 LSU·ha⁻¹ AL (1.7 LSU·ha⁻¹ AL on average). In the case of farms specializing in pig production, the stocking rate was lower and amounted to 1.0 LSU·ha⁻¹ AL.

Mid-sized farms in Opole voivodship were situated in 38 local communes, all outside NVZs. The area of 39 farms selected for investigations in this region ranged from 13.9 to 248.2 ha (on average – 68.4 ha). The analyzed agricultural farms were characterized by a very high proportion of arable lands in the structure of agricultural land (93.4%). Average mineral fertilization calculated per 1 ha AL was 116.4 kg N. Cereals dominated (75.3%) the cropping system in the examined farms of Opole Voivodship. Among 39 farms of this voivodship, animal production was carried out in 82.1% and in the remaining farms, farmers did not keep any animals. Pig production (56.1%) dominated livestock production system whereas cattle was kept in 43.9% of the examined farms. On average, 0.7 LSU·ha⁻¹ was raised per one farm.

At Field Scale Balance

When comparing nitrogen balances at field scale obtained using different methods, the highest values were obtained in the case of the 'MacroBil' balance used in a computer tool developed by IUNG in Puławy (Table 3) [29]. It gave the highest values for all types of farms despite the fact that in the methodology it did not take into account such elements as sowing material (E) introduced into the field or nitrogen fixation by free-living organisms (H). High balances also occurred in the case of 'net balance.' This balance also failed to take into consideration all elements described in literature such as crop residues remaining in the field (K) or seeding and reproduction material (E) (Table 1). The high surplus could have been the result of incorrect balancing on the output. The 'net balance' also did not take into account nitrogen losses in the form of ammonia emission (T, U) even though the input contained certain elements not completely dependent on the farmer, such as atmospheric nitrogen fixation (G, H) or deposition (F). Differences between these two balances, in the case of large-area farms, amounted to 18.8 kg N·ha⁻¹, in mid-sized farmsteads of Wielkopolska and Dolny Śląsk voivodships – 15.6 kg N·ha⁻¹, and in Opole Voivodship – 19.1 kg N·ha⁻¹ (Table 3).

The Europen Environmental Agency has published annual diffuse agricultural emmissions of nitrogen to freshwater across Europe [30]. The results show that the nitrogen surplus in Poland is not high (up to 10 kg N·ha⁻¹). In present work MacroBil balance, which is obligatory in Poland, indicated values much higher in all analyzed farms (Table 3). It seems that for environmental monitoring and agricultural control, omission of crop residues remaining in the field is necessary. The element of input is repeated of nitrogen cycle in agricultural lands and has significant impact for inflated balance. The output side of MacroBil should be corrected by ammonia emission from manures because the input takes some natural processes like nitrogen depositon and N_2 fixation by leguminous plants.

A more detailed balance used Ventura et al. [31] for farm control situated in the Valle Volta Nitrate Vulnerable Zone in Northern Italy:

$$N_{budget} = \Sigma N_{WD} + \Sigma N_F + \Sigma N_{IW} + \Sigma N_{BF} + \Sigma N_S - \Sigma N_{PP} - \Sigma N_{EW} - \Sigma N_V - \Sigma N_D - \Sigma_{NM}$$

...where: WD – wet deposition, F – fertilization, IW – irrigation water, BF – biological fixation, S – seeds, PP – plant products, EW – efflux water, V – volatilization from fertilizers (urea), D – denitrification, M – manure.

Analyzing budget of the balance for Valle Volta catchment area, some of the elements had minor impact for surplus. Calculated values for seeds (up to 0.8% of input) and irrigation (up to 2.4% of input) are not significant in balance.

Table 2. Mean values and standard deviation (s) of nitrogen in the separate elements of balance on the input in the groups of analyzed farms.

Balance components		Value	Balances at field scale			Balances at farm scale		
			large-area farm	mid-sized farms (W, DŚ, L)	mid-sized farms (O)	large-area farm	mid-sized farms (W, DŚ, L)	mid-sized farms (O)
Input [min.-max. kg N·ha⁻¹ AL]								
A	mineral fertilizers	mean	110.5	105.4	116.4	110.5	106.5	116.4
		s	35.1	61.0	37.3	35.1	61.0	37.3
B	manures	mean	45.9	88.7	55.4	2.3	8.1	3.8
		s	21.2	68.3	51.1	8.9	20.7	10.7
C	organic fertilizers	mean	0.0	0.0	0.0	0.0	0.0	0.0
		s	0.0	0.0	0.0	0.0	0.0	0.0
D	fodders and industrial feeds	mean	-	-	-	7.8	41.2	17.5
		s	-	-	-	13.8	58.2	27.7
E	sowing material	mean	1.8	2.0	2.7	0.5	4.0	0.7
		s	0.6	1.7	0.9	0.5	15.6	0.6
F	deposition from atmosphere	mean	16.6	16.9	10.8	16.6	16.9	10.8
		s	1.5	0.7	1.5	1.5	0.7	1.5
G	N₂ fixation by papilionaceous plants	mean	4.5	1.7	0.4	4.5	1.7	0.4
		s	4.1	4.1	0.8	4.1	4.1	0.8
H	N₂ fixation by free-living microorganisms	mean	10.0	10.0	10.0	10.0	10.0	10.0
		s	0.0	0.0	0.0	0.0	0.0	0.0
I	animals for breeding	mean	-	-	-	0.0	0.8	0.1
		s	-	-	-	0.0	1.6	0.8
J	sewage sludge	mean	0.0	0.0	0.0	0.0	0.0	0.0
		s	0.0	0.0	0.0	0.0	0.0	0.0
K	crop residues	mean	28.7	25.6	29.3	-	-	-
		s	10.7	23.2	20.1	-	-	-
L	others	mean	0.0	0.0	0.0	0.0	0.0	0.0
		s	0.0	0.0	0.0	0.0	0.0	0.0

W – Wielkopolska, DŚ – Dolny Śląsk, L – Lubuskie, O – Opole voivodship

In addition, it is difficult to estimate nutrient budgets, which makes such calculations useless for agricultural practice. Woli et al. [32] omitted seeds and irrigation in input for estimation N loss from drainage tiles of intensive midwestern U.S. farms and concentrated on main essential parameters like fertilization, atmospheric deposition, N₂ fixation, denitrification, and subdrainage N leaching.

The results of the expanded nitrogen balance, i.e. 'net balance' and according to Mazur et al., were similar despite the fact that there are considerable differences in the structure of the two balances (Table 3). The Mazur et al. balance, on the input, takes into account such inflating elements as crop residues remaining in the field (K) (Table 1). The result, however, was not high, which can probably be attributed to the output containing many more elements than the expanded 'net balance.' Such balance components as ammonia emissions from mineral fertilizers (U), denitrification (W), and nutrient leaching (X), after summation, compensate the surplus caused by the addition of the nutrient contained in crop residues remaining in the field (K). Elements affecting differences between these two balances comprised organic fertilizers (C) as their share was, practically speaking, non-existent as well as seeding and reproductive materials whose influence was negligible due to their very small quantities brought into the field (Tables 1 and 2).

Table 3. Mean values and standard deviation of nitrogen in the separate elements of balance on the output in the groups of analyzed farms.

Balance components		Value	Balances at field scale			Balances at farm scale		
			large-area farm	mid-sized farms (W, DŚ, L)	mid-sized farms (O)	large-area farm	mid-sized farms (W, DŚ, L)	mid-sized farms (O)
Output [min.-max. kg N·ha⁻¹ AL]								
M	plant products (main crop and by-product)	mean	113.9	134.2	161.3	38.8	28.3	70.5
		s	28.2	78.1	58.8	16.6	36.2	54.4
N	excess of fodder	mean	-	-	-	0.0	1.1	0.0
		s	-	-	-	0.1	3.8	0.0
O	animals	mean	-	-	-	6.9	25.7	14.3
		s	-	-	-	9.5	29.2	17.6
P	animal products	mean	-	-	-	21.2	36.8	4.9
		s	-	-	-	14.6	60.4	8.6
R	excess of manure	mean	-	-	-	0.0	2.0	0.0
		s	-	-	-	0.0	10.8	0.0
S	dead animals	mean	-	-	-	0.6	0.3	1.8
		s	-	-	-	0.7	0.7	1.8
T	ammonia emission from manures	mean	10.6	25.6	16.1	-	-	-
		s	5.4	19.9	15.2	-	-	-
U	ammonia emission from mineral fertilizers	mean	7.1	6.7	7.5	-	-	-
		s	2.2	3.9	2.4	-	-	-
W	denitrification from mineral fertilizers	mean	1.8	1.7	1.9	-	-	-
		s	0.6	1.0	0.6	-	-	-
X	nitrogen leaching from soil	mean	6.6	6.3	7.0	-	-	-
		s	2.1	3.7	2.2			

W – Wielkopolska, DŚ – Dolny Śląsk, L – Lubuskie, O – Opole voivodship

Salo and Turtola [33] chose two types of nitrogen balance:

$$N_{balance} = N_{fertilizer} + N_{slurry/manure} + N_{fixation} - NH_3\text{-}N_{volatilized\ from\ slurry/manure} - N_{harvest}$$

...and

$$N_{balance} = N_{fertilizer} - N_{harvest}$$

...to describe the relationship between results of N surface balance and nitrogen leaching from fields on two types of soil (sandy and clay). The results showed that annual N leaching was not adequately estimated using annual N balance, precipitation, total runoff, or drainage runoff.

The smallest nitrogen balances were obtained employing the classical 'on the field surface balance' and 'gross balance' (Table 2). The cause of such small values, in the case of the 'gross balance' was the limited number of elements on the input and output side taken into account when calculating the balance (Table 1). In the classical 'on the field surface balance,' calculations on the output side take into account, among others, losses of gaseous ammonia from manures (B) applied on the field, which can reach ever 60%. This can exert a significant impact on total balance. Moreover, in this balance, elements are taken into account on the input side, which are very important in many countries and are applied in considerable quantities (sewage sludge, composted organic matter, wastes from food industry, Table 2). The above-mentioned materials were, practically speaking, used in negligible amounts on the farms and, therefore, exerted no influence on the input level. Differences between extreme nitrogen balances calculated according to different methodologies reached almost 50 kg N·ha⁻¹ (80%) (large-area farms – 49.9 kg N·ha⁻¹, mid-sized farms in Wielkopolska and Dolny Śląsk voivodships – 46.3 kg N·ha⁻¹, mid-sized farms in Opole voivodship – 43.0 kg N·ha⁻¹).

Table 4. Comparison of different methods of nitrogen balance in analyzed farms.

Value	Balances at field scale [kg N·ha⁻¹ AL]							Balances at farm scale [kg N·ha⁻¹ AL]			
	'net balance'	'gross balance'	extend-ed 'net balance'	modified field surface by OECD	classical 'on field surface'	under Mazur et al.	MacroBil	OSPARCOM 'at farm gate balance'	OECD 'at farm gate bal-ance'	classical 'at farm gate'	'mixed'
Large-area farms											
min.	-3.7	-31.7	-25.3	-14.1	-34.7	6.8	17.7	-68.1	-28.8	33.1	-45.5
max.	127.2	96.1	113.8	117.5	108.0	114.6	150.7	136.9	164.0	419.2	146.5
mean	73.6	42.5	63.0	60.0	53.9	63.9	92.4	74.8	105.5	71.1	84.8
Mid-sized farms of Wielkopolskie and Dolnośląskie Voivodship											
min.	-89.3	-116.4	-89.3	-95.7	-95.7	-104.0	-71.7	-219.7	-9.2	-138.7	-140.9
max.	276.6	239.7	250.7	268.4	242.5	211.2	298.0	294.0	346.4	295.6	332.5
mean	88.5	59.9	65.8	80.5	57.8	66.0	104.1	43.3	115.1	66.5	91.4
Mid-sized farm of Opolskie Voivodship											
min.	-105.2	-128.7	-112.4	-112.5	-120.1	-123.6	-96.5	-57.7	-5.8	-55.8	-56.0
max.	179.3	157.6	158.8	170.1	149.6	139.7	188.1	132.2	169.9	137.2	137.7
mean	31.8	10.5	15.2	24.4	7.9	16.7	50.9	48.0	71.1	47.1	48.6

In particular cases it is necessary to use monitoring balances with a high number of components. For mapping of nitrogen concentrations in surface water Gebel et al. [34] apply complex "on field surface" balances that calculate such elements as:

- input: manure, mineral fertilizers, atmospheric N deposition, N-fixing by legumes, fermentation residues
- output: farm manure looses, denitrification in soil, harvest withdrawal, exported by-products, fermentation residues
- mobilization: mobilization crop residues, mobilization inter-crop, humus, manure
- immobilization: immobilization by-product (not exported), immobilization inter-crop, manure

A careful approach like this allows us to recognize locations of high risk of nitrogen leaching to surface water.

In Denmark, for complete expression of the nutrient cycle, both types of balances – at farm and at field scale are used [35]. The tool used by Danish scientists showed results on level 110 kg N·ha⁻¹ (since 1987 to 2007) and are decreasing. In the period surpluses decreased 65 kg N·ha⁻¹.

At Farm Scale Balance

At farm scale balance calculations conducted using different methods, as in the case of the field surface balance, provided contradictory results. In the case of the nitrogen balance, the highest of all the examined balances in all types of investigated farm were recorded for the 'farmgate' balance proposed by the OECD (Table 3). In the methodology of this balance, practically, no aspects of animal pro-duction, such as purchased feeds (D), sold animal products (P), or slaughtered animals (O) are taken into consideration (Table 1). This exerts a strong influence on the balance results as it does not reflect fully the turnover of all nutrients introduced into the farm. In the case of large-area and mid-sized farms from Wielkopolska and Dolny Śląsk voivodships, surpluses developed in this type of balance achieved values exceeding 100 kg N·ha⁻¹ agricultural land. The inflated result was also affected by improper balancing of the income and expenditure sides. In the balance methodology proposed by the OECD, apart from purchased mineral fertilizers (A) and manures (B), seeding material (E) and sewage sludge (J) on the income side such component sources as: deposition (F) and atmospheric nitrogen fixation (G, H) characteristic for the field surface balances) are also taken into account. On the output side, however, only sold agricultural produce are included. The increased income and a small number of elements on the output side led to excessively high balances.

On the farm scale, balance accounted for 21 dairy farms for 2003-06, located in southwestern Ireland showed surpluses up to 277 kg N·ha⁻¹ [36]. The balance accepted at input nitrogen in purchased mineral fertilizers, manures, and concentrates (industrial fodders). Whereas output included nitrogen in sold products such as milk or animals. The methodology lacks some elements of plant production and sold plant products, similarly to the modified OECD 'farmgate' balance. However, it confirmed the major contribution of mineral fertilizers (223-266 kg N·ha⁻¹) and industrial fodders (36-54 kg N·ha⁻¹) of input. Nitrogen from manures amounted to 12-22 kg N·ha⁻¹ in input.

High balances can also be observed in the case of a 'mixed' balance comprising, apart from purchased and sold elements, elements on which farmers had little influence and which are frequently taken into account in 'field surface balances' (deposition, symbiotic fixation, and fixation by free-living microorganisms, Tables 1 and 3). The classical 'farmgate' balance that takes into consideration elements of the flow of farmer-dependent components (purchased and sold products) showed the lowest values. This balance reflects fully the character of agricultural production, including products brought into plant production as well as those necessary for animal rearing. Maximum differences between individual 'farmgate' nitrogen balance results in the examined types of farms ranging from: 51.3 kg N·ha^{-1} in large-area farms and 48.6 kg N·ha^{-1} in mid-sized farms of Wielkopolska and Dolny Śląsk voivodships to 24.0 kg N·ha^{-1} mid-sized farms in Opole Voivodship.

Results of nitrogen balance calculated by Dalgaard et al. [37] with 'farmgate' methodology for 31 representative types of Danish farms (27 of conventional and 4 organic types, 2,138 farms total) showed large differentiation, but less in comparison with results in this paper. Surpluses range from 70 to 209 kg N·ha^{-1} for conventional farms and from 80 to 110 kg N·ha^{-1} for organic farms. Methodology applied by authors was similar to "mixed balance" at farm scale. A small proportion of farms had organic fertilizer imported on their farms. Quantities of nitrogen brought in to agri-ecosystem of particular types of farms analyzed by Dalgaard et al. [37] varyied from 0 to 22 kg N·ha^{-1}. In other words, in a narrower range than in investigated farms of Dolny Śląsk, Wielkopolska, Lubuskie, and Opole voivodships.

Comparisons of nitrogen balance results have been performed rarely until now. Such comparisons, albeit on a small scale, were made by Fotyma et al. [38] in Poland. These researchers calculated 4 balances for Poland – two in field surface scale ('gross balance' and 'extended') and two – at the farm scale ('ordinary OECD' and 'extended') for the period 1996-98. Similarly to our studies, differences between nitrogen balance results were considerable. In the field surface balance, the difference between the 'gross balance,' and the 'extended' balance amounted to 29.2 kg N·ha^{-1}. In this study, differences between the 'gross balance' and the 'extended' (OECD field surface) balances were smaller and fluctuated, for individual types of farms, from 13.9 to 20.6 kg N·ha^{-1}. The 'extended' balance calculated by Fotyma et al. [38] showed higher balances than the 'gross balance' confirming tendencies also recorded in our investigations. On the income side, the 'extended' balance took into consideration, alongside mineral fertilizers and manures, seeding and reproduction material as well as symbiotic nitrogen fixation and deposition. The 'farmgate' nitrogen balances calculated by Fotyma et al. [38] showed a difference at the level of 24.8 kg N·ha^{-1}. In experiments discussed in this study, differences between balances ranged from 24.0 to 71.8 kg N·ha^{-1}. Fotyma et al. [38] confirmed high proportions of mineral fertilizers and manures but low share of animal products as well as seeding and reproduction material in the balance income. According to

those researchers, proper determination of all balance elements, both on the side of income as well as expenditure, is of paramount importance for balance calculations.

Ehabe et al. [39] propose two types of balances to monitor the risk of environmental losses from farms. The first of them is "full balance," which is based on the principle that farm and household are two integrated parts of the whole. Input of this methodology comprises all of purchased and consumed products in agricultural production and by a farmer and his family (mineral and organic fertilizers, outside grazing, deposition, N fixation, sedimentation, purchased food). Output side take into account plant products (main and by-products), animal products, manures, burning of plant residues, leaching from soil, emission from soil, and storage of solid manures, erosion, and sewage. The second type of balance proposed by Ehabe et al. [39] was "partial balance." It is composed of only typical agricultural elements.

$$B_{partial} = \Sigma N_{MF} + \Sigma N_{OF} + \Sigma N_{IF} + \Sigma N_G - \Sigma N_{PP} - \Sigma N_{AP} - \Sigma N_A - \Sigma N_{PU} - \Sigma N_M$$

...where: MF – mineral fertilizers, OF – organic fertilizers, IF – industrial fodders, G – grazing, PP – plant products, AP – animal products, A – animals, PU – by products, M – manures (exported)

The comparison of these two types of balances showed significant differences of results for nitrogen. Calculated „full balance" for 18 agriforestry farms in southwest Cameroon trends toward zero (from -2 to -83 kg N·ha^{-1}). In case of "partial balance," which does not take into consideration natural processes, not dependent of farmers, evinced quite different results. In 12 of 18 farms analyzed by the authors, surpluses were recorded (from 1 to 78 kg N·ha^{-1}); in one the balance was zero, and in the remaining 5 balances from -2 to -30 kg N·ha^{-1} were noted.

Simplification and appropriate selection of the balance, leaving out elements of no significant impact on the final result but adding problems in the course of their calculation or estimation, will improve considerably work of advisory services. Furthermore, it will facilitate self-control in the management of means of production and help monitor hazards associated with agricultural production by the farmer. The balance should be based on those elements that the farmer can control to a considerable extent. According to some researchers, simplified balances can provide a convenient tool both for the farmer and agricultural advisors to help assess the fertilization effectiveness and limiting risks of nutrient losses and emissions into the environment [40].

Conclusions

Among field-scale nitrogen balances, the extended 'net balance' and the classical 'on the field surface' balance can be treated as the most reliable ones for monitoring requirements. In the classical 'on the field surface' balance, the input and output sides are well-balanced. In the extended 'net balance,' the expenditure side should by corrected by

denitrification and ammonia losses from mineral fertilizers because, on the income side, nitrogen fixation by free-living microorganisms was taken into consideration or, to simplify calculations, it is also possible to omit fixation by free-living microorganisms because, generally speaking, these processes counterbalance each other.

'Net balance' and 'MacroBil' nitrogen balances can inflate balances. In the case of the 'net balance', gaseous nitrogen losses are overlooked on the expenditure side, although on the income side natural processes such as deposition and atmospheric nitrogen fixation are taken into account. Overestimated nitrogen balance in the 'MacroBil' is affected by plowed-under secondary crops and intercrops and the absence, on the expenditure side, of nitrogen losses in the form of emissions into the atmosphere.

On the farm scale, the classical 'farmgate' balance is the most appropriate for the monitoring of fertilizer component emissions. In order to facilitate its application (simplification), this balance could be modified by omitting elements that do not have a significant impact on the balance, such as purchased seed and reproduction material, animals for rearing, and sold feeds, and animal deaths.

The calculation methodology of nitrogen balance on the farm scale proposed by the OECD gives high results in comparison with other balance methods. The income side is expanded by elements characteristic for balances on the field scale (nitrogen fallout, atmospheric fixation) which, to a significant extent, are outside farmers' control and are not connected with agricultural production. Also, the absence in this balance of some elements of animal production cause it to not fully reflect the true turnover of nutrients in agricultural production.

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