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ECOSYSTEM SERVICES BASED ON NITROGEN MANAGEMENT IN FARMS IN SELECTED REGION OF POLAND*

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Abstract. The aim of the research was to analyse potential financial gains and losses in agricultural production calculated on the basis of the nitrogen balance sheet structure. In the study, data from 130 agricultural farms situated in the following four provinces of Poland (Wielkopolskie, Lubuskie, Dolnośląskie and Opolskie) were used. Some of the analysed farms are situated in nitrate vulnerable zones (NVZ's). All farms selected for investigation had different sizes, specialisation, livestock density and production system. There were mid-sized farms ranging 10–200 ha, and large-area farms ranging from >200 ha. Production on the surveyed farms was carried out in a traditional and integrated way. The performed investigation extended from 2002 to 2006 and focused on three full vegetation seasons for each farm. Nitrogen balance was calculated on the basis of "the field surface" methodology. Ecosystem services in the balance sheet primarily involve natural processes such as deposition or N_2 fixation from atmosphere on the input, and gaseous losses on the output. In the case of large-scale farms, the estimated value of such services in the average is on the input 167 €·ha^{-1} and on the output 116 €·ha^{-1}. In the other two groups the input was lower than the output (mid-sized farms of Wielkopolskie and Dolnośląskie provinces - input: 154 €·ha^{-1}, output: 182 €·ha^{-1}; mid-sized farms of Opolskie province - input: 114 €·ha^{-1}, output: 136 €·ha^{-1}). Studies have shown the possibility of large nitrogen losses in crop production ranging on average from 342 to 623 € per 1 ha.

Key words: financial losses, sustainable development, nitrogen balance, non-point pollution, field surface balance

INTRODUCTION

The concept of ecosystem services was created for the valuation of elements of the environment, which allows for the assessment of society's dependence on nature in the context of sustainable development. It enables us to show the links between ecological and economic aspects and assess the consequences of different scenarios of spatial development as well as conservation, revitalization and renaturation. The value of services provided by ecosystems is estimated at more than $ 33 trillion. It is higher than the value of services and goods produced throughout the year by human beings. This value is estimated at about $ 15 trillion [Costanza et al. 1997]. Since 2007, the annual demand of the global economy for natural resources has exceeded the Earth's capacity by half. In 1976 it was still in balance [Brown 2012]. The quantity of used means of production has also increased [Miksch et al. 2016]. In the period 1950–2013, the consumption of fertilisers increased almost 13 times (from 14 to 180 million tons) [Brown 2014]. In the years 1961–1999 pesticide production increased by 854% [Balmford et al. 2005]. There are also unfavorable changes in the elements of the agricultural production space. The

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annual cost of biodiversity loss in the EU-25 is 50 billion € and soil degradation 39 billion € [Bowyer et al. 2009]. Natural resources used by agriculture are limited, including macronutrients in the soil such as nitrogen, phosphorus and potassium. In order to achieve a balance between environmental protection and economic efficiency, nutrients should be used rationally, as farm profitability depends on it [Sassenrath et al. 2012]. Farm accounting is the primary source of information in the analysis of economic activity. This analysis includes all activities leading to the critical evaluation of economic and production performance on the farm. Economic accounts in agriculture are carried out on the basis of several European legislative acts which are mainly intended to monitor agricultural income [Regulation UE 2013]. Nutrient balance is one of the nutrient turnover control tools employed in agriculture to help estimate nutrient losses derived from non-point sources and to assess environmental hazards, especially from the point of view of the agricultural impact on the quality of surface and ground water. Nutrient balance also makes it possible to evaluate the level of potential nutrient losses in agricultural production. More than 45 different nutrient balances are applied in Europe, making it very difficult to compare them [Gourley et al. 2007, Kupiec and Zbierska 2012]. The absence of a standardisation method, hierarchy assessment, and the degree of importance of individual elements means that obtained results cannot be compared and are not fully reliable Europe-wide. Incorrect diagnosis can result in reduced economical profitability of production and degradation of the natural environment. Due to the Nitrogen Directive (91/676/EU) it is obligatory to control and monitor nitrogen turnover in agricultural farms in the European Union on the basis of balance. In Poland, a regulation was implemented by the Ministry of the Environment in 2002 [O. J. No. 4, pos. 44] which introduced the field surface balance method as obligatory.

The aim of the research was to analyse potential financial gains and losses in different groups of farms of various production profile, calculated on the basis of the nitrogen balance sheet structure.

MATERIAL AND METHODS

A total of 130 farms in the four provinces were selected for detailed investigation (Fig. 1, 2 and 3). There were mid-sized farms ranging 10–200 ha, and large-area farms ranging from >200 ha. Data were obtained either from direct interviews or were acquired from local administrative and agricultural advisory centres. Ninety-one farms were situated in nitrate vulnerable zones (NVZ's) in Wielkopolskie, Lubuskie and Dolnośląskie provinces, of which 65 farms were mid-sized and were 26 large-area farms (Fig. 2). The remaining 39 units were mid-sized farms located in Opolskie province (Fig. 3). All farms selected for investigation had different sizes and management and production systems. Production on the surveyed farms was carried out traditional and integrated way. The performed investigation extended from 2002 to 2006 and focused on three full vegetation seasons for each farm.

Nitrogen balance was calculated on the basis of "the field surface" methodology according to the following formula [Parris 1998, Rae and Strutt 2003]:

$$N_{FF} + N_{FP} + N_D + N_{MF} + N_M + N_{SM} + N_{PR} - N_{PP} = N_{balance}(N_{DF} + N_{AF} + N_{AM} + N_O)$$

where:

FF – N_2 fixation by free-living microorganisms

FP – N_2 fixation by fabaceae plants

D – deposition from atmosphere

MF – mineral fertilisers

M – manures

Fig. 1. Location of the large-area farms

SM – sowing material
PR – ploughed crop residues
PP – plant products (main crop and by-product)
DF – denitrification from fertilisers
AF – ammonia emission from fertilisers
AM – ammonia emission from manures
O – others

The content of nitrogen in bought and applied mineral fertilisers (MF) was estimated with information supplied by producers. The nitrogen contained in self-produced and purchased manures (M) was calculated in accordance with the coefficients and directives of The Regulation of the Council of Ministers as of May 18th, 2005 [Regulation… 2005]. Manure quantities were calculated on the basis of estimated average-annual animal state according to guidelines from Regulation of Ministry of the Environment dated from 2005 [Regulation… 2005]. Sowing material (SM) used on fields was analysed according to information obtained from tables of food chemical composition and recommendations for practice [Furgal-Dzierzuk et al. 2003, Kunachowicz et al. 2005] or our own analyses. Biological N_2 fixation (FP) by various species of *Rhizobium* bacteria living in symbiosis with fabaceae plants was calculated on the basis of symbiotic nitrogen binding coefficients obtained from Gorlach and Mazur [2002]. The amount

Fig. 2. Location of the mid-sized farms

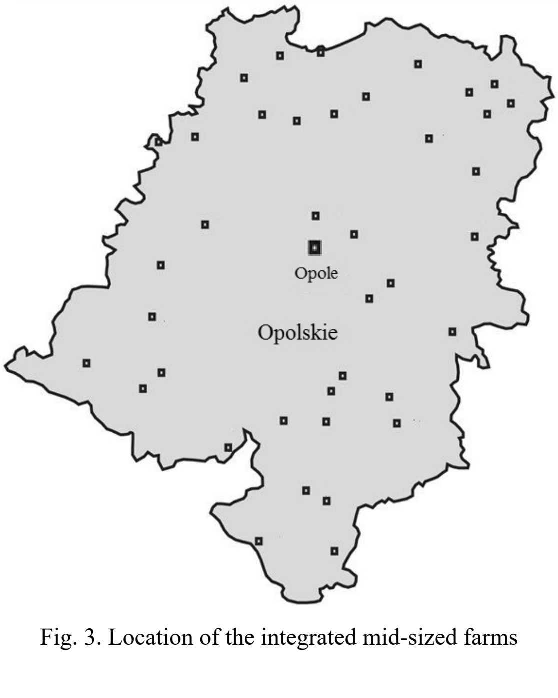

Fig. 3. Location of the integrated mid-sized farms

of nitrogen bound by free-living microorganisms (FF) in the soil was assumed at the level of 10 kg N·ha^{-1} AL (Agricultural Land) [Fotyma and Mercik 1995]. The amount of atmospheric nitrogen deposition (D) for the examined regions was adopted on the basis of the total nitrogen fallout (oxidised and reduced) [Environmental Protection 2006, Report… 2005a, 2005b, 2005c, 2005d]. Nitrogen in crop residues (PR) remaining in ploughed fields was calculated according to Gorlach and Mazur [2002] and Fotyma and Mercik [1995]. The content of nitrogen in the main crops**,** by-products and catch crops (PP) was calculated from information obtained from farms, literature data, tables of food chemical composition and recommendations for practice [Furgal-Dzierzuk et al. 2003, Kunachowicz et al. 2005] or our own analyses.

Calculations of ammonia emission (AM) from animal production is assumed to be 40% N for solid manure and 28% loss for liquid manure [Zbierska et al. 2002]. Emissions of N_2O following denitrification (DF) as well as NH_3 release from mineral fertilisers (AF) was calculated using coefficients supplied by Polish researchers [Fotyma and Mercik 1995, Skiba et al. 1997]. Nitrogen in other products (O) purchased and used as forage (e.g. distillery grain or pulps) or fertilisers (e.g. waste soil from mushroom production, sewage sludge) was calculated by Furgal-Dzierzuk *et al*. [2003], Gorlach and Mazur [2002] as well as Fotyma and Mercik [1995].

The value of each 1 kg of nitrogen from natural and anthropogenic sources was calculated by averaging the price of the 32 most popular nitrogen mineral fertilisers used in farms. The average value of 1 kg N was 5.3 € (22.4 PLN). A conversion rate of 1 zl = 4.20 € in 2016 was used.

RESULTS AND DISCUSSION

Large-sized farms were situated in 33 local communes. 26 of the farms were located on 7 NVZ's in the Wielkopolskie, Lubuskie and Dolnośląskie provinces. The area of the 26 large-area farms selected for investigation was in the range 209.0–11391.5 ha (on average – 1680.3 ha). The proportion of arable land in the total area of agricultural land (AL) amounted to 86.5%. Levels of mineral fertilisation 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 [Statistical … 2005]. This is considerably more than both the national average and the average for individual regions, for which fertilisation averages 54.8 N·ha^{-1} across the country and 66.9 kg N·ha^{-1} in Wielkopolska. Nitrogen constituted more than half of the purchased mineral fertilisers. Cattle were reared in all the examined large-area farms and constituted 81.4% of the livestock species structure. The number of livestock units (1 LSU = one head of milking cow or a group of animals with mass of 500 kg) in individual farms varied from 0.25 to 1.23 LSU·ha^{-1} of AL (on average 0.64 LSU·ha^{-1} AL).

The group of 65 mid-sized farms belonged administratively to 22 local communes, 21 of which were partially or completely situated in 6 NVZ's. The agricultural land area of the selected mid-sized farms ranged from 10.5 to 115.0 ha (on average – 24.7 ha). Arable land dominated (87.4%) in the agricultural land structure of this group of farms. The average mineral fertiliser application in the examined mid-sized farms was considerably higher than the domestic and regional average [Statistical … 2005]. The average amount of mineral fertilisers used under crop cultivation was 106.5 kg N·ha^{-1} of AL and varied from 0 to 340.4 kg N·ha^{-1} AL. In the group of 65 examined farms, 53.8% specialised in dairy cattle rearing and 43.9% in pig fattening. Some of farms in this group were without livestock.

The number of animals in farms specialising in dairy cattle ranged from 0.5 to 3.1 LSU·ha^{-1} AL (on average – 1.7 LSU·ha^{-1} AL). In the case of farms specialising in pig breeding, the stocking rate was lower and amounted to 1.0 LSU·ha^{-1} AL.

Mid-sized farms in Opole province were situated in 38 communes. Selected 39 of the farms in this region were integrated farms ranging from 13.9 to 248.2 ha (on average – 68.4 ha). The farms were characterised by a very high proportion of arable land (93.4%). Average mineral fertilisation calculated per 1 ha AL was 116.4 kg N. Cereals dominated (75.3%) in the cropping system in the examined farms. Animal production was carried out in 82.1% of the 39 farms, and the remaining farms did not contain any animals. Pig production (56.1%) was the dominant livestock production system, whereas cattle were kept in 43.9% of the examined farms. On average, 0.7 LSU·ha^{-1} was raised per farm. Analysed farms from Opole province were constantly monitored by the Opole Agricultural Advisory Center in Łosiów.

Nitrogen sources in fields are varied and can be divided into two types: natural and anthropogenic. Natural sources include processes which are fully or mostly independent of farmers, such as biological atmospheric nitrogen fixation by free living microorganisms or symbiotic fixation and deposition from the atmosphere. This is a nitrogen source which is practically free. The amount provided by fabaceae plants can be partially modified by the cultivation of various plant species from this family, and increasing their acreage, however the binding process is independent of the farmer. Anthropogenic sources are dependent on the farmer, meaning they can be substantially modified. These include the use of mineral or organic fertilisers and manures and the sowing of seed on the field. Ploughed catch-crops and crop residues also belong to this group. This is a secondary element of the balance sheet, because crop residues are not brought in from outside the farm, but supplement the soil in necessary nutrients. The real cost to the farmer is mainly the purchase of mineral fertilisers. Natural sources of nitrogen do not cost anything. Manures are often produced on the farm where they are used, and are therefore rarely purchased. Nitrogen balance elements which entail costs include some organic fertilisers, such as peat. However, these fertilisers constitute a marginal nitrogen income. There was no manufacture or purchase of any organic fertilisers in any of the analysed groups of farms. Some costs may be related to seed materials. Many farmers use their own seed, only supplementing it every few years by purchasing certified seed, primarily due to its high price.

The results of the field surface balance, taking into account elements other than fertilisation, show the potential gains and losses of payment methods related to revenue and the use of nitrogen. Annual nitrogen revenue fixation by free living microorganisms stands at 54 €·ha^{-1} (Table 1). Nitrogen from symbiotic fixation allowed a saving of up to 120 €·ha^{-1}. However, small acreages of these plants crops produce marginal quantities ranging from 2 to 24 €·ha^{-1}. Deposition from atmosphere introduces nitrogen up to 91 €·ha^{-1}. Seed material had almost no significant impact in the economic calculation. Ploughed crop residues offer significant savings which are equivalent to the combined amount from atmospheric fixation and nitrogen deposition. The financial value of nitrogen from manure is an important portion of income. There are real financial savings as a result of the fact that farmers from the surveyed farms do not buy manures.

Ecosystem services in the balance sheet primarily involve natural processes such as deposition or N_2 fixation from atmosphere on the input, and gaseous losses (denitrification and ammonia emission) on the output. In the case of large-scale farms, the estimated value of such services in the average is on the input 167 €·ha^{-1} and on the output 116 €·ha^{-1}. In the other two groups the input was lower than the output (mid-sized farms of Wielkopolskie and Dolnośląskie provinces - input: 154 €·ha^{-1}, output: 182 €·ha^{-1}; mid-sized farms of Opolskie province - input: 114 €·ha^{-1}, output: 136 €·ha^{-1}) (Tables 1 and 2). The total amount of fertilisers (mineral + manure) in all analysed farm groups was higher than uptake by crops. The difference ranged from 57 to 321 €·ha^{-1}.

The value of produced in analysed farms manure per 1 ha was a maximum of 1710 €·ha^{-1} (Table 1). However, only some of these resources may be used in individual farms due to environmental standards in Poland (170 kg N from manures per 1 ha). Mineral fertilisers incur real

Table 1. Structure of nitrogen balance input and the value of individual elements and surplus based in euro

Specification	Elements of input	Value			
		min.	max.	mean	SD
Large-area farms of Dolnośląskie, Lubuskie and Wielkopolskie provinces					
Input N (€·ha^{-1})	N_2 fixation by free-living microorganisms	54	54	54	0
	N_2 fixation by fabaceae plants	0	107	24	22
	deposits from the atmosphere	57	92	89	8
	mineral fertilisers	0	853	593	184
	manures	84	529	257	114
	sowing material	2	23	5	4
	ploughed crop residues	44	251	153	45
Summary input		660	1549	1174	231
Mid-sized farms of Wielkopolskie and Dolnośląskie provinces					
Input N (€·ha^{-1})	N_2 fixation by free-living microorganisms	54	54	54	0
	N_2 fixation by fabaceae plants	0	120	9	22
	deposits from the atmosphere	75	92	91	4
	mineral fertilisers	0	1825	565	325
	manures	0	1710	476	363
	sowing material	0	63	11	9
	ploughed crop residues	5	541	137	111
Summary input		459	2728	1342	493
Mid-sized farms of Opolskie province					
Input N (€·ha^{-1})	N_2 fixation by free-living microorganisms	54	54	54	0
	N_2 fixation by fabaceae plants	0	17	2	4
	deposits from the atmosphere	46	74	58	8
	mineral fertilisers	97	992	624	197
	manures	0	1622	297	271
	sowing material	4	29	14	5
	ploughed crop residues	12	404	157	104
Summary input		731	2144	1207	252

SD – standard deviation

cost. Some farmers annually bought nitrogen fertilisers to the value of 1825 €·ha^{-1}. In Europe, as in all OECD (Organisation for Economic Co-operation and Development) countries, there is a two-speed agriculture. Due to incomplete payments which are received by some countries and delays in development caused by system policies, the economic situation is not stable everywhere [Agricultural… 2014]. Poland is one such country, so rational management of nutrients largely determines the level of income.

Table 2. Structure of nitrogen balance output and the value of individual elements and surplus in euro

Large-area farms of Dolnośląskie, Lubuskie and Wielkopolskie provinces					
Value		min.	max.	mean	SD
Output N (€·ha^{-1})	Crops	340	960	611	135
Summary output		340	960	611	135
Surplus (€·ha^{-1})		79	896	563	184
Losses N (€·ha^{-1})	Denitrification from mineral fertilisers	0	14	9	3
	Ammonia emission from mineral fertilisers	0	55	38	12
	Ammonia emission from manures	23	127	69	27
	Others	40	748	450	169
Mid-sized farms of Wielkopolskie and Dolnośląskie provinces					
Output N (€·ha^{-1})	Crops	230	1719	720	356
Summary output		230	1719	720	356
Surplus (€·ha^{-1})		-308	1663	623	455
Losses N [€·ha^{-1}]	Denitrification from mineral fertilisers	0	29	9	5
	Ammonia emission from mineral fertilisers	0	117	36	21
	Ammonia emission from manures	0	504	137	106
	Others	4	1273	493	318
Mid-sized farms of Opolskie province					
Output N (€·ha^{-1})	Crops	383	1587	865	291
Summary output		383	1587	865	291
Surplus (€·ha^{-1})		-450	1067	342	370
Losses N (€·ha^{-1})	Denitrification from mineral fertilisers	2	16	10	3
	Ammonia emission from mineral fertilisers	6	63	40	13
	Ammonia emission from manures	0	477	86	81
	Others	15	877	325	216

SD – standard deviation

Financial losses due to nitrogen balance in the analysed farms ranges on average from 342 to 623 €·ha^{-1} (Table 2). The excess of nitrogen in the balance is the potential amount that can be dispersed into the environment, thus incurring financial losses.

Some authors claim that an economic calculation consisting of two components is important in order to rationalise activities. Firstly, the effect of given inputs should be maximised. Secondly, the effort required to achieve a particular purpose should be minimised [Zegar 2010].

The damage caused by emissions should be identified among the nutrient losses. The greatest losses occur through ammonia emissions from manure (Table 2). The phenomenon of emission cannot be eliminated from livestock production, but the level can be reduced by the farmer by proper storing manure, applying it at the recommended intervals, and mixing it with the soil immediately after applying it on the fields [Kuczyński 2002]. Among the studied farm groups, the medium-area farms of the Wielkopolskie and Dolnośląskie regions which are located in vulnerable areas display the least efficient nitrogen management. About 35% of these farms could lose more than 800 €·ha^{-1} a year, due to potential surplus nutrient dispersal in the environment (Table 3).

Table 3. The range of losses results expressed in euro

Group of farms	Range of results (€·ha^{-1})					
	-600– -301	-300–0	0–300	301–600	601–800	>800
	Share of results in different ranges (%)					
Large-area farms of Dolnośląskie, Lubuskie and Wielkopolskie provinces	0	0	4	58	27	12
Mid-sized farms of Wielkopolskie and Dolnośląskie provinces	2	8	17	22	17	35
Mid-sized farms of Opolskie province	8	8	26	31	18	10

Some authors say that farms are thriving businesses, however, the environment in which villagers live is as important as the economic aspects [Gietema 2006]. The integrated farms of Opolskie province have the best balances. The number of farms with balances above 600 €·ha^{-1} was 28%, while in large-scale farms it was 39%, and in farms located in NVZ's this was as high as 52%. The group of integrated farms has cooperated for many years with the Opole Agricultural Advisory Center in Łosiów for the implementation of new technologies. These farms are constantly monitored and the production process is optimized, which, as demonstrated by the research, gives positive results. Integrated farms also apply more stringent environmental and production requirements for the use of fertilisers. Their use should be more precise than in conventional farms.

CONCLUSIONS

1. The study shows that the financial value of loss of nitrogen in field crops can be considerable (up to 1663 €·ha^{-1}). This is probably due to poorly balanced plant cultivation, not only in terms of production and economic aspects, but also due to poor knowledge about the value of nitrogen from other sources.
2. By analysing the effectiveness of ecosystem services, it can be seen that intensity financial benefits from natural processes outweigh the losses in integrated farms from Opolskie province. This was mainly due to the lower nitrogen deposition from the atmosphere in the region, but also lower by 51 €·ha^{-1} ammonia emission from manures than in the other groups of farms. The intensity of animal production and the species structure of herd were of great importance.

3. Manures does not fully provide the nitrogen required by plants. Nitrogen ratios from manures to the harvested nutrient with plant yields averaged 0.48:1 in the examined farms. Manures are a free source of nitrogen and should be supplemented with this nutrient from fertilisers in order to reach the optimum level which does not cause financial losses and environmental problems.
4. The total amount of fertilisers (mineral + manure) in all analysed farm groups was higher than uptake by crops. The difference ranged from 57 to 321 $€·ha^{-1}$. This amount can be saved, for example, by the purchase of mineral fertilisers. Loss of mineral fertilisers to the environment equate to financial losses. The purchase of mineral fertilisers should be reduced to avoid these losses. The nitrogen sources in the soil are numerous and some of them allow on limitation purchase of mineral fertilisers and substantial financial savings up to a few hundred euros per 1 ha.

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USŁUGI EKOSYSTEMOWE NA PODSTAWIE ZARZĄDZANIA AZOTEM W GOSPODARSTWACH WYBRANYCH REGIONÓW POLSKI

Synopsis. Celem przeprowadzonych badań była analiza potencjalnych korzyści i strat finansowych w produkcji rolniczej obliczonych na podstawie struktury bilansu azotu. Do badań wytypowano 130 konwencjonalnych gospodarstw rolnych o różnej powierzchni i specjalizacji produkcji, zlokalizowanych w 4 województwach Polski (Wielkopolskie, Lubuskie, Dolnośląskie and Opolskie). Część gospodarstw zlokalizowana była na obszarach szczególnie narażonych na azotany pochodzenia rolniczego i objęta była Programem działań. Wszystkie analizowane gospodarstwa różniły się pod względem wielkości, specjalizacji, obsady zwierząt, oraz systemu produkcji. Do analiz wybrano gospodarstwa średnioobszarowe z przedziału 10–200 ha i wielkoobszarowe przekraczające powierzchnie 200 ha. Prowadziły one produkcję konwencjonalną i zintegrowaną. Dane obejmowały okres od 2002 do 2006 roku i obejmowały trzy sezony wegetacyjne dla każdego z gospodarstw. Bilans azotu został obliczony metodą „na powierzchni pola". Usługi ekosystemowe w bilansie obejmują przede wszystkim procesy naturalne, takie jak depozycja lub wiązanie N_2 z atmosfery po stronie przychodu oraz straty gazowe po stronie rozchodu. W przypadku gospodarstw wielkoobszarowych obliczone wartości usług ekosystemowych w przychodzie wyniosły średnio 167 €·ha^{-1} a w rozchodzie 116 €·ha^{-1}. W pozostałych dwóch grupach wartość usług w przychodzie była niższa niż w rozchodzie (średnioobszarowe województw wielkopolskiego i dolnośląskiego – przychód: 154 €·ha^{-1}, rozchód: 182 €·ha^{-1}; średnioobszarowe województwa Opolskiego – przychód: 114 €·ha^{-1}, rozchód: 136 €·ha^{-1}). Analizy wykazały możliwość generowania bardzo dużych strat finansowych w produkcji polowej wahających się od 342 do 623 € w przeliczeniu na 1 ha.

Słowa kluczowe: straty finansowe, zrównoważony rozwój, bilans azotu, zanieczyszczenia obszarowe, bilans na powierzchni pola

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