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Comparison of the phosphorus balance results based on '*field surface*' and '*farm gate*' methodology in large-scale farms

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Abstract. The aim of the study was the comparative analysis of the results of the phosphorus balance calculated by two methods, in the field scale and the farm scale, and assessment of usefulness of the application of balances in monitoring the agricultural production. Twenty-six large-scale farms were selected for studies with the area from 204.0 to 11391.5 ha. The analyses used data from the years 2002-2006. The spatial scope included the farms located in 33 municipalities, which administratively belonged to three provinces. Twenty six municipalities were located in 7 areas particularly nitrate vulnerable zones (NVZ's). The evaluation of phosphorous load of the selected farms in different regions was performed based on the calculation of the balance with two methods – *field surface* and *farm gate*. As research has shown although the balance of the phosphorus calculated with *the field surface* method was on average higher by 7.2 kg P_2O_5 ha^{-1} AL, the results obtained based on two different methodical approaches indicate similar trends. The higher balance was mainly affected by manures produced in the own farm. Maximal values of the balance in both methods remained at a similar level, reaching approx. 60 kg P_2O_5 ha^{-1} AL. In case of *the field surface balance*, 7 farms fitted in the standard, and in case of *the farm gate balance* 5 met recommendations concerning the acceptable balance for the analysed region.

keywords: phosphorus, agricultural pollution, *field surface balance*, *farm gate balance*, large scale farms

INTRODUCTION

The discussion about the size of the phosphorus emission to the environment from agricultural sources has lasted for many years. As some authors say, in Poland the views are that the level of fertilisation with this nutrient is low (The state…, 2007). Based on these views one can get the impression that agriculture does not have a negative impact on the water quality. Meanwhile, agriculture uses 90% of phosphorus obtained from minerals. They are used mostly for producing mineral fertilisers. However, already small surplus of this nutrient causes its accumulation in the soil, as an added value to the sustainable supply of this nutrient, not entirely defined in Poland (Sapek, 2008). However, the capacity of the soil to phosphor is limited and when the saturation with the nutrient is exceeded, the process of its release into the environment takes place, what can cause the uncontrolled process of eutrophication (Sibbesen and Sharpley, 1997). Another problem is the monitoring of pollution from agricultural sources, which in terms of nutrient dispersing in the environment is often inefficient and unreliable. The main problem is variety of balance methods, which are used to control agricultural production and give incomparable results (Fotyma et al., 2000; Kupiec, 2010; Kupiec and Zbierska, 2012). Using the models for the assessment of size and characteristics of pollution sources cannot be entirely correct and can generate significant mistakes (Ilnicki, 2014). The large problem also involves the belittling possibilities of ways the phosphorus gets to the environment other than fertilising. Poorly stored and kept manures and their inappropriate use is very often a standard in the Polish farms.

The aim of the studies was the comparative analysis of the results of the phosphorus balance calculated with methods in the field scale and in the farm scale and the assessment of usefulness of the application of balances in the agricultural production monitoring.

MATERIALS AND METHODS

Twenty six large scale farms were selected for studies. The analyses used data from the years 2002–2006. The spatial scope included the farms located in 33 municipalities, which administratively belonged to three regions (Fig.

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Fig. 1. Localization of analysed large area farms.

1). 26 municipalities partially or entirely were located in 7 special areas – nitrate vulnerable zones (NVZ's). The average size of the farm was 1680.3 ha, with the diverse surface from 209.0 to 11391.5 ha. Selected elements of the farm characteristics are shown in Table 1.

The assessment of the phosphorus load of the selected farms was performed based on the balance calculation with two methods:

field surface balance (Isermann, 1991; Oenema, 1999; Rozporządzenie..., 2002):

$$P_{\text{field surface balance}} = \Sigma P_{DEP} + \Sigma P_{MF} + \Sigma P_{M} + \Sigma P_{SM} + \Sigma P_{CCp} - \Sigma P_{MC} - \Sigma P_{CCh}$$

where:

DEP – deposition, MF – mineral fertilizers, M - manures,
SM – sowing material, CCp – by-product and catch crops plowed,
MC – main crops,
CCh – by-product and catch crops harvested from the field

farm gate balance (Barszczewski, 2004; Kaczyńska et al., 2004) – the method takes into account elements only to a large extent dependent on the farmer, meaning those, which were brought in or out from the farm by the farmer:

$$P_{\text{farm gate balance}} = \Sigma P_{MF} + \Sigma P_{PM} + \Sigma P_{PA} + \Sigma P_{CF} + \Sigma P_{SM} - \Sigma P_{C} - \Sigma P_{F} - \Sigma P_{AP} - \Sigma P_{A} - \Sigma P_{AD}$$

where:

MF – mineral fertilisers, PM – purchased manures,
PA – purchased animals for breeding, CF – concentrates and feeds,
SM – purchased sowing material, C – sold commodity crop,
F – sold feed plants, AP – sold animal products,
A – sold animals, AD – animal death

Both these methods are known and used in many countries around the world under the same name but in different modifications. Calculations of particular elements of both balances were performed according to Kupiec and Zbierska (2010) and Kupiec (2010). Utilisation of nutrient was calculated using the formula:

$$U = \frac{\text{output}}{\text{input}} \cdot 100$$

RESULTS AND DISCUSSION

Characteristics of farms

The share of arable lands in agricultural lands stood at the level of 86.5%. The area occupied by the grassland, was on average 12%. Crops pattern was dominated by grain (Table 2). They occupied 52.3% area of agricultural land. Among the cereals the largest surface was occupied by the winter wheat. Cereal yields were higher than provided for the country by the GUS (Rocznik..., 2005). In addition to cereals, a considerable area of fields was sown by industrial plants – mostly rapeseed, and fodder.

Among the special branches occurring in the farms we should distinguish the horticultural production, aimed mainly at fruit-growing and cultivation of vegetables (farms no.: 1, 2, 7, 16, 20). A small acreage (1 ha) of the farm no. 18 has been devoted to the cultivation of willow. Moreover, farm no. 2 in the area of 0.21 ha has conducted cultivation of plants under covers, mostly cucumbers and tomatoes under glass and foil. Farm no. 1 has a significant area of orchards and berries – 405 ha. Apart from farm no. 1 the orchard has also been owned by farms no. 7, 8, 18, 20.

The level of mineral fertilisation in the studied farms was very high (Table 1). Farms introduced in 1 ha AL on average 204 kg NPK, ranging from 0 to 317 kg ha^{-1} AL, that is considerably more than on average in the country and region. Farm no. 24 did not buy any mineral fertilisers in the studied period. Deficiencies of nutrients were supplemented only by the purchased manures and produced in the farm. Nitrogen is 54%, phosphorus (P_2O_5) 15% and potassium (K_2O) 31% of the applied fertilizers. In the analysed period the average use of the phosphorus in the group of the studied farms was 29.8 kg P_2O_5 ha^{-1}. The high level of fertilisation of phosphorus (over 50 kg P_2O_5 ha^{-1} AL) has been noted in farms no. 4, 8, and 21. In the period 26 studied farms did not purchase mineral fertilizers to supply.

The possession of livestock was a characteristic feature of all selected large scale farms in the study, giving a steady income from the sale of livestock or livestock products. The amount of livestock units (LSU) in farms ranged from 0.25 to 1.23 LSU ha^{-1} AL (on average 0.64, Table 1). Rearing of the cattle was conducted in each studied farm, and its share in the inventory structure was on average as much as 81.4%. The cattle load of 1 ha AL was

Table 1. Selected elements of the large-scale farms.

Farm No.	Area of AL [ha]	Specialisation		Other animals	LSU·ha^{-1} AL	Mineral fertilisers	
		plant production on arable land	animal production			NPK summary [kg·ha^{-1} AL]	Ratio# $N:P_2O_5:K_2O$
1	2254.0	cereals	dairy cattle	-	0.29	208.1	1:0.25:0.60
2	343.7	cereals	dairy cattle/pigs	-	0.25	184.9	1:0.27:0.58
3	1713.0	cereals	dairy cattle	horses	0.47	232.6	1:0.31:0.63
4	350.0	cereals	dairy cattle	horses	0.70	288.3	1:0.52:0.83
5	589.0	cereals	dairy cattle	horses	0.64	146.7	1:0.17:0.42
6	1447.5	cereals/feed plants	dairy cattle	horses	0.53	133.1	1:0.52:0.79
7	3395.5	cereals	dairy cattle/pigs	-	0.71	192.3	1:0.28:0.65
8	887.9	cereals	dairy cattle	pigs, poultry	0.37	244.5	1:0.36:0.59
9	381.5	cereals	dairy cattle	-	0.40	111.1	1:0.13:1.07
10	1168.5	cereals	dairy cattle	-	0.34	158.4	1:0.20:0.41
11	1891.0	cereals	pigs/dairy cattle	horses, sheep	1.23	276.5	1:0.45:0.93
12	316.0	cereals	dairy cattle	-	0.76	237.0	1:0.07:0.58
13	2042.0	cereals	dairy cattle	-	0.53	179.0	1:0.14:0.54
14	528.1	cereals	dairy cattle	pigs, sheep	0.62	150.8	1:0.36:0.44
15	364.5	cereals	dairy cattle	pigs, sheep	0.77	194.2	1:0.18:0.40
16	988.0	cereals	dairy cattle	pigs	0.47	153.2	1:0.19:0.33
17	2806.9	cereals	dairy cattle	pigs, horses, sheep	0.76	272.1	1:0.24:1.00
18	10887.0	cereals	dairy cattle	horses	0.29	246.2	1:0.22:0.58
19	614.0	cereals	dairy cattle	-	0.42	282.0	1:0.31:0.66
20	3150.8	cereals	dairy cattle/pigs	horses, sheep	0.94	303.6	1:0.29:0.79
21	373.2	cereals	dairy cattle	pigs	0.79	317.0	1:0.27:0.73
22	292.5	cereals	dairy cattle/pigs	-	0.95	162.0	1:0.41:0.41
23	3535.4	cereals/feed plants	dairy cattle	-	1.00	257.1	1:0.27:0.66
24	233.0	cereals	dairy cattle	pigs	1.08	0.0	0
25	975.9	feed plants	dairy cattle	-	0.52	233.1	1:0.17:0.39
26	195.0	cereals/feed plants	dairy cattle	-	0.81	140.8	1:0.34:0.44

nitrogen as 1

Table 2. Structure of sown area in analysed large area farms.

Crop pattern [%]					
cereals	root plants	papilio-naceous plants	industrial plants	feed plants	others
52.3	9.5	5.9	16.6	15.5	0.2

on average 0.52 LSU (0.1-1.0 LSU ha^{-1} AL). Rearing of the cattle in most cases was oriented to the production of milk. Fattening of animals and sale of the beef livestock resulted from the possession of calves from own livestock, or removing culled pieces from the herd, and was rather an additional activity. The pigs in the inventory structure was 15.9%. In farm no. 11 the production of the pork was dominant, and in farms no. 2, 7, 20, 22 next to the cattle it constituted the second important direction of animal production, and represented a similar level of intensity. The pig livestock calculated from the average annual state in the farms conducting the breeding of pigs was quite low and ranged from 0 to 0.73 LSU per 1 ha AL (on average 0.1 LSU ha^{-1} AL).

Besides cattle and swine, the large scale farms also held sheep and horses. Flocks of sheep were held in 19.2%, and horses in 30.8% of farms. The size of sheep herd in farms having this group of animals was on average annually from 3.6 (farm no. 15) to 167.3 LSU (farm no. 17), while horses from 1.3 (farm no. 6) to 117.2 LSU (farm no. 5). Farm no. 5 run the breeding of thoroughbred saddle horses and only in this farm the breeding of horses was on a very high level. In other farms the horse herds were of no importance in the general livestock turnover. Considering all studied large scale farms, on average one farm had 6.6 LSU of these animals.

In addition to the above-mentioned animals one of the farms (no. 8) run the breeding of poultry. The amount of poultry on average a year, per 1 ha in this farm, was 0.1 LSU. In particular years of research the animal production was maintained at a constant level, and changes in the inventory occurred in a very short range.

The animal production in the analysed farms was strongly associated with the crop production. Animal husbandry to a large scale modified the structure of crops, in which the large scale farmers had to consider the type and the area of fodder sown. The scale of production affected the economy of fertilisers, as well as the amount of purchased feed and fertilisers. Keeping livestock in agricultural farms entails the formation of large amounts of excrements, which in the form of manure can be a valuable complement of mineral nutrients in the soil. The amount of the produced solid manure per 1 ha of agricultural land (AL) averaged 6.7 t ha^{-1} per farm, and that of liquid manure 3.2 t ha^{-1}.

Because natural fertilisers, apart from nutrients, enrich the soil with organic matter, the mass of the produced fertilisers was entirely used in large scale farms for crops. Some farms bought manure, limiting or completely reducing the purchase of mineral fertilisers (farm no. 24).

Analysis of the phosphorus balance

The average value of the phosphorus balance obtained based on *the field surface balance* stood at the level of 15.3 kg P_2O_5 ha^{-1} AL, with fluctuations from -13.4 to 59.6 kg P_2O_5 ha^{-1} AL (Table 3). The highest percentage of the results (53.8%) ranged from 0-30 kg P_2O_5 ha^{-1} AL. 23.1% of the results was in the range of 30-60 kg P_2O_5 ha^{-1} AL and the same number of farms showed the negative balance. Farmers brought to the fields much smaller amounts of phosphorus with mineral fertilisers than in the case of nitrogen or potassium, what could affect the size of the balance. According to the Code of Good Agricultural Practice (Kodeks…, 2004) the phosphorus balance can be balanced in soils with the average content of absorbable forms of this nutrient. In soils with a low and very low content of phosphorus it is recommended to use approx. 50% larger doses of fertilisers in relation to their collection, and in soils with high and very high content, doses of fertilisers should be reduced by 50% in relation to collection. The share of soils with a low and very low content of phosphorus in the studied NVZ's (apart from the catchment of the River Orla) was small, therefore, it can be assumed that the balance of the nutrient should be close to zero.

Table 3. The balance of phosphorus in surveyed large-scale farms by *the field surface* method.

Specification	Value				
	min.	max.	average	standard deviation	[%]
Input [kg $P_2O_5 \cdot ha^{-1}$ AL]					
deposition from atmosphere	0.2	0.9	0.3	0.2	0.4
mineral fertilisers	0.0	65.2	29.8	15.9	47.1
manures	5.5	40.2	19.3	8.5	30.5
sowing material	0.4	1.8	0.8	0.3	1.3
by-product and catch crops plowed	7.8	14.3	13.1	4.0	20.7
Summary input	31.1	102.8	63.2	19.1	100
Output [kg $P_2O_5 \cdot ha^{-1}$ AL]					
main crops	20.1	65.0	41.6	8.7	86.8
by-product and catch crops harvested from the field	2.1	11.4	6.3	2.0	13.2
Summary output	25.7	74.3	47.9	9.8	100
Balance	-13.4	59.6	15.3	19.1	-
Utilisation of nutrient [%]	42.1	130.3	75.8	24.7	-

Table 4. The balance of phosphorus in analysed large-scale farms by *the farm gate* method.

Specification	Value				
	min.	max.	average	standard deviation	[%]
Input [kg $P_2O_5 \cdot ha^{-1}$ AL]					
mineral fertilisers	0.0	65.2	29.5	16.0	77.1
purchased manures	0.0	18.0	1.1	3.9	2.8
purchased animals for breeding	0.0	0.02	0.0	0.0	0.0
concentrates and feeds	0.0	62.5	7.5	13.6	19.6
purchased sowing material	0.0	1.3	0.2	0.3	0.5
Summary input	5.8	85.7	38.3	20.7	100.0
Output [kg $P_2O_5 \cdot ha^{-1}$ AL]					
sold commodity crop	0.0	30.5	17.8	7.5	58.9
sold feed plants	0.0	0.1	0.0	0.0	0.02
sold animal products	0.0	34.0	8.8	6.3	29.1
sold animals	0.1	19.2	3.3	4.4	11.0
animal death	0.0	1.8	0.3	0.3	1.0
Summary output	12.5	60.6	30.2	9.4	100.0
Balance	-36.5	59.5	8.1	22.0	-
Utilisation of nutrient [%]	29.2	396.9	110.1	87.0	-

The utilisation of phosphorus in 6 farms was greater than 100%. This can indicate the insufficient complementation of the macronutrient in soils of these farms and the plants using a certain pool of soil reserves. The average utilisation of phosphorus by the plants was high and stood at the level of 75.8%, with fluctuations from 42.1 to 130.3% (Table 3). Analysing individual elements of the input and output it can be noticed that the largest amounts of phosphorus were brought with mineral fertilisers and manures, and brought out with the main crop.

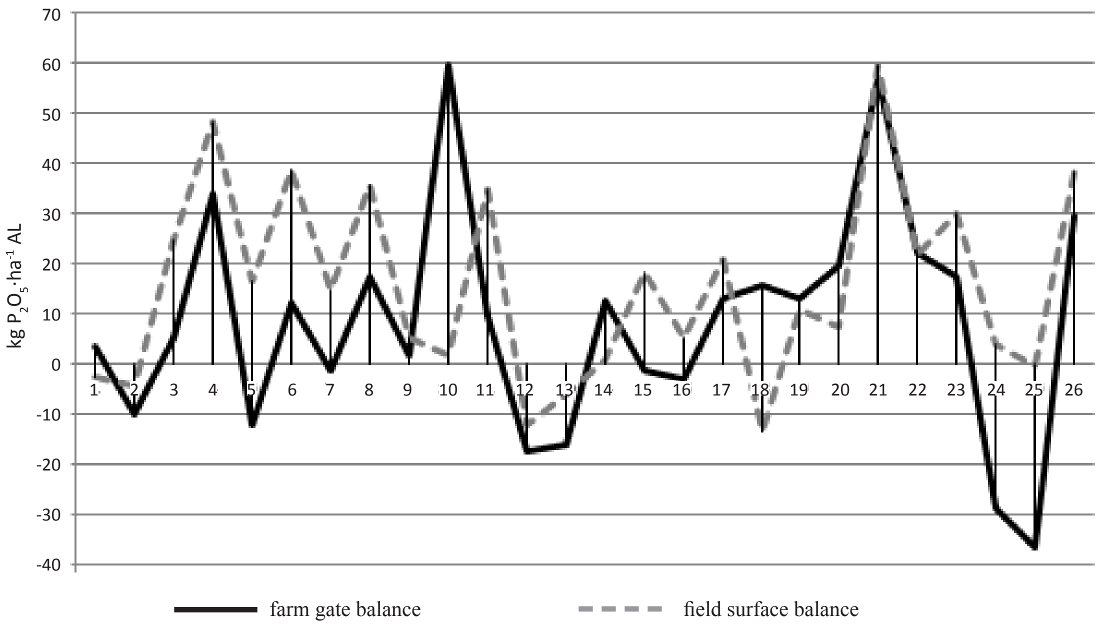

Fig. 2. Formation of the phosphorus balance calculated by two methods.

The balance calculated with *the farm gate* method showed more favourable results than *the field surface* (Table 4, Fig. 2). The phosphorus balance in the group of studied farms was close to balanced (8.1 kg P_2O_5 ha^{-1} AL), which confirms similar dependencies in *the field surface balance*. Considering the results it can be noticed that the significant share involved farms where balances were negative (34.6%). In more than half of the farms (53.8%) the results were within the range of 0-30 kg P_2O_5 ha^{-1} AL. Only in 3 farms the balance was greater than 30 but smaller than 60 kg P_2O_5 ha^{-1} AL. The utilisation of phosphorus was from 29.2 to 396.9%, on average 110.1% (Table 4). The main source of phosphorus income came from mineral fertilisers and purchased concentrates and feeds. Phosphorus in large quantities was taken out from farms in the sold crops and animal products (mainly milk).

According to Toczyński et al. (2013) the acceptable balance of phosphorus for the Wielkopolska region ranges in the scope -3.5–1.5 kg P·ha^{-1} (-8.0–3.4 P_2O_5), for Dolny Śląsk region -1.1–3.9 kg P·ha^{-1} (-2.5–8.9 P_2O_5) and for Lubuskie -2.1–2.9 kg P·ha^{-1} (-4.8–6.6 P_2O_5). Analysing results of *the field surface balance*, 7 farms were in this norm, and in the case of *the farm gate balance* – 5. In summary, it can be stated that the balance results performed with *the farm gate* method presented similar tendencies as in the case of *the field surface*.

Comparing the obtained balances in individual farms it can be observed that the calculated balance using *the farm gate* method most often showed lower values than *the field surface balance* (Fig. 2). In four farms quite a large discrepancy of results has been observed. In farms no. 10 and 18 results of *the farm gate balance* were much higher than calculated with *the field surface* method. The differences in balances were mainly influenced by the animal production. These two farms bought considerable amounts of industrial fodder (concentrates), reaching 63 kg P_2O_5·ha^{-1}. The sold animal products, livestock and animal death were in total at the level slightly exceeding 5 kg P_2O_5·ha^{-1}, and thus the amounts of phosphorus taken out of the farm were disproportionate in relation to its income. In the case of farms no. 24 and 25 *the farm gate balances* in turn were much lower than *the field surface balance*. Farm no. 24 did not purchase any mineral fertilisers. The phosphorus input in *the farm gate balance* was small. The sale included approx. half of the collected crops and animal products and livestock. The ratio of input to the output in this farm amounted to 1:3. In farm no. 25 the difference between balances resulted from large quantities of the sold animal products, mostly milk. As per 1 ha of the farm 34 kg P_2O_5·ha^{-1} was sold.

The non-parametric analysis was used for the assessment of differences between results of two analysed balances – test of order of the Wilcoxon pairs. The analysis

Table 5. The results of the test Wilcoxon's sequence pairs.

A pair of variables	Z	p
FSB & FGB	2.908068	0.003637

FSB – the field surface balance, FGB – the farm gate balance

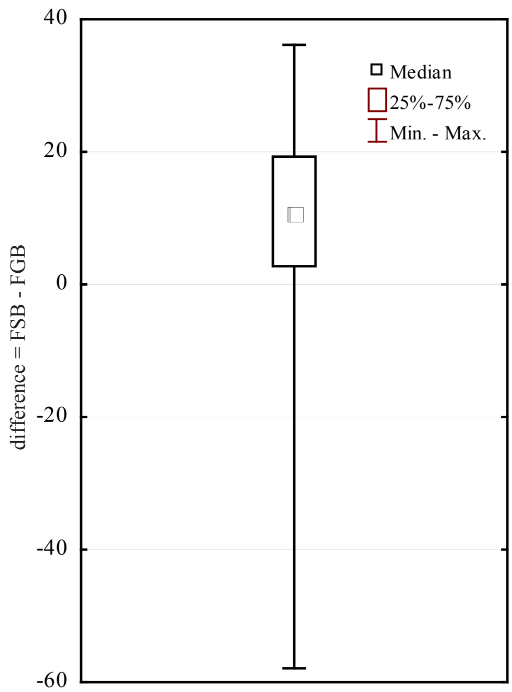

Fig. 3. Box-plot for differences in results based on the two analysed balances – the field surface balance (FSB) and the farm gate balance (FGB).

Table 6. Correlation coefficients (r) Pearson for the field surface balance of phosphorus and elements of input and output and selected characteristics of the farm.

Variable	Balance
AL area	-0.289772
Deposition	0.159602
Mineral fertilizers	**0.760093**
Manures	0.368646
Sowing material	0.045139
Plowed by-product and catch crops	0.335266
Main crops	0.204882
By-product and catch crops harvested from the field	0.337754
The share of cereals	0.424447
The share of papilionaceous	0.099961
The share of root plants	-0.274257
The share of industrial plants	0.203149
The share of feed plants	-0.056259

Marked correlations are significant at $p < 0.05000$

has shown that differences between results of two balances were significant (Table 5, Fig. 3). In addition, correlation coefficients (r) Pearson were calculated to demonstrate the relationship between the balance of both analysed balance sheets on one side and various elements of input and output, certain characteristics of farms, like agricultural area,

Table 7. Correlation coefficients (r) Pearson the farm gate balance of phosphorus and elements of input and output and selected characteristics of the farm.

Variable	Balance
AL area	-0.233428
Mineral fertilisers	**0.638950**
Purchased manures	-
Purchased animals for breeding	-
Concentrates and feeds	**0.512538**
Purchased sowing material	0.059903
Sold commodity crops	0.387691
Sold animal products	0.201360
Sold animal	-0.085663
Animal death	0.006080
Animal density	0.165260
The share of cereals	-0.074958
The share of papilionaceous	0.148021
The share of root plants	0.427272
The share of industrial plants	-0.043348
The share of feed plants	-0.172475

Marked correlations are significant at $p < 0.05000$

stocking density, participation of cereals, legumes, root crops, industrial and fodder in crop structure on the other. The results of correlation clearly indicate that in the balance sheet of phosphorus in *the field surface* methodology the greatest impact on balance have used mineral fertilisers (Table 6). In *the farm gate balance sheet*, elements which may significantly affect its result are purchased mineral fertilisers and introduced into a farm concentrates and feeds (Table 7).

CONCLUSIONS

1. The comparative analysis showed that the results of the phosphorus balance obtained based on two different methodological approaches, despite significant differences in results, indicate similar trends. Both methods can be used for monitoring agricultural pollution but each of them in different contexts.
2. Due to the statistically significant differences in results both analysed balance methods should not be used interchangeably. It is necessary to take into account differences between the balance results in the case of comparison results obtained from the different methods.
3. The phosphorus balance calculated using *the field surface* method was on average higher by 7.2 kg P_2O_5 ha^{-1} AL. The higher balance was affected mainly by manures produced and used in own farm, which constituted approx. 31% of the share in the input.
4. Results of the phosphorus balance, obtained from *the farm gate balance,* were higher than results of *the field surface balance* in six farms. In two analysed farms, the differences were significant (approx. 29 and 58 kg P_2O_5 ha^{-1}).

The higher balance in the farms was affected by the significant amounts of industrial fodder (concentrates) and feed supplements purchased by farmers. In both cases the leading production involved the breeding of dairy cattle.

5. The maximum values of the balance in both balances remained at a similar level, reaching approx. 60 kg P_2O_5 ha^{-1} AL. These are values significantly exceeding the recommendations for this region. In case of *the field surface balance*, 7 farms fitted into the standard, and in the case of *the farm gate balance* – 5.

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