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Nutrient balance and share of green fields in organic farms with different production profile

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Abstract. The aim of the study was to assess the nitrogen, phosphorus and potassium balance and the percentage of green fields on arable lands in 30 organic farms of different production profile located in the Lubelskie, Podlaskie and Mazowieckie voivodeships. The studied farms were divided into three groups: as (a) specialized in crop/horticultural production, (b) specialized in animal production and (c) with no specific specialization. Each group consisted of 10 farms. In specialized farms, the dominant branch had at least 60% share in the total final gross production expressed in PLN. The surveys were carried out in the selected farms in 2010–2012 years. The studied farms were characterized by a positive nitrogen balance of 22.5 kg N ha^{-1} year^{-1}. The phosphorus balance on an average was negative and amounted to -3.2 kg. It was the least negative in the animal group of farms, and the most negative in the crop/horticultural group of farms.The potassium balance was neutral and amounted to 0.4 kg K ha^{-1} year^{-1}. Negative values were recorded only in the crop/horticultural farms. The share of green fields on arable lands on an average amounted to 32% what shows on the presence of desirable activities undertaken by organic farmers towards reducing nutrient losses. The nitrogen balance in the organic farms was over twice lower than in the conventional farms what indicates smaller risk of significant nitrogen losses from organic arable fields.

Keywords: organic farming, nutrient balance, green fields, specialization in agricultural production

INTRODUCTION

Sustainable management of soil nutrients in organic farming should be based on maximizing of their biological retention and minimizing losses caused by excessive mineralization and leaching (Watson et al., 2002a). These latter processes, especially in the case of nitrogen and phosphorus, can be a source of the pollution of the ground and surface waters, thus contributing to their eutrophication (Andersen et al., 2017).

Sufficient supply of crops with nitrogen in organic farming can only be achieved through effective use of manure, compost and other organic fertilizers and appropriate structure of crop rotation with legumes grown as the main and catch crops (Mäder et al., 2002; Watson et al., 2002b). Nitrogen deficiency, apart from soil acidification, is usually the main factor limiting the level of crop productivity in organic farming (Stalenga, 2007).

Some authors point out that nutrient management in organic farming should be based on the ecological recycling agriculture concept indicating the need of integration of animal and crop production on each farm or farms in close proximity (Granstedt et al., 2008; Granlund et al., 2015). Lower input of nutrients can be achieved by increased recycling of nutrients, which can be provided by appropriate livestock density balanced with the amount of fodder produced on the farm. Thanks to that, a significant amount of nutrients taken up in the fodder can be efficiently recycled (Granstedt et al., 2008).

It is emphasized that nitrogen balance should indicate a surplus of 30–40 kg ha^{-1} of AL year^{-1} (Kopiński, 2009). It results from the fact that its gaseous losses are unavoidable and also certain amounts of nitrates, even in conditions of proper agricultural management, are leached. On the other hand, the permanent negative nitrogen balance may indicate excessive humus mineralization.

There is only few publications on the evaluation of nutrient balances in organic farming, but especially there is lack of research on the comparisons of organic farms with different production profile. Berry et al. (2003) reported positive N balances on seven of nine organic farms in the UK, whereas for P and K positive balances were noted respectively in six and in three farms. K deficits concerned mainly stockless farms, whereas positive or neutral K budget was calculated for farms with significant manure returns from farm animals fed with bought-in feed. P and K

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deficits in organic arable and dairy farms in Scandinavian countries were also reported by Torstensson et al. (2006) and Korsaeth (2012).

In recent years, organic farming in Poland has become more and more crop production-oriented with a concommitant trend to discontinue livestock production. In 2016, around 83.2% of organic farms in Poland did not raise animals (IJHARS, 2017). This is an unfavorable phenomenon, because it can bring to nutrient imbalance and to the deterioration of soil fertility.

The hypothesis of the research is that in specialized (stockless) organic farms there may appear problems associated with maintaining sustainable nutrient balance.

The aim of the research was to assess the balance of nitrogen, phosphorus and potassium and the share of green fields on arable lands in selected organic farms of different production profile.

MATERIAL AND METHODS

The research was carried out in 30 organic farms located in the Lubelskie, Podlaskie and Mazowieckie voivodeships. The studied farms were divided into three groups as follow:

specialized in crop/horticultural production (crop/horticultural farms),
specialized in animal production (animal farms)
with no specific specialization (mixed farms).

Each group consisted of 10 farms. The division criterion was the percentage share of a given branch in gross final production. In specialized (crop/horticultural or animal) farms, the dominant branch had at least 60% share in the total final gross production expressed in Polish złoty (PLN). In the non-specialized farms (mixed farms) the share of a particular branch (crop or animal) ranged from 40 to 60%.

The studied farms were selected based on the case study purposive (nonprobability) sampling approach mainly due to very small population of organic farms specialized in animal production fulfilling the assumed criteria.

Crop productivity was expressed in cereal units (CU) (Harasim, 2006). A cereal unit is a measure that allows to bring to the common denominator the value of crop and animal products. 1 CU corresponds to 100 kg of cereal grain.

The livestock density was expressed in the Livestock Units (LU). LU is defined as a reference unit which facilitates the aggregation of livestock from various species and age. According to Polish standards, 1 LU corresponds to one cow weighing 500 kg (Rozporządzenie Rady ..., 2004).

In all farms the surveys were carried out in 2010–2012 years in order to collect data to assess their organizational and production status and calculate the nutrient balance and share of green fields on arable lands.

The results of the organizational and production assessment of farms were related to the average for organic farms and for all farms in the three voivodships under study.

When calculating the share of permanent grasslands both permanent pastures and meadows were taken into account, whereas in the case of permanent plantations both orchards and berry plantations were included.

In order to assess the soil quality in the farms a special index (soil quality index) was used. This index is based on special soil classification in which 9 soil classes of arable land are distinguished. Within this scale very good soils belong to I–II class, good soils are in IIIa and IIIb class, medium-quality soils belong to IVa and IVb class, whereas weak and very weak (sandy) soils are in V and VI class. Within this classification it is assumed that soil quality index of 1 ha of arable lands of IVa class equals 1. The higher soil class the larger value of this index, and opposite the lower soil class the smaller value of the soil quality index.

Gross soil surface nutrient balance was calculated using the OECD (2006) method based on the analysis of crop rotation, crop productivity and animal density. On the input side, the amount of nutrients in mineral and organic fertilizers (manure, slurry, liquid manure) was taken into account. During storage, especially of slurry or liquid manure some quantities of nutrients are lost and their final amount in fertilizers applied on the field is smaller than the sum of their quantities contained in livestock excreta and in straw used for bedding. The amounts of nutrients in fermented organic fertilizers are defined as gross quantities and can be used in calculating farm gate nutrient balances. Whereas for soil surface nutrient balance net quantities were used basing on the assumptions given by Fotyma and Kopiński (2012) (Table 1).

Table 1. The content of NPK in different organic fertilizers in kg per ton (for manure) and per m^3 (for liquid manure or slurry) (Fotyma and Kopiński, 2012).

Type of organic fertilizer	Source of fertilizer	N	P	K
Manure	cattle	4.0	0.9	3.6
	pigs	5.2	1.7	3.2
	poultry	7.2	1.4	7.4
	mixed	4.6	1.3	3.5
Liquid manure	cattle	3.2	0.1	6.6
	pigs	2.8	0.2	3.4
Slurry	cattle	3.4	0.9	3.1
	pigs	4.3	0.1	1.9

In case of nitrogen, its biological fixation by symbiotic bacteria coexisting with legumes and by non-symbiotic organisms in the soil, as well as the nitrogen deposit from the atmosphere were additionally included.

On the output side, the quantities of NPK removed from the field with main and by-product yields were taken into account based on the values for the particular crops given by Fotyma and Kopiński (2012).

In addition, the percentage of crop cover on arable lands in the autumn and winter (so called "green fields") was calculated. This category includes: winter annual crops (e.g. winter wheat, winter rape, etc.), perennial fodder crops (e.g. grass/clover mixtures), winter catch crops for green manure or fodder (e.g. mixture of winter rye and winter vetch) and stubble crops (e.g. white mustard (mulched or not) for green manure or white turnip for fodder).

RESULTS AND DISCUSSION

Organizational and production characteristics of organic farms

The average area of agricultural land (AL) in the studied farms was 12.85 ha and it was slightly higher than the average for Lubelskie, Mazowieckie and Podlaskie Voivodships (9.40 ha), but clearly lower than the average for organic farms in these voivodships (20.62 ha) (Table 2). In the structure of land use, permanent plantations had a large share (17.3%), almost three times higher than the average in the examined voivodships (6.5%). This is a characteristic feature of organic farms in this region, among which, and especially in the Lublin province, there is a large group specialized in the production of soft fruits (Table 2). The share of permanent grasslands amounted to 18.3% and it was slightly lower than in the Lublin province (23.7%). However, it was more than twice smaller than the average for organic farms in this region (40.2%) (Table 2). The average soil quality index for the surveyed farms amounted to 0.67 points, with fluctuations from 0.35 to 1.14 (Table 2). Generally, it can be stated that the studied organic farms had relatively worse i.e. weak and very weak (sandy) soils than the average in the region (0.78 points).

A characteristic feature of organic farming in Poland, but also in other European countries, is the large share of poor/light soils (Facts and figures..., 2016). In regions with better soils, the competitiveness of organic farming against intensive (conventional) agriculture is not so substantial, which means that the number of organic farms in such areas is negligible. The agricultural productivity (both crop and animal) expressed in CU per 1 ha of AL was also diversified and at a fairly low level, as it was 27 units on average, fluctuating from 6.1 to 47.7 (Table 2). It was much lower than the average productivity for three voivodships, amounting to 72.8 units/ha of AL.

The livestock density in the studied organic farms amounted to 41.6 LU per 100 ha of AL and was about 30% lower than the average for 3 voivodships (Table 3), but clearly higher than the average for organic farms in this region (29 LU/100 ha AL). The structure of the animal stock was at a level close to the region's average. The differences noted concerned a higher share of horses and a smaller share of poultry in the group of organic farms compared to the region's average (Table 3).

In general, organic farms are characterized by low share of pigs in the livestock density. This is a typical situation, because owing to that it is possible to construct appropriate, soil fertility improving crop rotations with high share of legumes, their mixtures with grasses or other fodder crops for ruminants. Most studied organic farms conducted both crop and animal production. However, in the group of crop/horticultural farms, 7 did not raise animals at all, and fruit and vegetable production dominated there. Some crop/horticultural farms in order to improve the nutrient and organic matter balance purchased manure from neighboring conventional farms, which is in accordance with official regulations in organic farming (Commission Regulation..., 2008).

There were no large differences in crop yielding between compared groups of organic farms. The smallest yields, with the exception of the cereal mixtures, were obtained in the group of crop/horticultural farms. The smallest yields of wheat and cereal mixtures in the animal group was probably due to the lowest value of the soil quality index calculated for this group (Table 4).

An important problem in organic farms is high variability of yields, which is usually a consequence of unfavour-

Table 2. Key characteristics of the studied organic farms.

Specification	Average for the studied organic farms	Min	Max	Average for all organic farms in 3 voivodeships	Average for all farms in 3 voivodeships
Number of farms	30	-	-	-	-
Area of agricultural lands (AL) [ha/farm]	12.8	2.6	58.9	20.62	9.40
Share of arable lands [%]	65.3	8	91	48.4	70.3
Share of permanent plantations [%]	17.3	0	92	11.4	6.5
Share of premanent grasslands [%]	18.3	0	60	40.2	23.7
Soil quality index	0.67	0.35	1.14	b.d.	0.78
Agricultural production [CU/ha AL]	27.0	6.1	47.7	b.d.	72.8

b.d. – no data

Table 3. Livestock density and its structure in the organic farms.

Specification	Average for the studied organic farms	Min	Max	Average for all organic farms in 3 voivodeships	Average for all farms in 3 voivodeships
Livestock density [LU/100 ha AL]	41.6	0	107.0	29.0	56.2
Share of cattle [%]	76.1	0	100.0	61.6	74.9
of which cows [%]	40.9	0	92.8	no data	37.0
Share of pigs [%]	11.7	0	100.0	7.6	13.7
Share of goats and sheep [%]	0.0	0	0.0	7.5	0.3
Share of poultry [%]	3.5	0	57.8	2.2	7.2
Share of horses [%]	8.7	0	100.0	15.7	3.9

Table 4. Soil quality index and yields of main crops in t/ha in three groups of organic farms.

Specification	Agricultural profile of farms		
	crop/horticultural	mixed	animal
Soil quality index	0.68	0.67	0.66
		Yields [t ha^{-1}]	
Rye	1.75	2.29	2.30
Wheat	-	2.67	2.00
Barley	-	-	1.65
Triticale	2.75	3.22	2.38
Oat	1.70	2.14	2.57
Cereal mixture	3.10	3.04	2.35
Potato	12.00	15.71	14.29

able weather conditions. Frost losses may cause high weed infestation, which significantly reduces winter crop yields. Also, spring droughts or excessive rain during this period may limit the growth and development of crops.

Nitrogen balance

In the farms surveyed, the nitrogen balance was at a positive level of 22 kg N ha^{-1}, with fluctuations from -4 to +63 kg (Table 5). Most of nitrogen (about 29 kg ha^{-1}) came from natural fertilizers (manure) (Table 6). N_2 fixation was its another important source (17 kg ha^{-1}). The input of nitrogen from atmospheric deposit was assessed at a similar level. In total, the input of nitrogen in the studied organic farms amounted to 65 kg ha^{-1}. Nitrogen output in crop yields, on the average, amounted to 42.3 kg N ha^{-1}.

The structure of nitrogen balance in conventional farms in the region was quite different. Mineral fertilizers were the main source of nitrogen there, followed by manure. N_2 fixation was only a minor source of nitrogen. In total, nitrogen input on average in three voivodships was twice as large as in the studied group of organic farms (Table 6).

Nitrogen balance in particular groups of farms ranged from 17 kg in the crop/horticultural group, through 22 kg in the animal group of farms, up to 25 kg in the mixed group (Table 7). The positive result of the nitrogen balance in the mixed group was due to the significant share of legumes (mainly mixtures of clover with grasses, and mixtures of grain legumes with cereals) in the sowing structure. High share of legumes was noted also in the animal group of farms, however because of their small yields the input of nitrogen from biological fixation was respectively lower. As a consequence nitrogen balance in this group was by 3 kg of N lower than in the mixed group. Generally, despite the relatively small yields of fodder plants, input of nitrogen from symbiotic fixation was enough to meet the nu-

Table 5. Nitrogen, phosphorus and potassium balance on the field level in the studied organic farms.

Specification	Average for the studied organic farms	Min	Max	Average for all farms in 3 voivodeships#
N balance [kg ha^{-1} of AL]	22.5	-4	63	47.6
P balance [kg ha^{-1} of AL]	-3.2	-17	3	4.3
K balance [kg ha^{-1} of AL]	0.4	-68	40	3.9

average for 2009–2011

Table 6. Structure of nitrogen input in the studied organic farms [kg ha^{-1} of AL].

Specification	Average for the studied organic farms	Average for all farms in 3 voivodeships#
Mineral fertilizers	0.0	56.8
Manure	29.3	43.4
Seeds	1.8	2.2
N_2 fixation	16.7	6.2
Atmospheric deposit	17.0	17.0
Total inputs [kg ha^{-1} of AL]	64.8	125.6

average for 2009–2011

Table 7. NPK balance on the field level and share of green fields on arable lands in three groups of organic farms.

Specification	Agricultural profile of farms		
	crop/horticultural	mixed	animal
N balance [kg ha^{-1} of AL]	17	25	22
P balance [kg ha^{-1} of AL]	-7	-2	-1
K balance [kg ha^{-1} of AL]	-22	9	12
Share of green fields on arable lands [%]	18.3	39.6	41.6

tritional demand of succeeding plants. Smith et al. (2016) showed that it is possible to achieve positive N balances in organic farming, however in conditions of high rainfall and on lighter soils N balances might be negative mainly due to leaching. In addition, in long-term organic farms it is often observed high biological activity of soil (Martyniuk et al., 2001), and thus N_2 fixation by non-symbiotic microorganisms can be more intensive than in conventional farms.

Phosphorus balance

In the studied organic farms the phosphorus balance on average amounted to -3.2 kg, with fluctuations from -17 to 3 kg ha^{-1} of AL (Table 5). Phosphorus removal with crop yields, on the average, amounted to 8.8 kg. Manure was its main source (5.2 kg ha^{-1} of AL). In some organic farms, especially those specialized in crop production (mainly in vegetable) small phosphorus deficits were observed (Table 7).

Some authors (Berry et al., 2003, Entz et al., 2001, Gosling and Shepherd, 2005) indicate that organic farms, especially located on sandy soils, have only a slightly negative phosphorus balance. It is because phosphorus is relatively stable in soil and is not usually leached out, and also both in the sold crops and in animal products its content is usually low. In the conditions of sustainable management, phosphorus losses are negligible, and the flow of this nutrient down the soil profile may occur when the sorption capacity of the soil is exceeded, i.e. under conditions of very high phosphorus content and high hydration. In addition, some amounts of phosphorus are supplied with mineral feeds or feed additives. In organic farms, phosphorus resources in the soil are usually lower than in conventional farms, however, most often phosphorus content meets the standard levels approved by official fertilizing consultancy. Research conducted at IUNG-PIB has shown that in organic crop production system enzymatic activity of soil, mainly alkaline phosphatase is high (Martyniuk et al., 2001; Martyniuk et al., 2018). These enzymes can increase the availability of phosphorus for plants from soil mineral compounds. In addition, improved supply of phosphorus to plants in the organic farming may also be associated with a more intensive development of mycorrhiza. Some authors indicate that the organic farming strongly enhances the development of this type of symbiosis (Gosling et al., 2006).

Potassium balance

The balance of potassium in organic farms is usually negative (Andrist-Rangel et al., 2007; Stalenga et al., 2004), which is caused by high content of this nutrient in many market crops, especially in vegetables. In the studied farms, the potassium balance amounted to 0.4 kg ha^{-1} of AL per year, and varied between -68 and +40 kg (Table 5). Potassium removal with crops amounted to 30 kg ha^{-1} of AL. As far as the inputs are concerned manure was the main source of this nutrient (29 kg ha^{-1} of AL per year).

There was a very large variability of potassium balance in particular groups of farms. In mixed and animal farms the balance was positive, while crop/horticultural farms had a clearly negative result (Table 7). It should be noted that in the crop/horticultural group, as many as 7 farms did not have animal production, which is not a positive phenomenon, because it can lead to potassium imbalance. In these farms, vegetables, that usually take up a lot of potassium, had a significant share in the cropping structure.

Although potassium is not a biogenic nutrient, like nitrogen and phosphorus, the possible consequences of its negative balance can be dangerous for plants, especially during drought. In organic mixed farms with crop and animal production, it is possible to maintain a sustainable balance of phosphorus. However, in case of potassium, in farms with a high sale of crop products, its negative balance may be significant. It is especially relevant for Poland, where about 50% of soils are sandy, poor in nutrients. Some other authors also point out to problems with appropriate management of potassium in the organic system (Gosling and Shepherd, 2005; Andrist-Rangel et al., 2007), especially in stockless farms (Smith et al., 2016).

Share of green fields on arable lands

The share of green fields on arable lands in the studied group of organic farms on an average amounted to 32% (Table 7). In crop/horticultural farms, it was clearly below the average (18.3%), while the highest values of this indicator were recorded in animal (41.6%) and mixed (39.6%) farms. The high share of green fields in the surveyed organic farms indicates their high potential in reducing the effects of negative incidents (e.g. increased biogenic leaching in the autumn and winter, etc.) accompanying agricultural production (Table 7).

The results of the research indicate the need of regular monitoring by organic farmers of the soil nutrient content. Usually in organic farms there are no serious threats resulting from the excess of biogenic nutrients (nitrogen, phosphorus). On the contrary nutrient deficiencies are usually the main problem. This is particularly important for organic crop/horticultural stockless farms, which dominate among organic farms in Poland. When a nutrient concentration decreases below the average for a given soil type, it is necessary to apply natural mineral fertilizers approved in organic farming and/or implement appropriate measures (such as increased share of legumes and catch crop in the crop rotation or enhanced management of manure and crop residues) oriented on soil fertility improvement.

CONCLUSIONS

1. The nitrogen balance in all farms was at a positive level of 22 kg N ha^{-1}. It ranged from 17 kg in the crop/horticultural group of farms, through 22 kg in the animal farms, up to 25 kg in the mixed group.
2. The phosphorus balance on an average for all studied farms was negative and amounted to -3.2 kg. It was the least negative in the animal group of farms, and the most negative in the crop/horticultural group of farms.
3. The potassium balance in the studied farms was neutral and amounted to 0.4 kg ha^{-1} of AL per year. In mixed and animal farms it was on level of about 10 kg ha^{-1}, while crop/horticultural farms had clearly negative result amounting to -22 kg ha^{-1}.
4. The share of green fields on arable lands in the studied group of organic farms on an average amounted to 32% which indicates the presence of desirable activities undertaken by organic farmers towards reducing nutrient losses.
5. The nitrogen balance in the organic farms was over twice lower than in the conventional farms which is indicative of a smaller risk of significant nitrogen losses from organic arable fields.

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