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ENVIRONMENTAL AND ENERGY ASSESSMENT AT FARM LEVEL

Summary

This article presents the results of an environmental-energy analysis carried out for a sample farm. Completed assessment covered basic agri-environmental indexes and indicators and was extended to include the value of cumulated energy consumption of farm agricultural production. Performed computations and analysis allowed verifying production compliance with environmental standards. At the same time, they may constitute a basis for introducing changes aimed to improve farm production quality. Data acquired from the farm allowed carrying out rather detailed problem analysis. Whereas, it is worth noticing that lack of strict record of events in farms often makes it impossible to perform alike analyses, which are very useful in agricultural practice. It is worth extending the demonstrated analysis with economic viability aspects taking into account the effort to estimate the benefits and losses for environment.
***Key words**: N balance, organic matter balance, crop-structure, cumulative energy consumption*

OCENA ŚRODOWISKOWO-ENERGETYCZNA NA POZIOMIE GOSPODARSTWA ROLNEGO

Streszczenie

W artykule zaprezentowano wyniki analizy środowiskowo-energetycznej przykładowego gospodarstwa rolnego. Dokonano oceny w zakresie podstawowych wskaźników i mierników agrośrodowiskowych oraz poszerzono ją o wartość energochłonności skumulowanej produkcji rolniczej gospodarstwa. Przeprowadzone obliczenia i analiza pozwoliły na zweryfikowanie poprawności prowadzonej produkcji względem norm środowiskowych. Jednocześnie mogą one stanowić bazę dla wdrażania zmian służących poprawie jakości produkcji rolnej. Pozyskane dane z gospodarstwa pozwoliły na względnie szczegółową analizę problemu, natomiast warto zwrócić uwagę, iż brak prowadzenia dokładnej ewidencji zdarzeń w gospodarstwach rolnych często uniemożliwia dokonanie podobnych analiz, które są bardzo przydatne w praktyce rolniczej. Prezentowaną analizę warto poszerzyć o aspekty opłacalności ekonomicznej z uwzględnieniem próby szacunku korzyści i strat dla środowiska.
***Key words**: bilans N, bilans materii organicznej, struktura użytków rolnych, energochłonność skumulowana*

1. Introduction

Production carried out by a farm should reduce side effects for natural and agricultural ecosystem. If focused on profit maximisation only, it may soon bring about negative changes in environment. Therefore, it is important while carrying it out not to treat environment as the so-called free good, available in unlimited volume, which may be handled in any way. Especially soil, which is the basic production factor, should be treated by farmer in a special way, making it possible to improve its fertility and structure, and to reproduce organic matter (OM). This approach allows maintaining the resource in good condition for extended time, and also has positive influence on the quality of other environment components.

Today natural environment, including environment used for farm production purposes, is considered as a resource with certain value. Farm producers recognise the need for rational management of soil, water, energy, not only from the angle of received agri-environmental subsidies. Nevertheless, there are still farms characterised by non-rational environmental management, intensive and extensive - poorly organised. Therefore, all analyses and examinations of even single objects (farms) or specific productions are very important for the assessment of their impact on natural environment.

Certainly, possibilities to reduce adverse impact of agriculture on environment may be achieved by way of improving production technologies and techniques so as to bring down the consumption of natural resources. Farmers are expected introduce such operations in their agricultural lands (AL) and as regards livestock kept by them, which reduce negative impact on environment. According to Kagan [5], the so-called partial indicators are important in the assessment of farm impact on environment. They should be used to develop synthetic measure of farm impact on natural environment. They include: organic matter balance, net nitrogen balance, the share of permanent grassland (GL) in the structure of AL, the share of green fields, and crop rotation and the share of biological diversity in it. As extra (missing) indicators, the author proposes farm energy balance and the so-called consumption of active substances in plant protection. Many of the above mentioned indicators or measures function obligatorily in operations carried out by farms, and other are implemented additionally through subsidies from various programmes supporting good agricultural practices [18].

2. Research methodology

The analysis was prepared for the years 2012-2014 (some data for the year 2014 was assumed due to ongoing production). Its purpose is to attempt making an energy-environmental assessment for a farm. The results and analysis presented in this article are based on data originating from one individual farm located in Opolskie Voivodeship. Farm selection was made dependent on the possibility to obtain relatively complete data for the 3-year-period, which allowed making whole range of production-related computations. Documentation cards were prepared in order to acquire information from farm. These cards contained the following data: crops area, yield of cultivated plants, the way to proceed with by-product (ploughing, litter), volumes of brought-in natural and mineral fertilizers, production elements determining the OM balance, catch crops sowing, and numbers of treatments with plant protection agents. Moreover, documentation cards were prepared for each cultivated plant and GL and for animal production in order to determine cumulated energy consumption of farm agricultural production. This assessment may be useful for agricultural practice and making of decisions regarding farm production planning at farm level, so as to ensure that it is environmentally sustainable.

Acquired data allowed carrying out the analysis taking into account conventionally used indicators and measures including: crops structure, the share of plants improving soil fertility, the share of GL, arable land (ArL) fertilized with manure, the share of green fields, balancing of plant and animal production, the OM balance, the N balance, the volume of brought-in active substance with plant protection agents.

Since most often farm assessment involves analysis of selected single measures and indicators, this article also presents an attempt to extend it with the aspects of cumulated energy consumption for farm production. It is an important element in the assessment of farm impact on natural environment, through evaluation of production energy consumption.

Reproduction and degradation coefficients according to Eich and Kundler [7, 11] were used in the OM balance computations. The N balance for farm was computed using the NawSald application. Production of manure and nitrogen contained in natural fertilizers was calculated on the basis of manure calculator [6].

Publications [3, 10, 14, 15, 21, 22] were used to analyse energy inputs for agricultural production in the analysed farm. The following formula (1) was applied to compute cumulated energy consumption of crop production:

$$\mathbf{E_{cp} = E_m + E_f + E_{mat} + E_l\ [GJ],} \quad (1)$$

where:

E_{cp} – cumulated energy consumption of crop production [GJ],
E_m – objectified energy in tractors, farm machines, means of transport [GJ],
E_f – objectified energy in consumed fuel [GJ],
E_{mat} – objectified energy in materials (fertilizers, seed, plant protection agents) [GJ],
E_l – objectified energy in human labour [GJ].

The following energy streams (2) were used in computations of cumulated energy consumption of animal production (swine and fed cattle):

$$\mathbf{E_{ap} = E_f + E_l + E_m + E_{fo} + E_{en}\ [GJ],} \quad (2)$$

where:

E_{ap} – cumulated energy consumption of animal production [GJ],
E_f – objectified energy in consumed fuel [GJ],
E_l – objectified energy in human labour [GJ],
E_m – objectified energy in farm machines, means of transport [GJ],
E_{fo} – objectified energy in fodder [GJ],
E_{en} – consumed electric energy [GJ].

The component of energy contained in buildings was reduced in the above formula (2). Marciniak indicates in his studies [10] that percent share of energy consumed in this stream is slight (0.05%-0.21%). Whereas, energy stream concerning fodder covers purchased fodders only, since energy consumption for own fodder production (soilage, ensilage, corns and other) has been included in computations of energy consumption for plant production.

Obtained plant and animal production is given in corn units (CU). Energy consumption of both production types is given in $GJ \cdot CU^{-1}$. Effectiveness ratio of cumulated energy consumption has been computed as well (given in $CU \cdot GJ^{-1}$).

3. Research results and discussion

3.1. General information

The example farm runs mixed production: plant and animal. Total area of land used for agricultural purposes in the years 2013-2014 has not been subject to any essential changes, on average reaching: 29.54 ha, in this average ArL area – 26.10 ha and GL (on average) – 3.44 ha. Arable land soils fit within III-VI quality class range. Plant production is for sale and makes a source securing fodder. Table 1 below shows general information concerning the farm.

Animal production includes fed cattle and swine breeding in closed cycle. Every year animal production is kept at constant level, matching fodder supply conditions in the farm and its sales potential. Total livestock population per 1 ha of AL is 0.58 LSU (Livestock Unit) on average, which means that production in the farm is not balanced. The share of GL in total agricultural lands is negligible, yet sufficient for fodder production purposes. However, due to cattle being kept larger grassland area would be suggested.

Table 1. Basic information about the farm
Tab. 1. Ogólne informacje o gospodarstwie

Item	2012	2013	2014	Average	The structure of agricultural lands use [%]
Area of agricultural lands:	29.40	29.62	29.59	29.54	100.00
Arable lands	25.88	26.21	26.21	26.10	88.35
Grass lands	3.52	3.41	3.38	3.44	11.64
Soil guality - the share of quality classes [%]	Arable lands: III quality class – 5.11; IV quality class – 67.61; quality class V- 26.78; quality class VI – 0.50 Grasslands: III quality class – 83.00; IV quality class: 17.00				
$LSU \cdot ha^{-1}$ - cattle	0.39	0.38	0.38	0.38	X
$LSU \cdot ha^{-1}$ - pigs	0.20	0.20	0.20	0.20	X

Source: Own calculations based on data from farm / Źródło: Opracowanie własne na podstawie danych z gospodarstwa

3.2. Crops, structure, the share of plants positively affecting the soil

Cereals prevail in among plants cultivated in Polish farms. According to the data of National Agricultural Census [20], the structure of crops in Poland in 2010 was as follows: cereals (including grain mixtures and maize for grain) 73.3%, leguminous plants - only 0.4%, potatoes 3.7%, industrial plants 11.2%, fodder plants taking into account ensilage maize 8.3%, and other crops 3.0%.

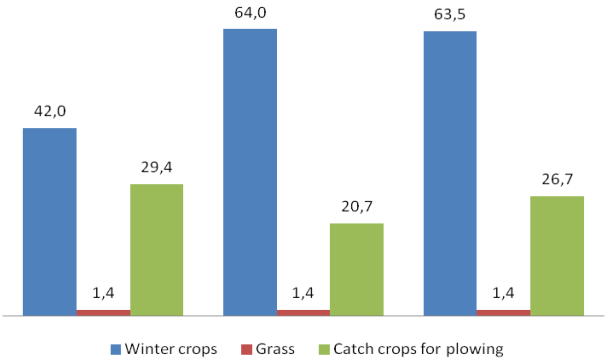
In the analysed farm there are similar tendencies as regards maintaining considerable area for corn cultivation, compared to other plants being grown. Table 2 below contains information concerning crops and their structure in the years 2012-2014.

The data provided above indicate that the share of corns reached 51%, on average. Sown corn for grain and rape reached 14.6% of share in total crops area. The share of grain-leguminous plant mixtures was slightly higher. The share of plants positively affecting soil structure and improving its MO balance (grassland – 1.4%) remained at very low level. Some positive effect is brought by leguminous plant mixed with corns. However, their share is by far too small in the aspect of positive impact on soil environment.

The structure of crops in the discussed farm is first of all subordinated to fodder- and market-related needs. Very low share of other fodder plants (e.g. papilionaceous, grass, leguminous) results from economic calculation of the farm. The farm adheres to the minimum determined by the package of the Agri-Environment Programme – sustainable agriculture, by way of introducing primarily 3 plant groups in its crop rotation. Since, aside from natural fertilizers, chemical fertilizers are applied as well, crops of the specified plants are less important. However, it should be observed that these plants increase soil fertility. Introduction of e.g. meadow clover into crop rotation may contribute to an increase in yielding of successive plants [2]. Owing to deep root system, many of them also positively affect soil, loosening and aerating the subsoil. The occurrence of structure-forming plants also influences growth of soil microorganisms [9].

3.3. The share of green fields and catch crops

In wintertime, the ArL plant cover not only protects soil from erosion, but also restricts "escape" of fertilizing components, positively affects water and air regime in soil and biological life. Ploughed catch crops additionally enrich soil with organic matter. The share of green fields ranged from 72.8% to 9.16%, meaning correct soil protection operations. The farm also participates in the Agri-Environment Programme - soil and water protection package, and in wintertime it is obliged to maintain green fields until the end of February. The farm fulfils this requirement. Figure 1 below shows the share of individual plant groups forming plant cover in wintertime.



Source: Own calculations based on data from farm / Źródło: Opracowanie własne na podstawie danych z gospodarstwa

Fig. 1. Particular groups of plants on the arable lands in the winter, in the years 2012-2014 [%]
Rys. 1. Udział [%] poszczególnych grup roślin na GO w okresie zimy, w latach 2012-2014

3.4. Soil organic matter, farmland fertilized with natural fertilizers, nitrogen balance

Positive result of soil organic matter balance is due to crop rotation abounding with plants enriching soil with humus. However, in recent years we have observed growing cultivation of plants, which have degrading effect, including cereals, rape and corn. At the same time, the share of perennial and leguminous plants has significantly dropped [8]. At simultaneous low livestock population of bred animals (according to the data from Statistical Yearbook of Agriculture 2013 [13], current livestock population of farm animals LSU·ha^{-1} is 0.44; since 2010 it dropped by 0.02), there is a risk of occurrence of organic matter degradation and soil fertility is jeopardised.

Opolskie Voivodeship belongs to regions characterised by quite intensive agricultural production. Consumption of mineral fertilizers prevails here. In marketing year 2011/2012 191.2 kg of NPK fertilizers per 1 ha of AL were used in this Voivodeship (calculated per pure component) [13]. In the same year, manure consumption per 1 ha of AR per pure NPK component was only 24.1 kg, and it was among the lowest in Poland [12].

Table 2. Crops and their structure on the farm in the years 2012-2013
Tab. 2. Zasiewy i ich struktura w gospodarstwie w latach 2012-2013

Crops	2012		2013		2014		Average	
	Sowings [ha]	Share [%]	Sowings [ha]	Share [%]	Sowings [ha]	Share [%]	Sowings [ha]	Share [%]
Total cereals	14.94	57.70	12.03	45.90	13.28	50.70	13.42	51.40
Maize for grain	3.70	14.30	3.90	14.90	3.80	14.50	3.80	14.60
Mix cereal-legume	3.00	11.6	4.76	18.20	5.00	19.10	4.25	16.30
Potatoes	0.40	1.50	0.40	1.50	0.40	1.50	0.40	1.50
Rape	3.32	12.8	4.75	1.50	3.36	12.80	3.81	14.60
Grass	0.37	1.40	0.37	1.40	0.37	1.40	0.37	1.40
Maize - ensilage	0.15	0.60	0.00	0.00	0.00	0.00	0.05	0.20

Source: Own calculations based on data from farm / Źródło: Opracowanie własne na podstawie danych z gospodarstwa

According to Kopiński et al. [8], only in four Voivodeships: Lesser Poland, Podlaskie, Greater Poland and Warmian-Masurian fertilizing with manure is fully sufficient to cover the OM losses, resulting from carried out plant production. Prevailing in Opolskie region crops of cereals, corn, rape and root crops cause degradation, with simultaneous deficiency of natural fertilizers. Farmers try to make up the OM losses in other ways – by ploughing catch crops, straw.

In the analysed farm animal production provides natural fertilizers covering the OM deficiencies due to plant production. Additionally, soil is enriched with ploughed biomass (after-crops, straw). Table 3 below shows the OM average, the plants have had degrading effect in the 3 years, and only introduction of organic mass from after-crops, straw and natural fertilizers compensates organic matter deficiencies.

The farm uses its own natural fertilizers, constituting additives to mineral fertilizers. Manure is applied to selected crops in ArL in amounts not exceeding permissible standards [7]. At the same time, manure minimum (5-7.5 tonnes per 1 ha of AL) is guaranteed [1]. Liquid manure is applied in permanent grassland in amount permitted by standards (Table 4). 17% to 18% of ArL was fertilized with manure. Model indicator for fertilizing with manure specifies that manure should be brought to 25% of soils in the farm [16]. Fertilizing plan is being prepared every year for the farm, which allows determining nutritional needs of plants. Fertilization applied in the farm guarantees maintaining nitrogen balance, which is safe from point of view of natural environment protection. Each year the balance result does not exceed 30 kg per 1 ha of AL.

3.5. Pesticide consumption

According to statistical data [12, 19], the sale of plant protection agents and their consumption successively grow and are regionally diversified. Their most intensive consumption is observed in fruit and vegetable production [4, 17]. Moreover, according to [16], Opolskie Voivodeship belongs to regions characterised by one of highest results in consumption of plant protection agents in active substance - kg per 1 ha, for selected agricultural, vegetable or fruit crops. In the years 2011-2012 in Poland average consumption of active substance per 1 ha of AL was 1.44-1.46 kg.

Herbicides and fungicides were used first of all in the analysed farm, practically in all of its plantations in ArL. In the years 2012-2014, 3.07-3.20 kg of active substance was brought in, calculated per 1 ha of AL. This is higher value compared to Polish average and literature data. These values are most often characteristic for vegetable plantations, and in case of agricultural crops they should be lower.

3.6. Cumulated energy consumption of production

Calculation of cumulated energy consumption of agricultural production in a farm makes it possible to determine actual energy expenditures incurred for production purposes, and not only energy expenditures specified as e.g. consumed fuel, electric energy or furnace fuels.

Energy consumption of agricultural production may be also specified in the amount of labour, operation of machinery and equipment, or the use of current means of agricultural production. Each of these elements is a carrier of cumulated energy, which becomes utilised for agricultural production purposes.

The data acquired from the analysed farm allowed carrying out computations of cumulated energy consumption for its agricultural production, taking into account division into plant and animal production (Table 5).

For plant production (from the GL and ArL), the value of produced CU per 1 ha reached 49.29, on average. The production of cereals, corn and rape (which results from Table 3) prevailed in it as the leading crops in the whole plant production. Produced CU per 1 ha of AL for animal production was ca. 14. This means that plant production delivers approximately 3.5 times more CU from 1 ha area.

Table 3. Organic matter balance [tons·ha^{-1}] (average for the years 2012-2014)
Tab. 3. Bilans MO [tony·ha^{-1}] (średnio dla lat 2012-2014)

Impact of crop plants	Impact of catch crops	Impact of plowed straw	Impact of natural fertilizers (manure)	Balance
-14.49	+ 4.67	+24.28	+14.88	+29.33
Per 1 ha of Arable land				
-0.56	+ 0.18	+ 0.93	+ 0.57	+1.12

Source: Own calculations based on data from farm / Źródło: Opracowanie własne na podstawie danych z gospodarstwa

Table 4. The use of natural fertilizers on the farm in the years 2012-2014
Tab. 4. Wykorzystanie nawozów naturalnych w gospodarstwie i bilans azotu

Item	2012	2013	2014
Manure (applied to ArL)			
The cultivated area used for manure	4.90	5.15	4.40
Amount per 1 ha of crops	39.00	37.00	40.00
Average amount per 1 ha of AL	6.50	6.50	5.90
Average amount per 1 ha of ArL	7.45	7.35	6.71
Liquid manure (used for GL)			
The cultivated area used for liquid manure	3.52	3.41	3.38
Average amount m^3 per1 ha of GL	35.00	35.00	35.00
Average amount m^3 per 1 ha AL	4.18	4.03	4.00
Balance N [kg·ha^{-1}]	28.50	26.80	23.78

Source: Own calculations based on data from farm / Źródło: Opracowanie własne na podstawie danych z gospodarstwa

Table 5. Measures and energy indicators assessment of farm agricultural production
Tab. 5. Mierniki i wskaźniki energetycznej oceny produkcji rolnej gospodarstwa

Item	Crop production	Animal production
Total CU	1453.83	413.02
Total CU per 1 ha agricultural land	49.29	13.98*
Total accumulated energy consumption [GJ]	454.41	108.18
Total accumulated energy consumption [GJ·CU^{-1}]	0.31	0.26
Energy efficiency in the accumulated energy [CU·GJ^{-1}]	3.20	3.82
Streams of energy[GJ]		
Machinery and equipment	69.27	2.48
Fuel	110.97	0.13
Chemical fertilizers	594.83	
Natural fertilizers	75.90	
Seed and planting materials	34.25	
Plant protection products (active substance)	27.78	
Fodder		97.25**
Electricity		7.92
Labour	38.61	0.41
Total	1052.18	10.94

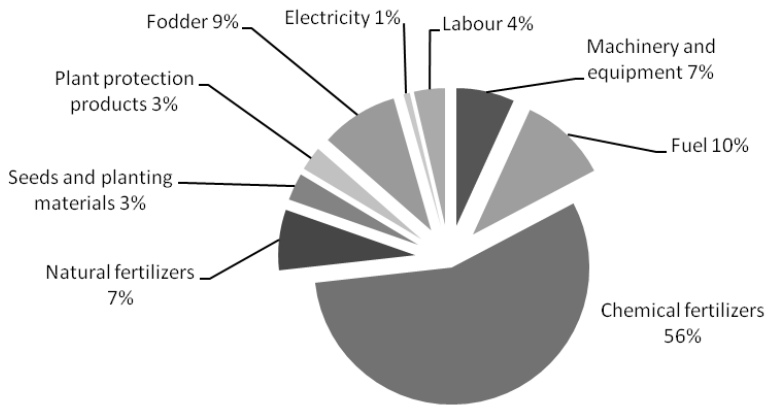
*To produce 13.98 CU of livestock production per 1 ha of AL, it was used 38,84 GJ of own fodders and 3.29 GJ of purchased feed. Feeds from the purchase were accounted for about 8% of the total energy feed
**Fodder with purchase

Source: Own calculations based on data from farm / Źródło: Opracowanie własne na podstawie danych z gospodarstwa

The above also confirms information concerning cumulated energy consumption of plant production specified in GJ, which was more than 3 times higher compared to energy consumption of animal production (108.18 GJ). Total cumulated energy consumption of plant production per CU reached 0.31 for the farm (in three years). Compared to research results [14] obtained for selected crops of conventional farms, this is at slightly lower, but still close level (at the same time one should remember that in the farm analysed in this article the whole plant production was taken into account (also extensive: grass, grassland). Cumulated energy consumption of animal production (average for 3 years) was 0.26 GJ·ha^{-1}. This result was lower due to different energy streams for this production (and first of all much smaller shares of the same streams, which appeared in plant production). E.g., energy consumption of machines engaged in plant production was 69.27 GJ, while for animal production it was 2.48 GJ. Low energy consumption of machines and equipment employed in animal production to a large extent involves breeding of fed cattle, which does not require using as many pieces of equipment as needed for dairy cattle.

When analysing energy efficiency of plant and animal production for the discussed farm, one should state that both production types are effective. According to Sławiński [14], effectiveness ratios of selected production types given in CU·GJ^{-1}, e.g. potatoes (2.2 – conventional crop) or rye (2,3 – ecological crop), may be deemed beneficial, which means that energy inputs incurred for producing of one corn unit are lower than crop energy value. In case of the analysed farm, energy efficiency (average for 3 years) reached higher level: 3.20 CU·GJ^{-1} for plant production and 3.82 CU·GJ^{-1} for animal production. This proves high energy efficiency of production.

The share of individual energy streams (Fig. 2) in general farm production indicates by far prevailing share of fertilizers (mineral, natural and calcium, jointly) – 63%. Further: fuel consumption - 10%, fodder consumption - 9%, and machines and equipment - 7%. The farm is fully equipped with new stock of machines. In practice, it uses external services only to a small extent. Alike relations are observed when comparing obtained results with literature data [14, 15].



Source: Own calculations based on data from farm / Źródło: Opracowanie własne na podstawie danych z gospodarstwa

Fig. 2. The share of energy streams in the production of farm
Rys. 2. Udział strumieni energetycznych w produkcji gospodarstwa

4. Summary and conclusions

The acquired data from the farm allowed for a relatively thorough analysis of the problem. Similar calculations and analysis for farms are only possible if they have keep accurate activities records. Some of presented indicators and measures prove that the farm ruins correct agricultural production as regards environmental issues. Table 6 below shows summary and systematised farm analysis, taking into account guidelines constituting a repair plan.

Table 6. Systematised farm analysis
Tab. 6. Usystematyzowana analiza gospodarstwa

Measure/indicator	Value	Comments
The share of GL [%]	11.64	Low. From point of view of cattle being bred, it is recommended to use larger area for green mass crops. There is 3.26 LSU of cattle on average per 1 ha of GL, which in case of lack of ArL would indicate the farm own fodder deficiency.
Crops structure	--	Prevailing share of corns and other plants degrading organic matter of soil. More extended crop rotation is recommended from point of view of soil environment protection and biodiversity, and plant protection as well as. There should be around 20% of plants positively affecting soil in main crop in ArL. Currently there is 1.4%.
Biodiversity	--	The farm biodiversity includes plants cultivated in ArL, and animals kept. Poor crop rotation should be enriched with structure-forming, melliferous plants.
LSU per 1 ha of AL	0.58	Low livestock population compared to the area possessed by the farm. It does not guarantee proper balancing of plant and animal production. Livestock population may be increased, which will allow acquiring more natural fertilizers and thus reducing the volume of applied chemical fertilizers (they constitute significant energy stream of production).
Green fields [%]	72.8-91.6	Correct share
OM [tons per 1 ha of ArL]	+ 1.12	Correct balance result, however obtained due to the influence of elements beyond production itself in the main crop (catch crops, straw, manure).
Natural fertilizers	Maximum 40 tonnes per 1 ha of ArL	Permissible dose of natural fertilizers per 1 ha of AL is not exceeded (regarding both manure and liquid manure). Applicable manure minimum is maintained. The share of ArL fertilized with manure should be increased to 25%.
Nitrogen balance	Up to 30 kg per 1 ha of AL	Correct result
Pesticide consumption in kg of a.s.* per 1 ha of AL	Ca. 3 kg per 1 ha of AL	High. It is necessary to consider possibility to introduce other protection methods, e.g. those resulting from implementation of more diversified crop rotation.
Cumulated energy consumption [GJ·CU^{-1}]	0.26 (animal); 0.31(plant)	Low, which proves correct and energy-saving management and selection of equipment and materials for carrying out production operations.

*a.s. active substance

Source: Own calculations based on data from farm / Źródło: Opracowanie własne na podstawie danych z gospodarstwa

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