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CUMULATIVE ENERGY INTENSITY AND EMERGY ACCOUNT IN CULTIVATION OF BUCKWHEAT (*FAGOPYRUM ESCULENTUM* MOENCH)

Summary

Buckwheat production and its consumption is still small. The little popularity of buckwheat cultivation could be attributed to the small yield and profitability of growing it (despite the high price which can be gained from its production) as well as lack of consumption patterns related to buckwheat products. However, it starts to attract adequate attention on part of both agricultural producers and consumers. Both nutritional value and content of beneficial biologically active substances starts to draw consumer awareness to it. Apart from theses aspects, buckwheat cultivation can be seen in the perspective of its impact on the natural environment. This paper undertakes the assessment of buckwheat production by consideration of the cumulative energy efficiency of its production and the emergy efficiency associated with it. The data used for the analysis derive from the basis of organic and conventional farms situated in the Opolskie province. The study with regard to both types of farms presents the results obtained from the consideration of cumulative energy efficiency taking into account the structure of expenditure incurred in connection with the use of machinery and equipment, fuels, means of production and human labor. In addition, selected parameters regarding energy efficiency of the production were determined on the basis of calculations. Consequently, the study demonstrated that higher cumulative energy efficiency of buckwheat cultivation is achieved in organic farms. The objective of the analysis involving emergy was to determine and compare the environmental burden associated with the production of buckwheat production in both cultivation systems. The results of emergy analysis indicate the smaller environmental burden of organic buckwheat production.
Key words: *Cumulative energy intensity, emergy, buckwheat, organic farming, conventional farming*

ENERGOCHŁONNOŚĆ SKUMULOWANA I RACHUNEK EMERGETYCZNY W PRODUKCJI GRYKI (*FAGOPYRUM ESCULENTUM* MOENCH)

Streszczenie

Uprawa gryki i jej spożycie są ciągle nieznaczne. Małego rozpowszechnienia uprawy tej rośliny należy upatrywać m.in. w niskiej wydajności i opłacalność produkcji, czy też braku nawyków konsumpcyjnych spożywania produktów gryczanych. Powoli jednak zyskuje ona uznanie zarówno ze strony producentów rolnych, jak i konsumentów. Doceniania się coraz bardziej jej wartości odżywcze i zawartość związków biologicznie czynnych ważnych dla zdrowia. Poza tymi aspektami na produkcję gryki warto spojrzeć z punktu widzenia jej wpływu na środowisko naturalne. W artykule dokonano oceny produkcji gryki poprzez pryzmat energochłonności skumulowanej produkcji oraz zagadnień emergetycznych. Przedstawiono wyniki dotyczące energochłonności skumulowanej i energii uprawy gryki na podstawie danych pochodzących z przykładowych gospodarstw ekologicznych i konwencjonalnych województwa opolskiego. W obu typach gospodarstw określono, po stronie dotyczącej energochłonności skumulowanej, wielkość i strukturę nakładów uprzedmiotowionych w wykorzystanych maszynach i urządzeniach rolniczych, paliwie, zużytych środkach produkcji i pracy ludzkiej. Obliczono także wybrane wskaźniki efektywności energetycznej produkcji, które wskazują na wyższą energochłonność skumulowaną uprawy gryki w gospodarstwach ekologicznych. Celem analizy emergetycznej było określenie i porównanie stopnia obciążenia środowiska produkcją gryki w dwóch systemach produkcji. Wyniki analizy emergetycznej wskazują na mniejsze obciążenie środowiska w ekologicznej produkcji gryki.
Słowa kluczowe: *energochłonność skumulowana, emergia, gryka, rolnictwo ekologiczne, rolnictwo konwencjonalne*

1. Introduction – general information on buckwheat and its cultivation in Poland

Buckwheat (*Fagotypum esculentum* Moench) is an annual dicotyledonous plant in the knotwheat family. Due to the application of the crops and agrotechnical parameters as well as chemical composition similar to grains, it is included in the cereal seed family. It is a thermophylic plant, yet, it is sensitive to high temperatures and late frosts. Its requirements with regard to water, air and soil conditions are large, however, it grows well on light and less productive soils [8, 13, 19, 34, 42]. The cultivation and consumption of buckwheat is still small in comparison to other types of grains. The reasons for its little popularity are associated with the small efficiency and profitability of its production (despite the high price which can be gained from its production) as well as lack of consumption patterns associated with buckwheat products.

However, it slowly starts to attract the attention of both agricultural producers and consumers. Both nutritional value and content of beneficial biologically active substances starts to get adequate recognition [9, 10, 11, 42] including the considerations resulting from the need to follow a gluten-free diet [1, 9, 10, 24]. Buckwheat is principally consumed in form of groats, flour, buckwheat honey. Besides, it finds application in the production of biodegradable packaging, peats, animal feed and herbal products [1, 43]. Buckwheat cultivation also has a long-standing tradition. It reached Europe via India and China around the 13th to 14th century. The largest areas of its cultivation include China and Russia. Among the European countries, Poland is the country with the greatest area of buckwheat crops, with a note that the total sown area is small in comparison to other grains (Table 1).

From the data found in Table 1, we can see that buckwheat makes only a small part of total crops in relation to all cereal seeds, i.e. between 0,78 and 1,16% of total cereal farming area in the period between the years 2010-2015. We can also note that the area of buckwheat crops has dropped by around 34% since 2010. On the basis of data provided by the National Statistical Office, we can see that the provinces with the greatest areas of buckwheat cultivation include Lubelskie and Dolnośląskie. The smallest areas with buckwheat production are found in Opolskie, Kujawsko-Pomorskie, and Małopolskie provinces. With a large degree of certainty, due to the smaller efficiency of production, buckwheat is even not as common as it might appear from this statistic. In addition, the considerable fluctuations in the crops can be attributed to the form of its pollination by entomophily [21]. The lower yield can be compensated by the relatively higher price that can be gained from the production of buckwheat in comparison to basic cereals. The National Statistical Office also provides data with the mean purchase value of buckwheat gained by the farmers equal to 1193,53 PLN·ton^{-1} in 2014 [35], with a remark that the mean price per 1 ton of buckwheat in Dolnośląskie province was equal to 1240,50 PLN between the years 2012-2014. This mean price was over 34% higher in comparison to the price of wheat and higher by 48% in comparison to rye [32]. Even higher revenues were gained from production in the organic farms. As shown by the study by Sadowski and Sławiński [33], the higher revenue gained from the organic farm resulted from the higher selling price of buckwheat (on average: 1362,00 PLN·ton^{-1} in the organic farms between 2001 and 2004 and 875,00 PLN·ton^{-1} in the conventional farms).

A decision by an agricultural producer regarding the type of farm production and farming system (organic vs. conventional) is usually guided by an economic account. Hence, basic cereals, corn and rape are the most common crops. Less common crops include extensive plants, such as buckwheat, which is characterized by considerable advantages in terms of its agrotechnical (e.g. phytosanitary measures) and health-related aspects. Despite the importance of the economic account in agricultural activity, the decision regarding the type of agricultural production and production system should also be guided by the impact of an activity on the natural environment. Since every type of agricultural production puts a strain on the natural environment, it is important to select such a type of activity which does not only generate a profit but also promotes the limitation in the deterioration of the natural resources. One of the methods, which can provide grounds for the assessment of the impact of agricultural production on the environment, is associated with the analysis of the cumulative energy intensity of production. In addition, its results can be boosted by application of emergy account with the aim of determining the sources of emergy which are derived from renewable and non-renewable sources in the process of production.

2. Objective, methods and scope of research

The objective in this paper is to report the results of a study into cumulative energy intensity of buckwheat cultivation and emergy account regarding this type of production. The analysis and comparison was undertaken for two production systems: organic and conventional ones. The research involved three examples of organic farms (further called E1, E2, E3 farms) as well as two conventional ones (named K1, K2) situated in the Opolskie province. The data for comparative analysis were derived from the basis of standardized cards (Cost account and profitability calculation of farm plant production) prepared by Opole Agricultural Advisory Centre in Łosiów. For the case of E1, E2, E3 and K1 farms the study was supplemented by data derived from interviews conducted directly with farmers. The resulting data made it possible to analyze the information regarding buckwheat production in the period involving:

a) E1 farm– 2014-2015,
b) E2 farm – 2014-2015,
c) E3 farm – 2013-2014,
d) K1 farm – 2011-2015,
e) K2 farm – 2012.

The analysis of cumulative energy intensity offers a tool used to assess the use of energy [MJ, GJ] needed for the production process. The cumulative energy for objectified means of production forms the gradually input in the process of production of a specific unit of an output product. The calculation of the cumulative energy intensity of buckwheat production takes into account the expenditure of work exerted in:

a) operation of machines and agricultural equipment associated with soil cultivation, fertilizing, sowing, operations, harvesting and transport,
b) human labor,
c) fuel use,

use of materials, including: seeds, mineral and natural fertilizers, plant protection agents: where the volume of fertilizers was converted into the pure active component and protection agent use and was expressed in terms of active substance content.

Table 1. Data for sown area and buckwheat yield in Poland between the years 2010-2015 compared to other grains
Tabela 1. Zasiewy i plony gryki w Polsce w latach 2010-2014 na tle produkcji zbóż ogółem i zbóż podstawowych

	2010	2011	2012	2013	2014	2015	2015 (2010=100)
Total grain sown area [ha]	7637653	7802971	7704322	7479493	7484955	7511848	98,0
Grain yield [dt·ha^{-1}]	35,6	34,3	37,0	38,0	42,7	37,3	
Buckwheat sown area [ha]	88525	75 768	71016	70384	62710	58529	66,1
Buckwheat yield [dt·ha^{-1}]	11,0	12,3	13,3	12,9	13,3	10,9	
Proportion of buckwheat in total grain-sown area [%]	1,16	0,97	0,92	0,94	0,84	0,78	0,77

Source: study results based on: [26, 27, 28, 29, 30, 31]

Table 2. Specific energy values of means of production and renewable sources
Tabela 2. Jednostkowa energia środków produkcji i źródeł odnawialnych

Type of emergy	Value	Unit	Source
Emergy of solar radiation	0,989E+11	$seJ \cdot ha^{-1} \cdot day^{-1}$	[15]
Emergy of evaporated water	1,28E+8	$seJ \cdot kg^{-1}$	[2, 14, 23]
Emergy of wind	2,79E+10	$seJ \cdot ha^{-1} \cdot day^{-1}$	[14, 22, 23]
Emergy of sowing material	6,50E+12	$seJ \cdot kg^{-1}$	own calculation
Emergy of fertilizers: N	4,04E+13	$seJ \cdot kg^{-1}$	[2]
Emergy of fertilizers: P	3,69E+13	$seJ \cdot kg^{-1}$	[2]
Emergy of fertilizers: K	0,187E+13	$seJ \cdot kg^{-1}$	[2]
Emergy of fertilizers: lime	1,68E+12	$seJ \cdot kg^{-1}$	[2]
Emergy of plant protection agents	1,48E+13	$seJ \cdot kg^{-1}$	[2]
Emergy of human labor	4,26E+13	$seJ \cdot h^{-1}$	[2]
Emergy of fuels	5,13E+12	$seJ \cdot kg^{-1}$	[2, 4]
Emergy of machines and equipment	7,29E+14	$seJ \cdot h^{-1}$	[23, 37]
Emergy of degraded organic matter in soil	11,02E+14	$seJ \cdot ha^{-1}$	[2, 14, 17]

Source: study results

Each of the above sources of expenditure was assigned with the specific energy use corresponding to it. For the case of E1, E2, E3 and K1 farms, the information was made of the types of machines and equipment used in the process. This, in turn, was used to determine the cumulative energy expenditure associated with their application. For the case of K2 farm, due to the lack of exact data regarding the machines, an assumption was made that work of the machines and equipment in the production can be derived from equivalent masses and efficiencies corresponding to an average farm, on the basis of norms found in [18, 25]. In the assessment of cumulative energy intensity of buckwheat production, it was adopted that the total value can be expressed by the total of the following components:

$$E_C = \sum E_M + \sum E_F + \sum E_{MAT} + \sum E_L \quad [MJ \cdot ha^{-1}], \qquad (1)$$

where:
E_C – total cumulative energy intensity,
$\sum E_M$ – cumulative energy expenditure in tractors, combine harvesters, machines and agricultural equipment and parts used for repairs,
$\sum E_F$ - cumulative energy intensity in the fuel used in production,
$\sum E_{MAT}$ – cumulative energy intensity in the materials used in production (fertilizers, plant protection agents and seeds),
$\sum E_L$ – cumulative energy intensity of the human labor.

The above terms were derived from the basis of data regarding the type of machines and equipment used in the production, their operating times, exploitation parameters [18, 25] and the specific rates converted into equivalent units of cumulative energy intensity corresponding to means of production used in agriculture [40, 41].

Whereas the cumulative energy intensity is a value that is relative to the technology of production and losses in the thermodynamic processes accompanying production, exergy and emergy are more objective measures. The emergy calculation is based on the determination of the use of exergy that is derived from renewable and non-renewable sources [20]. In other words, by its application it is possible to measure the use of the above resources in the production process together with the associated impact on the environment.

Emergy is defined as a measure by which the exergy of the means of production and the output can be converted into a common base called solar energy. In turn, emergy is defined as the product of exergy (Ex) of a given substance and its solar transformation (τ).

$$E_m = Ex \cdot \tau . \qquad (2)$$

Exergy is defined as the minimum input of work required to derive a given substance in a specific time on the basis of common components found in the surrounding environment [38]. For the case of complex products, such as machines and equipment, we can also apply a measure of the thermoecological cost [37], which expresses the cumulative exergy use of non-renewable resources (potential work) that imposes a burden on all phases of the processing of a final product.
Solar transformation forms the ratio of the energy of solar radiation, which was indirectly or directly applied in the generation of a given substance to the exergy of this substance. Hence, when we talk about the use of exergy, we can also refer to the corresponding use of emergy. The unit of emergy is expressed in terms of 1J of solar radiation (seJ). Table 2 found below contains a summary of the specific values of emergy in the particular means of production and emergy of renewable sources utilized in the production of buckwheat.

The calculations regarding the use of emergy in the production of buckwheat are based on an assumption that the vegetation period lasts for 100 days. The value of evapotranspiration was adopted to be equal to 150 mm. The values of the mean solar radiation and mean annual wind speed were taken from the data for the Opolskie province.

Due to the wide range of machines and equipment used in the process, the thermoecological cost associated with using them was adopted on the basis of [37] to be equal to 11,7E+6 $J \cdot \$^{-1}$. The value of a new machine was taken to be equal to 30 000$ and its depreciation period to be 12 000 hours. Hence, we can obtain the cumulative use of exergy equal to 2,94E+7 J per working hour of the machine. The solar transformation was adopted to be τ = 6,2E+7, including the Earth sedimentation cycle. Concurrently, this value was multiplied by 0,4, as this value corresponds to the proportion of iron ore use in steel production in Poland. The rest of steel takes its origin from recycling. Finally, we obtain the value of $E_m = 7{,}29 \cdot 1014 \ seJ \cdot h^{-1}$. A similar result is obtained from operations based on the equivalent financial value of the services paid in connection with the processes.

3. Results and discussion

3.1. Basic information regarding buckwheat cultivation in the analyzed farms

The data for the analysis was derived from two conventional (K1, K2) and three organic farms (E1, E2, E3). Since buckwheat was not cultivated in all farms every year, the information that was gathered could only provide conclusions with regard to selected periods. The presented results are not meant to be conclusive with regard to cumulative energy intensity and emergy in the production of buckwheat either for the entire Opolskie province or for the entire country. Nevertheless, we can say that the crop area of buckwheat is one of smallest in Poland. In the period between 2010-2015, the area used for its cultivation was equal to, for the respective years: 480 ha in 2010, 784 ha in 2011, 92 ha in 2012, 349 ha in 2013, 170 ha in 2014 and 190 ha in 2015. These crop areas are also some of the smallest figures for the country. Hence, the adoption of a few selected farms for this analysis can offer an approximation rather than comprehensive report on the quality of buckwheat production. Table 3 found below contains a summary of the basic information with regard to buckwheat production in the analyzed organic and conventional farms.

The results in terms of buckwheat yield in organic farms do not differ considerably in relation to the efficiency obtained for conventional farms. The mean yield for organic farms is equal to 10,91 $dt \cdot ha^{-1}$ in comparison to 11,74 $dt \cdot ha^{-1}$ in conventional farms. By comparing the above results to statistical data (Table 1: mean of 12,28 $dt \cdot ha^{-1}$ for the years between 2010-2015), we can note that the production results gained in the presented farms are not considerably lower. We can also remark at this point that both fertilization and plant protection in organic farms were based on natural mechanisms, whereas the use of chemical fertilizers and plant protection agents in conventional farms did not lead to considerably higher levels of buckwheat yield.

The area designated for buckwheat cultivation in organic farms was in the range from 0,8 ha to 7,85 ha. The production in E1 and E2 farms applied solution specific to commercial grain production. In these farms buckwheat formed a steady part of crop rotation and often accounted for a considerable proportion of the overall crop area. A similar crop system is maintained in K1 farm. Accompanying livestock production was not undertaken in E1 and E2 farms. The farmers provide biological components to the soil by application of legume plants as part of crop rotation. In the E3 organic farm, buckwheat production was undertaken in the third year after the soil is fertilized by manure originating from the farm. The chemical fertilization (per 1 ha) applied in conventional farms (converted to the pure component) was equal to: 6,0-10,3 kg N, 8,72-17,44 kg P and 24,9-49,8 kg K (K1 farm); 20, kg N, 26,16 kg P and 50,0 kg K (K2 farm).

3.2. Analysis of cumulative energy intensity

The cultivation of buckwheat in organic and conventional farms occurred in the years following grain crops. In farms E1 and E2 after picking forecrops, clover remained on the field, and was subsequently ploughed in the spring. The dates corresponding to the start of buckwheat production in conventional farms occurred in the second decade in April (K2) and the second decade in May (K1). For the case of organic farms, the production started in the first decade of May (E3) and second decade of March for the case of E1 and E2 farms (initiated by ploughing clover from forecrops).

Table 3.Characteristics of buckwheat cultivation in the examined farms
Tabela 3. Charakterystyka uprawy gryki w badanych gospodarstwach

Specification	Farms and years				
	K1	K2	E1	E2	E3
	2011/2012/2013/2014/2015	2012	2014/2015	2014/2015	2013/2014
Crop area [ha]	8,0/4,0/7,0/11,46/5,0	1,0	0,8/3,02	2,21/7,85	1,0/0,74
Soil valuation classes	V/V/ IV b, V/IV b, V/ IV b, V	III a, III b	III b/III b	IIIb, IIIb	IV a, IV b/ IV a, IV b
Variety	No name Panda/ Panda/ Panda/ Panda	Hruszowska	No name/ no name	No name/ no name	No name/ no name
Forecrop	Winter rye/ Spring barley/ Spring barley/ buckwheat/ buckwheat, winter wheat/ spring barley	Spring barley	winter rye + clover/winter rye + clover	winter rye + clover/winter rye + clover	Winter wheat/ winter wheat
Weed, disease and pest control	Crop rotation, mechanical, chemical	Crop rotation, mechanical, chemical	Crop rotation and mechanical weeding	Crop rotation and mechanical weeding	Crop rotation and mechanical weeding
Mineral and/or natural* fertilization, N,P,K [$kg \cdot ha^{-1}$]	6,0; 8,72; 24,9 12,0; 17,44; 49,8 10,30; 15,0; 42,70 8,9; 12,93; 30,94 9,0; 13,80; 37,35	20,0; 26,16; 50,0	------	------	35,25;21,0;40,46 35,25;21,0;40,46
Yield [$dt \cdot ha^{-1}$]	8,0/14,0/15,71/8,73/12,0	12,0	10,0/10,0	10,0/10,0	15,0/10,45

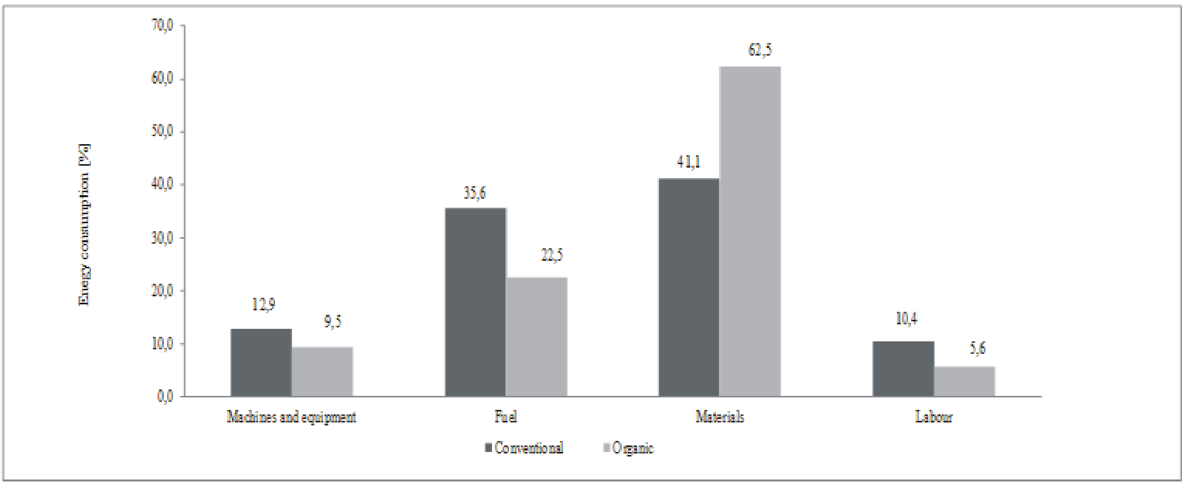
*Natural fertilization only in farm E3

Source: study results

Table 4. Cumulative energy intensity of buckwheat production [MJ·ha^{-1}] in the examined organic and conventional farms
Tabela 4. Energochłonność skumulowana w produkcji gryki [MJ·ha^{-1}], w badanych gospodarstwach ekologicznych i konwencjonalnych

Specification	Summary of data from the analyzed farms in particular years						
	K1 2011-2015	K2 2012	Average K1-K2	E1 2014-2015	E2 2014-2015	E3 2013-2014	Average E1-E3
Machines and equipment	1176,93	881,54	1029,24	1020,53	1036,12	967,72	1008,12
Fuel	3858,48	1816,32	2837,4	2563,86	2526,24	2104,03	2398,04
Materials	2408,77	4140,4	3274,59	8400,0	8400,0	3188,92	6662,97
Labour	660,02	1000,0	830,01	478,07	340,23	969,93	596,08
Total	8104,2	7838,26	7971,23	12462,46	12302,59	7230,6	10665,22

Source: study results



Source: study results

Fig. 1. Proportions of the components in cumulative energy intensity of buckwheat cultivation in the analyzed organic and conventional farms
Rys. 1. Udział poszczególnych składników energochłonność skumulowanej w produkcji gryki w badanych gospodarstwach ekologicznych i konwencjonalnych

Both in organic and conventional farms the activities concerning buckwheat cultivation were similar, with the exception of chemical fertilization and protection operations undertaken in conventional farms. In E1 and E2 farms, the ploughing of the clover remaining from growing forecrops occurred in March. In these farms, due to their commodity production characteristics and existence of large, modern and aggregated machines, the necessary activities associated with buckwheat cultivation took much less time (around 49-64% less in comparison to E3 farm and 28-66% less than in the case of conventional ones). This was accompanied by slightly increased fuel use (by 17-18%) in comparison to E3 farm. In the case of remaining farms, both organic (E3) as conventional ones (K1, K2), the list of activities was similar: stubble cultivation, harrowing, aerial spraying (in conventional farms), grain sowing and harvesting. In addition, E3 farm applied double harrowing.

The differences in cumulative energy intensity between organic and conventional farms were mostly affected by the application of chemical production agents in the latter type. Another factor was associated with the use of manure in E3 farm and application of lime fertilization in E1 and E2 farms. Table 3 contains a summary of the types of production agents applied during buckwheat cultivation together with the mean cumulative energy intensity in organic and conventional farms calculated per 1 ha of the crop area. On average, organic farms demonstrated higher by 25,26% energy intensity of buckwheat cultivation (Fig. 1). A similar relation was established on the basis of a study by Sławiński et al. [36], where the energy intensity of buckwheat production was on average higher by 27,27% in organic farms.

The smallest differences in cumulative energy intensity of the two types of farms were associated with the machines operations and agricultural equipment as well as the use of human labor. In terms of these two components, energy intensity was lower in organic farms. The duration of human labor was lower in organic farms by around 28,0%, which was primarily affected by the shorter working time recorded in E1 and E2 farms, in which the activities executed as part of production were performed with the use of modern aggregated machines.

The fuel use was characterized by higher energy intensity in conventional farms (by about 13%), which resulted from the additional procedures associated with use of fertilizers and plant protection agents. However, the cumulative energy intensity in organic farms associated with use of materials was higher by 50%, as lime fertilizers were used in E1 and E2 farms and based on manure in E3 farm (7,5 ton·ha^{-1}). In conventional farms, the materials used in production include plant protection agents and chemical fertilizers. In one paper [36], higher energy intensity of material use (by 11%) is reported with regard to organic farms and this is attributed to natural fertilization. However, mineral fertilization in this paper is lower in comparison to that report in [36], which affected such a considerable difference in the energy intensity associated with the material use.

Buckwheat forms a unique plant not only due to the low efficiency of its production, which is followed by the small popularity of its production. It is also seen as an extensive plant, as it requires considerable volumes of water and a soil that is rich in nutrients. However, its advantage associated with the little need for applying intensive fertilization in comparison to other plants is recognized as well. We can note that although the average yield of buckwheat is higher in conventional farms, the results recorded with regard to organic farms are better in the particular years. As a consequence of this and due to the scarcity of data regarding cumulative energy intensity of buckwheat production, it is quite difficult to state conclusions regarding the higher energy intensity of this production in the organic farms. It would be necessary to conduct research involving several consecutive years non-stop. An interest insight into the issue could be gained by comparing the cumulative energy intensity of buckwheat cultivation with another type of grain, that is winter wheat, which is the most popular cereal grown these days. The results found in Table 4 indicate considerably higher cumulative energy intensity of winter wheat in general (i.e. the difference of over three times is found) in relation to the data regarding buckwheat for the case of conventional farms. In general, winter wheat cultivation is much more intensive, as it involves the need to apply much more means of production. Hence, for the case of conventional farms we can clearly see the considerable differences with regard to energy intensity of its production. The lowest energy intensity is noted with regard to the use of materials. However, we can note a slightly higher cumulative energy intensity of winter wheat production in organic farms (by 5%) in comparison to the case of buckwheat cultivation. In organic farms, the largest difference expressed in terms of cumulative energy intensity was noted with regard to human labor and machinery use.

The above comparison indicates that for the case of organic farms the cultivation of both plants requires similar expenditure of work in production. The clearly distinct result that is obtained with regard to conventional farms indicates that buckwheat offers a potential as an alternative with a better energy efficiency.

The additional parameters offering the assessment of cumulative energy efficiency of buckwheat cultivation are presented in Table 5. The calculations concern an account with the nutritional value of buckwheat. The calculations are based on an assumption that 1 kg of buckwheat has a nutritional value of 14,36 MJ. The lower yield (by around 7%) in organic farms translated into lower nutritional value in MJ gained from a unit of area in this type of farms (15677,67). Such a level of energy efficiency calculated on the basis of the two parameters indicates the lower result obtained with regard to organic farms. Similar results regarding the energy efficiency of buckwheat cultivation were also obtained in a paper by Sławiński et al. [36].

Table 5. Comparison of cumulative energy of buckwheat and winter wheat cultivation in organic and conventional farm in the Opolskie province

Tabela 5. Porównanie energochłonności skumulowanej uprawy gryki i pszenicy na przykładzie wybranych gospodarstw ekologicznych i konwencjonalnych województwa opolskiego

Specification	Cumulative energy intensity [MJ·ha^{-1}]					
	K		Difference [%] Buckwheat = 100	E		Difference [%] Buckwheat = 100
	Buckwheat	Winter wheat		Buckwheat	Winter wheat	
Machinery and equipment	1029,24	2242,07	217,84	1008,12	2017,06	200.08
Fuel	2837,4	2664,62	93,91	2398,04	2371,91	98,91
Materials	3274,59	17495,26	534,27	6662,97	5686,00	85,33
Labour	830,01	1532,59	184,65	596,08	1172,49	196,70
Total	7971,23	23934,54	300,26	10665,22	11247,46	105,46

Source: study results with application of data from [16]

Table 6. Additional data (parameters of efficiency) used for assessment of cumulative energy efficiency of buckwheat cultivation in the examined organic and conventional farms

Tabela 6. Dodatkowe dane (wskaźniki efektywności) oceny energochłonności skumulowanej upraw gryki w badanych gospodarstwach ekologicznych i konwencjonalnych

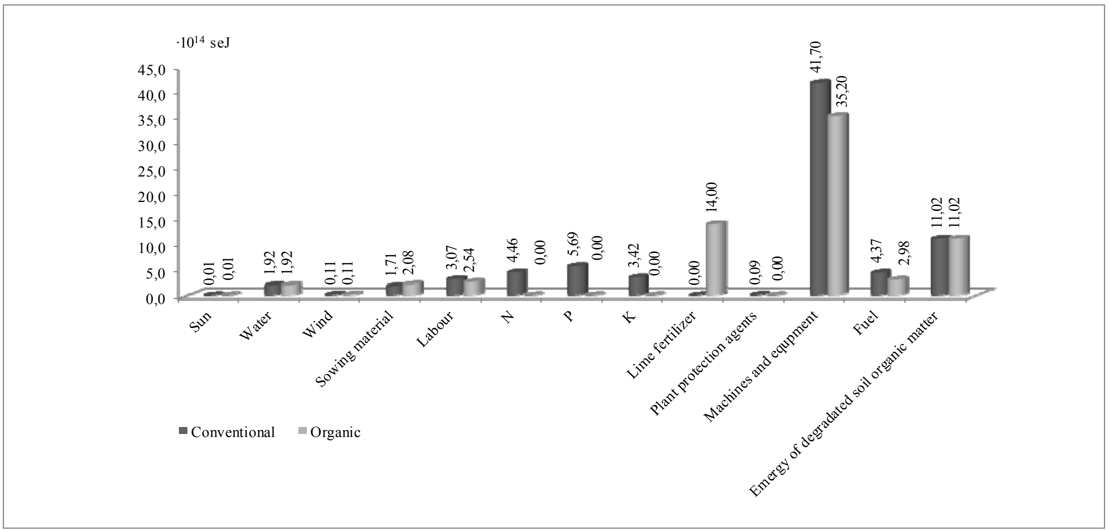
Coefficient	Unit	K	E
Yield	dt·ha^{-1}; GU*·ha^{-1}	11,74	10,91
Buckwheat nutritional value	Buckwheat nutritional MJ·kg buckwheat grain^{-1}	14,36	
Buckwheat yield nutritional value	Nutritional grain MJ ·ha^{-1}	16858,64	15677,67
Energy efficiency	MJ of cumulative energy intensity · GU^{-1}	679	978
Energy efficiency	Nutritional grain MJ·MJ of cumulative energy intensity^{-1}	2,11	1,47

Source: study results

*Grain Unit (GU) is a conventional measure used to determine the value of plant and animal products by means of a common measure. 1 GU corresponds to the starch and protein content in 100 kg of cereal grain

3.3. Emergy analysis of buckwheat cultivation

Figure 2 contains an illustration with the use of the earlier discussed components of emergy in buckwheat cultivation. The presented values are averaged data for the particular farm types.



Source: study results

Fig. 2. Components of emergy in buckwheat production, in the analyzed conventional and organic farms

Rys. 2. Składniki emergii w produkcji gryki, w analizowanych gospodarstwach konwencjonalnych i ekologicznych

On the basis of data in the above figure, we can note the higher environmental burden resulting from buckwheat cultivation in conventional farms, which is expressed by the cost of the emergy of machinery, fuel, labor and sown material. At the same time, the difference in terms of emergy use in the means of production is small. This is associated with the lack of environmental burden in connection with chemical agents in organic farms and relatively small impact on the environment of the conventional farms. In organic farms this burden can be attributed to the use of soil liming. As a consequence, the total use of emergy differs inconsiderably in the two systems of buckwheat production. It is slightly lower in organic farms (72,42 E+10^{14}seJ), in comparison to conventional ones, where it is 81,50 E+10^{14}seJ. A distinct situation is noted for the case of the use of energy in the cultivation of winter wheat. As reported by Kuczuk [16], the overall energy of production in conventional farms was in the analyzed case almost two times higher in relations to the organic farms.

The emergy account does not form a new calculation technique in itself; yet, it does not find such a common application in the assessment of the impact of agricultural activities on the environment compared to the classical measures/parameters, e.g. the balance of organic matter in soil, ratio of farmland and NPK balance.

Examples of emergy accounts in agricultural activities are known from the literature in the area, although greater focus is attracted by conventional production. Examples of research involving emergy analysis include items in [4, 12, 14], while emergy forms the focus of the impact of winter wheat production on the environment in these studies. In one paper [4] there is an additional report on the results of emergy analysis of spring barley, oats, vegetables and rape production. This study revealed that emergy is to a lesser degree affected by the cost of purchased means and that the production of spring vegetables and crops results in a lower environmental burden. In addition, a study by Ulgiati et al. [39] provided emergy calculation with regard to various crops produced in Italy. These data were subsequently used for the assessment of the role of agriculture in the country. The studies in [6, 16] allowed to draw conclusions with regard to emergy parameters referring to winter wheat cultivation in an organic and conventional production system.

Emergy account applies parameters, which can provide grounds for the assessment of the impact of a production system on the environment [3, 23]. The parameters applied in this study include: P_R – ratio is emergy derived from renewable sources, ELR (Environmental Loading Ratio), EYR (Field Ratio) and the total emergy use of specific grain production (per unit of this production – $Y \cdot GU^{-1}$) (Table 6.). The first is called the renewable fraction (PR), and is defined as follows:

$$P_R = \frac{E_{mR}}{E_{mR} + E_{mNMAT} + E_{mNM} + E_{mNS} + E_{mNF}}, \quad (3)$$

where:

E_{mR} – total emergy derived from renewable sources, such as sun, wind, water, sown material and labor,

E_{mMAT} – emergy of plant protection agents and fertilizers,

E_{mNM} – emergy of machines and equipment,

E_{mNS} – emergy of degraded organic material in the soil,

E_{mNF} – emergy of fuel.

The denominator of the above formula represents the total emergy cost (Y), and this parameter defines the ratio of emergy derived from renewable sources in relation to the total emergy use for the production. The other parameter (ELR) is given by the ratio of the emergy use from non-renewable sources to the emergy of renewable ones and takes the form:

$$ELR = \frac{E_{mNMAT} + E_{mNM} + E_{mNS} + E_{mNF}}{E_{mR}}. \quad (4)$$

Table 7. Emergy parameters describing the environmental impact of organic and conventional buckwheat cultivation
Tabela 7. Wskaźniki emergetyczne opisujące obciążenie środowiska w uprawie gryki

Coefficient	K	E	Remarks
P_R	0,13	0,13	Specific ratio of renewable resources in buckwheat cultivation.
ELR	6,58	6,85	Slightly higher in the analyzed organic production system; yet considerably lower in comparison to ELR in winter wheat production, e.g. [14, 16].
EYR	1,36	1,39	Similar values of efficiency.
$Y·GU^{-1}$	71,42 E+14	62,41 E+14	Total emergy use in generating GU is lower in organic farms.

Source: study results

In turn, Field Ratio expresses the ratio of emergy use in relation to the emergy of fertilizers, plant protection agents, fuel and emergy of machinery, in the form:

$$EYR = \frac{Y}{E_{mNMAT} + E_{mNF} + E_{mNM}}. \quad (5)$$

The results presented in Table 7 demonstrate the small environmental burden associated with both production systems. However, the use of environmental resources per unit of a final product is relatively smaller in the organic farms. This is affected by the lack of agricultural chemistry use for the organic cultivation in the first place, however, it also results from the non-intensive buckwheat production system in the conventional farms. It is interesting to interpret the result in terms of $Y·GU^{-1}$ in relation to the parameter described in Table 6: MJ of cumulative energy intensity multiplied by GU^{-1}. The result given by the first of the parameters, which describes the environmental burden, is better for the case of the organic farms despite the fact that the cumulative energy intensity of production is higher for the organic farms.

The above results relating to the emergy parameters can form the basis for further considerations of adopting organic production in agriculture in the place of the conventional type due to the small differences in the parameters characterizing the buckwheat production in them.

4. Conclusions

1. The yield obtained from the two production systems did not differ much. The mean buckwheat yield was lower in organic farms by 7%.
2. The overall cumulative energy intensity per 1 ha of buckwheat area was around 25% higher in organic farms in comparison to the conventional ones.
3. The higher cumulative energy intensity of organic farming was affected by the relatively high use of the means of production such as manure (E3) and lime fertilizers (E1, E2). In contrast, conventional farms did not record high intensity of buckwheat production expressed in terms of the use of chemical agents.
4. Conventional farms revealed higher value of nutritional product MJ per 1 ha (16858,64 MJ·ha-1) in relation to the organic farms (15677,67 MJ·ha-1), which can be attributed to the higher yield in the conventional farms. However, the recorded differences between the two production systems were small in this respect. In addition, the value of the nutritional MJ per 1 MJ of cumulative energy intensity was higher in the conventional farms ($2,11 MJ·MJ^{-1}$). This is also converted into the value of cumulative energy intensity that was needed for the production of an equivalent grain unit of buckwheat. In this case, the higher cost was associated with the organic production system ($978 MJ·GU^{-1}$).
5. The analysis of cumulative energy intensity showed that the less advantageous results gained in organic farms could be attributed to the lower yield associated with the use of the natural production means. Due to the fact that buckwheat cultivation is not extensive, the cumulative energy intensity is much lower than in other crops, such as winter wheat.
6. Emergy analysis gives other results, i.e. ones that are more favorable for the organic farms, especially in the aspect of their impact on the environment.
7. The total emergy use differs slightly in the two buckwheat cultivation systems. Nevertheless, it was lower for the case of organic farms ($72,42 E+10^{14}$seJ) for organic production in comparison to $81,50 E+10^{14}$seJ in the conventional one.
8. The emergy parameters: P_R, ELR, EYR and $Y·GU^{-1}$ indicate that the two systems affect the environment to a similar degree, which is inconsiderable. This certainly had to do with the small use of agricultural chemicals in conventional farms. The total energy use and, hence, the environmental burden calculated per grain unit was lower in the organic farms and equal to 62,41 E+14 $Y·GU^{-1}$, in comparison to 71,42 E+14 $Y·GU^{-1}$ in the conventional farms.
9. The highest emergy use could be attributed to the application of machinery and equipment and mineral fertilizers in the conventional farms.
10. An aspect that is worth consideration is connected with the emergy of degraded organic matter. For the case of E1 and E2 farms clover from forecrops was ploughed before sowing buckwheat, whereas in E3 farm the positive effect was associated with manure fertilization. Such components in the total crops should be accounted in total emergy account, since they promote the reproduction of organic matter and consequently reduce the environmental impact of agricultural production.

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