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Cost-, Cumulative Energy- and Emergy Aspects of Conventional and Organic Winter Wheat (*Triticum aestivum* L.) Cultivation

Anna Kuczuk[1,2]

[1] Department of Thermal Engineering and Industrial Facilities, Opole University of Technology, Opole, Poland

[2] Opole Agricultural Advisory Center, Łosiów, Poland

Correspondence: Anna Kuczuk, Department of Thermal Engineering and Industrial Facilities, Opole University of Technology, ul. Prószkowska 76, 45-758 Opole, Poland. Tel: 48-774-498-882. E-mail: a.kuczuk@po.opole.pl

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Abstract

The differences in the investment, cost, energy efficiency of cultivation in organic and conventional systems are considerable. This paper reports the results of emergy analysis and comparison of cost and energy efficiency of the two systems based on the example of growing winter wheat (*Triticum aestivum* L.). The differences between the two systems include the total cost of production as well as various levels of economic efficiency of production in a conventional system. It was noted that the cost of conventional production is decided on by the large cost of production materials. These farms demonstrate considerably lower energy efficiency of production. In contrast, in organic farms we can observe lower yield levels associated with the more extensive production quality. However, in the considerations we needs to take into account how the two types of production affect the natural environment. For this reason, emergy analysis was taken up, as its results indicate lower energy use in ecological cultivation.

Keywords: cost intensity of production, cumulative energy intensity, emergy, organic farming, conventional farming, winter wheat

1. Introduction

One of the principal objectives of agriculture is the security of food supply. This involves production of good quality food in sufficient amounts. The high quality of food products also results from lower environmental load, which can be associated with more efficient use of means of production, including sustainable use of the environment.

Competitiveness in agriculture involves various measures aimed at reducing cost and energy intensity of production. This aspect of production depends to a large extent on external factors, which makes its planning difficult. Nevertheless, operations aimed to increase energy efficiency take into consideration the reduction of the farming costs as well as the positive impact on environment. It is important to determine the weight of individual components in the cumulative energy intensity of production. They can also be used to control this intensity in a more planned manner.

On a local and global scale, agricultural production has an impact on the natural environment, and farming applies both renewable and non-renewable resources. In connection with this, in recent years we can observe a growing interest of consumers in food produced in an organic system. As a consequence, production in this type of farms is successively growing. This method is extensive as it involves a considerable or total elimination of mineral fertilisers and chemical plant protection agents. The procedures used to implement organic production reduce the cost and increase energy efficiency of production but can also considerably reduce crops (Seufert et al., 2012). This could raise concerns about security of food supply. However, scientific data (e.g., Badgley et al., 2007a; Badgley & Perfecto, 2007b) suggest that organic agriculture can secure sufficient supply of high quality food despite its lower efficiency, with a note that the organic production interferes with the environment significantly less than conventional production.

Therefore, it is very important to study the effect of implementing organic farming approach on crop yield, energy intensity of production and the cost of such production. This input can offer valuable information at the planning stage in crop production.

An additional measure, which offers objective means of assessing the use of the environment during farming, is the one associated with use of solar energy known as emergy (Odum, 1996). Emergy is defined by means of exergy of the substance which forms a raw material or a product of it and can be subsequently converted into solar energy through a unit of conversion called solar transformation (Odum, 1996; Brandt-Williams, 2002). 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 (Szargut, 2005). Such an approach leads to the application of a uniform measure for a variety of substances and offers an easy way to determine their exergy based on information in charts and boards (Szargut, 2005, 2007). The reference to exergy in relation to solar energy, which forms the origin of all natural resources and can be transformed into the output of production, can also promote a specific way of assessing the use of the environment. In addition, cash flows can be related to emergy by application of specific monetary resources (Odum, 1996). Due to the complexity of various production processes, we should often apply cumulative use of exergy (i.e. a measure of thermoecological cost) (Stanek, 2009) along with cumulative energy intensity.

Exergy and emergy analysis is becoming a more common measure of assessing activities in agriculture. It is also applied in the considerations of the impact of various cultivation systems on the environment. For example, the study in (Jankowiak & Miedziejko, 2009) undertakes emergy analysis of conventional production of winter wheat with an aim to determine the environmental impact of such production on the environment. Similarly, the work in (Ghaley & Porter, 2013) undertakes such an analysis of wheat production in two systems – conventional and organic as well as a complex agro-ecological one. The study in (Ghisellini et al., 2014) takes up the emergy assessment of cultivation in two regions of Italy over a period of 25 years. This work reports emergy levels derived from various sources (renewable and non-renewable ones). In addition, this study also takes into account the values of total emergy and variation of selected measures in the analyzed period. An integrated emergy and economic analysis of tea-leaf cultivation was performed in (Zeng et al., 2013). The calculated values of emergy parameters were applied for comparison of various substitutes of this plantation subsystem. In addition, the economic efficiency of the cultivation systems is undertaken by application of value of the investment and output/input parameters of the process.

Organic production and its exergy analysis forms the scope of the paper in (Shao et al., 2013). This paper undertakes an assessment of specific exergy components in farming production over the period from 1981-2001 and the environmental burden was referred to equivalent gha (global hectare) per capita. It is also indicated that the environmental burden is too high compared to its biocapacity. The study in (Chen et al., 2013) discusses various parameters to be used with regard to the comparison of the level of emergy use from renewable and non-renewable sources. The authors emphasize that the diverse approach to the input values of emergy has a considerable impact on the value of EEF (energy ecological footprint) and, hence, they suggest that great caution should be taken in calculations. Emergy analysis was also undertaken with regard to animal- (Jaklič et al., 2014) or horticulture-producing farms (Nakajima & Ortega, 2015).

The purpose of this paper is to report the results of costs comparison, cumulative energy intensity and emergy of winter wheat production in selected conventional and organic farms located in Opolskie Voivodeship (southwestern part of Poland).

The process of cultivation differs considerably in both types of farm. Conventional cultivation applies mineral fertilisers and chemical plant protection agents. Several farms from each group were taken for analysis with the aim of comparing production in them while ensuring that similar conditions of cultivation are maintained in the analysed period.

When the results are compared, one should take into account the fact that quality of nutritional parameters are important considerations in the production of organic food. Therefore, economic calculation in organic agricultural production should be subordinated to the desired quality of organic farming products.

This study is a follow-up of the analyses found in (Kuczuk, 2015), expanding on additional production years and selected aspects of the emergy calculations concerning winter wheat production in selected, organic and conventional farms.

2. Material and Methods

2.1 Conventional and Organic Farms—Basic Information, Selection of Farms

The comparison of selected organic and conventional farms in terms of costs, cumulative energy intensity and emergy analysis of winter wheat (*Triticum aestivum* L.) production was performed on the basis of detailed information obtained from eight conventional and three organic farms located in the Opolskie Voivodeship. The data acquired for the analysis of conventional farms was provided by Opole Agricultural Advisory Centre in Łosiów. Information was derived on the basis of cost-effectiveness sheets of winter wheat production. In the case of organic farms, the information was acquired and production cost-effectiveness sheets were completed following face-to-face interviews with farm owners. The analyzed organic farms were under control of certification body regarding compliance with organic production, in accordance with Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91.

Both conventional and organic farms were located mainly in the same administrative areas. The purpose of this selection was to make sure that soil and climate conditions are similar for all investigated farms.

In the analysed conventional farms (marked as K1 to K8), the area of winter wheat cultivation ranged from 1.00 ha up to 8.50 ha. Natural and production conditions for the plant cultivation were similar, mainly with regard to the soil valuation classes (Note 1): IIIa-IVb. For K1 and K3 farms the analysis involved production in the years 2011-2012, for farms K2 and K5 – production in year 2011, for K4 farm – production in the period between 2011 and 2014, while for K6, K7, K8 farms – production from 2013 to 2014. The differences in the production years reported with regard to conventional farms are associated with the structure of agricultural production (e.g. lack of winter wheat cultivation in specific years). In the consideration of this fact, the purpose of gaining data for four successive years was served by the application of other farms with similar farming conditions for the purposes of analysis.

In the case of organic farms (marked E1 to E3), the area of the cultivation was in the range from 0.75 ha to 29.33 ha (E1 farm was characterised by large scale production and in this respect was distinct from the other organic farms). The area of analyzed soil were valuated to be class II to class VI. The input data for the analysis of these farm came from the period between 2011 and 2014. Detailed data regarding winter wheat cultivation in conventional and organic farms is given in Tables 1a and 1b.

2.2 Costs of Winter Wheat Production

The costs of winter wheat production include: machine operating costs, equipment and means of transport, fuel costs, costs of materials (sowing material, manure and mineral fertilisers, plant protection agents), and labour costs. They were calculated in the same way as in another work (Sławiński, 2011), based on the following relation:

$$T_C = \Sigma C_M + \Sigma C_F + \Sigma C_{MAT} + \Sigma C_L \quad \text{[EUR/ha]} \tag{1}$$

Where,

ΣT_C: total winter wheat production costs [EUR/ha];

ΣC_M: cost incurred for the use of machines, equipment and means of transport;

ΣC_F: cost incurred for fuel;

ΣC_{MAT}: cost of materials use;

ΣC_L: labour costs.

Table 1a. Characteristics of winter wheat cultivation in the examined conventional farms

Specification	Farms and years							
	K1 2011/2012	K2 2011	K3 2011/2012	K4 2011/2012/ 2013/2014	K5 2011	K6 2013/2014	K7 2014/2013	K8 2013/2014
Crop area [ha]	2.00/2.00	1.00	1.00/1.00	5.00/6.00/ 5.50/3.00	2.00	4.27/4.57	8.50/4.90	1.00/1.00
Soil valuation classes	IIIb/IIIa	IIIa	IIIa/IIIa	IIIa/IVa/IVa/IIIb	IIIb	IVa, IVb/ IVa, IVb	IVa, IVb/ IVa, IVb	IVb/IVb
Variety	Jaga/Jenga	Bogatka	Kobra/ Bogatka	Bogatka/Zyta/ Bogatka/Arctis	Juliusz	Mewa/ Legenda	Legenda/ Mewa	Bogatka/ Banderola
Forecrop in following years	winter rape/winter wheat	winter rape	spring barley /maize	spring barley/ pea/maize + cerealsmix/maize	winter rape	spring barley/spring barley	spring barley/spring barley	cereals mix/ cereals mix
Weed, disease, and pest control	chemical	chemical	chemical	chemical	chemical	chemical	chemical	chemical
Mineral and/or natural* fertilisation N/P/K [kg/ha]	119/96/96/ 130/40/60	170/92/90	134/60/75/ 134/50/75	64+55*/32*/54*/ 60+72*/40+83*/ 40+71*/34+145* /84*/143*/61+ 145*/84*/143*	174/72/ 72	117+42*/60+ 24*/60+41*/ 102/60/90	117+85*/60+ 49*/60+83*/ 10+127*/60+ 73*/90+124*	150/45/90/ 148.5/90/135
Yield [dt/ha]	83.1/64.0	75.0	55.0/55.0	64.0/45.0/40.0 /60.0	85.0	60.19/74.4	60.0/74.08	50.0/70.0

Note. * Manure fertilisation.

Source: Study results on the basis of Kuczuk (2015).

Table 1b. Characteristics of winter wheat cultivation in the examined organic farms

Specification	Farms and years		
	E1 2011/2012/2013/2014	E2 2011/2012/2013/2014	E3 2011/2012/2013/2014
Crop area [ha]	18.74/29.33/5.66/11.48	1.50/1.75/1.00/0.75	7.50/7.13/5.35/1.55
Soil valuation classes	IIIa-VI/IIIa-VI/IIIa-V/IIIa-IV	IIIb/IIIb/IIIb/IIIa-IIIb	II, IIIa/II, IIIa/II-IIIa/II-IIIa
Variety	Zyta/Zyta/No name/No name	Almari/Almari/No name/No name	No name/No name/No name/No name
Forecrop in following years	buckwheat/buckwheat/ buckwheat + red clover + oat/buckwheat + red clover	red clover oat with pea/red clover + oat with pea/red clover/red clover	pea + potatoes + various vegetables + oat with pea/pea + potatoes + various vegetables/pea + potatoes + various vegetables + lacy phacelia/red clover
Weed, disease, and pest control	crop rotation, mechanical weeding	crop rotation, mechanical and manual weeding	crop rotation, mechanical weeding
Natural fertilisation N/P/K [kg/ha]	0/0/0/0	87/16/70/38/10/43/0/0/	0/0/0/0
Yield [dt/ha]	32.02/39.72/35.0/45.0	40.0/22.86/30.0/40.0	40.0/21.04/54.95/58.06

Source: Study results on the basis of Kuczuk (2015).

2.3 Cumulative Energy Intensity Assumptions

The study of cumulative energy intensity of winter wheat production took into account the input of energy in: mineral fertilisation and liming, natural fertilisers, machine operation (including transport), fuel, plant protection agents, sowing material and labour (Wójcicki, 2005b, 2007, 2008) Cumulative energy intensity was calculated for pure ingredients of NPK in mineral fertilisers and manure (Pruszka, 2006; Wójcicki, 2007, 2008). In the case of conventional farms, the researchers computed cumulative energy of plant protection agents in active ingredient (Wójcicki, 2007). The types of machines and equipment employed were specified for the analysed farms, which enabled cumulative energy intensity to be estimated. When assessing cumulative energy intensity of winter wheat production, it was assumed that its overall value is made up by the total of the above terms. Hence, the following formula is derived:

$$E_T = \Sigma E_M + \Sigma E_F + \Sigma E_{MAT} + \Sigma E_L \quad \text{[MJ/ha]} \tag{2}$$

in which, in the same way as above, individual components include the cumulative investment in machines, equipment, means of transport and parts for repair (ΣE_M), energy in fuel (ΣE_F), energy use for the manufacture of materials used in the production (seeds, mineral fertilisers and manure, plant protection agents - ΣE_{MAT}), and total equivalent energy intensity of labour (ΣE_L).

Individual components were determined on the basis of data concerning the type of machines and equipment used in production, their operating time, specific operating and maintenance costs (Marks & Makowski, 2007). The cumulative energy intensity was derived by application of coefficients in (Wójcicki, 2007).

2.4 Emergy Assumptions

During the calculation of emergy use in production of winter wheat, both renewable and non-renewable sources were taken into account. The emergy is calculated in accordance with the relation:

$$E_m = E_x \cdot \tau \tag{3}$$

Where, E_x is the exergy of a given component and τ is the solar transformation (Odum, 1996; Miedziejko, 2009). It is expressed in terms of 1J of solar radiation (seJ).

The vegetation period of winter wheat was adopted to take from the third decade of September until the third one of July. The emergy of solar radiation was adopted on the basis of the measured mean annual solar exposition taken for the province (Opole Voivodeship) (Klugmann-Radziemska, 2008). After transformation it was adopted at a level of 3.09E+13 seJ/ha. Similarly as in (Jankowiak & Miedziejko, 2009), it was assumed that the mass of evaporated water is equal to m = 5E+06 kg/ha, which is balanced by the precipitation, whose exergy is equal to E_x = 4.94 kJ/kg (Odum, 1996), and its solar transformation is 2.5 E+04 seJ/J (Brandt-Williams, 2002). The emergy of the water input is, hence, equal to 6.4E+14 seJ/ha. For the case of wind, the mean value adopted for the province was taken to be 2.5 m/s (on the basis of Environment, 2014). After a conversion into geostrophic velocity and further calculations (Odum 1996; Miedziejko 2009) (E_x = 1.32 E+10 J/ha; τ = 0.25E+04 seJ/J), we can obtain the value of the emergy equal to E_m = 3.3E+13 seJ/ha. The exergy of the sowing material and its solar transformation was adopted following (Jankowiak & Miedziejko, 2009) to be equal to E_x = 16.79E+06 J/kg and τ = 25.1E+04, respectively. In addition, the level of emergy equivalent to human labour was adopted following (Jankowiak & Miedziejko, 2009) to be equal to Em = 4.26 E+13 seJ/h.

With regard to calculations for non-renewable resources, we take into account the emergy of the machines and equipment, fuel, fertilisers and plant protection agents. Due to the variety of machines and equipment use, following the results in (Stanek, 2009) it was adopted that the thermoecological cost is equal to 11.7E+06 J/$, the mean value of the machines (cumulative exergy use) is 30.000 $ and depreciation period is equal to 12.000 working hours. Hence, we assume the total exergy use to be equal to 2.94E+07 J per hour of work of the machines and equipment. The solar transformation was adopted to be equal to τ = 6.2E+07, accounting for the Earth sedimentation cycle (Odum, 1996). Concurrently, this value was multiplied by 0.4, as this value corresponds to the proportion of iron ores in steel production in Poland. The rest of steel takes its origin from recycling. Finally, we obtain the value of E_m = 7.29E+14 seJ/h. A similar result is gained from operations based on the equivalent financial value of the services paid in connection with the processes (Jankowiak & Miedziejko, 2009).

For the case of diesel fuel, the adopted values were E_x = 44.5E+06 J/kg and τ = 11.09E+04 seJ/J, respectively, which gives E_m = 4.8E+12 seJ/kg. The emergy of the components of mineral fertilisers was adopted to be equal to (Brandt-Williams, 2002): N – 1.68E+12 seJ/kg; P – 3.63E+13 seJ/kg; K – 0.187E+13 seJ/kg, respectively, for agricultural lime: 1.68·E12 seJ/kg. The emergy of plant protection agents was calculated by taking the value of E_m = 1.48E+13 seJ/kg of the active substance (Brandt-Williams, 2002). The loss of soil organic matter (associated with soil degradation) as a result of cultivation of winter wheat was adopted on the basis of data in (Jankowiak & Miedziejko, 2009; Odum, 1996; Brandt-Williams, 2002; Kuś, 1995) to be equal to E_m = 11.02+14 seJ/ha. The emergy analysis was limited to the mean values of material and service input for both farm types (i.e. conventional and organic ones). This stems from the fact that it is very difficult to determine the use of emergy for machines and equipment, which however, forms a considerable part of the total balance. This is due to the diverse characteristics of the machines and various cost of cost of services incurred by the farms in the particular years of the analysis.

3. Results and Discussion

While analysing the data in Tables 2a and 2b, and in Figure 1 we can see that mean total cost per 1 ha of crop was approximately 78% higher for the examined conventional farms than in the case of organic farms (i.e. 933.44 EUR and 523.86 EUR, respectively).

The mean economic efficiency of production in the examined organic farms is considerably higher (1.98). This result is primarily affected by lower production costs and relatively high income in organic farms. As a result of the lower level of the overall cost, the organic farms (E1 and E3) have a comparable economic efficiency compared with the conventional ones (K1, K5). In the organic farm (E2), the operating cost of machines and equipment was higher compared to E1 and E3 farms. This resulted from the cost of manure fertilization, and also from less efficient field work in E2 farm. Straw collecting and pressing costs were higher as well. Another reason for the poor result in the E2 farm was that 1/3 of total winter wheat crop area was flooded in 2012. This fact caused negative economic result of winter wheat cultivation in that farm. The farm incurred production costs associated with cultivation of an area of 1.75 ha, while area of harvest was only 1.20 ha.

While analysing the structure of costs summarized in Figure 1, we see that in the case of conventional farms, prevailing costs (on average) were the ones associated with the use of materials, primarily fertilisers and plant protection agents (57%). Concurrently, machinery and equipment operation costs were prevailing in the case of winter wheat production in organic farms. On average, they constituted more than 53% of total costs in these farms. Also in this group of farms, the cost of labour and fuel consumption (Ucinek, 2011-2014) was slightly higher compared to conventional farms.

Table 2a. Mean costs, revenues, profits [EUR/ha] and economic efficiency of winter wheat cultivation in the examined conventional farms

Specification	Summary of data for farms in specific years								
	2011-2012 K1	2011 K2	2011-2012 K3	2011-2014 K4	2011 K5	2013-2014 K6	2013-2014 K7	2013-2014 K8	Average K1-K8
Operating cost of machinery and equipment	226.82	326.46	155.50	233.48	245.41	242,48	348,09	304.24	260.31
Fuel cost	72.72	141.07	110.42	129.56	91.94	67,03	67,57	125.99	100.79
Material cost	448.63	592.98	526.99	626.66	470.99	451,51	487,99	650.13	531.98
Labour cost	32.25	54.68	41.59	37.29	39.41	23,01	23,08	71.59	40.36
Total cost	780.42	1115.19	834.49	1026.99	847.74	784,04	926,73	1151.94	933.44
Total revenues	1589.63	1519.49	1193.13	973.21	1722.09	823.84	665.74	1103.84	1198.87
Profit	809.20	404.31	358.64	-57.38	874.35	39,80	-260,99	-48.10	264.98
Economic efficiency	2.03	1.36	1.43	0.96	2.03	1.02	0.72	0.97	1.32

Source: Study results.

Table 2b. Mean costs, revenues, profits [EUR/ha] and economic efficiency of winter wheat cultivation in the examined organic farms

Specification	Summary of data for farms in specific years			
	2011-2014 E1	2011-2014 E2	2011-2014 E3	Average E1-E3
Operating costs of machinery and equipment	277.94	340.09	217.21	278.41
Fuel cost	67.37	125.38	87.05	93.27
Material cost	83.35	190.12	79.70	117.72
Labour cost	16.87	50.85	35.62	34.45
Total cost	445.52	706.43	419.58	523.86
Total revenues	906.14	880.54	1056.25	847.44
Profit	460.62	173.98	636.67	423.76
Economic efficiency	2.05	1.26	2.62	1.98

Source: Study results.

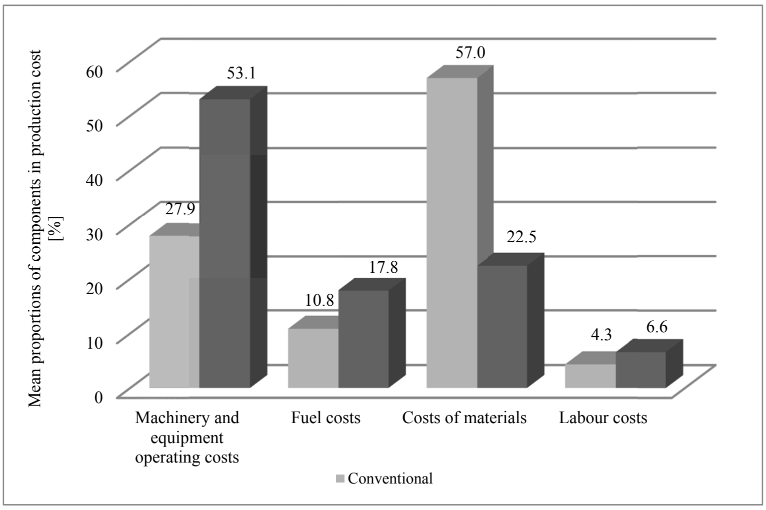

Figure 1. Mean proportions of components in production costs for conventional and organic farms

Source: Study results.

Tables 3a and 3b contain calculation results concerning cumulative energy intensity of the winter wheat production in the examined agricultural farms – both conventional and organic ones. In case of a two- or four-year research, the specified values are values averaged over the entire period of analysis. The data indicates that conventional farms have a higher cumulative energy efficiency for winter wheat production. An average result for this group of farms was 23934.54 MJ/ha. For the case of organic farms the average value of cumulative energy intensity was 11247.46 MJ/ha, respectively. We can see that the difference in the mean energy use for production was significant, reaching over 100%. For conventional farms, the average value was similar compared to the value of energy use for winter wheat production, as specified by (Marks & Makowski, 2007).

When we compare values calculated for organic farms to available literature data, they are close to the mean values of cumulative energy use noted for organic cultivation of winter rye given by (Sławiński, 2011). Also, in another work (Sławiński, 2010), the study involved a comparison between conventional and organic farms, which indicated the difference in cumulative energy intensity during rye production at a level of 65%.

Information in Tables 3a and 3b, and Figures 2 also indicates that energy use in production materials was at the prevailing component of cumulative energy intensity in conventional and organic farms. However, the energy use for producing them formed 73.1% of the cumulative energy intensity of winter wheat production in conventional farms in contrast to the figure for organic ones (50.6%). The highest proportion in this respect was noted in the K7 farm (79.09%). while the lowest value in the K8 farm (64%) in the group of conventional ones. These figures were primarily attributable to the use of mineral fertilisers, especially nitric, and sowing material. Also in other works (e.g. Dobek, 2007; Marks & Makowski, 2007; Kurek, 2011; Szwejkowska & Bielski, 2012; Piringer & Steinberg, 2008) the proportion of material share in the formation of energy intensity was the highest. For the organic farms, the highest ratio of energy use for production of materials per 1 ha of cultivation was noted in the E1 farm (80.86%), which was associated with the expenses associated with soil liming.

Table 3a. Cumulative energy intensity of winter wheat production [MJ/ha] in the examined conventional farms

Specification	Summary of data for farms in specific years								
	2011-2012 K1	2011 K2	2011-2012 K3	2011-2014 K4	2011 K5	2013-2014 K6	2013-2014 K7	2013-2014 K8	Average K1-K8
Machines and equipment	1965.25	2514.82	1454.61	2737.40	4375.67	1416.46	1416.87	2055.51	2242.07
Fuel	2009.95	3669.12	2923.20	3464.10	2608.70	1830.53	1839.80	2971.58	2664.62
Materials	16453.60	19139.30	18416.30	15985.50	21842.40	16501.10	16712.00	14911.90	17495.26
Labour	1197.50	2450.00	1635.00	1331.75	1545.00	802.00	804.50	2495.00	1532.59
Total	21626.30	27773.24	24429.11	23518.75	30371.77	20550.09	20773.17	22433.99	23934.54

Source: Study results on the basis of Kuczuk (2015).

Table 3b. Cumulative energy intensity of winter wheat production [MJ/ha] in the examined organic farms

Specification	Summary of data for farms in specific years			
	2011-2014 E1	2011-2014 E2	2011-2014 E3	Average E1-E3
Machines and equipment	896.19	3299.23	1855.75	2017.06
Fuel	993.59	3731.35	2390.78	2371.91
Materials	10098.75	4983.75	1975.50	5686.00
Labour	497.71	1870.25	1149.50	1172.49
Total	12486.20	13913.93	7371.53	11247.46

Source: Study results on the basis of Kuczuk (2015).

The remaining part of energy expenditure in the farm was due to the energy needed for machinery and equipment and associated with fuel consumption. The values of cumulative energy intensity (machines and equipment and fuel) ranged from 3246.99 MJ/ha (K6) up to 6984.37 MJ/ha (K5), respectively. With regard to organic farms, the highest energy use on machines and equipment and fuel was noted in E2 farm (7030.58 MJ/ha). This was, however, due to the application of outdated machinery and inconvenient layout of the field for the purposes of works.

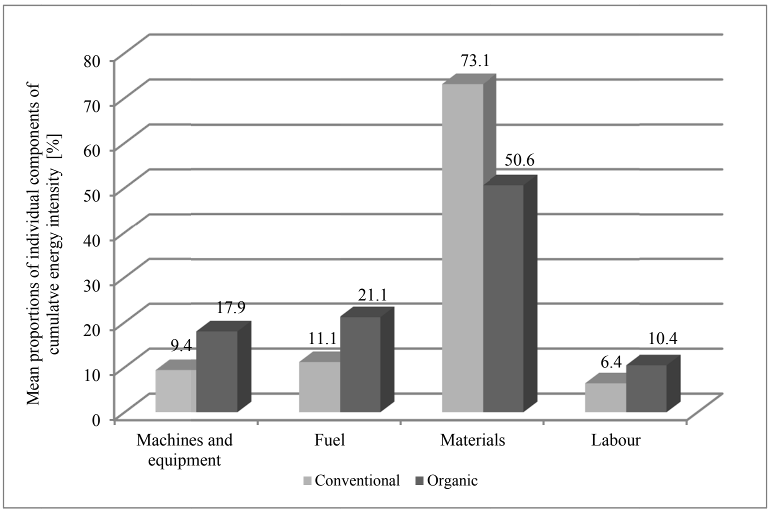

Figure 2. Mean proportions of individual components of cumulative energy intensity in conventional and organic farm production

Source: Study results.

As we can see from Figure 2, the ratio of relative energy use for machines and equipment and labour (together) was higher in organic farms (28.3%) compared with 17.5% in case of conventional farms, however, in conventional farms the use of cumulative energy in these components was higher expressed in absolute values. This stems from the need to include additional specialist operation in conventional farms in the overall calculation, such as the sow of chemical fertilisers and plant protection agents.

Tables 4a and 4b shows further parameters specific for the production in the examined farms from cost and energy point of view. The difference in crop yield for the two types of farms is clearly visible. The average crops in conventional farms were 66.98 dt/ha, while in the organic ones: 39.06 dt/ha, and this figure means a considerable degree of difference (by over 70%). Such a difference in crop yields is often observed during a comparison of organic and conventional farming methods. However, beneficial habitat features (e.g. good soil quality, climate, water conditions) and strict compliance with good agricultural practice can lead to comparable yield gained from organic and conventional farms (Sufert et al., 2012), as observed with regard to E3 farm (see also Table 1b).

Table 4a. Additional production parameters in the examined conventional farms

Specification	Farms and years								
	2011-2012 K1	2011 K2	2011-2012 K3	2011-2014 K4	2011 K5	2013-2014 K6	2013-2014 K7	2013-2014 K8	Average K1-K8
Yield [GU/ha], [dt/ha]	73.55	75.00	55.00	52.25	85.00	67.30	67.04	60.00	66.98
Energy efficiency [GU/GJ of cumulative energy]	3.39	2.70	2.25	2.26	2.80	3.28	3.23	2.66	2.82
[Nutritional MJ/ha]	78926.51	80482.50	59020.50	56069.48	91213.50	72214.26	71940.62	64386.00	71781.67
Nutritional MJ/MJ of cumulative energy	3.63	2.90	2.42	2.42	3.00	3.52	3.47	2.85	3.03
Production cost of 1dt [euro/dt]	10.77	14.87	14.87	22.31	9.97	11.92	13.98	19.87	14.82
Total cost/nutritional MJ [euro/MJ]	0.0099	0.0139	0.0141	0.0183	0.0093	0.0109	0.0129	0.0179	0.0130
Energy efficiency $[\frac{nutritional\ MJ\ in\ grain + MJ\ of\ straw}{MJ\ of\ cumulative\ energy}]$	7.06	5.86	4.60	4.41	5.72	6.81	6.71	5.55	5.84

Source: Study results.

Table 4b. Additional production parameters in the examined organic farms

Specification	Farms and years			
	2011-2014 E1	2011-2014 E2	2011-2014 E3	Average E1-E3
Yield [GU/ha], [dt/ha]	40.44	33.22	43.52	39.06
Energy efficiency [GU/GJ of cumulative energy]	3.27	2.52	6.30	3.98
[Nutritional MJ/ha]	40708.05	35643.02	46687.90	41013.00
Nutritional MJ/MJ of cumulative energy	3.28	2.70	6.76	4.20
Production cost of 1dt [euro/dt]	11.51	21.99	11.93	15.15
Total cost/nutritional MJ [euro/MJ]	0.0457	0.0827	0.0375	0.0128
Energy efficiency $[\frac{nutritional\ MJ\ in\ grain + MJ\ of\ straw}{MJ\ of\ cumulative\ energy}]$	5.92	4.89	12.23	7.68

Source: Study results.

This difference resulted from an extensive organic production and lack of application of chemical fertilisers and chemical plant protection agents. However, this value is converted into the value of nutritional energy in flour (nutritional MJ) obtained from crops. Nevertheless, if we look at energy efficiency represented by the ratio between the number of obtained grain units (Note 2) (GU) and GJ of cumulative energy intensity (Wójcicki, 2005a), we can state that in organic farms this indicator is 42% higher. In the case of conventional farms, the average value is 2.82 GU/GJ, while for organic farms: 3.98 GU/GJ. If we take the total of nutritional energy calculated for grain and fuel energy in straw per 1 MJ of the cumulative energy, then, on average it is 5.84 for conventional farms and 7.68 for organic ones.

The mean specific cost was equal to 14.82 EUR/dt in conventional farms and 15.15 EUR/dt in organic farms, respectively. The value for this component for organic farms was higher because of the value recorded in the E2 farm. This relation transfers linearly into the mean specific cost of production per nutritional value. It was equal to 0.0130 EUR/MJ for the examined conventional farms and 0.0128 EUR/MJ for organic farms.

In case of the organic farms, the proportion of particular constituents of cumulative energy intensity was varied. This resulted both from applied agrotechnical measures and from the special characteristics of the farms. For example, in case of the E1 farm, large area of winter wheat crop was combined with the use modern, high-capacity and aggregated machines. This led to relatively low specific cost relative to the machinery, equipment and fuel use (993.59 MJ/ha – Table 3b). On the other hand, during the period under study the farm had high cumulative energy use for liming, which resulted in the higher cumulative energy intensity of production. The machine park available in the E2 farm was outdated, not much aggregated, which brought about the need for repeated machine runs and relatively high number of machine-hours. This was also clearly reflected in the production cost. That was the only one among the studied organic farms, in which high the share in energy use for production was largely dependent on straw pressing and transportation cost. This cost was associated with accompanying animal production on the farm. In the same farm, the calculated energy balance was to a large extent affected by manure fertilization. Within the examined group of organic farms, E3 farm was characterised by the lowest cumulative energy intensity of production. Its energy balance was not burdened because of fertilising, liming, or straw handling. On the other hand, energy expenditures related to machine and equipment operation and fuel use did not significantly affect balance proportions, compared to other farms.

Beside analysis of cumulative energy intensity, another option is offered by emergy analysis, as the latter offers the possibility of assessing the effect of the production of winter wheat on the natural environment.

Figure 3 presents the mean values of emergy calculated for the tested group of farms in the examined period. The calculations account for emergy from renewable sources – sun, win, Water, grain and labour and from non-renewable ones – including machines and equipment on farms, fuel, fertilisers and plant protection agents. In addition, the research involved the effect of the load imposed on the environment resulting from the degradation of the organic matter in soil. One can note clearly that the emergy input from machines and equipment and chemical fertilisers forms the largest proportion in the total balance.

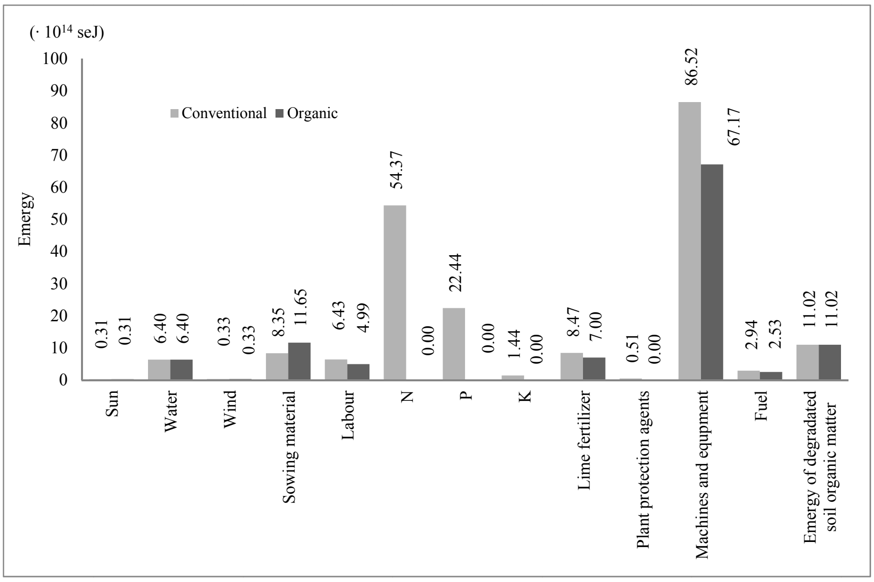

Figure 3. Values of emergy from various sources in conventional and organic production of winter wheat (in the examined farms)

Source: Study results.

Figure 4 presents the proportions of the components of emergy representing cumulative energy intensity for the production of winter wheat. One can note the higher proportion of emergy use by the machines and equipment in comparison to the cumulative energy efficiency in them (Figure 3). This results from the higher value of solar transformation τ for the machines and equipment made of metal, as their manufacturing imposes a greater burden on the environment. In addition, the emergy in the materials used for their manufacture is relatively higher in comparison to the cost of fuel and labour.

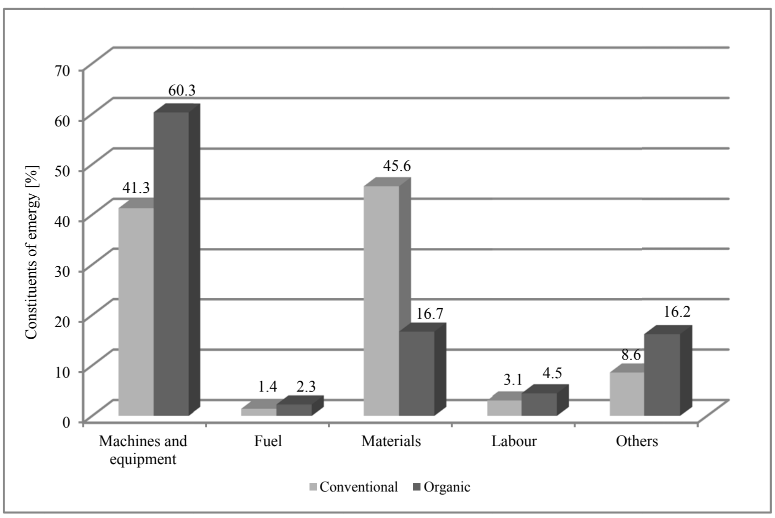

Figure 4. Constituents of emergy use in the examined conventional and organic farms

Source: Study results.

In comparison to the cumulative energy intensity of winter wheat cultivation, we can note the decreased relation of emergy of the materials – principally fertilisers and fuel.

The total emergy from renewable sources, i.e. sun, wind, water, sowing material and labour is denoted as E_{mR}.

The emergy in mineral fertilisers and plant protection agents is denoted as E_{mNMAT}, the emergy in machines and equipment – as E_{mNM}, the emergy in fuel – as E_{mNF}, and the emergy of degraded soil as E_{mNS}. On the basis of the values of emergy calculated above, it was possible to calculate efficiency and environmental sustainability parameters, applied in the emergy use calculation (Jankowiak & Miedziejko, 2009; Singh et al., 2016; Zeng et al., 2013).

The first parameter is called the renewable fraction (P_R), as forms the ratio of emergy derived from renewable sources in relation to the total emergy use (Y) for the production of winter wheat:

$$P_R = \frac{E_{mR}}{E_{mR} + E_{mNMAT} + E_{mNM} + E_{mNS} + E_{mNF}} \tag{4}$$

The next parameter is environmental loading ratio (ELR) and is given by the ratio of the emergy use from non-renewable sources to the emergy of renewable ones:

$$ELR = \frac{E_{mNMAT} + E_{mNM} + E_{mNS} + E_{mNF}}{E_{mR}} \tag{5}$$

In addition, the ratio of the emergy use to the grain unit (Y/GU) was derived during calculations (Table 5).

Table 5. Emergy parameters in the examined group of farms

Parameter	Conventional farms	Organic farms
Total emergy use Y [seJ/ha]	191.77E+14	111.39E+14
Renewable fraction P_R	0.107	0.21
Environmental loading ratio [ELR]	8.27	3.01
Y/GU	2.86E+14	2.85E+14

Source: Study results.

One can observe that for the case of organic farms, the burden imposed on the environment (on average) constitutes 60% of the value of the total environmental burden in the conventional farms. For the organic farms, the renewable fraction (P_R) is two times higher in the conventional farms. It is also indicated by the environment loading ratio (ELR), which is equal to 8.27 in the group of conventional farms and 3.01 in organic farms, respectively. Similar results are found in one paper (Coppola et al., 2008), and the reported value of ELR (depending on soil type and location of the farm) was equal to 7.3 and 8.5 for conventional farms, while for organic ones it was 2.3 and 2.4, respectively. In this respect, interesting results are presented in (Singh et al., 2015). This work includes emergy analysis for six different combinations of crop rotation of corn and wheat. The calculation undertakes the variations in the value of ELR, depending on the doses and types of fertilisers. The value of ELR equal to 3.74 corresponds to the crop rotation with the option of ploughing on the mass of green cover (while its value can be related to the value of ELR calculated in this paper for organic farms). At the same time, the lower values of ELR, such as 8.32 and 10.02 are associated with the application of both mineral fertilisers and varieties of organic fertilisers. Similarly, higher results of ELR (10.59, 12.00, 37.77) are reported for conventional wheat cultivation in a number of papers (Wang et al., 2014; Jankowiak & Miedziejko, 2009; Ghaley & Porter, 2013).

However, if we relate the emergy use to specific crop yield (GU), we can note that the value of this parameter in both types of farms was similar: 2.86E10+14 in case of conventional farms, and 2.85E+14 in case of organic farms respectively. This is due to the lower mean crop levels registered in organic farms. This result may seem surprising, showing almost identical emergy consumption in the organic and conventional production of winter wheat. This may suggest that organic production burdens the environment as much as conventional production.

Nevertheless, if we assume that yields of winter wheat are comparable to those achieved in conventional production (this may occur in individual cases of organic farms), emergy consumption in organic production proves to be significantly lower.

The lower level of yields is more often observed in organic farms, but it is worth noting the fact that organic food often has a higher nutritional value and has a better biological tests. Researches in this area are well documented (e.g. Krejčířová et al., 2007; Mäder et al., 2007; Murawska et al., 2015; Petr et al., 2004; Worthington, 2004). The aim of my study was not such analysis, but the analysis presented in this paper can give arguments for a broader implementation of organic production despite lower yields.

4. Conclusions

The study regarding cost-, energy- and emergy intensity of accumulated winter wheat production in conventional and organic farms has led to the statement of the following conclusions:

a) The decision to stop the use of chemical mineral fertilisers and chemical plant protection agents brought about lower yields in the examined organic farms. On average, for organic farms the crop yield was 39.06 dt/ha, while for conventional farms it was 70% higher – 66.98 dt/ha. The beneficial weather conditions in 2014 promoted the increase in crops both in organic and conventional farms. In constrast, the conditions in 2012 were comparably worse due to severe frost, which led to losses in crops on E3 farm (i.e. crop level of 21.04 dt/ha). In addition, in E2 farm the yield was smaller due to the flooding of a part of the cultivation area.

b) On average, the total cost of production per 1 ha of winter wheat was 933.44 EUR in conventional farms and 523.85 EUR in the organic ones. However, taking into account lower crop yield in organic farms, the mean specific cost was 14.82 EUR in conventional farms and 15.15 EUR in organic farms.

c) In conventional farms, considerable proportion of the overall cost was associated with the purchase of fertilisers and plant protection agents (57.0%), while in organic farms the majorits of cost was assocaited with machine and equipment operation (53.1%).

d) Economic effectiveness ratio was 1.32 for conventional farms and 1.98 for organic farms. This was due to the higher sales prices of the production from organic farms (in particular this concerns E3 farm) as well as to the lower total cost of production per 1 ha. In conventional farms the higher production cost was accompanied by the lower market prices of products (in particular this concerns the crops in 2014 due to the high supply of agricultural products in Poland). This had a major impact on the lower economic efficiency of production. On average, the production of winter wheat in K4, K7 and K8 farms can be considered as ineffective from the economic perspective.

e) The lack of mineral fertilising and application of chemical plant protection agents in organic farms led to a radical reduction of cumulative energy intensity of winter wheat cultivation. The mean cumulative energy intensity in the examined conventional farms was almost two times higher, i.e. equal to: 23934.54 MJ/ha. In case of organic farms it was 11247.46 MJ/ha.

f) Organic farms have two times smaller cumulative energy use for production. This can be converted into energy efficiency, expressed as the the ratio of nutritional grain MJ plus energy MJ in straw to MJ of cumulative energy intensity. It was aproximately 30% higher in organic farms (i.e. 5.84 in conventional farms and 7.68 in organic ones).

g) Energy efficiency expressed as the ratio of GU to GJ of cumulative energy intensity indicated its higher result (by around 40%) in the group of organic farms. This results from the lower energy use for production in organic farms.

h) The emergy use in the production of winter wheat from organic farms per 1 ha is 42 % lower in relation to the value for production in conventional system.

i) The higher value of P_R in organic farms indicates a more effective use of the natural environment during the production cycle of winter wheat. This is also noticeable in the value of ELR, which was two times higher in the conventional farms.

j) The analysis of organic farming presented in this article can promote its grater application. Organic agriculture has the potential to provide enough food for the world (Badgley et al., 2007a, Badgley et al., 2007b), and this type of production offers higher quality food compared to conventional farming. The results of the analysis, as well as reported results indicate lower environmental load of organic production. All of this is important from the point of view of the security of food supply. As consumer awareness increases, quality food produced in a clean environment is in high demand. However, it is important to strive to gain independence from the processed imported food produced on an industrial scale.

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Notes

Note 1. The grading of soils classification in Poland is based on the production value of soils. Polish grading system stands out of 8 arable land classes I, II, IIIa, IIIb, IVa, IVb, V, VI and 6 classes of grassland I, II, III, IV, V, VI. Regarding the quality classes of arable land: I – best arable soils, II – very good arable soils, IIIa and III b – average-good arable soils, IVa and IVb – average arable soils; V – poor arable soils, VI – the poorest arable soils.

Note 2. 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.