ENERGETICKÁ ÚČINNOST RŮZNÝCH PRODUKČNÍCH SYSTÉMŮ ŘEPKY OZIMÉ

The energy efficiency ratio of different winter rapeseed production systems

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Summary. The energy efficiency ratio of winter rapeseed produced in farming systems with different input levels was investigated in a four-year field experiment. The study was carried out in 2011-2014 in the Agricultural Experiment Station in Bałcyny operated by the University of Warmia and Mazury in Olsztyn (north-eastern Poland). In a conventional high-input system, the energy input associated with the production of winter rapeseed was estimated at 30 GJ per hectare. In an integrated system, the demand for energy was reduced by around 21%. Agricultural materials, including fertilizers, had the highest share of energy inputs in both production systems. The biomass of winter rapeseed cultivated in the high-input (conventional) system accumulated the highest amount of energy (219 GJ/ha). Winter rapeseed biomass produced in the integrated system accumulated 17% less energy on average in comparison with the high-input system. Despite the above, due to a lower demand for energy, the integrated production system was characterized by a higher energy efficiency ratio (7-10%) than the conventional system.

***Keywords**: winter rapeseed, biomass yield, energy input, energy output, energy gain, energy efficiency ratio*

Souhrn: Ve čtyřletém polním pokusu byl zkoumán poměr energetické účinnosti řepky ozimé, produkované v pěstebních systémech s různými úrovněmi vstupů. Studie se uskutečnila v letech 2011-2014 na zemědělské pokusné stanici v Bałcyny, provozované Univerzitou Warminsko-Mazurskou v Olštýně (severo-východní Polsko). V konvenčním systému s vysokými vstupy byl energetický vstup spojený s produkcí řepky ozimé odhadován na 30 GJ na hektar. V integrovaném systému byla potřeba energie snížena o přibližně 21 %. Zemědělský materiál, včetně hnojiv, měl nejvyšší podíl z energetických vstupů v obou produkčních systémech. Nejvyšší množství energie (219 GJ/ha) akumulovala biomasa řepky ozimé pěstované v systému s vysokými vstupy (konvenční). Biomasa řepky ozimé pěstované v integrovaném systému akumulovala v průměru o 17 % méně energie než v systému s vysokými vstupy. Nicméně, díky nižší spotřebě energie se integrovaný produkční systém vyznačoval vyšším poměrem energetické účinnosti (7 – 10 %) než konvenční systém.

***Klíčová slova**: řepka ozimá, výnos biomasy, energetický vstup, energetický výstup, energetický zisk, poměr energetické účinnosti*

Introduction

Energy consumption continues to grow rapidly in all industries and areas of human activity. According to estimates, the demand for energy will increase by 50% by 2030 and will double by 2050 (Gołaszewski 2009). Agriculture is a highly energy-intensive branch of the economy, but field crop production has a much higher energy efficiency ratio (2-30) than animal production (0.03-0.5) and greenhouse production (0.002), which points to its highest energy efficiency when compared with other agricultural sectors. Plant raw materials have a growing number of applications on the renewable energy market; therefore, the optimal production technology should be selected based on an evaluation of its energy efficiency ratio (Bielski et al. 2014). Mineral fertilization is the most energy-intensive component of the production process which accounts for around 75% of total inputs in the production of winter rapeseed (Bielski 2014, Budzyński et al. 2015, Jankowski et al. 2015, 2016). The volume of energy accumulated in the biomass of winter rapeseed can exceed 300 GJ/ha in a high-input production system (Budzyński et al. 2015). Winter rapeseed is characterized by unfavorable distribution of accumulated energy. Only 18% of energy is accumulated in rapeseed oil, 22% is accumulated in oil cake, whereas more than 60% of energy is accumulated in straw (Jankowski et al. 2015).

The aim of this study was to determine the energy balance of winter rapeseed biomass produced in systems with different levels of agricultural inputs (production intensity).

Materials and Methods

The experiment was carried out in 2011-2014 in the Agricultural Experiment Station in Bałcyny operated by the University of Warmia and Mazury in Olsztyn (north-eastern Poland). The experimental variables were two winter rapeseed production systems (Table 1). The experimental field had an area of 0.5 ha, and the experiment had a completely randomized design with three replications. Each year, the experiment was established on Haplic Luvisol originating from boulder clay (IUSS 2006). Winter wheat was the preceding crop.

The energy inputs associated with the production of winter rapeseed were determined by process analysis. The energy inputs associated with the use of tractors and agricultural machinery were calculated by multiplying the material consumption of one machine unit by an energy equivalent of 112 MJ/kg (Pawlak 1989). Fuel consumption, labor and the efficiency of tractors and agricultural machinery were determined by direct field measurements. The energy expenditure associated with labor was calculated with the use of an energy equivalent of 40 MJ/hour (Pawlak 1989). The energy expenditure associated with the consumption of Diesel oil was determined based on an energy equivalent of 48 MJ/kg (Wójcicki 2000). The energy inputs associated with production materials were determined based on the indicators proposed by Wójcicki (2000): seeds – 24 MJ/kg, nitrogen fertilizers – 77 MJ/kg N, phosphorus fertilizers – 15 MJ/kg P_2O_5, potassium fertilizers – 10 MJ/kg K_2O, crop protection chemicals – 300 MJ/kg of active ingredient, and the indicator proposed by Fore et al. (2011) sulfur fertilizers – 8.9 MJ/kg.

Table 1. Winter rapeseed production systems

Agricultural treatment		Integrated system	Conventional system
Variety		MONOLIT open-pollinated variety	ARTOGA hybrid variety
Pre-sowing fertilization (kg/ha)	P_2O_5	112	150
	K_2O	192	240
	N	20	30
Seeding rate (seeds per m^2)		70	50
Number of fungicide treatments		2	3
Top-dressing (kg/ha)	N	75	77
	N + S	35 + 40	52 + 60
	N	70	105

The unit energy value of biomass from winter rapeseed (seeds, straw) was determined by adiabatic combustion in the IKA C 2000 calorimeter with the use of the thermal-dynamic analogy method. The lower heating value (LHV) of biomass was calculated based on moisture content at harvest (Kopetz et al. 2007). The energy value of seeds and straw was calculated as the product of LHV (MJ/kg DM) and biomass yield (t/ha DM).

The energy efficiency of winter rapeseed production was determined based on energy gain (Equation (1)), the unit energy consumption ratio (Equation (2)) and the energy efficiency ratio (Equation (3)).

$$\text{Energy gain (GJ/ha)} = \text{Energy output (GJ/ha)} - \text{Energy input (GJ/ha)} \quad (1)$$

$$\text{Unit energy consumption ratio for 1 Mg DM of biomass (MJ)} = \frac{Energy\_input\_(MJ/ha)}{Biomass\_yield\_(Mg\_DM/ha)} \quad (2)$$

$$\text{Energy efficiency ratio} = \frac{Energy\_output\_(GJ/ha)}{Energy\_input\_(GJ/ha)} \quad (3)$$

Results and Discussion

Energy inputs

In Europe, the energy inputs associated with the cultivation of winter rapeseed range from 13 to 35 GJ per ha (Budzyński et al. 2015). In our study, the energy input associated with the production of winter rapeseed was determined at 23-24 GJ per ha in the integrated system, and it was approximately 4-8 GJ higher per ha in the conventional system (by around 27%) (Table 2).

In both production systems, the most energy-consuming components were materials (84-88%), including fertilizers (81-85%) and fuel (9-11% (Table 2). The high value of chemically bound energy in fertilizers explains their high share of energy inputs in the analyzed systems. Similar observations were made by Jankowski (2007) and Fore et al. (2011). The energy inputs associated with fertilizers (59-69%) and fuel (7-24%) are also high in other energy crops, including maize, sweet sorghum, giant miscanthus, Amur silver grass, Virginia fanpetals, alfalfa and timothy grass (Jankowski et al. 2016).

Table 2. Energy inputs (MJ/ha) associated with the analyzed production systems in 2011-2014

Production system		Labor	Tractors and machines	Fuel	Materials				∑
					seeds	fertilizers	pesticides	total	
Integrated	2010/2011	145	927	2 777	86	19 818	669	20 574	24 424
	2011/2012	110	766	2 250	86	18 586	726	19 399	22 525
	2012/2013	176	1 018	3 300	117	18 586	741	19 444	23 939
	2013/2014	117	760	2 334	117	20 126	449	20 692	23 902
	Average	137	868	2 665	102	19 279	646	20 027	23 697
Conventional	2010/2011	149	945	2 802	72	27 514	693	28 279	32 174
	2011/2012	113	783	2 274	72	24 819	750	25 641	28 812
	2012/2013	176	1 018	3 300	91	24 819	708	25 618	30 113
	2013/2014	117	760	2 334	91	25 127	707	25 925	29 136
	Average	139	876	2 678	82	25 570	715	26 366	30 059

Energy outputs

In the Polish climate, the energy output of winter rapeseed biomass is highest in conventional (high-input) production systems (Jankowski 2007, Budzyński et al. 2015). In this study, the total energy output of winter rapeseed biomass in the high-input system ranged from 178 GJ/ha to even 324 GJ/ha, subject to weather conditions in the analyzed year. A decrease in energy inputs lowered total energy output by 11-22% (Table 3). Similar differences in energy efficiency between the evaluated production technologies were observed by Jankowski (2007) and Budzyński et al. (2015).

The distribution of accumulated energy in the biomass of winter rapeseed is determined by yield. An increase in yield induced by the high-input technology decreased the amount of energy accumulated in seeds and increased energy accumulation in straw (Table 3). A similarly unfavorable distribution of energy accumulated in the biomass of winter rapeseed was observed by Budzyński et al. (2015). The cited authors demonstrated that around 43% of energy was accumulated in seeds in medium-input and low-input systems. In the high-input system, seeds accumulated up to 37% of total energy.

Table 3. The volume of energy (GJ/ha) accumulated in the biomass of winter rape in 2011-2014

Production technology		Energy output		
		seeds	straw	seeds + straw
Integrated	2010/2011	69.57	90.19	159.76
	2011/2012	122.97	129.92	252.87
	2012/2013	110.49	88.45	198.94
	2013/2014	119.50	109.62	229.12
	Average	105.63	104.55	210.18
Conventional	2010/2011	74.66	103.82	178.48
	2011/2012	145.16	178.79	323.94
	2012/2013	120.77	106.00	226.77
	2013/2014	143.08	122.96	266.04
	Average	120.92	127.89	248.81

Energy efficiency ratio

The energy gain of winter rapeseed produced in the conventional system was determined at 90.86 GJ/ha (seeds) and 218.75 GJ/h (seeds + straw), and it was 11% and 17% higher than in the integrated system, respectively. It should be noted that energy inputs per 1 t DM of seeds were 12% (seeds) and 8% (seeds + straw) lower on average in the integrated system than in the conventional system (Table 4).

In Europe, the energy efficiency ratio of rapeseed has been determined in the range of 2.4 (Venturi and Venturi 2003) to 3.6-5.4 (Jankowski 2007, Bielski et al. 2014, Jankowski et al. 2015). In the presented study, the energy efficiency ratio of winter rapeseed cultivated in the conventional (high-input) system reached 4.07. In the less energy-intensive integrated system, the above parameter increased to 4.48. The energy efficiency ratio of both seeds and straw was determined at 9.59 in the integrated system and 8.36 in the conventional system (Table 4). Other authors also reported higher energy gains and higher energy efficiency ratios in less energy-intensive crop production systems (Jankowski 2007, Bielski et al. 2014, Budzyński et al. 2015).

Table 4. Energy analysis of winter rapeseed biomass in 2011-2014

Production technology		Energy gain (GJ/ha)		Unit energy consumption ratio for 1 Mg DM of biomass (GJ)		Energy efficiency ratio	
		seeds	seeds + straw	seeds	seeds + straw	seeds	seeds + straw
Integrated	2010/2011	45.15	135.34	8.11	2.65	2.85	6.54
	2011/2012	100.44	230.36	4.23	1.58	5.46	11.23
	2012/2013	86.55	175.00	5.01	2.20	4.62	8.31
	2013/2014	95.60	205.22	4.62	1.88	5.00	9.59
	Average	81.93	186.48	5.50	2.08	4.48	8.92
Conventional	2010/2011	42.48	146.30	9.96	3.10	2.32	5.55
	2011/2012	116.34	295.13	4.59	1.55	5.04	11.24
	2012/2013	90.666	196.65	5.76	2.40	4.01	7.53
	2013/2014	113.94	236.90	4.71	1.99	4.91	9.13
	Average	90.86	218.75	6.26	2.26	4.07	8.36

Conclusions

1. The energy inputs associated with the production of winter rapeseed biomass were around 27% higher in the conventional system than in the integrated system.
2. The highest energy gain was noted when winter rapeseed was produced in the conventional system.
3. Conventional production technologies are characterized by high energy demand, but the relevant energy gain is 10-15% higher per ha than in integrated systems.
4. In the evaluated production systems of winter rapeseed biomass, an increase in energy inputs decreased the energy efficiency ratio.

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