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Energy balance of catch crops production

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Abstract

The aim of this paper was to evaluate catch crops for energy production and effectiveness in the areas with limited precipitation. Eight plant species: *Brassica napus*, *Lolium multiflorum*, *Lolium perenne*, *Phacelia tanacetifolia*, *Raphanus sativus* var. *oleiformis*, *Sinapis alba*, *Trifolium incarnatum*, *Trifolium subterraneum*, and un-seeded control were observed from 2005 to 2007. Energy content of biomass (MJ kg^{-1}) and energy production (GJ ha^{-1}) of catch crops, volunteers and weeds were determined and energy balance (inputs, gain, and effectiveness) was calculated. Energy content of above-ground biomass of catch crops (15.65–20.21 MJ kg^{-1}) was significantly ($P < 0.05$) influenced by species and year. In average of 2005–2007, the total energy production was 18.19 GJ ha^{-1} in un-seeded control (production of weeds and volunteers) and ranged from 24.74 to 57.02 GJ ha^{-1} in the stands with evaluated catch crops. Catch crops represented 43–94% of the total energy production depending on plant species. Gain of positive energy balance of evaluated catch crops was influenced particularly by the year in relation to soil moisture by contrast to the un-seeded control. In all three years, positive energy balance was reached only by the stand with *S. alba*. *P. tanacetifolia* performed at the lowest value of additional energy and *R. sativus* performed at the highest energy accumulation in underground biomass.

Key words: calorific value, energy production, intercrop, volunteers, weed.

Introduction

Catch crops represent an important part of crop rotation in crop management and ecology. Catch crops have a positive effect on soil fertility, elimination of erosion, and on limiting nutrient loss. They are also very acceptable as breakers of crop rotations and can increase yields of the main crops (Joelsson, Kyllmar, 2002). Catch crops also contribute to weed control (Poggio, 2005; Rasmussen et al., 2006). Biomass production of catch crops is one of the main factors leading to stable circulation of organic matter in arable land. Input of organic matter to the soil is associated with the increase in soil fertility and soil aggregate stability (Brant et al., 2011).

In spite of the general advantages of the above-mentioned catch crops, their growing should also bring energy profit in the agro-ecosystem in terms of energy input and output. This principle of energy balance is widely used for the evaluation of energy use efficiency (EUE), mainly for the comparison of different cropping systems (Alluvione et al., 2011; Moreno et al., 2011; Zentner et al., 2011), annual or perennial crops (e.g., Boehmel et al., 2008) or different crop species (Venturi, Venturi, 2003). In principle, energy balance comes from the comparison of inputs and outputs. Energy outputs are divided into energy of plant production, residue of plants, and irreversible energy loss. Input of energy consists of energy of the outer environment (sunlight, energy in soil, atmosphere and infrastructures of the surrounding environment), and energy of technological inputs, which consists of direct part (energy of human work, fossil energy, other energy sources – draught animal, etc.), and indirect part (energy of mechanisms, products of chemical industry, organic fertilizers, seeds, etc.) (Hülsbergen et al., 2001). Parameters most frequently used in considering EUE are net energy gain (difference between energy production and inputs of energy) and energy output/input ratio, which represents conversion of energy inputs into outputs (e.g., Venturi, Venturi, 2003; Angelini et al., 2005).

The previous research of energy balance was focused mainly on the evaluation of the most frequent field crops such as wheat, barley, sunflower, sorghum, winter rape, sugar beet (e.g., Venturi, Venturi, 2003; Moreno et al., 2011) or alternative energy crops such as industrial hemp (Prade et al., 2011) or giant reed (Angelini et al., 2005) usually under different crop management (e.g., Zentner et al., 2011). In spite of the wide range of published results, there is a lack of information about energy balance calculated for catch crops, mainly in terms of EUE and suitable species selection. Moreno et al. (2011) reported that effectiveness of energy input was strongly reduced in semi-arid environment, therefore it must be remembered, that environment, such as level of precipitation, could strongly influence EUE.

The aim of the research reported in this paper was: i) to compare a range of catch crops in terms of their energy production and effectiveness, ii) to determine which species of catch crops can produce significantly higher EUE as compared with the un-seeded control with only weeds and volunteers in the area with limited precipitation.

Materials and methods

Experimental locality. The experiment was established in Central Bohemia, Czech Republic in an experimental field station in Červený Újezd (50°04′30″ N, 14°10′20″ E, 398 m a.s.l.). The long-term annual temperature is 7.9°C and precipitation 526 mm. According to the latest climatic regionalization of the Czech Republic (Moravec, Votýpka, 2003), the locality falls into Class III, which is characterized by an average duration of the main vegetative period within the range of 160–177 days, the average annual total of precipitation below 580 mm and the rainless period of more than 22 days. Particle size distribution of the soil in the experimental site was in categories of soil particles < 0.01 mm, 0.01–0.05 mm, 0.05–0.1 mm and 0.1–2 mm as follows 53.21%, 38.54%, 2.32% and 5.93%, respectively.

Experimental design. Eight plant species cultivated as catch crops: winter rape (*Brassica napus* L.) variety 'Bristol', seeding rate – 10 kg ha^{-1}, Italian ryegrass (*Lolium multiflorum* Lamk.) variety 'Lonar', 40 kg ha^{-1}, perennial ryegrass (*Lolium perenne* L.) variety 'Prolog', 20 kg ha^{-1}, phacelia (*Phacelia tanacetifolia* Benth.) variety 'Větrovská', 10 kg ha^{-1}, fodder radish (*Raphanus sativus* L. var. *oleiformis* Pers.) variety 'Ikarus', 25 kg ha^{-1}, white mustard (*Sinapis alba* L.) variety 'Veronika', 20 kg ha^{-1}, crimson clover (*Trifolium incarnatum* L.) variety 'Kardinál', 25 kg ha^{-1}, subterranean clover (*Trifolium subterraneum* L.) candivar, 30 kg ha^{-1}, and un-seeded control were observed from 2005 to 2007. The experiment was designed in random blocks. Each experimental treatment consisted of four plots (replicates) sized 30 m^2 each (3 × 10 m). The catch crop sowing followed the *Triticum aestivum* L. ('Alana') harvest (19 Aug. 2005, 24 Aug. 2006 and 13 Aug. 2007). Straw was chopped and spread in the field during harvest. The field was prepared by a rotary tiller to a depth of 0.08 m. Catch crops were sown on the soil surface (24 Aug. 2005, 30 Aug. 2006 and 14 Aug. 2007), which was then harrowed.

Biomass production of catch crops. Dry above-ground biomass production of catch crops, volunteer cereals and weeds was ascertained on patches sized 0.1 m^2 (20 Oct. 2005, 1 Nov. 2006 and 1 Nov. 2007) in two pseudo-replicates per experimental plot. Plants were cut near the surface. Samples were dried at 80°C and dry matter yield (kg ha^{-1}) was determined. Total above-ground biomass production and dynamics of catch crops growth in the experimental years were presented by Brant et al. (2009). Dry underground biomass production of catch crops (except for *T. subterraneum*) was determined by using the methodology of root-wash. A soil block (avg. diameter 120 mm, height 200 mm including above-ground biomass) was sampled from each replication. Dry weight of catch crops above-ground biomass was determined in each sample. Dry weight of underground biomass was weighed after root-wash on sieve with 0.2 mm mesh size. The following calculation showed the ratio between dry above-ground and underground biomass production values. Production of underground biomass per unit area was calculated from above-ground biomass production values per each replicate and from the ratio between above-ground and underground biomass assessed for each species.

Energy content of catch crops biomass. Energy content of biomass (MJ kg^{-1}) was established as an arithmetic mean from measurements of four average (i.e. mixed) sample in each treatment. Calorific value in the dry biomass of catch crops, volunteers and weeds was measured by the automatic adiabatic calorimeter system Model IKA C 5000 control (IKA®, Werke GmbH & Co. KG, Germany). The calorific value was calculated according to ISO 1928: 2009, without ash and with no correction for dissolution heat of sulphuric and nitric acids.

Energy balance of catch crops. Energy balance of catch crops was assessed according to methods published by Preininger (1987). Total energy production (GJ ha^{-1}) was calculated from biomass production (kg ha^{-1}) and energy content of biomass (MJ kg^{-1}). Energy inputs included energy of soil preparation, seeds, seeding and harrowing. Energy of seeds was calculated from the seeding rate (kg ha^{-1}) and energy content of seeds (MJ kg^{-1}). Energy gain (difference between energy production and inputs of energy, GJ ha^{-1}) and energy effectiveness (how much energy is produced from one unit of energy input, GJ GJ^{-1}) were calculated.

Statistical analysis. The data were statistically evaluated by using one-way *ANOVA* in *Statistica 9.1* (2010) followed by Tukey post-hoc test ($\alpha = 0.05$). Dunnett test ($\alpha = 0.05$) was used to evaluate energy gain of the above-ground biomass of catch crops as compared with the un-seeded control.

Results and discussion

Energy content of catch crops biomass. Energy production from a certain area of land primarily depends on biomass yield because the content of energy in biomass has smaller variability than the yield (Fuksa et al., 2012). However, determining the content of energy in biomass is important for a precise calculation of energy balances. Calorific value of the above-ground biomass of evaluated catch crops ranged from 15.65 to 20.21 MJ kg^{-1} (Table 1). These values correspond with values found by Kocourková et al. (2004) in grass biomass (17.00–18.50 MJ kg^{-1}), Alluvione et al. (2011) in the straw of winter rape (17.25 MJ kg^{-1}), wheat 18.17 (MJ kg^{-1}) or maize (18.67 MJ kg^{-1}) and Fuksa et al. (2012) in grassland biomass (16.89–18.62 MJ kg^{-1}). Energy content was significantly influenced by year and species. Influence of year on energy content in plant biomass was described by Fuksa et al. (2006) in silage maize. In the assessed catch crops species, the lowest values were found in *P. tanacetifolia* and species from the *Brassicaceae* family in all experimental years. The highest values

Table 1. Calorific value (MJ kg^{-1}) in above-ground and underground biomass of studied catch crops in 2005–2007

Species	Above-ground biomass MJ kg^{-1}			Underground biomass MJ kg^{-1}		
	2005	2006	2007	2005	2006	2007
Brassica napus	17.29 A	17.48 A	18.77 B	17.69 A	17.81 A	18.03 A
Lolium multiflorum	17.56 A	17.49 A	19.10 B	18.56 A	18.54 A	18.72 A
Lolium perenne	16.59 A	17.56 A	19.11 B	18.47 A	18.52 A	18.58 A
Phacelia tanacetifolia	15.65 A	15.81 A	17.78 B	18.26 A	18.22 A	17.90 A
Raphanus sativus	16.01 A	16.44 A	18.18 B	17.01 A	17.05 A	18.02 B
Sinapis alba	17.09 A	17.03 A	18.46 B	18.52 A	18.65 A	18.47 A
Trifolium incarnatum	16.98 A	18.50 B	20.21 C	19.32 A	19.41 A	18.77 A
Trifolium subterraneum	15.73 A	18.13 B	19.62 C	–	–	–
Mean	16.61 A	17.31 B	18.90 C	18.26 A	18.28 A	18.32 A
P-value	< 0.000	< 0.000	< 0.000	< 0.000	< 0.000	< 0.000
+/– Limits	0.70	0.23	0.56	0.56	0.58	0.32

Note. Letters express statistical differences among the years within each row for above-ground or underground biomass (Tukey test, $\alpha = 0.05$); *P-value* and *+/– Limits* (Tukey test, $\alpha = 0.05$) express differences among the species within each column for above-ground or underground biomass.

were usually observed in grass species. The reason for lower energy content in the biomass of *S. alba*, *R. sativus* and *P. tanacetifolia* could be the species' phenological development to the generative stage. The formation of generative parts might have reduced the energy content in leaves and stalks at this stage. These changes directly depend on changes in the chemical composition of plants, which is related to energy content in plants (Yajing et al., 2007) or leaf/stem ratio and energy content in these different plant parts (Hakl et al., 2010).

Lower variability in energy content among the evaluated catch crops was found in underground biomass (17.01–19.41 MJ kg^{-1}) compared to above-ground biomass. Nevertheless, in accordance with Alluvione et al. (2011), no substantial differences were found between the above-ground and underground biomass. Similarly as in the above-ground biomass, significant differences were found in the energy content of the underground biomass of evaluated species, with higher values measured in the roots of grasses and legumes by contrast to species from the *Brassicaceae* family and *P. tanacetifolia*. Except for *R. sativus*, differences among the years were not determined for the energy content of underground biomass. Interaction between the year and the species was not significant. Differences of calorific values among the years were more substantial in above-ground biomass by contrast to underground biomass. Energy contents in the above-ground biomass of volunteers were significantly lower in 2005 and 2006 (17.48 and 17.63 MJ kg^{-1}) by contrast to 2007 (19.44 MJ kg^{-1}) in average of all tested treatments. Energy contents in the above-ground biomass of weeds ranged on average from 17.50 to 17.92 MJ kg^{-1}, respectively in 2005 and 2006. In 2007, the average value amounted to 18.80 MJ kg^{-1}. Measured calorific values of volunteers and weeds were in agreement with values published by Alluvione et al. (2011) in wheat (18.17 MJ kg^{-1}) and Fuksa et al. (2006) in weed species (16.80–18.21 MJ kg^{-1}). The highest values of energy content were found in the above-ground biomass of catch crops, volunteers and weeds in 2007. In 2007, the highest production of the above-ground phytomass of catch crops (1478–5336 kg ha^{-1}) was determined by contrast to 2005 and 2006 (175–1799 kg ha^{-1} and 104–1808 kg ha^{-1}, respectively). A detailed description of the growth dynamics of catch crops as related to meteorological conditions in this experiment was published by Brant et al. (2009). Based on meteorological characteristics it was evident that the respective years differed namely in soil moisture conditions. The year 2007 differed considerably from the previous years by being rich in precipitation not only before but also after the sowing date of the catch crops (Brant et al., 2009).

Total energy production of catch crops. Average values of total energy production of the above-ground biomass of individual species of catch crops, volunteers and weeds in 2005–2007 are summarized in Table 2. In the un-seeded control, total energy production was 18.19 GJ ha^{-1} and ranged from 24.74 to 57.02 GJ ha^{-1} in the stands of studied catch crops on average of years 2005–2007. Catch crops represented 43–94% of total energy production depending on plant species. The lowest and the highest production in absolute and relative values was found in *L. perenne*, and in *S. alba* and *R. sativus*, respectively. Talgre et al. (2011) informed about the most effective *S. alba* and *R. sativus*, which produced the highest biomass from 9 tested catch crops in 2008–2010, as well. Marcinkevičienė and Bogužas (2011) also obtained the highest dry mass yield of *S. alba* in the autumn (920 kg ha^{-1}) while the yields of *L. multiflorum* and *B. napus* were lower (59.8% and 37.0%, respectively), in the sustainable farming system.

Total energy production of catch crops was lower than values ranging from 100 to 300 GJ ha^{-1}, generally reported for common crops grown on arable land in suitable conditions (Fuksa et al., 2006; Boehmel et al., 2008). However, it could be more similar to values published by Moreno et al. (2011) for the semi-arid area (18–26 GJ ha^{-1}). Slightly higher values were also observed in permanent grassland. Rösch et al. (2009) claimed the energy production of permanent grassland to range from 66 GJ ha^{-1} (low-input grassland) to 119 GJ ha^{-1} (high-input grassland), and Fuksa et al. (2012) published values from 87 to 199 GJ ha^{-1}, depending on the number of cuts and fertilization intensity.

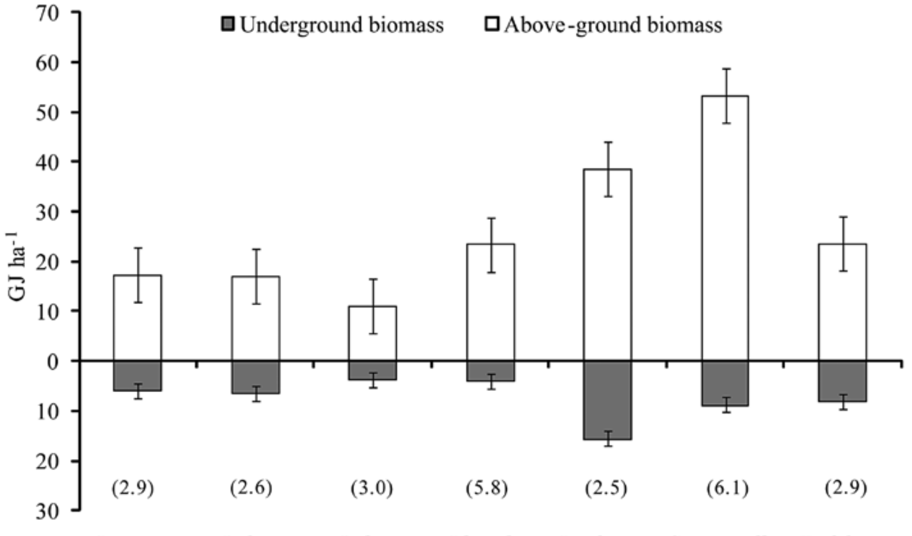
Table 2. Energy production (GJ ha^{-1}) of catch crops, volunteers and weeds (average of years 2005–2007)

Species	Catch crop		Volunteers		Weeds		Total
	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}	%	GJ ha^{-1}
Brassica napus	17.29	70	6.38	26	1.07	4	24.74
Lolium multiflorum	17.12	63	8.90	32	1.40	5	27.42
Lolium perenne	11.09	43	13.07	50	1.78	7	25.94
Phacelia tanacetifolia	23.41	82	4.06	14	1.28	4	28.75
Raphanus sativus	38.56	91	3.36	8	0.26	1	42.19
Sinapis alba	53.75	94	2.58	4	1.09	2	57.02
Trifolium incarnatum	23.96	71	8.60	25	1.22	4	33.78
Trifolium subterraneum	22.27	68	9.23	28	1.21	4	32.71
Un-seeded control	–	–	16.47	91	1.72	9	18.19
P-value	< 0.000		< 0.000		0.006		< 0.000
+/– Limits	8.31		4.51		1.18		9.16

Note. P-value and *+/– Limits* (Tukey test, α = 0.05) express differences among species within each column.

The proportion of volunteers was negatively related to the biomass production of planted catch crops and ranged from 4% to 50%. The highest proportion of volunteers was found in treatments with *L. perenne* and the lowest proportion was in the treatment with *S. alba*. The results document the interspecific competition between volunteers and catch crops. As for energy production, a positive effect of the biomass of volunteers can be seen; however, it is necessary to take into account that their production is lower as compared with that of productive catch crop species (*S. alba* and *R. sativus*). For species of lower growth in the autumn term of sowing (grasses, legumes and *B. napus*), the proportion of volunteers ranged from 25% to 50% and its contribution to energy production was significant. Volunteers have similar functions as catch crops, e.g., sorption of nutrients. Beaudoin et al. (2005) commented that volunteers can take up as much N as catch crops.

The lowest energy production was found in weeds. The value was lower than 2 GJ ha^{-1} in all evaluated treatments. Weeds participated in total energy production by 9% in the un-seeded control and by 1–7% in treatments with catch crops. The low proportion of weeds in the production of biomass and energy could be caused by dormancy of seeds in the autumn period and by the competition between the catch crops and volunteers. Our results support a conception that the planting of catch crops is important for weed control, which is in agreement with the suggestions of Rasmussen et al. (2006) about the connection of catch crops management and weed control under conversion to organic farming. The evaluation of energy production in underground biomass of selected catch crops (Fig.) shows the highest value in *R. sativus* (15.58 GJ ha^{-1}), moderate values in other species from the *Brassicaceae* family, *L. multiflorum* and *T. incarnatum* (5.90–8.79 GJ ha^{-1}), and the significantly lowest values in *L. perenne* (3.68 GJ ha^{-1}) and *P. tanacetifolia* (4.04 GJ ha^{-1}). In the majority of catch crops, the ratio of energy accumulated in above-ground biomass to energy in underground biomass ranged from 2.5 to 3.0. There were



Notes. The ratios of energy accumulated in above-ground to underground biomass are in brackets. Vertical limits indicate standard error of the mean.

Figure. Energy production (GJ ha^{-1}) in the above-ground and underground biomass of selected catch crop species, average of years 2005–2007 only two species (*S. alba* and *P. tanacetifolia*), which exceeded the value of 5. Alluvione et al. (2011) reported values around 2–3 for wheat and soybean, too, with values over 5 being found in maize.

Energy balance of catch crops. From the perspective of total energy balances, it is not only the total production of energy that is significant, but it is also important to consider necessary energy inputs. Börjesson (1996) published the energy production of 106 GJ ha^{-1} in *B. napus* and 130 GJ ha^{-1} in *T. aestivum* (seed/grain and straw) and primary energy inputs amounting to 17.2 and 19.5 GJ ha^{-1}, respectively. Fuksa et al. (2012) set out values of energy inputs in permanent grassland within a range from 1.6 to 3.1 GJ ha^{-1} depending on the number of cuts and from 3.1 to 20.2 GJ ha^{-1} depending on fertilization intensity. In the intensive cropping system, fertilizers may represent up to 78% of total energy inputs (Angelini et al., 2005). As compared with these data, significantly lower values of energy inputs (0.76–1.29 GJ ha^{-1}) were determined in the evaluated catch crops, while in the un-seeded control this value was only 0.30 GJ ha^{-1} (Table 3). Differences in the total additional energy of catch crop stands resulted from different energy contents in seeds and seeding rates at comparable crop management in all experimental years. However, the observed stands showed also lower energy production as already mentioned in the previous part of discussion.

Table 3. Inputs of additional energy (GJ ha^{-1}) calculated in each year (2005–2007) for catch crops and un-seeded control

Species	Seeds			Soil tillage	Seeding	Harrowing	Total
	MJ kg^{-1}	kg ha^{-1}	GJ ha^{-1}	GJ ha^{-1}			
Brassica napus	28.69	10	0.29	0.30	0.13	0.12	0.84
Lolium multiflorum	18.44	40	0.74	0.30	0.13	0.12	1.29
Lolium perenne	18.70	20	0.37	0.30	0.13	0.12	0.92
Phacelia tanacetifolia	20.72	10	0.21	0.30	0.13	0.12	0.76
Raphanus sativus	26.35	25	0.66	0.30	0.13	0.12	1.21
Sinapis alba	24.17	20	0.48	0.30	0.13	0.12	1.03
Trifolium incarnatum	20.54	25	0.51	0.30	0.13	0.12	1.06
Trifolium subterraneum	22.41	30	0.67	0.30	0.13	0.12	1.22
Un-seeded control	–	–	–	0.30	–	–	0.30

On average of three years, all tested catch crops except *B. napus* and *L. perenne* achieved positive energy balance based on energy gain in comparison to un-seeded control; however, significant differences were found among the individual years (Table 4). On average of all treatments, energy gain amounted to 19.28, 16.81 and 57.94 GJ ha^{-1} in 2005, 2006 and 2007, respectively. Calculated relations among these results correspond with the sum of precipitation recorded in the vegetation period of catch crops. A detailed description of precipitation was published by Brant et al. (2009). In 2005 and 2006, the sum of precipitation was 36.2 and 36.4 mm, respectively, from the sowing date of catch crops to the date of biomass sampling. In 2007, the sum of precipitation during the same period was 129.6 mm. In 2007, positive energy balance was found in a majority of tested plant species in optimal moisture conditions. The only species that achieved significantly positive energy balance in all three years was *S. alba*. Effectiveness of the utilization of global radiation and other vegetative factors could play an important role for EUE of individual catch crop species, too (Brant et al., 2011). Positive energy balance of catch crops depended also on the production of un-seeded control in the individual years. Our results show the importance of weather course and year on the utilization of identical energy inputs each year. In spite of relatively low energy inputs in catch crops, a significantly positive balance was found each year only in some species. This is in accordance with the results of Moreno et al. (2011) on reduced effectiveness of energy inputs under arid and semi-arid conditions. In terms of catch crop yield in humid conditions, Masilionytė and Maikštėnienė (2011) determined the weak relationship between biomass production of catch crops and amount of precipitation in range from 159.8 to 256.8 mm during August–October.

Table 4. Energy gain (GJ ha^{-1}) of the above-ground biomass of catch crops and un-seeded control in 2005–2007

Species	Energy gain GJ ha^{-1}			
	2005	2006	2007	2005–2007
Brassica napus	15.47	16.91	39.30	23.90
Lolium multiflorum	16.20	3.98*	58.12*	26.13*
Lolium perenne	15.67	8.39	51.01*	25.02
Phacelia tanacetifolia	19.18*	21.09	43.70	27.99*
Raphanus sativus	28.53*	16.50	77.89*	40.98*
Sinapis alba	35.45*	31.96*	100.57*	55.99*
Trifolium incarnatum	15.95	16.15	66.07*	32.72*
Trifolium subterraneum	18.26*	19.23	56.98*	31.49*
Un-seeded control	8.84	17.11	27.73	17.89
Mean	19.28	16.81	57.94	31.34

* – represents statistical differences as compared with the un-seeded control (Dunnett test, α = 0.05)

Influence of the year is obvious in the evaluation of energy effectiveness, as well (Table 5). These values are directly derived from the values of energy production and input; therefore, statistical significance was not calculated. The highest value was found in the un-seeded control (60.64 GJ GJ^{-1}); the evaluated catch crops ranged from 21.27 to 55.19 GJ GJ^{-1} on the average of years 2005–2007. Higher energy effectiveness was determined only in *S. alba* by contrast to the un-seeded control in 2005 and 2007.

Table 5. Energy effectiveness (GJ GJ^{-1}) of the above-ground biomass of evaluated catch crops and un-seeded control in 2005–2007

Species	Energy effectiveness GJ GJ^{-1}			
	2005	2006	2007	2005–2007
Brassica napus	19.49	21.21	47.96	29.55
Lolium multiflorum	13.58	4.09	46.14	21.27
Lolium perenne	17.96	10.08	56.21	28.08
Phacelia tanacetifolia	26.33	28.85	58.72	37.97
Raphanus sativus	24.60	14.65	65.43	34.89
Sinapis alba	35.31	31.93	98.33	55.19
Trifolium incarnatum	16.00	16.18	63.12	31.77
Trifolium subterraneum	15.94	16.73	47.61	26.76
Un-seeded control	30.47	58.03	93.43	60.64
Mean	22.19	22.42	64.11	36.24

These observed values of catch crops are higher than those published by Hülsbergen et al. (2001) for main crops grown on arable land: for potatoes (4.3 GJ GJ^{-1}), winter barley (9.4 GJ GJ^{-1}), spring barley (9.9 GJ GJ^{-1}), winter wheat (14.4 GJ GJ^{-1}) and sugar beet (11.1 GJ GJ^{-1}). Generally, EUE decreases with the higher intensity of management (Alluvione et al., 2011). Fuksa et al. (2012) found this parameter decreasing from 55.19 to 9.86 GJ GJ^{-1} with the increasing number of cuts and fertilization intensity in permanent grassland. Moreno et al. (2011) determined the system of organic farming (5.36 $GJGJ^{-1}$) about 2.3 times more energy efficient than the conventional or conservation systems (2.35 and 2.38 GJ GJ^{-1}, respectively) under the semi-arid conditions over a 15-year period. The influence of year on energy gain and energy effectiveness objectively shows an important effect of weather course on the annual utilization of identical energy inputs to the system of catch crops management.

Conclusions

1. Energy content of the above-ground biomass of catch crops was significantly influenced by the species and year. The lowest values were found in *Phacelia tanacetifolia* and in species from the *Brassicaceae* family. The highest values were usually recorded in grass species. Lower variability in energy content among the evaluated catch crops was found in underground biomass compared to above-ground biomass.

2. Total energy production and balance of a catch crop stand result from an interaction among the used catch crop species, presence of volunteers and weeds in relation to weather conditions in the particular year. The lowest and highest absolute and relative values of energy production were found in *Lolium perenne*, and in *Sinapis alba* and *Raphanus sativus*, respectively. As a result of very low energy inputs to the growing system, catch crops showed very high values of energy effectiveness.

3. Selection of suitable catch crop species plays a very important role in areas with limited precipitation. Almost all tested species reached positive energy balance in the year with favourable conditions; however, this significantly positive balance across all evaluated years was reached in stands with *S. alba*. As for the other evaluated parameters, the lowest value of additional energy was found in *Phacelia tanacetifolia* and the additional intensive accumulation of energy in underground biomass was recorded in *R. sativus*.

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Tarpinių augalų produkcijos energinis balansas

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Santrauka

Straipsnio tikslas – įvertinti iš tarpinių pasėlių gaunamos energijos kiekį ir efektyvumą regionuose, kur iškrinta ribotas kiekis kritulių. 2005–2007 m. tirti aštuonių rūšių augalai: *Brassica napus*, *Lolium multiflorum*, *Lolium perenne*, *Phacelia tanacetifolia*, *Raphanus sativus* var. *oleiformis*, *Sinapis alba*, *Trifolium incarnatum*, *Trifolium subterraneum* ir nesėtas kontrolinis variantas. Nustatyta tarpinių pasėlių, iš sėklų pabirų išaugusių augalų ir piktžolių biomasės energijos kiekis (MJ kg^{-1}) bei energijos gamyba (GJ ha^{-1}) ir apskaičiuotas energijos balansas (sąnaudos, prieaugis, efektyvumas). Tarpinių augalų antžeminės biomasės energijos kiekiui (15,65–20,21 MJ kg^{-1}) esminės ($P < 0,05$) įtakos turėjo augalo rūšis ir metai. 2005–2007 m. bendros energijos produkcijos gauta vidutiniškai 18,19 GJ ha^{-1} nesėtame kontroliniame variante (piktžolės ir augalai, išaugę iš sėklų pabirų), o pasėliuose su tirtais tarpiniais augalais ji svyravo nuo 24,74 iki 57,02 GJ ha^{-1}. Tarpiniai augalai sudarė 43–94 % bendros energijos produkcijos, priklausomai nuo augalų rūšies. Palyginus su kontroliniu variantu, tirtų tarpinių augalų teigiamam energijos balanso prieaugiui turėjo įtakos metų sąlygos, ypač dirvožemio drėgnis. Visais trimis tyrimų metais teigiamas energijos balansas buvo tik *S. alba* pasėliuose. Mažiausia pridėtinės energijos vertė buvo *P. tanacetifolia* pasėlių, o požeminėje masėje daugiausia energijos sukaupė *R. sativus*.

Reikšminiai žodžiai: augalai, išaugę iš sėklų pabirų, energijos gamyba, piktžolės, tarpinis augalas, šiluminė vertė.