Tomasz PISKIER*, **Leszek MAJCHRZAK****
*Department of Biological Foundations of Agriculture, Koszalin University of Technology, Poland
**Department of Agronomy, Poznań University of Life Sciences, Poland
e-mail: piskier@poczta.onet.pl

ENERGY EFFECTIVENESS OF HYBRID RYE PLOUGHED CULTIVATION TECHNOLOGIES

Summary

The impact of hybrid rye ploughed cultivation technologies on the size and structure of energy inputs and on the value of production energy effectiveness index were studied in a single-factor field experiment. The compared technologies differentiated the size and structure of energy inputs to a minimal extent. Accumulated energy inputs supplied to rye production increased by an average of 18.63 GJ·ha^{-1} and depended mainly on energy input in materials (85%). The most advantageous energy effectiveness index - 4.2 - was recorded when a technology which involved sowing 110 pcs·m^{-2} sprouting caryopses was applied. Delaying sowing by two weeks with respect to the recommended date caused substantial yield decrease which, in turn, caused an energy effectiveness index decrease. The index value in this technology was only 3.01.
Keywords: *cultivation technologies, grain yield, energy effectiveness index, hybrid rye*

EFEKTYWNOŚĆ ENERGETYCZNA ORKOWYCH TECHNOLOGII UPRAWY ŻYTA HYBRYDOWEGO

Streszczenie

W jednoczynnikowym doświadczeniu łanowym porównywano wpływ orkowych technologii uprawy żyta hybrydowego na wielkość i strukturę nakładów energetycznych oraz wartość wskaźnika efektywności energetycznej produkcji. Porównywane technologie w minimalnym stopniu różnicowały wielkość i strukturę nakładów energetycznych. Nakład energii skumulowanej poniesionej na produkcję żyta wyniósł przeciętnie 18,63 GJ·ha^{-1} i zależał w głównej mierze od wartości energii wniesionej w formie materiałów (85%). Najkorzystniejszy wskaźnik efektywności energetycznej uzyskano stosując technologię, w której wysiano 110 szt·m^{-2} kiełkujących ziarniaków, a jego wartość wyniosła 4,2. Opóźnienie wysiewu żyta hybrydowego o dwa tygodnie od zalecanego terminu spowodowało wyraźne zmniejszenie plonu, co spowodowało pogorszenie wskaźnika efektywności energetycznej. Wartość wskaźnika tej technologii wyniosła zaledwie 3,01.
Słowa kluczowe: *technologie uprawy, plon ziarna, wskaźnik efektywności energetycznej, żyto hybrydowe*

1. Introduction

Introducing new varieties of agricultural crops entails the necessity to develop and verify cultivation technologies. Production of the right size and quality of yield is conditioned on synchronising agrotechnical procedures with habitat conditions [8]. Hybrid rye is a species whose economic importance is continuously increasing. This stems mainly from its favourable qualities such as plant height (they are lower than population varieties) and their resistance to lodging [3]. Such qualities make it possible to apply higher rates of fertilizers which have a positive impact on yield [2]. While developing technologies, a lot of attention is also paid to sowing quantity. Rye is characteristic of its strong ability of tillering for production purposes [8]. This is one of the most important features which determines the size of yield. An increase in sowing does not translate directly into an increase in the number of ears per unit area, as the phenomenon of field self-regulation occurs [14, 15]. Another important agrotechnical factor is the time of sowing. It has a decisive impact on the growth, development and, ultimately, also productivity of cereal [5]. In research concerning wheat, delaying sowing by 2 weeks resulted in a decrease of yield by approx. 15%, when the delay was 4 weeks, the decrease exceeded 30% [13].

Assessment of the amount and structure of energy inputs is widely used to compare agricultural production technologies [16, 12, 17]. Comprehensive comparative assessment of the applied technologies which includes both energy inputs and the energy value of yield allows to calculate the energy effectiveness index [4].

2. Objective

The objective of the experiment was to analyse the amount and structure of energy inputs supplied for the cultivation of hybrid rye in production conditions and to define and compare the value of the energy effectiveness index for the cultivation technologies applied.

3. Methods and conditions

The single-factor field experiment was conducted in the years 2010 and 2011 on the Farm Frites farm in Bobrowniki near Słupsk.

On designated areas of 2 ha each, five cultivation technologies of Visello hybrid rye were applied:
1 - recommended technology (control) - caryopsis density 170 pcs·m^{-2}, sowing depth 2 cm, sowing date 15.09,
2 - sparse sowing - caryopsis density 110 pcs·m^{-2}, sowing depth 2 cm, sowing date 15.09,
3 - dense sowing - caryopsis density 250 pcs·m^{-2} , sowing depth 2 cm, sowing date 15.09,
4 - deep sowing - caryopsis density 170 pcs·m^{-2}, sowing depth 5 cm, sowing date 15.09,
5 - delayed sowing - caryopsis density 170 pcs·m^{-2}, sowing depth 2 cm, sowing date 30.09.

Soil conditions on the entire area of the experiment were similar. Soil of loamy sand granulometric composition is included in the IVa class. Winter rye was sown in the second decade of September in the amount of 60 kg·ha^{-1} which corresponded to 174 pcs.·m^{-2} of sprouted seeds. Each year, the forecrop was winter rape, the total amount of mineral fertilisation was 161 kg·ha^{-1} N, 69 kg·ha^{-1} K_2O and 69 kg·ha^{-1} P_2O_5. Pursuant to the recommendations of the Institute of Plant Protection, comprehensive chemical protection and retardants were used.

The Terrano ploughing aggregate, was used for stubble cultivation, the Amazone ZA-M Compact 1750 spreader was used for mineral fertilisation and the Gregoire Besson 9-furrow plough was used for ploughing. These tools were aggregated with the 930 230 kW Fendt Vario tractor. The Rapid RDA 600S seeder was used for sowing and the Lemken 4000 sprinkler was used for the application of plant protection products and foliar fertilisation.

The energy input (E_{tech}) supplied for the production of winter rye was determined with the use of the accumulated energy consumption method [1, 19].

$$E_{tech} = \sum E_{mat} + \sum E_{agr} + \sum E_{pal} + \sum E_r \quad (\text{MJ·ha}^{-1}) \quad (1)$$

Since it was not possible to determine the amount of human labour energy supplied (ΣE_r) in field conditions, this component of accumulated energy was omitted and the following formula proposed by Piskier [11] was adopted.

$$E_{tech} = \sum E_{mat} + \sum E_{agr} + \sum E_{pal} \quad (\text{MJ·ha}^{-1}) \quad (2)$$

where:

ΣE_{mat} – total energy consumption of used materials (MJ·ha^{-1}),

ΣE_{agr} – total energy consumption of aggregates (MJ·ha^{-1}),

ΣE_{pal} – total energy consumption of fuel (MJ·ha^{-1}).

The efficiency of machines was defined by simplified timing and fuel consumption while performing particular procedures was measured by direct measuring. Berofe the start and after on each agrotechnical the tractors were refuel. The amount of fuel added was use as a consumption value of the prefious agrotechnical operation.

Energy supplied in materials was calculated by multiplying the weight of material used during the production and the value of energy included in it, with the following values adopted: seed material 9 MJ·kg^{-1}, nitrogen fertilisers 77 MJ·kg^{-1} N, potassium fertilisers 10 MJ·kg^{-1} K_2O, phosphate fertilisers 15 MJ·kg^{-1} P_2O_5, diesel oil 48 MJ·kg^{-1}, pesticides 300 MJ·kg^{-1}, active substance and rye grain 9 MJ·kg^{-1} [19].

The energy effectiveness index was calculated by dividing the energy value of rye grain yield by the accumulated energy input used for its cultivation and nursing. The size of yield was adopted according to data from the harvester. The calculations did not include energy inputs related to the storage of plants.

4. Results and discussion

The accumulated energy inputs used in the tested technologies of rye production was approx. 18.63 GJ·ha^{-1} and there were no significant differences among the tested technologies (table 1). Minimal differences of ca. 1% occurred only in the case of diversified amount of seeds sown. The structure of energy inputs was almost identical in the tested technologies. The main accumulated energy input was in materials. On average, this stream constituted 84.9% of the accumulated energy intake. In the technology where sparse sowing was used, this value amounted to 84.7%, whereas in the technology with dense sowing - 85.1%. Energy supplied in aggregates and fuel was identical in all of the applied technologies, because the same cultivation and nursing procedures were used in all cases. The value of energy supplied in aggregates was 0.88 GJ·ha^{-1}, which constituted 4.7% of the accumulated energy input, whereas the value of energy supplied in fuel was 1.94 GJ·ha^{-1}, which constituted 10.4% (table 1).

Table 1. The size of accumulated energy inputs supplied in the cultivation of hybrid rye in various cultivation technologies (on average, in the years 2010-2011)

Cultivation technology	Supplied energy [GJ·ha^{-1}]			Accumulated energy input [GJ·ha^{-1}]
	materials	aggregates	fuel	
Recommended	15.81	0.88	1.94	18.63
Sparse sowing	15.63	0.88	1.94	18.45
Dense sowing	16.05	0.88	1.94	18.87
Deep sowing	15.81	0.88	1.94	18.63
Delayed sowing	15.81	0.88	1.94	18.63

Source: Own work

In experiments concerning the size and structure of energy inputs in the production of spring and winter barley performed by Nasalski [9], the results were similar. Accumulated energy input supplied for the production of spring barley was 18.2 GJ·ha^{-1}, whereas in the case of winter barley - 17.7 GJ·ha^{-1}. In both examples referred to above, the energy supplied in materials, which constituted approx. 80% in the case of winter barley and 70% in the case of spring barley, determined the size of energy inputs. In the cited paper (as it is the case with own experiments) the sum of accumulated energy supplied in aggregates and fuel constitutes 16.7% in the case of winter barley. Spring barley required a higher number of mechanical procedures which entailed an increased share of energy inputs in aggregates and fuel. Experiments concerning winter rape [6] confirm that material inputs, which constituted 75%, determined the size of energy inputs supplied for the production of plants. Energy supplied in aggregates and machines in the cultivation of rape constituted only 3.1% and this number is significantly lower than the number obtained in own experiments. A similarly significant difference occurs in the size of energy inputs supplied in fuel. In experiments conducted by Jankowski and Budzyński [6], the participation of that stream constitutes over 20%, whereas in own research, it exceeds 10%. Research on energy effectiveness of winter barley production with the application of diversified rates of nitrogen fertilisation [10] showed similar correlations as in the case of own experiments. This correlation concerned the application of the recommended rate of nitrogen fertilisation. Accumulated energy input was approx. 18 GJ·ha^{-1} and this value to a large extent depended on the value of energy supplied in materials (approx. 82%).

The size of hybrid rye yield in the conducted experiment depended on the technologies used (table 2). The highest grain yield of 86.1 dt·ha^{-1} was achieved with the sowing rate decreased to 110 pcs·m^{-2} (sparse sowing). A similar yield (85.0 dt·ha^{-1}) was achieved when the sowing rate was increased to 250 pcs·m^{-2} (dense sowing). Translated into yield energy value, these values amount to 77.49 GJ·ha^{-1} and 76.50 GJ·ha^{-1} respectively.

Table 2. Energy effectiveness of hybrid rye cultivation (on average in the years 2010, 2011)

Cultivation technology	Grain yield dt·ha^{-1}	Yield energy value GJ·ha^{-1}	Accumulated energy input GJ·ha^{-1}	Energy effectiveness index
Recommended	77.5	69.75	18.63	3.74
Sparse sowing	86.1	77.49	18.45	4.20
Dense sowing	85.0	76.50	18.87	4.05
Deep sowing	80.0	72.00	18.63	3.86
Delayed sowing	62.3	56.07	18.63	3.01

Source: Own work

The application of too deep sowing resulted a grain yield of 80.0 dt·ha^{-1} which corresponds to an energy value of 72.0 GJ·ha^{-1}. Recommended technology (control) in field conditions allowed to achieve a yield of 77.5 dt·ha^{-1} which corresponds to 69.75 GJ·ha^{-1}.

The smallest yield was achieved in standard production technology, but delaying sowing by two weeks (delayed sowing). The size of yield was 62.3 dt·ha^{-1} which corresponds to 56.07 GJ·ha^{-1}.

Accumulated energy inputs did not vary substantially depending on the technology used (table 2). The yield energy value determined differences in terms of the energy effectiveness index. In the recommended rye cultivation method, the energy effectiveness index was 3.74. The most favourable value of the energy effectiveness index was achieved using the technology with reduced number of seeds sown (sparse sowing). It was higher by 12.2% than in the control technology and totalled 4.20. In dense sowing conditions the production energy effectiveness index was 4.05 and in deep sowing conditions - 3.86. The lowest value of the energy effectiveness index was observed in the case of delayed rye sowing. This value was 3.01 and it was lower than in the case of the recommended control technology by almost 20%, while with respect to the most advantageous result (sparse sowing), the difference amounted to 28%.

Many authors point to the right selection of cultivation technology as the factor which determines whether it is successful and effective [7, 18]. Own experiments confirm this correlation. Analyses of energy effectiveness enabled to choose the most advantageous hybrid rye cultivation method in given conditions. The energy effectiveness index depends on many factors, the most complex of which is the value of accumulated energy input,. In barley experiments conducted by Nasalski [9], the energy effectiveness index depended on the plant cultivation method and in the case of winter barley it amounted to 2.94 and in the case of spring barley - 2.37. The difference resulted from an increased number of agrotechnical procedures performed in the production of spring barley. In other experiments concerning the diversification of rates of nitrogen fertilisation [10] the value of the energy effectiveness index was 2.23 - in the case of 90 kg·ha^{-1} nitrogen fertilisation rate. Results of own experiments show that the used technologies of hybrid rye cultivation have a more advantageous energy effectiveness index. This is not conclusive, as Nasalski [10] included also the value of energy input supplied for the harvesting of crops.

5. Conclusions

1. The sum of accumulated energy input supplied for the cultivation of hybrid rye is approx. 18.63 GJ·ha^{-1} and is to a small extent differentiated by the technologies used.
2. Irrespective of the rye cultivation technology used, energy inputs in materials, which constitute 85% of accumulated energy inputs, determine the size of energy inputs.
3. The most advantageous hybrid rye cultivation method in test conditions is the technology in which the amount of seeds sown was reduced to 110 pcs·m^{-2}. Its energy effectiveness index was 4.20.

6. References

[1] Anuszewski R., Pawlak J., Wójcicki Z.: Energochłonność produkcji rolniczej. Metodyka badań energochłonności produkcji surowców żywnościowych. IBMER Warszawa, 1979.

[2] Bujak H., Dopierała A., Dopierała P., Kaczmarek J.: Ocena wartości hodowlanej linii mieszańców żyta ozimego. Biuletyn IHAR, 2003, 230: 243-253.

[3] Dopierała P., Bujak H., Kaczmarek J., Dopierała A.: Biuletyn IHAR, 2003, 230: 235-242.

[4] Dzienia S., Pużyński S., Wereszczaka J.: Reakcja pszenicy ozimej na zmniejszenie intensywności uprawy roli. Journal of Research and Applications in Agricultural Engineering, 2003, vol. 48(3): 28-32.

[5] Grabiński J., Jaśkiewicz B., Podolska G., Sułek A.: Terminy siewu w uprawie zbóż. Studia i Raporty INNG-PIB, 2007, 9: 37-45.

[6] Jankowski K., Budzyński W.: Energy potential of oilseed crops. Electronic Journal of Polish Agricultural Universities, 2003, vol. 6(2), Series Agronomy. http://www.ejpau.media.pl /volume6/issue2/ agronomy/art-03.html.

[7] Klepacki B.: Organizacyjne i ekonomiczne uwarunkowania postępu technologicznego w gospodarstwach indywidualnych. Wyd. SGGW, Warszawa 1990.

[8] Leszczyńska D., Noworolnik K., Grabiński J., Jaśkiewicz B.: Ilość wysiewu nasion jako czynnik kształtujący plon ziarna zbóż. Studia i Raporty INNG-PIB, 2007, 9: 17-28.

[9] Nasalski Z., Sadowski T., Rychnicki B., Rzeszutek I.: Porównanie uprawy jęczmienia ozimego i jarego w stanowisku po ziemniaku. Acta Scientarum Polonorum, Agricultura, 2004a, 3(1): 99-106.

[10] Nasalski Z., Sadowski T., Stępień A.: Produkcyjna, ekonomiczna i energetyczna efektywność produkcji jęczmienia ozimego przy różnych poziomach nawożenia azotem. Acta Scientiarum Polonorum, Agricultura, 2004b, 3(1): 83-90.

[11] Piskier T.: Efektywność energetyczna produkcji biomasy w teorii i praktyce. Technika Rolnicza Ogrodnicza Leśna, 2011, 3: 5-7.

[12] Piskier T., Majchrzak L.: Wielkość i struktura nakładów energetycznych bezorkowej i orkowej uprawy żyta hybrydowego. Inżynieria Rolnicza, 2013, 3(146), T.2: 295-300.

[13] Podolska G.: Reakcja odmian i rodów pszenicy ozimej na wybrane czynniki agrotechniczne. Cz. II. Wpływ terminu siewu na plon i strukturę plonu nowych odmian i rodów pszenicy ozimej. Biul. IHAR, 1997, 204: 163-168.

[14] Ruszkowski M.: Produkcyjność roślin zbożowych. Mat. sesji nauk. „Podstawy produkcyjności roślin". IUNG Puławy, 1985: 71-92.

[15] Ruszkowski M.: Obsada a produktywność roślin zbożowych. Mat. konf. nauk. „Obsada a produktywność roślin uprawnych". IUNG Puławy, 1988, cz. I.

[16] Starczewski J., Dopka D., Korsak-Adamowicz M.: Ocena energetycznej efektywności wybranych technologii uprawy żyta jarego. Acta Agrophysica, 2008, 11(3): 733-739.

[17] Szempliński W., Kisiel R., Budzyński W.: Porównanie rolniczej, energetycznej i ekonomicznej efektywności różnych sposobów produkcji ziarna jęczmienia jarego. Rocz. AR w Poznaniu, Rolnictwo, 1998, 52: 25-32.

[18] Szwejkowska B., Bielski S.: Ocena energetyczna produkcji nasion soczewicy jadalnej (Lenus culinaris Medic.). Annales UMCS, Lublin-Polonia, 2012, vol. LXVII (3), Sectio E: 54-60.

[19] Wójcicki Z.: Wyposażenie i nakłady materiałowo energetyczne w rozwojowych gospodarstwach rolniczych. IBMER Warszawa. ISBN, 2002, 83-86264-62-4.