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EFFECTS OF COVER CROP AND WEED CONTROL METHOD ON YIELD AND ENERGY EFFICIENCY OF WHEAT

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ABSTRACT

A field experiment on growing spring wheat on rendzina soil was conducted in the central-eastern part of Poland during the period 2009-2011. The study included two factors: 3 types of stubble crop (white mustard, lacy phacelia, and a mixture of legumes - narrow-leaf lupine with field pea) and 3 weed control methods in wheat (mechanical, combined mechanical and chemical, chemical). Grain yield and energy efficiency of wheat production were evaluated. The study found that the legume mixture stubble crop resulted in the highest increase in grain yield (on average by 9.2%) compared to the control treatment. On the other hand, mechanical-chemical and chemical weed control contributed to higher wheat yields by 13.2 and 9.8%, respectively, relative to the mechanical treatments. The highest energy efficiency of wheat grain production was obtained in the treatment without stubble crop (control), whereas stubble cropping reduced this efficiency by 7-10%. In the structure of energy inputs, mineral fertilizers (on average 37%) and fuel (31%) were predominant.

Key words: energy inputs, in-crop weed control, cover crops, monoculture, spring wheat.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is among the oldest and most extensively grown of all crops throughout the world (Shahin et al., 2008). Over the last 10 years, cereals have dominated in the crop structure in Poland (accounting on average for about 74%), while in non-livestock farms the percentage of this group of crops exceeds even 90% of the arable land area. In this situation, cereals are often grown after each other, that is, they are grown in monoculture, both cereals monoculture (with various cereal species grown) and single-species monoculture. On better soils, spring wheat is also grown in cereals monoculture alongside winter wheat. Such a crop production system in arable land leads to reduced yields, which is primarily caused by the increased occurrence of agricultural pests (weeds, diseases, pests) and by soil fertility degradation.

In the case of continuous cereal cropping, field regeneration factors are sought (Kotwica, 2008). A great importance is therefore attributed to cover cropping, since cover crops perform phytosanitary functions, enrich the soil with nutrients and organic matter, and stimulate its biological activity (Harasimowicz-Hermann and Hermann, 2006; Weber et al., 2012; Doneda et al., 2012). To significantly reduce weed in cereals can help correct agro-technology, taking into account the different methods of taking care of crops (Kierzek and Wachowiak, 2004; Dubis, 2012; Buczek et al., 2013).

Evaluation of the effectiveness of these factors, in addition to evaluation of their effect on crop yields, should be an important element in considering the use of stubble cropping and weed control in cereal crops (Kiani and Houshyar, 2012). Analysis of energy efficiency gives the possibility to obtain comparable results, regardless of the time of research and price relations. The inputs such as fuel, electricity, machinery, seeds, fertilizers, and chemicals significantly consume energy supplies in the production system of modern agriculture (Hatirli et al., 2006; Yadav and Khandelwal, 2013). Efficient use of energy helps to achieve increased production and productivity and contributes to the economy, profitability, and competitiveness of agricultural sustainability of rural communities (Singh et al., 2002; Sahabi et al., 2013). Research on energy efficiency of cover cropping and weed control in cereal crops has

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been undertaken sporadically (Jaskulski and Jaskulska, 2004; Piskier, 2008; Harasim and Gawęda, 2010).

The aim of the present study was to evaluate the effects of stubble cropping and weed control in spring wheat crops on grain yield and energy efficiency of spring wheat production.

MATERIAL AND METHODS

A field study was conducted in the central-eastern part of Poland (51°18'N, 23°36'E) during the period 2009-2011. The experiment was established on rendzina soil with an alkaline pH (pH in 1 M KCl – 7.5), characterized by very high availability of phosphorus (141.8 mg P kg^{-1} soil) and potassium (19.0 mg K kg^{-1} soil). The soil humus content was 1.7%.

The experiment was set up as a split-plot design in three replicates. The harvested plot area was 24.0 m^2. Spring common wheat (cv. 'Bombona') was grown in a 3-year cereals monoculture – in 2005 after spring barley, whereas in 2010 and 2011 wheat was grown after wheat. The study included two factors: I – types of stubble (cover) crop: A – control treatment (without stubble crop), B – white mustard (at a seeding rate of 15 kg ha^{-1}), C – lacy phacelia (10 kg ha^{-1}), D – a mixture of legumes (narrow-leaf lupine - 100 kg ha^{-1}, with field pea - 100 kg ha^{-1}); II – in-crop weed control methods: M - mechanical (harrowing twice – at the cracking stage (BBCH 21) and at the 3-4 leaf stage (BBCH) of wheat, M-Ch - mechanical-chemical weed control (harrowing at the 3-4 leaf stage (BBCH) and spraying with a mixture of herbicides (Chwastox Turbo 340 SL (a.i. MCPA + dicamba) at a rate of 2.0 dm^3 ha^{-1} + Puma Universal 069 EW (a.i. fenoxaprop-P-ethyl) at a rate of 1.2 dm^3 ha^{-1}), and Ch - chemical weed control (herbicide application as in the treatment with combined mechanical and chemical weed control).

Mineral fertilization was applied at the following rates: 70 kg N, 26 kg P, and 33 kg K ha^{-1}. The stubble crops were sown in the second 10-day period of August and ploughed under in autumn in the third 10-day period of October during autumn ploughing. Spring wheat was sown in the first 10-day period of April at a rate of 220 kg ha^{-1}.

The analysis of energy efficiency was performed following the method recommended by the FAO, according to which the yield energy value is determined by assuming that 1 kg of grain dry matter corresponds to 18.36 MJ (Wielicki, 1990). The evaluation included the grain yields from the period 2009-2011 which were converted to dry matter and then to MJ. The value of energy inputs accumulated in production means was determined based on the actual use of fertilizers, seeds, and crop protection agents. The labour and machinery inputs, on the other hand, were determined by the technological method based on the type of treatments and machines employed, using the "Catalogue of norms and standards" (1999). The inputs related to the use of energy carriers, labour, investment expenditure, and materials were converted into MJ, applying the energy consumption indicators used in cost-benefit analysis of energy efficiency (Anuszewski, 1987). These calculations were made following the methodology given in the paper by Harasim (2006). The energy efficiency index (Ee) was calculated according to the following formula: Ee = Pe/Ne, where Pe – means the yield energy value per 1 ha and Ne – energy inputs made to obtain such yield.

RESULTS AND DISCUSSION

The statistical analysis showed that both experimental factors had a significant effect on the variation in spring wheat grain yield (Table 1). However, the interaction between stubble crop and weed control method was not proven. Regardless of the weed control method, the highest grain yield was obtained in treatment D where the legume mixture (narrow-leaf lupine with field pea) was the stubble crop. In control treatment A (without stubble crop) and after the white mustard and lacy phacelia stubble crops (B, C), the grain yields were similar and significantly lower (by 5.4-8.4%) than the yield obtained after the legume mixture. An earlier study (Harasim and Gawęda, 2010) did not find stubble crops to significantly affect spring wheat yield; this research only found an increasing trend in the yield compared to the productivity achieved in the control treatment without stubble crop. The results of other authors' studies (Kuś and Jończyk, 2000; Cutforth, 2013) showed that the production effects of stubble cropping vary depending on habitat and weather conditions.

Wheat grain yield was dependent on in-crop weed control method (Table 1). Significantly higher yields were obtained when mechanical-chemical and chemical weed control was used (by 13.2 and 9.8%, respectively) than under the conditions of mechanical weed control. A similar result was obtained by Głowacka (2009), since the increase in grain yield obtained from the spring wheat crops with mechanical-chemical and chemical weed control was 9.8 and 11.5%, respectively, compared to the mechanical weed control treatment.

Table 1 The grain yield of spring wheat (t ha^{-1}) depending on the stubble crop and weed control methods (mean of years 2009-2011)

Stubble crop*	Weed control methods**			
	M	M-Ch	Ch	Mean
A	4.00	4.43	4.28	4.24
B	4.13	4.38	4.48	4.33
C	3.96	4.68	4.51	4.38
D	4.25	5.00	4.65	4.63
Mean	4.08	4.62	4.48	4.39

$LSD_{0,05}$:
stubble crops: 0.245
weed control methods: 0.193
stubble crop × weed control method – n.s.

*A – control treatment (without stubble crop);
B – white mustard, C – lacy phacelia;
D – narrow-leaf lupin with field pea
n.s. – no significant difference **M – mechanical;
M-Ch – mechanical-chemical; Ch – chemical.

The differences in yield energy values were similar as in the case of the grain yield (Table 2), which does not require the relationships found to be analysed again.

Table 2. Energy values of spring wheat grain (GJ ha^{-1})

Stubble crop*	Weed control methods**			
	M	M-Ch	Ch	Mean
A	62.4	69.1	66.8	66.1
B	64.5	68.4	69.9	67.6
C	61.8	73.0	70.4	68.4
D	66.3	78.0	72.6	72.3
Mean	63.8	72.1	69.9	68.6

*Explanations as in Table 1.

The energy inputs, which included labour and the use of seeds, mineral fertilizers, crop protection agents, fuel as well as tractors and machines, were more dependent on the use of stubble cropping than on in-crop weed control method (Table 3). Stubble cropping resulted in an increase in inputs by 1.8-3.4 GJ ha^{-1} compared to their level in the control treatment (without stubble crop). The highest inputs (on average 19.5 GJ ha^{-1}) were made to grow wheat after the legume mixture, which was significantly associated with the seeding rate of this cover crop. On the other hand, the weed control methods resulted in small differences in the value of energy inputs (about 0.7 GJ ha^{-1}). The energy inputs for wheat production in the treatments with mechanical-chemical and chemical weed control were at a similar level (Table 3). Głowacka (2009) also obtained very similar results concerning the effect of weed control in wheat crops on energy inputs.

Table 3. The energy inputs incurred on production of spring wheat (GJ ha^{-1})

Stubble crop*	Weed control methods**			
	M	M-Ch	Ch	Mean
A	15.7	16.4	16.3	16.1
B	17.5	18.2	18.2	18.0
C	17.4	18.3	18.1	17.9
D	18.9	19.9	19.7	19.5
Mean	17.4	18.2	18.1	17.9

*Explanations as in Table 1.

Mineral fertilizers (accounting on average for about 37%) and fuel (31%) were the dominant items in the structure of energy inputs (Table 4). The energy inputs associated with plant protection agents had the lowest percentage (about 4%). Stubble cropping using the legume mixture (narrow-leaf lupin with field pea) contributed to an increase in the percentage of seed-related energy inputs (up to 16%). The structure of energy inputs for spring wheat production was similar to an earlier study (Harasim and Gawęda, 2010). The study of Shahin et al. (2008), Khan et al. (2010), Dubis (2012) and Yadav and Khandelwal (2013) also demonstrated that mineral fertilization, particularly with nitrogen, belongs to the most energy-consuming components of spring and winter wheat as well as barley production technology. In the case of mechanical weed control in the wheat crop, on the other hand, the percentage of crop protection agents in the energy inputs was low (2%). Głowacka (2009) found similar relationships in the structure of energy inputs; in her research, the percentage proportion of mechanical weed control was 2.4%.

Table 4. The structure of energy inputs (%)

Type of energy input	Stubble crop				Weed control methods**			
	A	B	C	D	M	M-Ch	Ch	Mean
Human labour	5.9	6.6	6.6	6.2	6.4	6.3	6.3	6.3
Seeds	10.2	10.0	9.8	16.1	12.0	11.5	11.5	11.7
Mineral fertilizers	41.1	36.9	36.9	34.0	38.2	36.4	36.7	37.1
Plant protection agents	4.1	3.7	3.7	3.4	2.0	4.4	4.5	3.7
Fuel	29.0	32.6	32.7	30.6	31.5	31.3	31.1	31.3
Tractors and machines	9.7	10.2	10.3	9.7	9.9	10.1	9.9	9.9
All inputs	100	100	100	100	100	100	100	100

*Explanations as in Table 1.

The energy efficiency index was more dependent on the use of stubble cropping than on the use of weed control in the wheat crops (Table 5). The highest energy efficiency was found in the control treatment (without stubble crop) for all weed control methods. The investigated stubble crops reduced the energy efficiency of spring wheat production at a similar level (7-10%). But the mechanical-chemical and chemical weed control methods were more efficient (by 10 and 5%, respectively) than mechanical weed control, which was associated with the higher grain yields obtained under these systems (Table 1). The lower efficiency of the treatments with stubble crops was more determined by the relatively higher energy inputs (Table 3) than by the increase in grain yield (Table 1). Likewise, the research of Piskier (2008) found higher energy efficiency of spring wheat production where chemical weed control was used, compared to mechanical weed control, primarily due to the higher grain yield. The ecological impact of cover cropping on the environment can also be included in its beneficial effects (Kuś and Jończyk, 2000; Harasimowicz-Hermann and Hermann, 2006; Kassam et al., 2013), but it is difficult to estimate this impact in cost-benefit analysis of energy inputs.

Under average farming conditions, about 4 energy units in the primary yield per 1 unit of energy input should be obtained in plant production. In the case of the present authors' own research, this requirement was fulfilled in the production of spring wheat in a 3-year monoculture without stubble crop, but with mechanical-chemical or chemical weed control (Table 5). From the point of view of energy efficiency, the use of stubble cropping and a selected in-crop weed control method is justified in the case when the increase in yield exceeds, in energy terms, the inputs for plant production.

Table 5. The energy efficiency index of spring wheat production

Stubble crop*	Weed control methods**			
	M	M-Ch	Ch	Mean
A	3.97	4.21	4.10	4.11
B	3.69	3.76	3.84	3.76
C	3.55	3.99	3.89	3.82
D	3.51	3.92	3.69	3.71
Mean	3.67	3.96	3.86	3.83

*Explanations as in Table 1.

CONCLUSION

Stubble cropping generally caused an increase in spring wheat grain yield. Compared to the control treatment, the legume mixture stubble crop resulted in the highest increase in grain yield (on average by 9.2%).

The energy efficiency index of wheat production was more determined by the use of stubble cropping than by weed control method used in wheat crops.

Stubble cropping reduced the energy efficiency of spring wheat production, whereas the use of mechanical-chemical or chemical weed control increased it.

Monoculture cropping without stubble crops, but with mechanical-chemical weed control in wheat crops, was characterized by the highest energy efficiency.

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