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EFFECT OF COVER CROPS AND DIFFERENT DOSES OF HERBICIDES ON THE YIELD AND QUALITY OF SOYBEAN GROWN IN DIRECT SOWING

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ABSTRACT

Soybeans serve as one of the most valuable crops in many countries, including Poland, due to the high nutritional value of its seeds, its resistance to diseases and pests. Under the climatic conditions of Poland, soybean yield is largely dependent on weather conditions in a particular growing season, primarily temperature and rainfall. The aim of this study was to evaluate the effect of cover crops (winter rye, winter oilseed rape, and white mustard), mulching method (aboveground biomass mulching after mowing or desiccation) and reduced herbicide rates (down to 75 and 50% of the recommended rate) on soybean seed quality and yield. The present study showed that the weather conditions in the particular study seasons and mulching treatments caused the greatest variation in soybean seed yield and its quality. The highest yield was obtained from control treatments, desiccated winter rye and white mustard. The applied herbicide rates did not cause variations in seed yield and yield component traits. The protein and oil content was affected by the type of the mulch plant used. Mulch with rye and winter rape favors increased protein content, while more oil seed were accumulating after the white mustard and both mulch forms of rape.

Key words: soybean yielding, mulching, reduced doses of herbicides, protein and crude oil content

INTRODUCTION

Soybean is one of the most valuable crop plants, with particularly high commercial qualities. Consumption of soy foods is increasing worldwide mainly due to their acclaimed health benefits. Proteins and lipids, some vitamins and minerals such as K, Ca, Zn, Fe, B, and P, are major nutritionally-important components of soybeans; carbohydrates are major constituents quantitatively. Soy foods are also good sources of dietary fibre, B-vitamins, calcium, and omega-3 essential fatty acids [Lokuruka 2010, Bellalou 2015]. It yields well in Poland and, as a leguminous plant, is a desired component of crop rotation, especially in crop rotations with a high frequency of cereals. The interest in soybean cultivation is becoming ever wider due to the possibility of growing it under no-tillage, which has a beneficial effect on soil properties, and obtaining plant material that compensates the deficiency of complete proteins.

Progress in the introduction of no-tillage is associated with the invention of more efficient herbicides which, if used competently, allow weed infestation to be reduced, even in the case of long-term use of this tillage technology [Owen 2000, Vitta et al. 2004]. The interest in no-tillage is also related to the possibility of shortening the time of field preparation for sowing and reducing energy consumption and costs

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of production [Yalcin and Cakir 2006]. Nevertheless, the results of studies [Małecka and Blecharczyk 2002, Wilkins et al. 2002, Pederson and Lauer 2003, Małecka et al. 2004, Temperly and Borges 2006] are evidence of varying (frequently reduced) yields of this crop under no-tillage conditions compared to the quantity of yield obtained in the conventional tillage system. Kuś [1999], on the other hand, claims that extreme reduced tillage practices need not lead to reduced crop yields. Other researchers express similar opinions, justifying this by using appropriately selected chemical or mechanical crop protection [Sanyal and Shrestha 2008] or a proper previous crop [Onwualu and Ahaneku 2001, Blecharczyk et al. 2006, Fecak et al. 2010], and also by higher nitrogen fertilization and more favorable hydrothermal conditions during the growing season [Weber 2004, Pabin et al. 2006].

The aim of this study was to evaluate the effect of cover crops (winter rye, winter oilseed rape, and white mustard), mulching method (aboveground biomass mulching after mowing or desiccation) and reduced herbicide rates (down to 75 and 50% of the recommended rate) on soybean seed quality and yield.

MATERIALS AND METHODS

Experimental Field

In the period 2006–2009, a controlled field study was conducted at the Czesławice Experimental Farm (51°30'N; 22°26'E), belonging to the University of Life Sciences in Lublin, Poland. This region is characterized by a moderate continental climate. It was located on grey-brown podzolic soil (sandy), designated as PWsp – Haplic luvisol (Dystric Siltic), with the granulometric composition of silt (34% of fine particles). The soil contained 15.0 g kg^{-1} of humus as well as 14.6 mg P 100 g^{-1} soil, 28.1 mg K 100 g^{-1} soil, and 5.3 mg Mg 100 g^{-1} soil, whereas the pH (in 1 mole dm^{-3} KCl) was 5.6. The experiment was set up as a split-plot design in three replicates; the sowing plot area was 33.6 m^{-2}. The harvested plot area was 15 m^2. Experimental factors: I. Cover crop species and mulching procedures: A – control treatment without mulch (conventional tillage); B – mowed winter rye; C – desiccated winter rye; D – mowed winter oilseed rape; E – desiccated winter oilseed rape; F – desiccated white mustard; II. Rates of a foliar-applied herbicide – Basagran 600 SL (a.i. bentazon 600 g l^{-1}): A. 100% rate (2.0 l ha^{-1}); B. 75% rate (1.5 l ha^{-1}); C. 50% rate (1.0 l ha^{-1}).

In all treatments, the herbicide was applied at the 3–4 true leaf stage of soybean. Winter wheat was the previous crop for the cover crops, while the pre-previous crop was sugar beet grown using only mineral fertilizers. Tillage: pre-sowing ploughing to a depth of 22 cm and harrowing for cover crops were done in autumn; 26.2 kg P and 99.6 kg K per hectare were applied at the time of ploughing, while 25 kg N (1/2 of the planned rate) was applied right before sowing. In the control treatment, the same P and K fertilization was used during autumn ploughing. Cover crops were sown at a higher rate – winter oilseed rape cv. 'California' at an amount of 180 seeds per 1 m^2 (8 kg ha^{-1}), winter rye cv. 'Dańkowskie Złote' – 400 seeds per 1 m^2 (150 kg ha^{-1}), and white mustard cv. 'Polka' at an amount of 200 seeds per 1 m^2 (40 kg ha^{-1}). Winter oilseed rape and white mustard were sown 28–29 of September, whereas winter rye 15–21 of September. Soybean was harvested 18.09.2007, 4.09.2008 and 16.09.2009 accordingly.

In spring, at the beginning of plant growth, the second half of the N dose (25 kg ha^{-1}) was applied in the rye and oilseed rape crops, whereas in the control treatment the full rate of N (50 kg ha^{-1}) and in the plot after white mustard ½ of the rate; they were applied on the day of soybean sowing not to stimulate the growth of weeds in autumn and early spring.

In the control treatment, right after the soybean was sown, the following mixture of herbicides was soil-applied: Afalon Dyspersyjny 450 EC at a rate of 1 l ha^{-1} (a.i. linuron 450 g l^{-1}) + Sencor 70 WG at a rate of 0.3 kg ha^{-1} (a.i. metribuzin 70%).

Before sowing, seeds of soybean cv. 'Aldana' were dressed with Funaben T 480 SL (a.i. 332 g of thiuram and 148 g of carbendazim in kg of the seed dressing) at an amount of 200 g per 100 kg of seeds, while after two days the seeds were inoculated with two bacterial strains of *Bradyrhizobium japonicum* and *Rhizobium leguminosarum*.

The soybean was sown at the turn of April and May at a density of 100 full-value seeds per 1 m^2, a row spacing of 21 cm, and a depth of 4 cm, using Väderstad's Carrier Drill CRD 300 (equipped with disks to cut straw and crop residue).

Desiccation of the winter rye and oilseed rape crops was carried out about 14 days before soybea sowing, using the herbicide Roundup Energy 450 SL at a rate of 2.0 dm^3 ha^{-1} (a.i. glyphosate (N-(phosphonomethyl) glycine) 450 g dm^3 of the herbicide). The rye and oilseed rape crops were mowed with a mower-shredder about 3–4 days before soybean sowing and the obtained plant material was evenly distributed over the en btire surface of the plot. The herbicide was used at the planned rates in the soybean crop at the 2–3 true leaf stage (V2/V3--two/three sets of unfolded trifoliolate leaves) [Fehr and Caviness 1980]. The following traits were investigated: yield of seed (t ha^{-1}), weight of 1000 seeds (g), number of pods per plant (pcs.), number of seeds in pod (pcs.), the length of pod (cm), plant stand before harvest per 1 m^2, total protein content (%), crude oil content (%). The content of protein, oil and fiber in soybean seed was determined at the Department of Agricultural Ecology of the University of Life Sciences in Lublin on an Omega Analyzer G spectrophotometer.

Statistical Analysis

The study results were statistically analyzed by analysis of variance (ANOVA), while the differences between means were estimated by Tukeys HSD test at a significance level P = 0.05.

Weather conditions at the study site

In the first year of the experiment (2007), the mean air temperature in particular months of the growing season was higher than the long-term mean (fig. 1). Except for June and September, these months were characterized by lower total rainfall than the long-term mean (fig. 2). In June the amount of rainfall was higher by 19.4 mm, while in September by 53.5 mm. In the second year of the study (2008), May was cold (average temperature 12.5°C) and wet (103.8 mm) and this did not promote soybean growth and delayed its emergence. On the other hand, the summer during this growing season was warm and dry. The year 2009 proved to be favorable for soybean development in terms of thermal conditions. In particular months of the growing season, the recorded temperatures were generally higher than or similar to the long-term mean (May, July). Lower than average rainfall was recorded in the initial period of soybean growth (April) as well as during maturation and harvest (July, August, September).

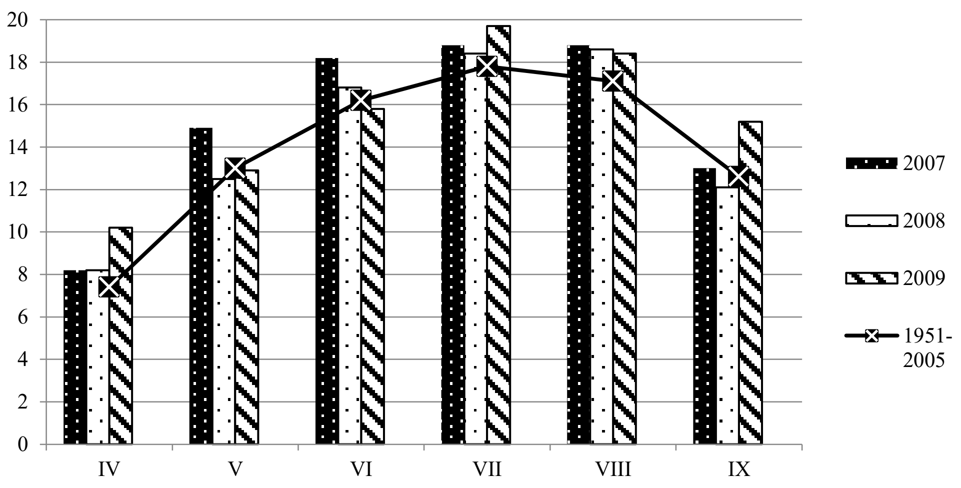

Fig. 1. Mean monthly air temperature (°C) at the Czesławice Meteorological Station in 2007–2009

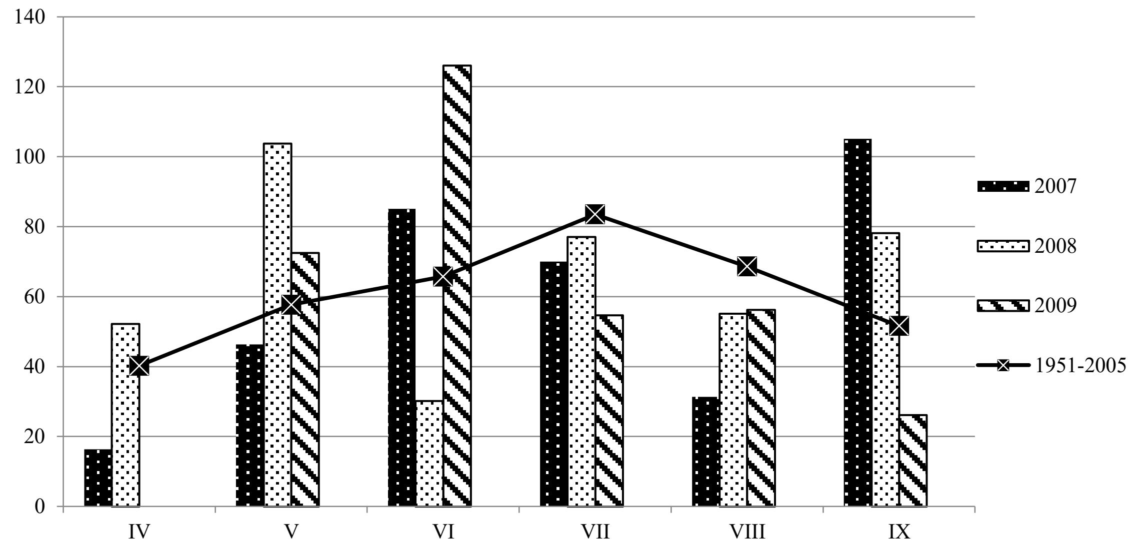

Fig. 2. Total rainfall and rainfall distribution (mm) at the Czesławice Meteorological Station in 2007–2009

RESULTS AND DISCUSSION

Seed yield

The weather conditions in the particular study seasons caused significant differences in soybean seed yield. Significantly the highest seed yield (2.11 t ha^{-1}) was obtained in the first year of the study, while the yield in 2008 and 2009 was lower by respectively 28.9 and 18.5% (tab. 1). Taking into account the mulching treatments, a significantly higher seed yield was found in the plots without mulch (A), after desiccated winter rye (C) and after white mustard (F) compared to treatments B, D and E (on average by more than 40%). Impact of mulch plants on yield was as follows: after white mustard (2.32 t ha^{-1}) was obtained, after rye – on average 1.72 t ha^{-1}, and after oilseed rape – on average 1.22 t ha^{-1}. Analyzing the mulching method used in spring, desiccation had a more beneficial effect on soybean seed yield than mowing – both in the case of rye and oilseed rape. The interaction between years and mulching treatments showed that in 2007 a higher yield was obtained from treatments A, C and F, in 2008 from treatment F, while in 2009 from treatments A and F compared to treatments B, D and E. No statistically significant differences were found in the soybean yield depending on herbicide rate. Only a declining trend in yield was observed with decreasing herbicide rate.

The researchers who used no-tillage in growing soybean [Bujak et al. 2001, 2004, Barzali et al. 2003] found a decrease in yield compared to conventional tillage. Similar results were obtained by Gawęda and Szymankiewicz [2007] under no-till conditions in which they obtained a 19% lower soybean seed yield than under plough tillage. Using rye and winter vetch mulching, Uchino et al. [2009] proved a 7–29% decrease in soybean seed yield compared to conventional tillage. However, Gallaher et al. [1977] drew attention to the possibility that an increase in yield can be obtained by using a proper mulching practice. The soybean seed yield was found to be higher by 30 to 46% when this crop was sown directly in mulch from winter rye killed with herbicides 10 days before sowing compared to sowing soybean in rye stubble after harvest of the rye crop for silage. It is known from the domestic literature [Skrzypczak et al. 1999] that also in the case of maize, grown for green fodder as the main crop, better efficacy of desiccation two weeks prior to sowing was confirmed relative to desiccation done immediately before sowing. In the study by Bełkot and Pięta [2005], the highest soybean yield was obtained from plots where winter wheat was grown as a catch crop. Additionally, the number of healthy soybean seedlings and plants at anthesis were highest in plots after winter wheat and rye cultivation.

Table 1. Yield of seed (t ha^{-1})

Cover crop species	Herbicide doses (%)			Mean for years			Mean
	50	75	100	2007	2008	2009	
A*	2.72	2.30	2.36	2.83	1.81	2.73	2.46
B	1.32	1.54	1.46	2.09	1.36	0.87	1.44
C	2.00	1.94	2.07	2.26	1.80	1.94	2.00
D	0.89	1.23	1.04	1.44	0.86	0.86	1.05
E	1.25	1.43	1.50	1.64	0.94	1.60	1.39
F	2.13	2.17	2.67	2.39	2.24	2.34	2.32
Mean	1.72	1.77	1.85	2.11	1.50	1.72	

LSD$_{(0.05)}$ for:
years of study – 0.201
mulching procedures – 0.475
herbicide doses – n.s.
years × cover crop species – 0.799

A* – control, B – mowed winter rye, C – desiccated winter rye, D – mowed winter oilseed rape, E – desiccated winter oilseed rape, F – desiccated white mustard, n.s. – not significant

Table 2. Weight of 1000 seeds (g)

Cover crop species	Herbicide doses (%)			Mean for years			Mean
	50	75	100	2007	2008	2009	
A*	169.2	165.1	167.5	179.7	148.7	173.3	167.2
B	181.4	178.1	183.4	179.8	169.9	193.3	181.0
C	173.8	172.9	172.8	173.1	169.5	176.9	173.2
D	180.9	189.1	185.2	197.6	160.9	196.8	185.1
E	171.8	174.3	176.5	178.9	166.5	177.3	174.2
F	183.3	181.1	180.6	180.4	187.2	177.4	181.7
Mean	176.7	176.8	177.7	181.6	167.1	182.5	

LSD$_{(0.05)}$ for:
years of study – 4.45
mulching procedures – 7.68
herbicide doses – n.s.
years × cover crop species – 16.35

Explanation as in Table 1

Table 3. Number of pods per plant (pcs.)

Cover crop species	Herbicide doses (%)			Mean for years			Mean
	50	75	100	2007	2008	2009	
A*	14.6	12.8	13.0	8.5	16.2	15.7	13.5
B	8.2	10.2	9.0	10.1	6.0	11.2	9.1
C	11.6	11.3	12.2	12.2	6.6	16.3	11.7
D	8.5	8.9	6.7	6.9	4.5	12.8	8.1
E	10.6	13.0	11.7	15.9	5.1	14.3	11.8
F	10.5	9.7	11.4	8.3	7.7	15.6	10.5
Mean	10.7	11.0	10.7	10.3	7.7	14.3	

$LSD_{(0.05)}$ for:
years of study – 1.23
mulching procedures – 2.10
herbicide doses – n.s.
years × cover crop species – 4.41

Explanation as in Table 1

Table 4. Number of seeds in pod (pcs.)

Cover crop species	Herbicide doses (%)			Mean for years			Mean
	50	75	100	2007	2008	2009	
A	2.04	2.14	2.36	1.97	2.25	2.00	2.07
B	2.06	2.06	2.09	1.90	2.22	2.09	2.07
C	2.14	2.10	2.02	1.87	2.22	2.18	2.09
D	2.07	2.04	1.99	1.86	1.96	2.29	2.04
E	1.92	2.04	2.07	1.89	2.06	2.09	2.01
F	1.98	2.14	1.98	1.86	2.30	1.93	2.03
Mean	2.04	2.09	2.09	1.89	2.17	2.10	

$LSD_{(0.05)}$ for:
years of study – 0.084
mulching procedures – n.s.
herbicide doses – n.s.
years × cover crop species – 0.301

Explanation as in Table 1

Many authors make the efficacy of herbicides in growing soybean dependent on the effectiveness of their action as well as on the influence of weather, habitat conditions and tillage system [Pfleeger et al. 2011, Byker et al. 2013, Nakatani et al. 2014]. Raskar and Bhoi [2002] as well as Bujak and Frant [2009] did not find an increase in yield in the case of the herbicide mixtures used by them. Different results were obtained by Tiwari et al. [2006] and by Das and Rakesh Pandey [2013]. According to these researchers, the use of chemical agents increases soybean yield by 22.2–45.8%.

Thousand seed weight

The thousand seed weight (TSW) showed a significant variation between years. The largest seeds were obtained in 2007 and 2009. In 2008 the seed weight proved to be significantly lower (respectively by 8.0 and 8.4%) (tab. 2). As far as the effect of mulch is concerned, a significantly higher seed weight was found after mowed rye and oilseed rape (treatments B and D) and after white mustard (F), compared to treatments A, C and E. The interaction data proved a higher TSW in the following treatments: A and D in 2007 and 2009 relative to 2008 as well as in treatment B in 2009 compared to 2008. The herbicide did not cause differences in the trait in question. A trend was only found towards a higher TSW in the treatments with the 100% herbicide rate.

Acko and Trdan [2009] find that there is an increase in TSW of soybean under lower plant density conditions and in a longer growing season, which corroborates with the results obtained in the present study. Bujak and Frant [2009] report that 1000 seed weight is a genetically determined characteristic, but which is usually modified by habitat conditions. This modification is due to row spacing and in-row seeding rate: the higher number of plants per $1m^2$, the lower TSW of soybean. According to Esbenshade et al. [2001] as well as Nowak and Wrobel [2010], the trait in question largely determines seed yield, which is also dependent on the cultivar and row spacing. In the study by Vyas and Khandwe [2012], cultivar JS 95-60 gave higher seed yield with 75 kg per ha seed rate planted at 30 cm row spacing. Whereas, cultivar JS 97-52 gave higher seed yield at 45 cm spacing with 55 kg per ha seed rate.

Number of pods per plant

Plants produced significantly the most pods in 2009 (14.3 pods), less by 28.0% in 2007, while least in 2008 (respectively by 46.2 and 25.2%) (tab. 3). Taking into account the mulching treatments, the highest number of pods was produced by plants in the control plots (A) as well as after desiccated rye (C) and oilseed rape (E). A significantly lower number of pods, but only relative to the control treatment, was produced by plants after white mustard (10.5 pods), whereas the lowest number was produced after mowed rye (B) and oilseed rape (D) 9.1 and 8.1 pods (on average less by 32.5 and 40%). The interaction data proved a decrease in the number of pods per plant in 2007 compared to 2009: in the control plots by 45.9%, after white mustard by 46.8%, while after mowed oilseed rape by 46.1%. The study did not prove statistically significant differences in the variation in the number of pods depending on herbicide rate; a slightly increasing trend in this number was only observed in the treatments with the 75% rate of the herbicide Basagran 600SL compared to the 100 and 50% rates.

Number of seeds per pod

The number of seeds per pod was significantly affected mainly by year (tab. 4). A larger amount of seeds per pod (respectively by 14.8 and 11.1%) was found in 2008 and 2009 compared to 2007. The interaction data show that there were more seeds per pod in the plots after mowed rye (B) and desiccated rye (C), and after white mustard (F) in 2008 as well as in the plots after desiccated rye (C) and mowed oilseed rape (D) in 2009 compared to 2007. On average, neither the incorporation of mulch alone nor the herbicide rates caused differences in the number of seeds per pod.

Pod length

The trait in question was clearly influenced by weather conditions throughout the study period, since a significant difference in pod length was found in

Table 5. The length of pod (cm)

Cover crop species	Herbicide doses (%)			Mean for years			Mean
	50	75	100	2007	2008	2009	
A	4.3	4.5	4.2	3.8	4.9	4.4	4.4
B	4.3	4.3	4.2	3.9	4.5	4.4	4.3
C	4.4	4.3	4.2	3.8	4.6	4.5	4.3
D	4.3	4.2	4.2	3.8	4.4	4.6	4.3
E	4.3	4.3	4.4	3.9	4.5	4.5	4.3
F	4.3	4.4	4.2	3.6	4.8	4.4	4.3
Mean	4.3	4.3	4.2	3.8	4.6	4.5	

$LSD_{(0.05)}$ for:
years of study – 0.19
mulching procedures – n.s.
herbicide doses – n.s.
years × cover crop species – 0.40

Explanation as in Table 1

Table 6. Stand density of soybean plants before harvest per m^2

Cover crop species	Herbicide doses (%)			Mean for years			Mean
	50	75	100	2007	2008	2009	
A	80.0	77.0	80.7	96.7	76.6	64.4	79.2
B	59.9	53.3	58.1	66.0	61.8	43.6	57.1
C	64.2	62.4	64.2	62.5	75.0	53.4	63.6
D	43.9	53.6	54.0	60.8	58.9	31.8	50.5
E	37.1	44.3	50.9	35.9	57.1	42.7	45.2
F	68.9	73.7	75.4	87.6	70.5	60.0	72.7
Mean	59.0	60.7	63.9	68.3	66.7	49.3	

$LSD_{(0.05)}$ for:
years of study – 5.71
mulching procedures – 9.80
herbicide doses – n.s.
years × cover crop species – 21.04

Explanation as in Table 1

Table 7. Total protein content and crude oil content in seeds (%)

Cover crop species	Total protein herbicide doses (%)			Mean	Crude oil herbicide doses (%)			Mean
	50	75	100		50	75	100	
A	34.0	33.6	33.4	33.7	18.5	17.9	18.2	18.2
B	34.0	33.8	33.9	33.9	18.2	18.4	18.0	18.3
C	32.9	32.4	33.1	32.8	18.2	19.1	18.5	18.3
D	34.4	34.7	34.6	34.6	19.1	18.4	17.7	18.4
E	33.5	33.2	33.9	33.5	18.6	18.8	18.6	18.7
F	33.9	33.5	33.3	33.6	18.7	18.6	18.3	18.5
Mean	33.8	33.5	33.7		18.6	18.5	18.2	

$LSD_{(0.05)}$ for:
cover crop species – 1.02
herbicide doses – n.s.
years × cover crop species – 2.30

$LSD_{(0.05)}$ for:
cover crop species – n.s.
herbicide doses – n.s.

Explanation as in Table 1

the individual seasons (tab. 5). The longest pod was produced by plants in 2008 (4.6 cm), while the shortest one in the first year of the study (on average 16.5% relative to the following years).

The variation in this trait was also proved by the interaction of years with mulching treatments in 2007. Compared to the first year, longer pods were produced by plants in 2008 and 2009 in all treatments (A–F), whereas in 2008 in treatments A and F relative to 2009.

Pod length in each treatment with mulch (rye, oilseed rape, and white mustard) was not dependent on mulch plant species or mulching method. Herbicide rate was not found to significantly affect this trait.

Plant density

The number of plants per 1m^2 before harvest of the soybean crop significantly varied between years and in the individual mulching treatments (tab. 6). The highest number of soybean plants was found in 2007 (68.3 plants per m^2), whereas this number was lower (by 2.3%) in 2008 and lowest in 2009, by as much as 27.0%. When considering the mulching treatments, it was found that the control treatment (A – without mulch) and after white mustard mulch (F) showed the highest plant density (79.2 and 72.7 plants per m^{-2}). A significantly lower plant density was found in the other treatments: after both forms of winter rye (B and C) and after winter oilseed rape (D and E), which showed a decrease respectively by 24.8 and 16.3% as well as by 33.6 and 40.5%. The interaction effect of the factors in question in 2009 produced a lower density in treatments B, D and F compared to 2007, which resulted from soil moisture deficiency during the time of soybean sowing. The herbicide rates did not cause statistical changes in plant density, but only an increasing trend in the trait in question with increasing herbicide rate.

On average for the 3-year study period, the mulch biomass yield was as follows: white mustard (2.1 t ha^{-1}), winter rye (3.8 t ha^{-1}), and winter oilseed rape (3.9 t ha^{-1}). In spite of the highest quantity of biomass, white mustard had the most beneficial effect on plant density and seed yield of soybean. On the other hand, the large vegetative biomass that was left by winter rye and winter oilseed rape reduced germination, emergence and initial growth of soybean sown into the mulch. The studies of Kwiatkowski et al. [2016] and Parylak et al. [2009] confirm that white mustard biomass has by far the most beneficial effect on the growth and development of crops.

There is a paucity of studies concerning the effect of cover crops (mulch plants) on the soybean yield structure. In the literature of the subject, such papers usually relate to cereal crops and they show divergent results. Using a white mustard cover crop in the cultivation of spring barley, Kwiatkowski [2006] observed a beneficial effect of its biomass on increasing the number of plants per crop and number of ears per unit area as well as a significant improvement in the ear structure (ear length, weight and number of grains per ear). In the study by Majchrzak and Skrzypczak [2010], an increase in thousand grain weight (TGW) of spring wheat was obtained under the influence of white mustard cropping after skimming. In turn, Gawęda [2011] showed a 9.3% decrease in TGW in a spring barley crop sown after white mustard.

Total protein content

The protein content in soybean seed was significantly affected by the type of the mulch plant used (tab. 7). The highest amount of this component was found in soybean seed harvested from the plots after mowed winter rye (B) 33.9%, and mowed winter oilseed rape (D) 34.6%. Soybean seed from treatment C was characterized by a significantly lower amount of protein (by 3.2 and 5.2%) compared to B and D.

The interaction data proved a decrease in the protein content in soybean seed in the treatment after mowed rye (B) and desiccated rye (C) in 2008 relative to 2009 (respectively by 8.8 and 7.6%). The applied herbicide did not modify significantly the total protein content.

Crude oil content

In spite of the absence of significant differences, there appeared some tendencies towards changes in the amount of the component in question (tab. 7). In the first two years of the study, its average content in soybean seed was the same (18.6%). It was only in the third year of the study (2009) that a decrease in the seed oil content to 18.1% was recorded. Among the mulch plants, soybean seed after white mustard (F) and both forms of winter oilseed rape mulch (D and E) accumulated more of this component, respectively by 18.5, 18.7 and 18.4%, than after both forms of winter rye mulch (B and C) 18.3%. The lowest percentage of this component was found in seeds harvested from the control plot (18.2%).

There was a certain trend towards an increase in oil content with decreasing herbicide rate; after application of the 100, 75 and 50% rates of the herbicide Basagran 600 SL the seed oil content was 18.2, 18.5, and 18.6%, respectively.

Protein content and oil content in soybean seed are considered to be the most important quality characteristics. Lorenc-Kozik et al. [2007] claim that protein and oil yields are dependent on weather conditions. A cold and wet summer results in better accumulation of protein and worse accumulation of oil. On the other hand, there are divergent opinions on the effect of herbicides on the traits studied. Akanksha Gupta and Saxena [2008] found a significantly higher (by 4.8 and 3.2%) seed protein and oil content in soybean grown in chemically weeded plots compared to manual weed control. Rakhimova and Dozorov [2014] claim that herbicides cause an increase in protein content and a decrease in oil content. In the study by Hassan [2015], weed control treatments significantly influenced plant height, weight of plants, weight of pods per plant, seeds per plant, weight of 1000 seeds, and seed yield. But oil and protein percentage was not affected by weed control treatments.

CONCLUSIONS

Years and mulching treatments caused the greatest variation in soybean seed yield. On average, the highest yield was obtained from treatments A, C and F (2.26 t ha^{-1}), while a significantly lower yield (by 40%) from treatments B, D and E. A high mulch biomass (especially oilseed rape mulch) or quickly regrowing plants of rye and oilseed rape (mainly in the mowed treatments: B and D) created great competition for the habitat factors or could have caused the adverse phenomenon of allelopathy.

In the light of the statistical analysis, the applied herbicide rates did not cause variations in the traits studied.

The protein content was affected by the type of the mulch plant used. Mulch with rye and winter rape favors increased protein content, while more oil seed were accumulating after the white mustard and both mulch forms of rape.

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