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WEED INFESTATION OF A SOYBEAN (*GLYCINE MAX* (L.) MERR.) CROP GROWN UNDER NO-TILLAGE AND USING MULCH FROM VARIOUS COVER CROPS AND ITS MANAGEMENT, INCLUDING REDUCED HERBICIDE RATES

Elżbieta Harasim*, Dorota Gawęda, Magdalena Gocół

University of Life Sciences in Lublin, Department of Herbology and Plant Cultivation Techniques, 20-950 Lublin, Akademicka 13, Poland.

*Corresponding author. E-mail: elzbieta.harasim@up.lublin.pl

ABSTRACT

A field study was conducted over the period 2007-2009 on grey-brown podzolic soil (sandy), designated as PWsp, with the granulometric composition of silt and classified in agricultural land suitability class 2. The study evaluated weed infestation of a soybean crop grown under no-tillage with mulch from winter rye, winter oilseed rape, and white mustard as well as using herbicide rates reduced by 25% and 50% in relation to the standard rate (2 L ha^{-1}). The studied factors were as follows: I. mulch plant species and mulch management method; II. rates of the foliar herbicide Basagran 600 SL. It is desirable to investigate the influence of these factors on weed infestation of a soybean crop for ecological reasons. The effects of these mulches showed that there was significantly lower weed infestation when the mulch crops had been desiccated, while it was highest when they had been mowed. No significant differences were found in the number of weeds due to the herbicide rates applied. The control treatment was characterized by an extremely low number of species (17) and weed individuals (6.4 weeds m^{-2}) in relation to all the mulched plots. The values of the air-dry weight of weeds were much influenced by the herbicide rates. Among the rates applied, only the 75% rate effectively reduced the weed dry weight (by 11.4%).

Key words: *Glycine max* L. Merr, direct drilling, cover crops, species composition of weeds, number and dry weight of weeds.

INTRODUCTION

Due to its biological properties, the soybean is not very competitive against weeds. It belongs to thermophilous plants, its emergence occurs after two-three weeks from sowing, and after two or three true leaves have formed its growth is inhibited as a result of the high-energy process of symbiosis with rhizobia. The low growth rate of soybean after emergence is especially dangerous, in particular when the spring period is cool or dry (Jędruszczak, 2008). Weeds that appear during this period pose a great threat to this plant, since their competitive ability leads to reduced yields and many other negative effects, including an increase in the soil seed bank; seed viability can persist for a number of years and weed seeds are a serious source of weed infestation of the field (Knezevic et al., 2002; Gesimba and Langat, 2005; Sodangi et al., 2007; Vollmann et al., 2010; Mohammadi and Amiri, 2011; Jędruszczak, 2008). Daugovish et al. (2003) reported that up to 80% yield loss of soybean may occur as a result of weed competition in many parts of the world. Weeds that are present before or emerge after this period do not cause significant yield loss. Mulugeta and Boerboom (2000) suggested that weeds needed to be removed between the V2 to V4 stage to protect soybean yield. According to Knezevic et al. (2003), the critical time for weed removal in soybean coincided with V3, V2 and V1 for row spacing of 7.5, 15 and 30 inches, respectively. This frequently forces farmers to carry out tillage operations or to use herbicides, thus increasing cultivation costs or introducing crop protection chemicals into the environment (Bujak et al., 2001; Silva et al., 2007a).

Herbicides belong to weed-reducing factors with the strongest effect. Nevertheless, their long-term use leads to the development

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of species biotypes that are not very sensitive or are resistant or even genetically mutated (Vila-Aiub and Ghersa, 2005; Adamczewski, 2009). Their appearance forces one to verify existing weed control technologies. The rational management of herbicides with different mechanisms of action is a very important practice. Furthermore, the use of herbicides with little soil residual activity and optimisation of doses and number of applications reduce the selection pressure, decreasing the risks of selection of plant resistance to herbicides (Silva et al., 2007b). In a soybean crop, weed control can be achieved by using one or more control methods, which are as follows: preventive, mechanical, chemical, biological and cultural (Wilson et al., 2009).

Both in the world and in Poland, one can now observe that environmentally friendly weed management methods are undertaken. Weed infestation and competitiveness of weeds can be reduced by the intentional incorporation of mulch in interrows or into the soil (Majchrzak et al., 2003; Stupnicka-Rodzynkiewicz et al., 2006; Pabin et al., 2007; Bond and Grundy, 2001; Kruidhof et al., 2008). Proven effective production of soybean under Polish conditions (Jędruszczak, 2006, 2008; Dobek and Dobek, 2008) with the possibility of using mulching to enhance soil fertility and productivity (Baumann et al., 2000; Malik et al., 2000) and with a simultaneous reduction in herbicide rates can become an alternative cultivation technology for this crop.

The aim of the present study was to determine weed infestation of a soybean crop grown under no-tillage using mulch from winter rye, winter oilseed rape and white mustard, as well as reduced herbicide rates.

MATERIAL AND METHODS

Plant material and growth conditions

In the period 2007-2009, 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. This region is characterized by a moderate continental climate. The experiment was located on grey-brown podzolic soil (sandy), designated as PWsp, 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^{-}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 in plots with the sown area of 33.6 m^{-2} and the harvested area of 15.0 m^2.

Experimental factors:

I. Cover crop species and mulching procedures: A – control treatment without mulch (conventional tillage) using the full recommended rate of the following soil herbicides: Afalon Dyspersyjny 450 SC (1 dm^3 ha^{-1}, (a.i. linuron 450 g per liter of herbicide) + Sencor 70 WG 250 g dm^3 ha^{-1} (a.i. metribuzin 70% per liter of herbicide) - the soil herbicides were applied right after soybean sowing; 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}): 100% rate – 2.0 L ha^{-1}; 75% rate – 1.5 L ha^{-1}; 50% rate –1.0 L ha^{-1}. The herbicide was applied at the 3-4 true leaf stage of soybean in all treatments.

Winter wheat was the previous crop for the cover crops. 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. The cover crops were sown at the recommended seeding times at a higher rate - winter oilseed rape cv. 'California' at an amount of 180 seeds per 1m^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}).

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 were applied on the day of soybean sowing not to stimulate the growth of weeds in autumn and early spring. In spring no tillage operations were carried out. Weed management was based on the incorporated mulches and the application of the foliar herbicide. Desiccation of the winter rye and winter oilseed rape crops was carried out about 14 days before soybean 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 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 entire 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).

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 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: *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). In the second and third year of the study, interventional application of the herbicide Fusilade Forte 150 EC was necessary due to the strong occurrence of *Echinochloa crus-galli*.

The following characteristics of weed infestation were the object of the study: number of weeds, number of species and weed species composition as well as air-dry weight of weeds. Weed infestation of the soybean crop was evaluated using the dry-weight-rank method on two dates: 1. before application of the foliar herbicide; 2. before harvest of soybean seed. On the first date, weed species were identified and their individuals were counted in four randomly selected sampling areas of 0.25 m^2 in each plot (1 m^2 in total), leaving them in the soybean crop. On the second date, the same procedure was repeated, but weeds were cut out from the sampling area, dried and their dry weight was weighed.

Weather conditions in the study area

The weather conditions varied. The mean air temperature for the growing period was as follows in the successive years: 17.1°C, 16.8°C, 16.6°C; it was higher than the long-term mean (15.3°C). Only in the first year was the total rainfall (338.0 mm) close to the long-term mean (327.1 mm), but it was lower in the following years of the study by 15.8% and 11.3%, respectively, compared to the long-term mean. In the last 10-day period of August and in the first ten days of September in each year, the rainfall was relatively low and did not pose a threat to soybean seed harvest (Figures 1 and 2).

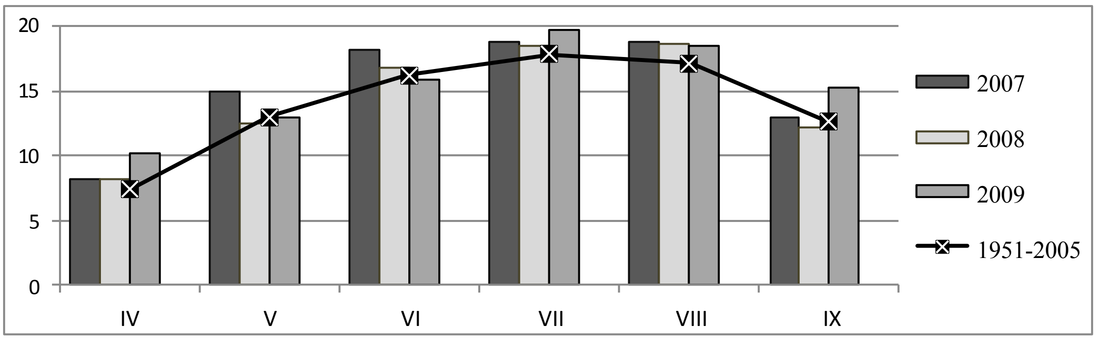

Figure 1. Mean monthly air temperature (°C) at the Czesławice Meteorological Station in 2007-2009

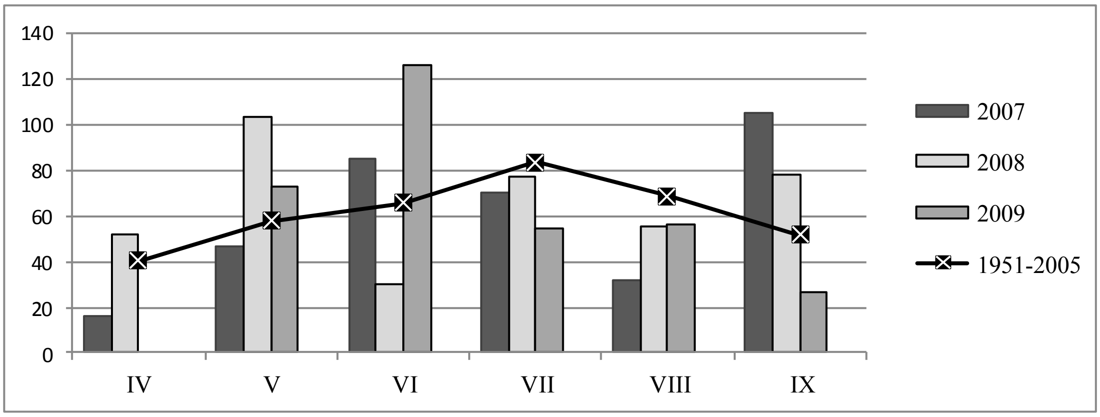

Figure 2. Total rainfall and rainfall distribution (mm) at the Czesławice Meteorological Station in 2007-2009

Statistical analysis

The study results were statistically analysed by analysis of variance (ANOVA), while the differences between means were estimated by Tukey's HSD test at a significance level p=0.05.

RESULTS

Number of weeds

Weed infestation of the soybean crop before the herbicide treatment and before soybean harvest was significantly modified by year, mulches used, and the interaction of these factors.

Throughout the study period (Table 1), a higher number of weeds occurred in the first year, on average 86.2 weeds·m^{-2}, than in the next two years when it decreased on average by 23.8% and 7.5 %. The herbicide Fusilade Forte 150 EC used against *Echinochloa crus-galli* contributed to this decrease. Before soybean harvest (Table 2), significantly more weeds were found in 2008, in 2009 their number was lower by 3.3%, and in 2007 it was lowest (by 40.2%).

Table 1. Number of weeds in soybean (pcs m^{-2}) depending on cover crop species before herbicide treatment

Cover crop species	Years of study			Mean
	2007	2008	2009	
A*	85.9	8.8	8.2	34.3
B	85.8	76.5	155.0	105.8
C	81.8	72.4	67.0	73.7
D	104.0	79.5	100.3	94.6
E	64.2	72.1	83.1	73.1
F	95.4	84.8	64.7	81.6
Mean	86.2	65.7	79.7	
$NIR_{(0,05)}$ for: years − 0.90 cover crop species − 1.51 in interaction: years × cover crop species – 3.15				

A* – control, B – mowed winter rye, C – desiccated winter rye; D – mowed winter oilseed rape; E – desiccated winter oilseed rape; F – desiccated white mustard.

As far as the effects of the mulches are concerned (Table 2), significantly the greatest weed infestation was found on both evaluation dates in the mowed plots after winter rye (B) and winter oilseed rape (D), on average 100.2 weeds·m^{-2} before the herbicide treatment and on average 86.1 weeds·m^{-2} before harvest; weed infestation was significantly lower after desiccation (C and E) and it was lowest after white mustard (F). The control treatment (A) was characterized by an extremely low number of weeds – 6.4 weeds m^{-2} – relative to the other treatments. There were no significant differences in the number of weeds due to the herbicide rates applied.

Table 2. Number of weeds in soybean (pcs m^{-2}) depending on cover crop species and years of study before herbicide treatment

Cover crop species	Herbicide doses (%)			Years of study			Mean
	50	75	100	2007	2008	2009	
A*	9.2	5.5	4.4	6.5	9.7	3.2	6.4
B	104.2	107.8	107.1	38.0	113.1	168.6	106.4
C	43.9	42.0	39.0	27.3	64.9	32.4	42.0
D	72.9	65.6	58.3	28.3	77.6	91.6	65.7
E	42.9	43.9	54.7	32.9	63.3	46.1	47.2
F	44.4	31.8	32.6	22.6	56.7	28.8	36.3
Mean	52.9	49.6	49.4	25.9	64.4	62.3	
$NIR_{(0,05)}$ for: years – 0.61 cover crop species – 1.10 herbicide doses – n.s.							

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.

Air-dry weight of weeds

The values of the air-dry weight of weeds were much influenced by the herbicide rates (Table 3). The incorporation of each of the mulches (B-F) resulted in an increase in the weed dry weight and this increase was most pronounced in the mowed treatments (after rye (B) and oilseed rape (D)). The air-dry weight was most effectively reduced by the 75% rate of herbicide, in the case of the 100% rate this reduction was weaker (the dry weight was lower by 13.2%), and it was weakest (by 14.4%) for the 50% rate. Significantly the highest weed dry weight was found in 2009 (230.5 g m^{-2}).

Table 3. Air-dry weight of weeds in soybean (g m^{-2}) depending on herbicide rate and years of study before harvest

Cover crop species	Herbicide doses (%)			Years of study			Mean
	50	75	100	2007	2008	2009	
A*	10.8	1.7	4.1	6.9	3.7	5.8	5.5
B	242.9	234.5	264.4	153.4	205.9	382.4	247.2
C	146.8	139.8	167.2	152.0	140.2	161.7	151.3
D	397.7	338.1	380.3	225.5	417.3	473.3	372.0
E	240.9	218.0	236.5	198.2	279.5	217.7	231.8
F	132.6	91.6	107.3	113.1	76.4	142.0	110.5
Mean	195.3	170.7	193.3	141.5	187.2	230.5	
$NIR_{(0,05)}$ for: years – 0.61 cover crop species − 2.74 herbicide doses − 0.60 in interaction: years × cover crop species − 5.81							

A*– control, B – mowed winter rye, C – desiccated winter rye; D – mowed winter oilseed rape; E – desiccated winter oilseed rape; F – desiccated white mustard.

Species composition of weeds

The segetal flora that infested the soybean crop was abundant. Before application of the herbicide, a total of 57 weed species were found, including 46 annual weeds and 11 perennial ones (Table 4). More species occurred in 2008 and 2009 than in the first study season (2007). The average number of weed individuals of all species was in total 76.9 weeds m^{-2}; annual therophytes were dominant (73.5 weeds m^{-2}), but there were few perennials (3.4 weeds m^{-2}). Before soybean harvest the total number of weed species increased to 61, whereas the number of weeds decreased to 50.8 weeds m^{-2} (Table 5). In the mulched plots, there was a reduction in annual taxa compared to the observation before herbicide application; their number greatly varied from 44 in the plot after mowed rye (B) to 34 after desiccated oilseed rape (E). In the control treatment (A), the number of 17 species remained constant, with some species changing at the times of observation (Tables 4 and 5). Among annual species, the following occurred most frequently: *Echinochloa crus-galli*, *Viola arvensis*, *Chenopodium album, Stellaria media*, and *Matricaria maritima* subsp. *inodora*. The mowed plots after rye (B) were intensely inhabited by regrowing plants of *Secale cereale* and *Apera spica-venti*, while after oilseed rape (D) by its regrowth sprouts, even in the desiccation treatments (C and E). *Elymus repens* was predominant among perennial species and, apart from it, *Equisetum arvense* and *Cirsium arvense* also marked their presence.

Table 4. Species composition and number of weeds in soybean (pcs m^{-2}) depending on cover crop species before herbicide treatment

Species	Cover crop species						Years of study			Mean
	A	B	C	D	E	F	2007	2008	2009	
I. Short-term										
Echinochloa crus-galli (L.) P. BEAUV.	28.0	17.6	36.3	21.6	26.8	21.2	54.4	9.8	11.6	25.3
Viola arvensis MURR.	0.4	13.4	9.2	14.1	7.9	13.2	1.4	12.1	5.7	9.7
Matricaria maritima subsp. *inodora* (L.) DOSTÁL	0.1	3.2	1.5	3.2	2.7	2.2	0.2	2.7	3.5	2.1
Chenopodium album L.	0.1	7.5	8.6	9.4	13.3	16.7	13.3	7.9	6.7	9.3
Geranium pusillum BURM. f. ex L.	0.2	2.8	1.9	2.8	3.1	5.2	1.0	6.7	0.3	2.7
Poa annua L.	0.2	1.4	0.6	3.8	0.9	0.7	1.1	2.4	0.2	1.2
Stellaria media (L.) VILL.	0.0	4.3	2.1	6.5	3.0	7.7	6.4	4.2	1.2	3.9
Galinsoga parviflora CAV.	0.0	0.5	1.0	0.8	1.3	1.4	0.5	1.2	1.0	0.9
Galium aparine L.	0.0	0.3	0.2	0.1	0.2	0.1	-	0.3	0.3	0.2
Secale cereale L.	-	23.3	0.4	-	-	-	2.0	1.5	8.3	3.9
Apera spica-venti (L.) P. BEAUV.	-	15.0	-	8.3	-	0.4	0.2	0.2	11.2	3.9
Capsella bursa-pastoris L. MEDIK.	-	4.4	6.2	5.2	4.7	5.5	0.8	4.4	7.8	4.3
Veronica arvensis L.	-	2.9	0.2	2.6	0.5	0.4	0.2	1.0	2.1	1.1
Myosotis arvensis (L.) HILL	-	1.2	0.4	0.8	0.1	0.4	0.5	0.8	0.1	0.5
Other species	0.4	4.0	3.1	11.0	5.8	4.0	1.8	5.0	16.6	4.5
Total I	29.2	101.8	71.5	90.2	70.3	79.1	83.8	60.2	76.6	73.5
Number of short-term species I	13	37	33	35	36	32	28	39	36	46
II. Perennial										
Elymus repens (L.) GOULD	4.3	2.8	0.9	3.8	1.3	1.7	1.6	4.2	1.8	2.6
Equisetum arvense L.	0.5	0.8	0.1	0.1	0.4	0.6	0.3	0.4	0.5	0.3
Cirsium arvense (L.) SCOP.	0.1	0.1	0.1	0.1	0.2	0.1	0.0	0.1	0.2	0.1
Other species	0.2	0.3	1.1	0.6	0.8	0.1	0.2	0.3	0.6	0.4
Total II	5.3	4.0	2.2	4.6	2.7	2.5	2.1	5.0	3.1	3.4
Number of perennial species II	4	9	9	6	7	5	8	7	7	11
Total I + II	34.5	105.8	73.7	94.6	73.0	81.6	85.9	65.2	79.7	76.9
Number of species I + II	17	46	42	41	43	37	36	46	43	57

A*– control, B – mowed winter rye, C – desiccated winter rye; D – mowed winter oilseed rape;
E – desiccated winter oilseed rape; F – desiccated white mustard;
*0.0 - the species found in a number less than 0.1 plant m^{-2}, – the species did not occur.

Table 5. Species composition and number of weeds in soybean (pcs m^{-2}) depending on cover crop species before soybean harvest

Species	Cover crop species						Mean
	A	B	C	D	E	F	
I. Short-term							
Echinochloa crus-galli (L.) P. BEAUV.	0.4	8.4	17.0	9.3	15.5	3.3	9.0
Chenopodium album L.	0.2	9.8	4.7	7.3	6.3	9.7	6.3
Stellaria media (L.) VILL.	0.2	2.4	2.0	3.7	1.4	1.4	1.9
Capsella bursa-pastoris L. MEDIK.	0.2	0.9	0.9	0.2	0.9	1.5	0.8
Amaranthus retroflexus L.	0.2	0.4	0.2	0.5	0.1	0.1	0.2
Viola arvensis MURRAY	0.1	10.7	4.4	4.4	4.3	5.5	4.9
Polygonum aviculare L.	0.1	0.9	0.4	0.2	0.4	0.3	0.7
Polygonum lapathifolium L.	0.1	0.3	0.2	0.1	0.5	0.1	0.4
Galeopsis tetrahit L.	0.0	0.5	0.6	0.4	0.7	0.6	0.5
Matricaria maritima subsp. *inodora* (L.) DOSTÁL	0.0	0.4	0.2	0.2	0.3	0.1	0.2
Conyza canadensis (L.) CRONQUIST	0.0	0.1	0.2	0.4	0.3	0.1	0.2
Apera spica-venti (L.) P. BEAUV.	-	27.8	-	12.5	-	-	6.7
Secale cereale L.	-	21.4	-	0.0	-	-	3.6
Plantago intermedia GILIB.	-	2.8	2.8	1.8	3.0	2.0	2.1
Poa annua L.	-	2.7	0.7	2.0	1.5	0.3	1.2
Galinsoga parviflora CAV.	-	1.2	1.9	1.7	2.5	1.0	1.4
Geranium pusillum Burm. f. ex L.	-	0.9	0.4	0.5	0.9	1.4	0.7
Veronica arvensis L.	-	0.5	0.2	0.4	0.2	0.2	0.2
Other species	0.2	2.1	2.0	14.5	4.8	1.9	4.0
Total I	1.7	94.2	38.8	60.1	43.6	29.5	45.0
Number of short-term species I	13	32	29	31	26	29	46
II. Perennial							
Elymus repens (L.) GOULD	3.7	8.5	1.3	3.9	2.4	5.5	4.2
Equisetum arvense L.	0.7	0.3	0.1	0.3	0.2	0.3	0.3
Cirsium arvense (L.) SCOP.	0.2	0.4	0.1	0.3	0.5	0.7	0.3
Other species	0.1	2.1	1.7	1.0	0.5	0.5	1.0
Total II	4.7	11.6	3.2	5.5	3.6	7.0	5.8
Number of perennial species II	4	11	13	9	8	10	15
Total I + II	6.4	105.8	42.0	65.5	47.2	36.5	50.8
Number of species I + II	17	44	42	40	34	39	61

A*– control, B – mowed winter rye, C – desiccated winter rye; D – mowed winter oilseed rape;
E – desiccated winter oilseed rape; F – desiccated white mustard;
*0.0 - the species found in a number less than 0.1 plant m^{-2}, – the species did not occur.

The used foliar herbicide (Basagran 600 SL) modified weed infestation of the soybean crop between years (Table 6). Weeds infested the soybean crop most intensely in the second year of the study (2008) - 52 species. The lowest number of weed species was found after the 100% rate of the herbicide was applied and these were mainly annual species. As regards the evaluation before the herbicide treatment, individual taxa responded differently to the herbicide. After application of each rate of the herbicide Basagran 600 SL, the number of the following weeds dominant in spring decreased: *Echinochloa crus-galli*, *Viola arvensis*, and *Chenopodium album*, whereas *Apera spica-venti*, *Galinsoga parviflora* and *Plantago intermedia* occurred more frequently. The application of the herbicide at the full rate and at the rate reduced by 25% resulted in an additional decrease in the number of weeds such as: *Stellaria media*, *Galinsoga parviflora*, *Poa annua*, and *Geranium pusillum* (Table 6).

Table 6. Species composition and number of weeds in soybean (pcs m^{-2}) depending on herbicide dose before soybean harvest

Species	Herbicide doses (%)			Years of study			Mean
	50	75	100	2007	2008	2009	
I. Short-term							
Echinochloa crus-galli (L.) P. BEAUV.	8.1	8.7	10.2	7.2	11.8	8.0	9.0
Apera spica-venti (L.) P. BEAUV.	7.3	6.5	6.3	0.0	4.2	15.9	6.7
Chenopodium album L.	6.3	6.1	6.6	9.1	3.5	6.4	6.3
Viola arvensis MURR.	5.6	4.6	4.5	0.7	5.8	8.2	4.9
Secale cereale L.	3.1	4.0	3.6	-	2.2	8.5	3.6
Stellaria media (L.) VILL.	2.1	1.7	1.8	0.9	3.7	0.1	1.9
Plantago intermedia GILIB.	1.9	2.1	2.2	1.3	4.8	0.1	2.1
Galinsoga parviflora CAV.	1.8	1.3	1.1	0.2	1.9	1.0	1.4
Poa annua L.	1.5	1.4	0.6	0.4	1.2	2.0	1.2
Geranium pusillum BURM. f. ex L.	0.9	0.6	0.6	0.1	1.9	0.1	0.7
Capsella bursa-pastoris L. MEDIK.	0.7	1.0	0.8	0.2	1.9	0.2	0.8
Polygonum aviculare L.	0.6	0.4	0.3	0.4	0.9	0.1	0.4
Galinsoga ciliata (Raf.) S. F. Blake	0.6	0.6	0.6	0.2	0.4	1.2	0.6
Veronica arvensis L.	0.4	0.2	0.1	-	0.6	0.2	0.2
Other species	5.5	4.7	3.6	1.9	7.6	6.0	5.2
Total I	46.4	43.9	43.9	22.6	52.4	58.0	45.0
Number of short-term species I	37	38	34	25	37	28	46
II. Perennial							
Elymus repens (L.) GOULD	5.2	3.8	3.7	2.6	9.1	1.5	4.2
Sonchus arvensis L.	0.4	0.4	0.1	0.1	0.0	0.8	0.2
Equisetum arvense L.	0.2	0.3	0.4	0.6	0.5	0.1	0.3
Cirsium arvense (L.) SCOP.	0.2	0.3	0.3	-	0.1	0.7	0.3
Other species	0.6	1.0	1.0	0.7	2.1	0.4	0.8
Total II	6.6	5.8	5.5	2.6	11.8	3.5	5.8
Number of perennial species II	12	13	12	7	15	7	15
Total I + II	53.0	49.7	49.4	25.2	64.2	61.5	50.8
Number of species I + II	49	51	46	32	52	35	61

A*– control, B – mowed winter rye, C – desiccated winter rye; D – mowed winter oilseed rape;
E – desiccated winter oilseed rape; F – desiccated white mustard;
*0.0 - the species found in a number less than 0.1 plant m^{-2}, – the species did not occur.

DISCUSSION

The results of this study on weed infestation of soybean grown under no-tillage with mulch showed a significantly higher weed infestation compared to conventional (plough) tillage for this crop and after application of the soil herbicides (Afalon Dyspersyjny + Sencor + Basagran 600 SL) immediately after sowing. Under conventional tillage (control treatment), the number of weed species was very low – 17 species at each time of investigation, whereas their numbers were as follows: 34.3 weeds·m^{-2} (Table 2) and 6.4 weeds·m^{-2} after application of the herbicide Basagran 600 SL. Under no-tillage with mulch from various cover crops (Table 5), the number of species was from 44 to 34, while the average number of weed individuals was 44.4 weeds·m^{-2}. Among the mulch crops, weeds occurred most frequently in the mowed plots after rye and oilseed rape (105.8 and 65.6 weeds·m^{-2}), while their number was lowest after white mustard (36.5 weeds·m^{-2}).

The presented results confirmed the results of other authors proving that no-tillage with mulch leads to increased weed infestation of crops. Wesołowski et al. (2000) and Bujak et al. (2001) recorded an increase in the weed infestation parameters (number and air-dry weight of weeds) under no-tillage with mulch from overwintering white mustard in the range of 71.6-87.1% in relation to the ploughed plots. This was confirmed by Gawęda (2004) and the subsequent study by Bujak et al. (2004) showing that no-tillage causes an increase in the number and weight of weeds from 40% to more than double this percentage. The results of many studies on the effect of mulching on flora communities are dependent on mulch management, applied in the experiment. Skrzypczak et al. (1999) and Majchrzak et al. (2003) think that the best effect in reducing weed infestation, apart from desiccation, after winter rye mulch requires additional post-emergence herbicides, whereas Stupnicka-Rodzynkiewicz et al. (2006) stress the good effectiveness of mulches when there are good soil moisture conditions and the mulch is mixed with the soil after a month from maize sowing.

The need to protect the environment, including the preservation of weed species diversity, forces the implementation of tillage systems with reduced intensity of tillage operations, including direct drilling (Dzienia et al., 2006). In the opinion of Rodriguez and Barroso (2012) as well as Monsefi et al. (2013), it is necessary to use good chemical protection which allows weed infestation to be significantly reduced. No-tillage technology (also used in this study) may be associated with reduced crop yields (Dzienia et al., 2006). It should be pointed out here that in the present experiment the soybean seed yield obtained after the desiccated rye mulch and after white mustard did not decrease in relation to the control treatment (the average seed yield was 2.26 t ha^{-1}), which proves that such treatments can be used in agricultural practice without excessive application of herbicides, at the same time maintaining relatively high weed species diversity.

Among the applied rates of the foliar herbicide (Basagran 600 SL), only the 75% rate of the herbicide significantly reduced the weed dry weight - by 11.4% (Table 3). The recommended rate caused damage to soybean plants and the covering of growing young weeds, which blocked the movement of active matter, while the 50% rate was too small. The generally low efficacy of the herbicide resulted from the need to apply spraying at the 3-4 leaf stage of soybean when many weeds were already at advanced growth stages. Weeds with very small seeds (which occur most frequently) have very early and intense emergence; they combine a fast growth rate and a very large root absorption area per unit of weight, in particular in the presence of nitrogen in the soil (Liebman and Davis, 2000), and therefore they do not respond to the herbicide incorporated into the soil. Besides, the active substance of the herbicide Basagran 600 SL – bentazon – is selective to many weed species, acts through contact, is mainly absorbed by leaves, moves very poorly, and is immediately metabolized in the plant (Tomlin, 1997). Many arable weed species show very low sensitivity to bentazon, among others *Echinochloa crus-galli*, *Apera spica-venti, Taraxacum officinale, Cirsium arvense, Elymus repens, Rumex acetosella, Poa annua,* as well as self-sown cereals.

According to Wesołowski et al. (2000), Bujak et al. (2001) and Jędruszczak et al. (2006), soybean crops grown on loess soils under no-tillage were infested in 90% by species such as: *Echinochloa crus-galli, Galinsoga parviflora*, *Galium aparine* and *Matricaria maritima* subsp. *inodora*. Subsequent research in this region reveals that *Chenopodium album* and *Polygonum nodosum* occur under no-tillage, while from perennials – *Equisetum arvense* (Bujak et al., 2004).

So far, many authors have thought that herbicides are the best protection against weeds (Ferri and Vidal, 2002; Marinov-Serafimov, 2009). Such an approach is applied in conventional soybean cultivation and protection. Under conventional tillage, the number of both species and weed individuals is strongly reduced. This cannot form an absolute basis for the assumptions of environmentally friendly soybean cropping. The first beneficial results of the environmentally friendly approach are presented in this paper for two mulch plants (desiccated rye and white mustard) in the case of which the diversity of weed species was saved without any detriment to soybean yield. It can become an alternative cultivation technology for this crop.

CONCLUSIONS

The aim of weed management is to reduce the occurrence of weeds to a level at which they do not cause significant competition for the crop plant. In countries with well-developed farming, reduced use of crop protection agents and cover cropping are a priority, which is justified environmentally and economically. In this study, growing soybean under no-tillage with mulch from desiccated winter rye and white mustard plants allowed weed species diversity to be maintained, without decreasing soybean seed yield. However, it was proven that mowed and desiccated winter oilseed rape mulch and mowed winter rye mulch, as well as a reduced herbicide rate lead to a significant increase in the number of weeds and a distinct decrease in soybean seed yield. The weaker effectiveness of these mulches (and the herbicide rate lower by 50% but also the recommended rate) may be due to the biological properties of these plants, the growth stage, the state and level of weed infestation, weather conditions during plant growth as well as the condition of the crop plant.

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