Bulgarian Journal of Agricultural Science, 20 (No 6) 2014, 1340-1348
Agricultural Academy

WEED BIODIVERSITY IN FIELD PEA UNDER REDUCED TILLAGE AND DIFFERENT MINERAL FERTILIZATION CONDITIONS

M. HALINIARZ[1*], D. GAWĘDA[1], C. KWIATKOWSKI[1], M. FRANT[1] and M. RÓŻAŃSKA-BOCZULA[2]
[1]*University of Life Sciences in Lublin, Department of Herbology and Plant Cultivation Techniques, 20-950 Lublin, Poland*
[2] *University of Life Sciences in Lublin, Department of Applied Mathematics and Computer Science, 20-950 Lublin, Poland*

Abstract

HALINIARZ, M., D. GAWĘDA, C. KWIATKOWSKI, M. FRANT and M. RÓŻAŃSKA-BOCZULA, 2014. Weed biodiversity in field pea under reduced tillage and different mineral fertilization conditions. *Bulg. J. Agric. Sci.,* 20: 1340-1348

Soil, as the living environment of plants, is the most important factor affecting agrophytocenoses. Tillage is considered to be one of the basic elements modifying soil physical, chemical and biological properties and determining the germination, growth and development of both cropped vegetation and weeds. Therefore, a study was undertaken to determine the effects of long-term reduced tillage and mineral fertilization on weed biodiversity in field pea crops under the climatic conditions in south-east Poland. A field study was conducted in the period 1999–2006 (two crop rotations) on lessive soil (agricultural land class 2). The experiment included different tillage systems and two levels of mineral fertilization. Field pea was grown in a four crop rotation: potato – spring wheat – field pea (edible form) – winter wheat. In the field pea crop, ploughless tillage and tillage with shallow pre-sowing ploughing, compared to plough tillage, resulted in an increase the number of weeds and air-dry weight of weeds in both crop rotations. In the second crop rotation, the study found an increase in the number and dry weight of weeds under the conditions of lower mineral fertilization compared to higher fertilization. Reduced tillage contributed to an increased proportion of perennial weeds in weed infestation, especially *Elymus repens* (L.) P.B. In the second crop rotation, the biodiversity of weed communities in the field pea crop was found to be lower compared to the period 1999-2002.

Key words: conservation tillage, flora of agrophytocenoses, NPK rates, *Pisum sativum* (L.)

Introduction

Soil, as the living environment of plants, is the primary factor determining the flora of a particular area. It affects both the condition of the crop plant and unwanted vegetation, i.e. weeds. Soil tillage, which is of great importance in providing proper conditions for plant emergence and growth, is a key element of soil environment management (Małecka et al., 2012). Any modifications in agronomic practices affect soil physical, chemical and biological properties as well as the incidence of pests and diseases (Deike et al., 2008; Małecka et al., 2009, 2012; Velykis and Satkus 2012; Aziz et al., 2013). No-till leads to soil compaction, especially in the first years of its use, which can be a cause of inhibited plant emergence and poorer development of the root system as well as of greater pressure from pathogenic fungi and pests (Małecka et al., 2012). Hanavan et al. (2008) showed that in a field pea plantation *Sitona lineatus* (L.) colonization was lower and it occurred later under direct drilling conditions compared to conventional tillage. Furthermore, tillage modifications have a significant effect on weed emergence, the soil seed bank, and weed seed distribution in the soil profile (Torresen et al., 2003; Wrzesińska et al., 2013; Légère et al., 2005; Ozpinar, 2006; Chauhan and Johnson, 2009; Shirtliffe and Johnson, 2012). Long-term reduced tillage leads to the accumulation of weed seeds in the topsoil (0-10 cm), which has a significant influence on weed infestation of a field (Torresen et al., 2003). Therefore, a study was undertaken to determine the effects of

E-mail: malgorzata.haliniarz@up.lublin.pl

long-term reduced tillage and mineral fertilization on weed biodiversity in field pea crops under the climatic conditions in south-east Poland.

Materials and Methods

A field study was conducted in the period 1999–2006 (two crop rotations) at the Czesławice Experimental Farm (51° 18′ 23″ N, 22° 16′ 2″ E) belonging to the University of Life Sciences in Lublin. The experiment was set up as a split-block design in four replicates. The area of each experimental plot was 180 m^2.

This static field experiment was carried out on lessive soil, classified as soil class II and good wheat soil complex. The plough layer was characterized by slightly acidic pH (6.5–6.6 in 1 mol KCl), a humus content of 16.2 g kg^{-1} soil, a high content of phosphorus and potassium as well as a medium content of magnesium.

Field pea (cv. 'Agra') was grown in a four crop rotation: potato – spring wheat – field pea (edible form) – winter wheat; in the first crop rotation, all plants were grown simultaneously. The experiment compared three tillage systems and two levels of mineral fertilization.

The experimental factors were as follows:

I. Tillage systems: A – conventional (7 ploughings per crop rotation); B – reduced (3 ploughings per crop rotation); C – reduced (1 ploughing per crop rotation). Ploughing was replaced mainly by cultivating or disking. In the case of field pea, tillage in individual treatments was as follows: A, A1– skimming (10–12 cm) + double harrowing + autumn ploughing (18–20 cm); B, B1 – cultivating (10–12 cm) + harrowing + shallow autumn ploughing to a depth of 15 cm; C, C1 – disking (10–12 cm) + harrowing + subsoiling 35–40 cm. In the spring, cultivating (10–12 cm) + harrowing + sowing were done in all treatments.

II. Mineral fertilization levels: a,a1 – 127.4 kg NPK ha^{-1} and b,b1 – 191.2 kg NPK ha^{-1} on an average annual basis per crop rotation, including fertilization for field pea cropping: a,a1 – 112.6 kg NPK ha^{-1} (N – 20; P – 26.2; K – 66.4); b,b1 – 168.9 kg NPK ha^{-1} (N – 30; P – 39.3; K – 99.6).

Field pea was sown in the first 10-day period of April at a rate of 1.2 million seeds per 1 ha. Before sowing, seeds were dressed with Funaben T 480 FS (tiuram, carbendazim) at a rate of 200 g per 100 kg seeds. Immediately after sowing, Stomp 330 EC (pendimethalin) was used at 4 l ha^{-1}. Decis 2,5 EC (deltamethrin) at a rate of 0.3 l ha^{-1} or Fastac 100 EC (alpha-cypermethrin) at 0.12 l ha^{-1} were used to control pests, if necessary.

During the years covered by the study, the growing seasons of pea were characterized by varying weather conditions (Figure 1). The first growing season was very wet; the total rainfall was 465.6 mm and it was higher by as much as 108.0 mm than the long-term mean. The seasons in 2000, 2001 and 2006 can be considered to be average, since the total rainfall in particular years was close to the mean total rainfall for 1966-2002. On the other hand, the growing seasons in

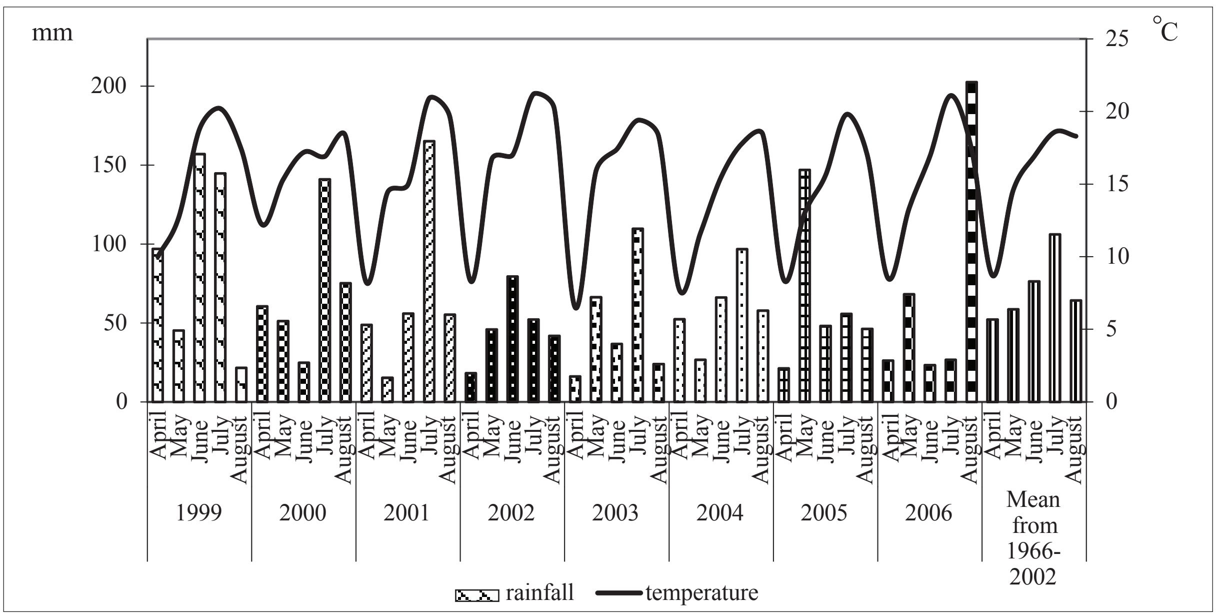

Fig. 1. Rainfall and air temperature in the growing season of pea (April-August), according to the Meteorological Station in Czesławice

2002, 2003, 2004 and 2005 were definitely dry. The average air temperature during the period from sowing to harvest in the years 1999, 2000, 2002 and 2003 was higher than the long-term mean for 1966-2002. The 2002 growing season was particularly warm and also characterized by the lowest amount of rainfall. During the duration of the experiment, the lowest average air temperatures for the months April-August were recorded in 2004 and 2005.

Weed infestation of the crop was determined using the dry-weight-rank method at the pod and seed maturation stage (BBCH 81/82). The evaluation involved the determination of the botanical composition, number and air-dry weight of weeds. The sampling area was delineated with a 1 m × 0.5 m quadrat frame in two randomly selected places in each plot.

The results obtained for the number and dry weight of weeds were analysed by Statistica 10.0 software using analysis of variance, whereas the significance of differences was estimated by Tukey's test at $\alpha = 0.05$. Species diversity was assessed based on the number of species in the community and ecological biodiversity indices - Shannon's diversity index H and Simpson's dominance index C (Topham and Lawson, 1982). These biological indices were calculated using the following formulas:

$$H = -\sum_{i=1}^{s} p_i \log_n p_i$$

$$C = \sum p_i^2 ,$$

where: s – number of species, pi – the proportion of individuals of the i-th species to the total numbers of individuals.

Results

In the first crop rotation of the present experiment, tillage systems had the greatest effect on the number of weeds (F=140.37). The year of the study (F=94.70) and the interaction of year with tillage system (F=30.26) also proved to be an important factor (Tables 1, 3). Mineral fertilization had very low importance and it was statistically insignificant (F=3.75) (Table 3). In the second crop rotation, the study showed the experimental factors to have a significantly smaller effect on the number of weeds in field pea. It should be noted, however, that the greatest impact was found in the case of tillage (F=15.69), similarly to the period 1999-2002. Unlike the first crop rotation, mineral fertilization proved to be an important factor here (p=0.013). This can be explained by the twice higher number of weeds in 2005 at the lower level of fertilization compared to treatment b1 (Tables 1, 2, 3). In the plots with higher mineral fertilization (b1), the number of weeds was lower by 17.8 plant·m^{-2} relative to that found under conditions of the lower fertilization rates (a1). Replacing ploughing with disking and cultivating (C,C1), or shallow pre-sowing ploughing (B,B1), compared to the treatments with conventional plough tillage (A,A1), resulted in an increase in the number of weeds by respectively 261.1 and 39.4% in the first rotation, while in the period 2003-2006 by 112.6 and 29.3%. The highest value of this trait was found in the unploughed plots (C, C1) in 2002 and 2003. The number of weeds differed significantly between experimental years, with its highest value in the 4th year of the first crop rotation and in the 3rd year of the second crop rotation (Tables 1, 3).

The statistical evaluation of the sources of variation in the first crop rotation demonstrates that the year of the study

Table 1
Number of weeds per 1 m² of pea crop in 1999-2002 and 2003-2006

Years	Tillage systems			Levels of mineral fertilization		Mean
	A,A1	B,B1	C,C1	a,a1	b,b1	
1999	13.6	16.9	38.4	23.8	22.1	23.0
2000	24.0	34.0	86.8	51.6	44.9	48.2
2001	9.4	20.7	21.8	21.1	13.4	17.3
2002	36.3	44.4	153.3	81.0	74.9	78.0
Mean	20.8	29.0	75.1	44.4	38.8	-
$LSD_{0.05}$	tillage systems - 8.39; years - 10.66; tillage systems x years - 23.75					
2003	23.7	47.2	135.1	72.4	64.8	68.6
2004	29.7	41.2	51.7	41.5	40.1	40.8
2005	67.9	81.2	81.2	101.8	51.7	76.8
2006	43.9	43.8	83.2	63.0	50.8	56.9
Mean	41.3	53.4	87.8	69.7	51.9	-
$LSD_{0.05}$	tillage systems – 20.70; fertilization – 14.07; years – 26.29; tillage systems x years – 58.57					

(F=70.60) and tillage system (F=23.37) had a great effect on weed dry weight. This trend continues throughout the period 2003-2006, during which the values F=61.58 and F=18.52 were obtained for year and tillage system, respectively. As in the case of the number of weeds, mineral fertilization was observed to significantly affect weed weight (p=0.004) in the second crop rotation. Nevertheless, its influence on the trait in question was significantly lower (F=8.71) compared to year and tillage system (Table 4). The dry weight of weeds in the treatment with ploughless tillage (C) and with shallow pre-sowing ploughing (B) was higher compared to the treatments with conventional plough tillage (A) by respectively 102.5 and 11.1% in the first crop rotation, whereas in the period 2003-2006 it was higher by 70.8 and 23.3%. An increase in weed weight as a result of replacing ploughings by disking and cultivating (C,C1) was most evident in the years 2000 and 2003 (Table 2). In the second crop rotation (2003-2006), the study showed an increase in weed dry weight under the conditions of lower mineral fertilization (a1), which was 12.7 $g \cdot m^{-2}$ compared to that found in treatment b1. The highest value of the trait in question in the plots with lower mineral fertilization was found in 2005. The dry weight of weeds differed significantly between years (Tables 2, 3, 4).

Weed infestation of pea was significantly affected by weather conditions during the study period (Figure 1 and Tables 1, 2, 3, 4). The highest number and dry weight of weeds were found in the years 2002, 2003 and 2005, which were characterized by a small amount of rainfall, much different from the long-term mean. An insufficient amount of rainfall was observed especially in the month of sowing (April), which resulted in poor competitiveness of pea against weeds. A high dry weight of weeds was also found in the year 2000 in which high rainfall and the highest air temperature were recorded in April.

Table 2
Air-dry matter of weed in g m^{-2} of pea crop in 1999-2002 and 2003-2006

Years	Tillage systems			Levels of mineral fertilization		Mean
	A, A1	B, B1	C, C1	a, a1	b, b1	
1999	21.4	20.1	32.1	21.0	28.1	24.6
2000	67.4	69.8	112.8	86.9	79.7	83.3
2001	5.8	12.0	13.7	9.0	12.1	10.6
2002	17.6	22.5	68.2	36.0	36.2	36.1
Mean	28.0	31.1	56.7	38.2	39.0	-
$LSD_{0.05}$	tillage systems – 11.07; years - 14.06; tillage systems x years - 31.32					
2003	46.8	64.0	122.8	73.1	82.6	77.9
2004	17.1	20.9	18.3	19.4	18.0	18.7
2005	84.6	93.9	100.6	115.1	70.9	93.0
2006	28.1	39.1	60.4	49.8	35.3	42.6
Mean	44.2	54.5	75.5	64.4	51.7	-
$LSD_{0.05}$	tillage systems – 12.63; fertilization – 8.59; years – 16.05; tillage systems x years – 35.74; fertilization x years – 26.94					

Table 3
F-value and probability of the significance of main effects and their interaction for number of weeds in 1999-2002 and 2003-2006

Source of variation	1999-2002		2003-2006	
	F	p	F	p
Years	94.7	0.000**	4.92	0.004**
Tillage systems	140.37	0.000**	15.69	0.000**
Levels of mineral fertilization	3.75	0.057	6.43	0.013*
Years x tillage systems	30.26	0.000**	4.08	0.001**
Years x levels of mineral fertilization	0.22	0.885	2.44	0.072
Tillage systems x levels of mineral fertilization	0.36	0.702	0.52	0.600

In the first crop rotation, weed communities were dominated by annual species in all experimental treatments (Table 5 and Figure 2). In the plough treatment (A), *Galinsoga ciliata* (21.2%)*, Veronica arvensis* (17.2%) and *Galium aparine* (11.4%) had the highest percentage contribution to weed infestation. Reduced tillage resulted in a decline in the numbers of these species. Under ploughless tillage conditions (C), compared to treatment A, the percentages of the above-mentioned taxa in the weed community decreased by 44%, 58% and 83%, respectively. On the other hand, the reduction in tillage operations contributed to a substantial increase in the numbers of *Apera spica-venti*, which accounted for as much as 50.5% of total weed infestation in treatment C. Among perennial weeds, *Elymus repens* was predominant and its proportion in weed infestation slightly increased under reduced tillage conditions. In the conservation tillage system during the period 2003-2006, the percentage of perennial weeds in weed infestation was observed to increase markedly; this increase was 46.1% in treatment B1 and 150.3% in treatment C1 (Table 6 and Figure 2). This was caused by the higher incidence of *Elymus repens*. During the second crop rotation, *Galinsoga ciliata* was the most numerous annual weed; under conventional tillage conditions, it accounted for as much as 55.9% of total weed infestation, in treatment B1 – for 39.3%, whereas in the no-ploughing treatment its percentage was 30.3%. In treatment C1, similarly as in the first crop rotation, *Apera spica-venti* had a high proportion in the weed community (21.6%). In treatment B1, this species occurred in very low numbers, whereas in treatment A1 it was not found to occur.

Table 4
F-value and probability of the significance of main effects and their interaction for weight of weeds in 1999-2002 and 2003-2006

Source of variation	1999-2002		2003-2006	
	F	p	F	p
Years	70.6	0.000**	61.58	0.000**
Tillage systems	23.37	0.000**	18.52	0.000**
Levels of mineral fertilization	0.05	0.833	8.71	0.004**
Years x tillage systems	3.95	0.002**	5.44	0.000**
Years x levels of mineral fertilization	0.64	0.592	7.31	0.000**
Tillage systems x levels of mineral fertilization	0.61	0.548	0.09	0.915

Table 5
Percentage of dominant species of weeds in the pea (mean from 1999-2002)

Weed species	Tillage systems			Levels of mineral fertilization	
	A	B	C	a	b
I. Short-lived					
Galinsoga ciliata (Raf.) S. F. Blake	21.2	19.3	11.8	15.4	14.9
Viola arvensis Murray	17.2	14.5	7.2	10.6	10.6
Galium aparine L.	11.4	5.5	1.9	3.6	5.2
Chenopodium album L.	9.6	5.5	1.9	3.8	4.1
Apera spica-venti (L.) P. Beauv.	8.2	11.8	50.5	33.3	35.8
Galinsoga parviflora Cav.	2.9	2.4	1.9	2.9	1.3
Matricaria maritima ssp. *inodora* (L.) Dostál	2.9	2.4	1.3	1.8	1.8
Stellaria media (L.) Vill.	2.9	2.4	2.1	2.3	2.3
Other short-lived weeds	9.3	12.1	6.3	8.0	8.8
Total short-lived weeds	85.6	75.9	84.9	81.6	84.8
II. Perennial					
Elymus repens (L.) Gould	7.7	16.6	11.5	13.7	10.1
Other perennial weeds	6.7	7.5	4.7	4.7	5.1
Total perennial weeds	14.4	24.1	15.1	18.4	15.2

Table 6
Percentage of dominant species of weeds in the pea (mean from 2003-2006)

Weed species	Tillage systems			Levels of mineral fertilization	
	A1	B1	C1	a1	b1
I. Short-lived	%				
Galinsoga ciliata (Raf.) S. F. Blake	55.9	39.3	30.3	45.9	28.9
Galium aparine L.	8.5	5.1	1.8	2.6	6.2
Galinsoga parviflora Cav.	7.7	10.5	3.6	6.5	6.6
Avena fatua L.	3.9	2.8	0.7	1.7	2.3
Viola arvensis Murray	1.5	1.5	0.3	0.7	1.2
Chenopodium album L.	1.5	1.1	0.9	0.9	1.3
Matricaria maritima ssp. *inodora* (L.) Dostál	1.5	0.6	0.9	0.9	1.0
Apera spica-venti (L.) P. Beauv.	-	0.7	21.6	10.6	11.2
Other short-lived weeds	3.4	3.2	2.1	2.4	2.8
Total short-lived weeds	83.9	64.8	62.2	72.2	61.5
II. Perennial					
Elymus repens (L.) Gould	14.0	30.3	33.9	24.4	33.9
Other perennial weeds	2.1	4.9	3.9	3.4	4.6
Total perennial weeds	16.1	35.2	37.8	27.8	38.5

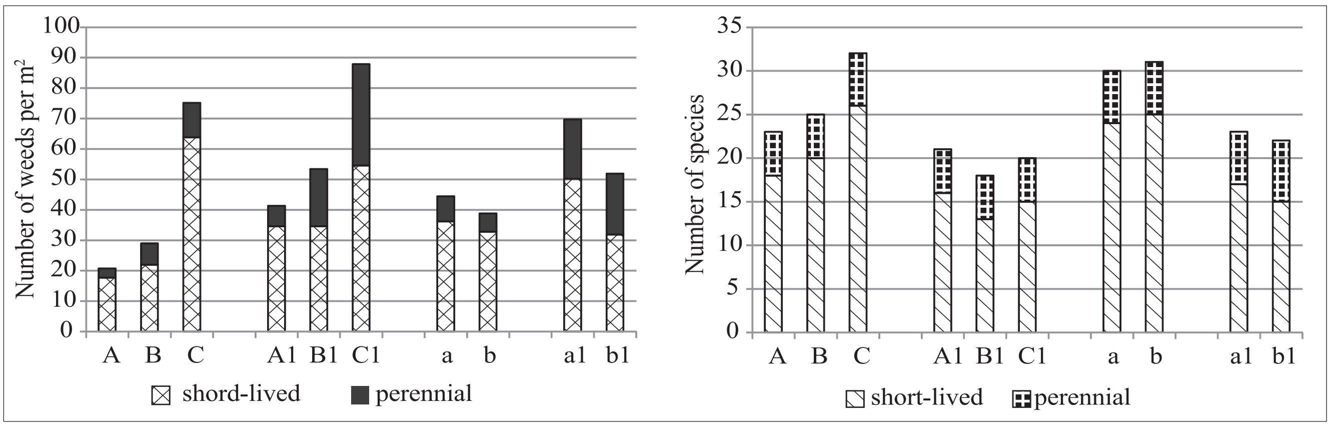

Fig. 2. Influence of tillage systems (A,B,C,A1,B1,C1) and mineral fertilization levels (a,b,a1,b1) on the number of weed and the number of species short-lived and perennial in the pea crop in 1999-2002 and 2003-2006

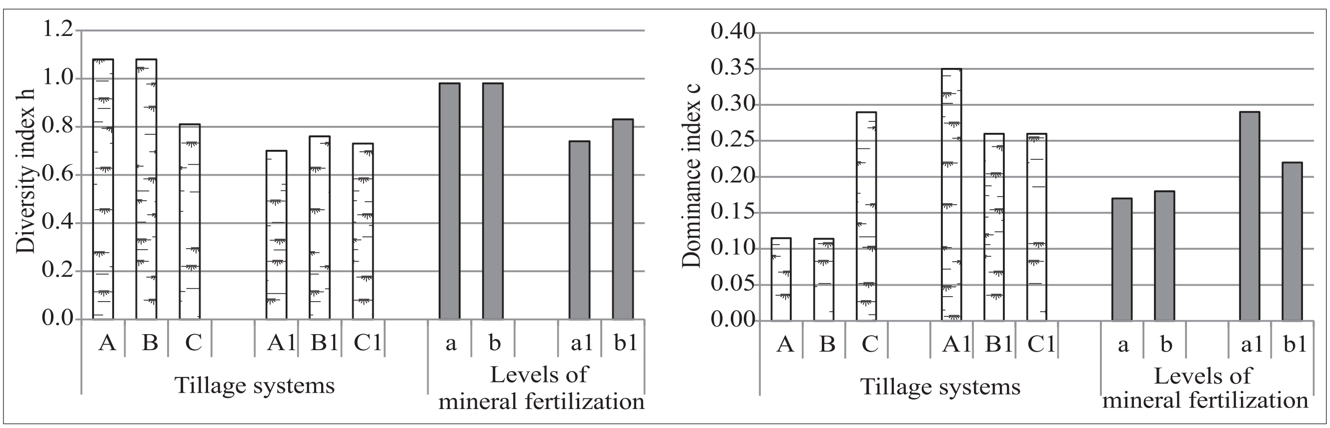

Fig. 3. Values of diversity index h to diversity index H and dominance index c to dominance index C

In both crop rotations, mineral fertilization did not significantly differentiate the qualitative structure of weed infestation of the field pea crop (Tables 5, 6).

In the first crop rotation, despite that the highest number of weed species occurred in the ploughless tillage system (C) (Table 5 and Figure 2), weed communities found there were characterized by the lowest biodiversity (H=0.81) and the highest dominance index (C=0.29) (Figure 3). Over the period 2003-2006, there was a clear decrease in the biodiversity of weed communities and an increase in the dominance indices (C) in all tillage treatments (Table 6 and Figures 2, 3). The biodiversity indices (H) in these treatments were at a similar level, but the dominance of *Galinsoga ciliata* under plough tillage conditions had an effect on the high dominance index (C=0.35) of this community. In analysing mineral fertilization rates, greater biodiversity of the communities was found in the first crop rotation, whereas in the period 2003-2006 the intensely fertilized community (b1) was characterized by higher Shannon's index (H).

Discussion

Weed infestation is a huge problem in growing pea. Field pea is sown in wide rows and is characterized by protracted and uneven emergence. Proper soil moisture conditions are a very important element that affects the germination of this plant, Drought greatly limits emergence and reduces the plant density per unit area, which results in lower competitiveness against weeds (Velykis and Satkus, 2010). Hence, it is very important to develop an optimal tillage method that will combine the soil protective effect and reduction in weed infestation of a field pea plantation (Velykis and Satkus, 2010; Woźniak, 2012). The effect of tillage on weed infestation of fields is not unambiguous. Błażewicz-Woźniak et al. (2011) did not show agronomic practices to significantly affect weed infestation of *Scorzonera hispanica*. They only found a slight increase in the number of perennial weeds during spring ploughing. In the case of faba bean, the use of reduced tillage resulted in a decline in the number of weeds, with a simultaneous increase in their dry weight. Tillage did not affect weed richness, but direct drilling promoted the growth of nuisance weeds (Giambalvo et al., 2012). Mas et al. (2003) did not show tillage systems to have a significant influence on weed biomass. Other authors demonstrate that reduced tillage, in particular replacing ploughing with shallow soil disturbances that do not turn the soil over and the total abandonment of tillage, contributes to increased weed infestation of agrophytocenoses, especially in the initial years of reduced tillage treatments (Torresen et al., 2003; Blecharczyk et al., 2004; Ozpinar, 2006; Knezević et al., 2009). The reasons for this phenomenon are seen, among others, in an increase in soil organic matter which reduces the efficacy of herbicide action (Torresen et al., 2003). Usman et al. (2010) showed that reduced tillage limited weed infestation of a winter wheat crop. One of the reasons for such correlations can be the increased biological activity of soils under no-till, which is associated with large numbers and diversity of microorganisms decomposing weed seeds and with the multiplication of *Pseudomonas* ssp. bacteria that inhibit weed germination (Małecka et al., 2009).

The present study confirmed the results obtained by many researchers. Long-term reduced tillage had an effect on increased weed infestation of field pea as expressed by the number and dry weight of weeds. A distinct increase in weed infestation was observed under conservation tillage conditions. Woźniak (2012) obtained similar results in the climatic condition of the Lublin region. This author showed that in ploughless tillage the weed infestation parameters increased by 100% in the case of the number of weeds and by 13% for their dry weight. Weed competitiveness of field pea clearly decreased under adverse soil moisture conditions. A study carried out in Lithuania demonstrated that in the first two years of the experiment, which were favourable for pea growth due to high soil moisture content, the number of weeds determined at the pea growth stage BBCH 30-32 and their dry weight determined at BBCH 73-75 did not differ significantly between tillage systems (plough tillage, shallow ploughing, ploughless tillage). But in the last year of the study, which was dry and in which pea emergence was unreliable, the weed infestation parameters were significantly higher under reduced tillage compared to conventional tillage (Velykis and Satkus, 2010).

Tillage also affects the diversity of weed communities in agroecosystems. Long-term conservation tillage, in particular replacing the plough by implements that do not turn the soil over, very often contributes to an increased proportion of perennial and monocotyledonous weeds (Locke et al., 2002; Giambalvo et al., 2012). Buhler et al. (1994) conducted a 14-year study on the dynamics of weed infestation in agroecosystems depending on tillage system. They found that more numerous and diverse weed communities formed under reduced tillage conditions relative to plough tillage. The present study confirms these relationships. Long-term conventional tillage contributed to a substantial increase in the percentage proportion of *Elymus repens* in the community. Gruber and Claupein (2009) found that shallow ploughing or replacing ploughing by tillage treatments that do not turn the soil over contributed to a marked increase in the numbers of *Cisrsium arvense*. In the study of Woźniak (2012), *Cirsium arvense*, *Elymus repene* and *Convolvulus arvensis* appeared under ploughless tillage. Velykis and Satkus (2012) also found that reduced tillage caused an increase in the number of perennial species. In the present experiment, a substantial increase in the percentage contribution of *Apera spica-venti* to weed infestation of the pea crop was observed under ploughless tillage. Similarly, Blecharczyk et al. (2010) noted higher weed infestation with common windgrass under zero tillage, Mas et al. (2003) observed an increased incidence of *Avena sterilis* under ploughless tillage conditions, while Blecharczyk et al. (2004) found the same for *Echinochloa crus-galli*.

The effect of reduced tillage on weed biodiversity is diverse. Légère et al. (2005) assessed that soil tillage intensity had little effect on the species diversity of weed communities in agroecosystems. The above-mentioned authors found the highest number of species under no-till conditions, but the values of Shannon's index H did not show unambiguously that weed diversity increased under conservation tillage. Mas et al. (2003) made opposite observations. In their research, weed communities under zero tillage were characterized by the highest Shannon's index (H). The study of Jędruszczak and Antoszek (2004) demonstrates that weed biodiversity in a wheat monoculture under the soil and climatic conditions of Czesławice was higher under conventional tillage and direct drilling than in ploughless tillage. The present experiment does not fully confirm the results obtained by Jędruszczak and Antoszek (2004). The biodiversity of weed communities was greater in the first crop rotation. Over the period 1999-2002, agrophytocenoses in which ploughless tillage was used (C) were characterized by the lowest Shannon's index H. The next four years contributed to a decrease in weed biodiversity in the case of all tillage systems.

As far as the above considerations are concerned, it should be noted that mineral fertilization is a factor which affected weed infestation of field pea to a much lesser extent (Tables 3, 4). The present study showed that in the first crop rotation fertilization did not have a significant effect on the qualitative and quantitative parameters of weed infestation. It was only in the period 2003-2006 that intensive mineral fertilization affected a significant decrease in the number and dry weight of weeds, which might have been associated with atypical weather conditions (dry years). The rich literature on the subject does not confirm such effect. Sobkowicz and Podgórska-Lesiak (2007) even showed that enhanced nitrogen fertilization increased the number and dry weight of weeds in field pea. Bujak and Frant (2006) found intensive NPK fertilization to have a limited effect on potato, while Piekarczyk (2010) did not show this factor to affect weed infestation of winter wheat. In the present study, NPK fertilization did not differentiate the species composition of the communities. Similar results were also obtained by Andersson and Milberg (1998).

Conclusions

In the field pea crop, ploughless tillage and tillage with shallow pre-sowing ploughing, compared to conventional plough tillage, increased the number of weeds by respectively 261.1 and 39.4% in the first rotation, while in the second crop rotation by 112.6 and 29.3%.

Under the conditions where ploughing was abandoned, the air-dry weight of weeds was significantly higher relative to the treatments with conventional plough tillage and shallow pre-sowing ploughing by respectively 102.5 and 11.1% in the first rotation, whereas in the period 2003-2006 by 70.8 and 23.3%.

In the second crop rotation, an increase in the number and dry weight of weeds was observed under the conditions of lower mineral fertilization compared to the treatment with higher fertilizer rates.

Reduced tillage contributed to an increased proportion of perennial weeds in weed infestation, especially *Elymus repens* (L.) P. B.

In the second crop rotation, the biodiversity of weed communities in the field pea crop was found to be lower compared to the period 1999-2002.

Year and tillage system were factors that significantly differentiated the studied traits. Mineral fertilization had a much lesser effect on weed infestation of field pea.

References

Andersson, T. N. and P. Milberg, 1998. Weed flora and the relative importance of site, crop. Crop rotation and nitrogen. *Weed Science*, **46**: 30-38.

Aziz, I., T. Mahmood and R. K. Islam, 2013. Effect of long term no-till and conventional tillage practices on soil quality. *Soil and Tillage Research*, **131**: 28-35.

Błażewicz-Woźniak, M. and M. Konopiński, 2011. Effect of soil cultivation and intercrop plant growing upon weed infestation of Spanish salsify (*Scorzonera hispanica* L.). *Acta Scientiarum Polonorum Hortorum Cultus*, **10** (2): 153-166.

Blecharczyk, A., I. Małecka and Z. Sawinska, 2010. Weed infestation of field pea in direct drilling. *Progress in Plant Protection/Postępy w Ochronie Roślin*, **50** (2): 775-778 (Pl).

Blecharczyk, A., I. Małecka and G. Skrzypczak, 2004. Effect of reduced tillage on yield, weed infestation of maize and soil properties. *Acta Scientiarum Polonorum Agricultura*, **3** (1): 157-163 (Pl).

Buhler, D., D. Stoltenberg, R. Becker and J. Gunsolus, 1994. Perennial weed populations after 14 years of variable tillage and cropping practices. *Weed Science*, **42**: 205-209.

Bujak, K. and M. Frant, 2006. Effect of simplified tillage and mineral fertilization on weed infestation of potato growing on loess soil. *Acta Agrobotanica*, **59** (2): 345-352 (Pl).

Chauhan, B. and D. E. Johnson, 2009. Influence of tillage systems on weed seedling emergence pattern in rainfed rice. *Soil and Tillage Research*, **106**: 15-21.

Deike, S., B. Pallutt, B. Melander, J. Strassemeyer and O. Christen, 2008. Long-term productivity and environmental effects of arable farming as affected by crop rotation, soil tillage intensity and strategy of pesticide use: A case-study of two long-term field experiments in Germany and Denmark. *European Journal of Agronomy*, **29 (4)**: 191-199.

Giambalvo, D., P. Ruisi, S. Saia, G. Di Miceli, A. S. Frenda and G. Amato, 2012. Faba bean grain yield, N_2 fixation, and weed infestation in a long-term tillage experiment under rainfed Mediterranean conditions. *Plant and Soil*, **360** (1-2): 215-227.

Gruber, S. and W. Claupein, 2009. Effect of tillage intensity on weed infestation in organic farming. *Soil and Tillage Research*, **105** (1): 104-111.

Hanavan, R. P., N. A. Bosque-Pere, D. J. Schotzko, S. O. Guy and S. D. Eigenbrode, 2008. Early-season aerial adult colonization and ground activity of pea leaf weevil (*Coleoptera*: *Curculionidae*) in pea as influenced by tillage system. *Journal of Economic Entomology*, **101** (5): 1606-1613.

Jędruszczak, M. and R. Antoszek, 2004. Tillage systems and biodiversity of weed communities in winter wheat monoculture. *Acta Scientiarum Polonorum Agricultura*, **3** (2): 47-59 (Pl).

Knezević, M., R. Bolicević and L. Ranogajec, 2009. Influence of soil tillage and low herbicide doses on weed dry weigh and cereals crop yields. *Herbologia*, **10** (1): 79-88.

Légère, A., F. C. Stevenson and D. L. Benoit, 2005. Diversity and assembly of weed communities: contrasting responses across cropping systems. *Weed Research*, **45** (4): 303-315.

Locke, M. A., K. N. Reddy and R. M. Zablotowicz, 2002. Weed management in conservation crop production systems. *Weed Biology and Management*, **2**: 123-132.

Małecka, I., A. Blecharczyk and T. Dobrzeniecki, 2009. The productivity and environmental consequences of long-term ploughless tillage systems in field pea. *Fragmenta Agronomica*, **26** (3): 118-127 (Pl).

Małecka I., D. Swędrzyńska, A. Blecharczyk and M. Dytman-Hagedron, 2012. Impact of tillage systems for pea production on physical, chemical and microbiological soil properties. *Fragmenta Agronomica*, **29** (4): 106-116 (Pl).

Mas, M. T. and A. M. C. Verdú, 2003. Tillage system effects on weed communities in a 4-year crop rotation under Mediterranean dryland conditions. *Soil and Tillage Research*, **74** (1): 15-24.

Ozpinar, S., 2006. Effects of tillage systems on weed population and economics for winter wheat production under the Mediterranean dryland conditions. *Soil and Tillage Research*, **87** (1): 1-8.

Piekarczyk, M., 2010. Effect of fertilisation dose, plant protection input and sowing rate of winter wheat on weed infestation in short-time monoculture. *Annales UMCS Agricultura*, **65** (2): 48-57 (Pl).

Shirtliffe, S. J. and E. N. Johnson, 2012. Progress towards no-till organic weed control in western Canada. *Renewable Agriculture and Food Systems*, **27** (1): 60-67.

Sobkowicz, P. and M. Podgórska-Lesiak, 2007. Changes in weed infestation in pure stands and mixtures of two pea cultivars with barley affected by nitrogen fertilization. *Progress in Plant Protection/Postępy w Ochronie Roślin*, **47** (3): 271-275 (Pl).

Topham, P. B. and H. M. Lawson, 1982. Measurement of weed species diversity in crop/ weed competition studies/. *Weed Research*, **22** (5): 285-293.

Torresen, K. S., R. Skuterud, H. J. Tandsaether and M. B. Hagemo, 2003. Long-term experiments with reduced tillage in spring cereals. I. Effects on weed flora weed seed bank and grain yield. *Crop Protection*, **22** (1): 185-200.

Usman, K., S. K. Khalil and M. A. Khan, 2010. Impact of tillage and herbicides on weed density and some physiological traits of wheat under rice-wheat cropping system. *Sarhad Journal of Agriculture*, **26** (4): 475-487.

Velykis, A. and A. Satkus, 2010. Weed infestation and changes in field pea (*Pisum sativum* L.) yield as affected by reduced tillage of clay loam soil. *Zemdirbyste-Agriculture*, **97** (2): 73-82.

Velykis, A. and A. Satkus, 2012. Response of field pea (*Pisum sativum* L.) growth to reduced tillage of clayey soil. *Zemdirbyste-Agriculture*, **99** (1): 61-70.

Woźniak, A., 2012. Weed infestation of pea (*Pisum sativum* L.) crop under the conditions of plough and ploughless tillage. *Acta Scientiarum Polonorum Hortorum Cultus*, **11** (2): 253-262.

Wrzesińska, E., S. Pużyński and A. Komorowska, 2013. The effect of tillage systems on soil seed bank. *Acta Agrobotanica*, **66** (1): 113-118.

Received April, 7, 2014; accepted for printing October, 2, 2014.