Acta Sci. Pol. Hortorum Cultus, 21(5) 2022, 139–151

https://czasopisma.up.lublin.pl/index.php/asphc ISSN 1644-0692 e-ISSN 2545-1405 https://doi.org/10.24326/asphc.2022.5.12

ORIGINAL PAPER

Accepted: 1.06.2022

SEED YIELD AND WEED INFESTATION OF PEA (*Pisum sativum* L.) AND SOIL PROPERTIES IN THE SYSTEMS OF CONVENTIONAL AND CONSERVATION AGRICULTURE

Andrzej Woźniak

Department of Herbology and Plant Cultivation Techniques, University of Life Sciences in Lublin, Poland

ABSTRACT

Seed yield and weed infestation of pea as well as soil properties were evaluated in the systems of conventional (TA) and conservation (CA) agriculture. In both agricultural systems, pea was grown in crop rotation: potato – winter wheat – pea – winter barley. Shallow ploughing (10–12 cm) after previous crop harvest and pre-winter ploughing (20–25 cm) were performed, whereas a pre-sowing cultivation set was deployed in the springtime in TA. In CA, glyphosate was applied after previous crop harvest, and post-harvest residues were left on the filed surface (4.5 t ha^{-1}). A cultivation-sowing set was used in the springtime, and pea was sown at the beginning of April. The study demonstrated that the agricultural systems tested had no significant effect on pea seed yield. A higher number and air-dry weight of weeds, and a higher weed species number were demonstrated in TA than in CA. Also, a higher number and air-dry weight of weeds were recorded in 2020 than in the other study years. Contents of organic C and total N in the soil and the number of earthworms were higher in CA than in TA.

Key words: legumes, crop rotation, tillage system, post-harvest residues

INTRODUCTION

Conservation agriculture is a farming system based on crop rotation, surface tillage and mulching [Kertész and Madarász 2014]. Its benefits to the natural environment include soil protection against erosion, water protection against eutrophication, as well as landscape protection and enhancement of biodiversity [Smith et al. 1998, Rasmussen 1999, Javůrek et al. 2008, Kertész et al. 2011]. This farming system is beneficial for the biological and chemical processes in the soil as well as for the better use of water and nutrients by crops. Conservation agriculture also means benefits related to agricultural production and food security [Kertész and Madarász 2014]. It is most effective in soils exposed to erosion, but also in precipitation-deficient regions [Döring et al. 2005, Soane et al. 2012, Siddique et al. 2012]. This mainly applies to semi-arid and Mediterranean regions, where the retention of water in the soil provides a certain degree of drought resistance and an evident level of economically acceptable yields [López-Bellido et al. 1996, De Vita et al. 2007].

Plant productivity depends on many biotic and abiotic factors that influence each other and are difficult to predict [Knight 2004, Jones et al. 2006]. Nevertheless, plants in no-till system yield lower than in the conventional ploughing system [Morris et al. 2010, Gruber et al. 2012, Woźniak 2013]. According to Davis et al. [2005] and Peigné et al. [2007], the no-till system and simplified crop rotations increase weed

✉ andrzej.wozniak@up.lublin.pl

infestation, which in turn reduces crop yield [Fykse and Waernhus 1999, Bilalis et al. 2001, Woźniak and Rachoń 2019]. In the no-till system, weed seeds accumulate on the surface of the field and their seedlings emerge at the same time [Tørresen and Skuterud 2002, Gruber and Claupein 2009, Woźniak 2018]. According to Hoffman et al. [1998] and Bàrberi et al. [2001], 60 to 90% of the weed seed bank is found on the soil surface in the no-till system, and according to many authors [Cardina and Sparrow 1996, Vanasse and Leroux 2000, Buhler et al. 2001, Fracchiolla et al. 2018, Feledyn-Szewczyk et al. 2020], these seeds are the main source of field infestation.

Post-harvest residues or intercrops left as mulch play an important role in conservation agriculture as they enrich the soil with organic matter, which has a positive effect on its bioactivity, an increase in the organic carbon content, an improvement in the structure and water absorption of the soil [Li et al. 2014]. According to Morris et al. [2010], the soil coverage with plant residues should be at least 30% to meet the aforementioned goals. Other benefits of leaving plant residues on the field surface include limiting water evaporation, increasing microbial biomass, better availability of nutrients, maintaining the balance of organic carbon in the soil, activating soil enzymes, and increasing the stability of soil aggregates [Wang et al. 2019, Pranagal and Woźniak 2021]. The plant residues left on the field surface suppress weeds and create a suitable habitat for beneficial insects [Lu et al. 2000].

Based on the literature, hypotheses were formulated in this study assuming that (a) the yields of pea seeds in conventional and conservation farming systems will be similar, (b) pea stand infestation in the conservation agriculture will be lower than in the conventional tillage system, and (c) conservation agriculture will have a more beneficial effect on soil properties than the conventional system. Given the above, this study aimed to evaluate the impact of conventional and conservation agriculture on the yield of pea seeds, the structure of weed infestation and soil properties.

MATERIAL AND METHODS

Experiment design and agronomic management

A field experiment was conducted in the years 2019–2021 at the Uhrusk Experimental Farm belonging to the University of Life Sciences in Lublin (51°18'N, 23°36'E). The experiment was established with the method of randomized blocks (6 m × 25 m) in three replications. Peas seed yield, infestation of pea crops, and soil properties were evaluated in the systems of conventional (TA) and conservation (CA) agriculture. In both agricultural systems, pea was sown in crop rotation: potato – winter wheat – pea – winter barley. In TA, shallow ploughing (10–12 cm) was performed after previous crop harvest and pre-winter ploughing (20–22 cm) in the late autumn. A pre-sowing cultivation set, consisting of a cultivator, a string roller, and a harrow, was deployed in the springtime. In CA, only glyphosate was applied at a dose of 4 L ha^{-1} (a.s. 360 g L^{-1}) after previous crop harvest, whereas a cultivation-sowing set was used in the springtime. In both agricultural systems, pea of Tarchalska cultivar was sown at the beginning of April, at a sowing density of 100 seeds per m^2. The same fertilization was applied on all plots, including: 20 kg N ha^{-1}, 17 kg P ha^{-1}, and 66 kg K ha^{-1} before sowing. Weed control included twofold field harrowing: the first time – before emergence and the second time – at the third pea leaf stage. Pest control involved the application of an insecticide containing deltamethrin.

Soil and weather conditions

The soil the experiment was established on was classified as Rendzic Phaeozem [IUSS Working Group WRB 2015]. It had a composition of sandy clay and slightly alkaline pH (pH_{KCl} = 7.1). Mineral fraction distribution in its arable layer was as follows: 52% sand (2.0–0.05 mm), 24% dust (0.05–0.002 mm), and 24% clay (<0.002 mm). The content of total N in the soil was at 0.70 g kg^{-1}; contents of available forms of P, K and Mg were at 0.13 g kg^{-1}, 0.20 g kg^{-1} and 0.06 g kg^{-1}, respectively; whereas organic C content reached 11.5 g kg^{-1}.

On the study area, the growing season starts in the mid-March and spans for 215 days on average. The annual sum of precipitation in the three study years ranged from 515 to 522 mm, with 337 to 357 mm of rainfall recorded since April till September and from ca. 158 to 184 mm since October till March (Tab. 1). The highest air temperatures are recorded since June till August, whereas the lowest ones since December till February (Tab. 2).

Table 1. Average monthly precipitation (mm)

Months	Years			
	2019	2020	2021	1989–2018
January	30	25	35	30
February	13	22	66	30
March	35	30	6	37
April	12	35	40	45
May	77	57	77	68
June	41	65	37	70
July	71	73	34	83
August	90	65	96	68
September	46	52	75	60
October	31	34	14	49
November	38	34	16	38
December	37	31	23	25
Precipitation total	522	521	515	604

Table 2. Average monthly air temperature (°C)

Months	Years			
	2019	2020	2021	1989–2018
January	–3.3	1.2	0.0	–2.2
February	2.1	2.8	–3.3	–1.5
March	4.8	4.3	–0.5	2.4
April	9.7	8.2	12.8	8.6
May	13.7	11.2	15.9	14.1
June	21.8	18.9	18.9	17.2
July	18.4	18.9	19.3	19.5
August	19.6	19.8	20.8	18.5
September	14.3	15.1	15.5	13.5
October	10.4	10.7	10.0	8.0
November	6.0	5.2	3.1	2.7
December	2.5	1.3	0.1	–1.0
Mean temperature	10.0	9.8	9.4	8.3

Production features and statistical analysis

The following production features were evaluated in the study: (1) seed yield and its components (plant number per m^2 before harvest, pod number per m^2, weight of seeds per plant, and 1000 seed weight), (2) structure of weed infestation of pea crop (weed number per m^2, air-dry weight of weeds, species composition of weeds), and (3) soil properties (contents of organic C and total N, and number of earthworms per m^2).

Pea seeds were harvested using a plot harvester at the full maturity stage and seed moisture content of 14%. Plant number and pod number per m^2 were counted twice on the surface area of m^2 of each plot, seed weight per plant was determined using 30 randomly selected plants, whereas 1000 seed weight was established by measuring the weight of 2 × 500 seeds.

Weed infestation structure was evaluated with the frame method in two terms: (1) at the third pea leaf stage (13–14 stage in the BBCH scale – Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie), and (2) at the flat pod stage (75–76 BBCH) [Meier 2001]. This method consists in determining the species composition and weed number per surface area of m^2 of each plot. This surface area was selected at random, twice, using a 0.5 m × 1.0 m frame. The air-dry weight of weeds was determined at the flat pod stage (75–79 BBCH), by picking up weeds from the surface area marked by the frame, removing their root system and placing their aerial parts in an airy and dry room on openwork shelves.

The content of organic C in the soil was determined with the Tiurin method, whereas that of total nitrogen with the Kjeldahl method. The number of earthworms per m^2 was determined in the second half of May, by hand-picking the earthworms from 2 soil samples collected from the surface area of 0.25 m × 1.0 m and from the 0–0.25 m soil layer, and counting them.

Study results were developed statistically using the analysis of variance (ANOVA), whereas the significance of differences between mean values determined for agricultural systems and study years were determined with the HSD Tukey test, at $p < 0.05$.

RESULTS

Seed yield and its components

Pea seed yield was differentiated only by study years (Tab. 3). A higher seed yield was recorded in 2021 than in 2019 and 2020, with the differences reaching 14.1% and 36.6%, respectively. Significant differences in pea seed yield were also noticed between 2019 and 2020. The high variability of the seed yield in particular study years was due to significant differences in the plant number per m^2 before harvest (by 5.7–58.0%), pod number per m^2 (by 7.4–62.7%), seed weight per plant (by 9.7–23.2%), and 1000 seed weight (by 2.5–9.8%). In turn, the agricultural systems compared had no significant effect on the differences in seed yield and its components (Tab. 4).

Weed infestation

At the third pea leaf stage (13–14 BBCH), greater weed density per m^2 occurred on TA than on CA plots (Tab. 5). Also, a higher weed number in pea crop was noted in 2020 than in 2019 and 2021. The ANOVA components allow inferring that the weed number was affected to a greater extent by study years than by the agricultural systems (Tab. 6). At the flat pod stage (75–76 BBCH), a higher weed number per m^2 was recorded on TA than CA plots, and also in 2020 compared to the other study years. At this developmental stage of pea, the weed number was found to be more strongly influenced by the agricultural systems than by study years. The weed density in pea crop was also significantly affected by the interaction of agricultural systems and study years. In 2020 and 2021, more weeds were recorded in the conventional than conservation system.

The air-dry weight of weeds depended on the agricultural system, study year, and their interaction. Nearly twofold higher air-dry weight was produced by weeds in the TA than CA system. Also, a significantly higher air-dry weight of weeds was determined in 2020 compared to the other study years. This trait was also influenced by the interaction of agricultural systems and study years. Weeds produced a higher air-dry weight in 2020 and 2021, and on TA than on CA plots. The ANOVA components allowed concluding that the air-dry weight of weeds was affected to a greater extent by the agricultural system than by the study year.

The agricultural systems and study years were also drivers of differences in the composition of weed communities infesting pea crops (Fig. 1). In 2019, at the third pea leaf stage (13–14 BBCH), the most abundant weed species found in the TA system included: *Consolida regalis, Papaver rhoeas, Avena fatua*, and *Veronica persica,* whereas in the CA system they included: *A. fatua*, *Apera spica-venti*, *C. regalis*, and *V. persica*. In 2020, the weed community on TA plots was predominated by: *A. spica-venti*, *Chenopodium album*, *Anthemis arvensis*, and *P. rhoeas*, whereas on CA plots by: *Capsella bursa-pastoris*, *A. arvensis*, *A. fatua*, and *V. persica*. In 2021, the species prevailing in the TA system included: *A. fatua*, *A. spica-venti*, *P. rhoeas*, and *V. persica*, whereas those prevailing in the CA system included: *C. bursa-pastoris*, *A. fatua*, *C. regalis*, and *A. spica-venti*.

Table 3. Yield seeds and its components

Specification	Years (Y)	Agricultural systems (AS)		Mean
		TA[a]	CA	
Seed yield (t ha^{-1})	2019	4.31	4.18	4.25
	2020	3.71	3.40	3.55
	2021	5.02	4.68	4.85
	mean	4.35	4.09	–
	$HSD_{0.05}$ for AS – ns; Y – 0.34; AS × Y – ns			
Plant number per m^2	2019	59.3	56.7	58.0
	2020	40.0	37.7	38.8
	2021	62.3	60.3	61.3
	mean	53.9	51.6	–
	$HSD_{0.05}$ for AS – ns; Y – 6.1; AS × Y – ns			
Pod number per m^2	2019	276.0	287.0	281.5
	2020	189.3	182.0	185.7
	2021	294.3	310.0	302.2
	mean	253.2	259.7	–
	$HSD_{0.05}$ for AS – ns; Y – 22.8; AS × Y – ns			
Weight of seeds per plant (g)	2019	7.32	7.12	7.22
	2020	6.79	6.08	6.43
	2021	8.08	7.77	7.92
	mean	7.39	6.99	–
	$HSD_{0.05 \text{ for}}$ AS – ns; Y – 0.71; AS × Y – ns			
1000 seed weight (g)	2019	253	242	247
	2020	225	226	225
	2021	238	243	241
	mean	238	237	–
	$HSD_{0.05}$ for AS – ns; Y – 10.5; AS × Y – ns			

TA[a] – conventional agriculture; CA – conservation agriculture; ns – not significant

Table 4. Effect of agricultural systems (AS) and study year (Y) on the yield and its components

Specification	Value	AS	Y	AS × Y
Seed yield (t ha^{-1})	*F*	6.24	51.70	0.40
	p	ns	<0.01	ns
Plant number per m^2	*F*	1.50	54.35	0.10
	p	ns	<0.01	ns
Pod number per m^2	*F*	0.83	103.90	0.99
	p	ns	<0.01	ns
Weight of seeds per plant (g)	*F*	1.74	7.81	0.25
	p	ns	<0.05	ns
1000 seed weight (g)	*F*	0.19	15.74	2.27
	p	ns	<0.01	ns

ns – not significant

Table 5. Number and air-dry weight of weeds

Specification	Years (Y)	Agricultural systems (AS)		Mean
		TA	CA	
Number of weeds per m^2 (13–14 BBCH of pea)	2019	17.4	11.4	14.4
	2020	24.9	18.4	21.7
	2021	17.7	12.7	15.2
	mean	20.0	14.2	–
	$HSD_{0.05}$ for AS – 1.5; Y – 1.8; AS × Y – ns			
Number of weeds per m^2 (75–76 BBCH of pea)	2019	28.3	27.9	28.1
	2020	48.7	16.7	32.7
	2021	26.6	16.2	21.4
	mean	34.5	20.3	–
	$HSD_{0.05}$ for AS – 2.4; Y – 3.6; AS × Y – 6.5			
Air–dry weight of weeds in g m^{-2} (75–76 BBCH of pea)	2019	34.6	30.2	32.4
	2020	68.9	22.1	45.5
	2021	32.9	19.8	26.4
	mean	45.5	24.0	–
	$HSD_{0.05}$ for AS – 1.7; Y – 2.6; AS × Y – 4.6			

TA[a] – conventional agriculture; CA – conservation agriculture; ns – not significant

Table 6. Effect of agricultural systems (AS) and study year (Y) on the number and air-dry weight of weeds

Specification	Value	AS	Y	AS × Y
Number of weeds per m^2 (13–14 BBCH of pea)	*F*	546.85	355.25	3.41
	p	<0.01	<0.01	ns
Number of weeds per m^2 (75–76 BBCH of pea)	*F*	119.52	13.96	78.30
	p	<0.01	<0.05	<0.01
Air–dry weight of weeds in g m^{-2} (75–76 BBCH of pea)	*F*	721.58	205.24	266.99
	p	<0.01	<0.01	<0.01

ns – not significant

Table 7. Chemical properties of soil and the number of earthworms (in 0–25 cm soil layer)

Specification	Years (Y)	Agricultural systems (AS)		Mean
		TA	CA	
Organic C content (g kg^{-1})	2019	7.80	9.06	8.43
	2020	8.07	9.13	8.60
	2021	7.81	9.24	8.52
	mean	7.89	9.14	–
	$HSD_{0.05}$ for AS – 0.13; Y – ns; AS × Y – ns			
Total N content (g kg^{-1})	2019	0.75	0.99	0.87
	2020	0.83	0.97	0.90
	2021	0.86	1.06	0.96
	mean	0.81	1.01	–
	$HSD_{0.05}$ for AS – 0.06; Y – ns; AS × Y – ns			
Number of earthworms per m^2	2019	15.3	22.0	18.7
	2020	14.4	19.7	17.1
	2021	17.0	19.6	18.3
	mean	15.6	20.4	–
	$HSD_{0.05}$ for AS – 1.42; Y – ns; AS × Y – ns			

TA[a] – conventional agriculture; CA – conservation agriculture; ns – not significant

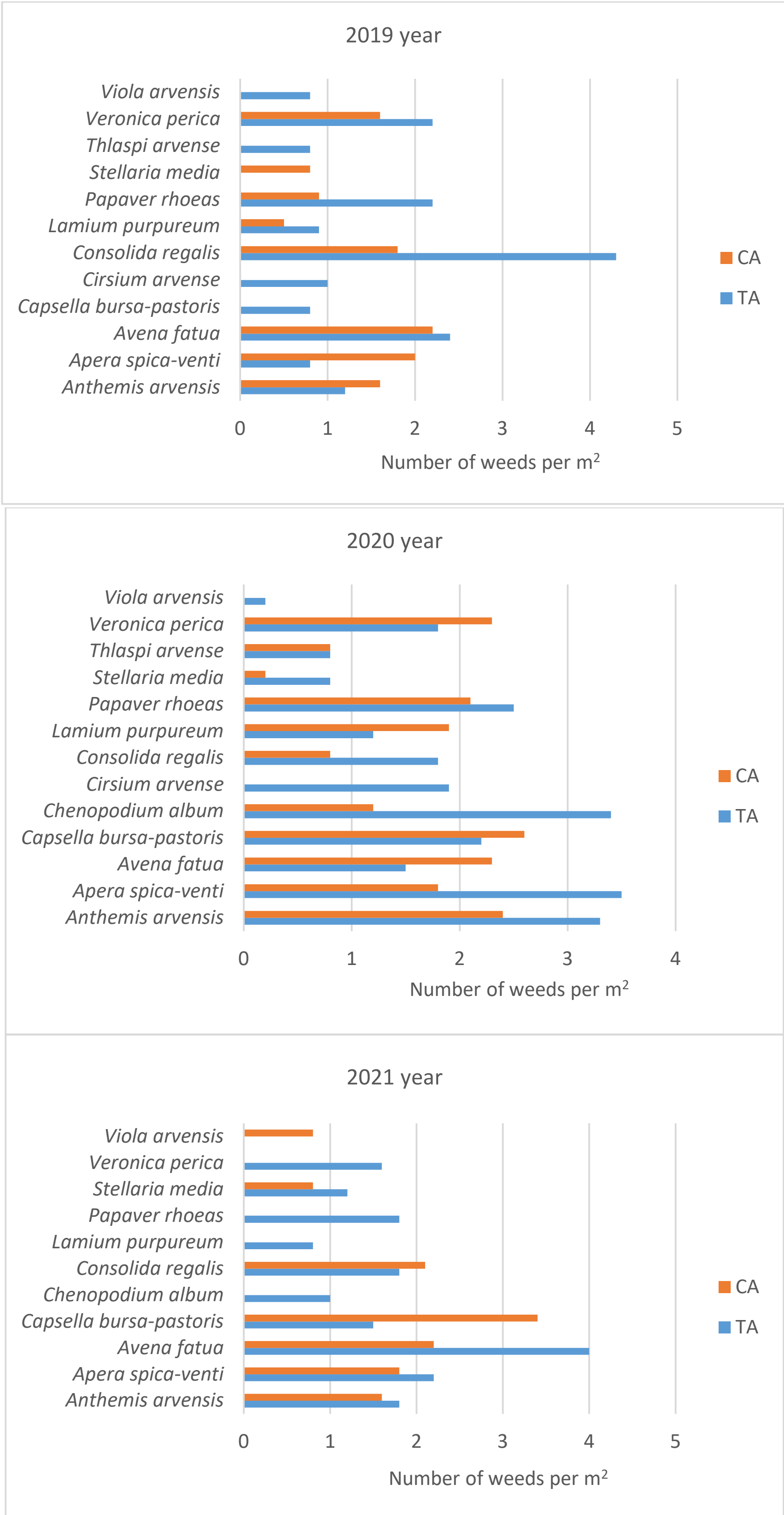

Fig. 1. Species composition of weeds in pea crop (13–14 BBCH)., CA – conservation agriculture, TA – conventional agriculture

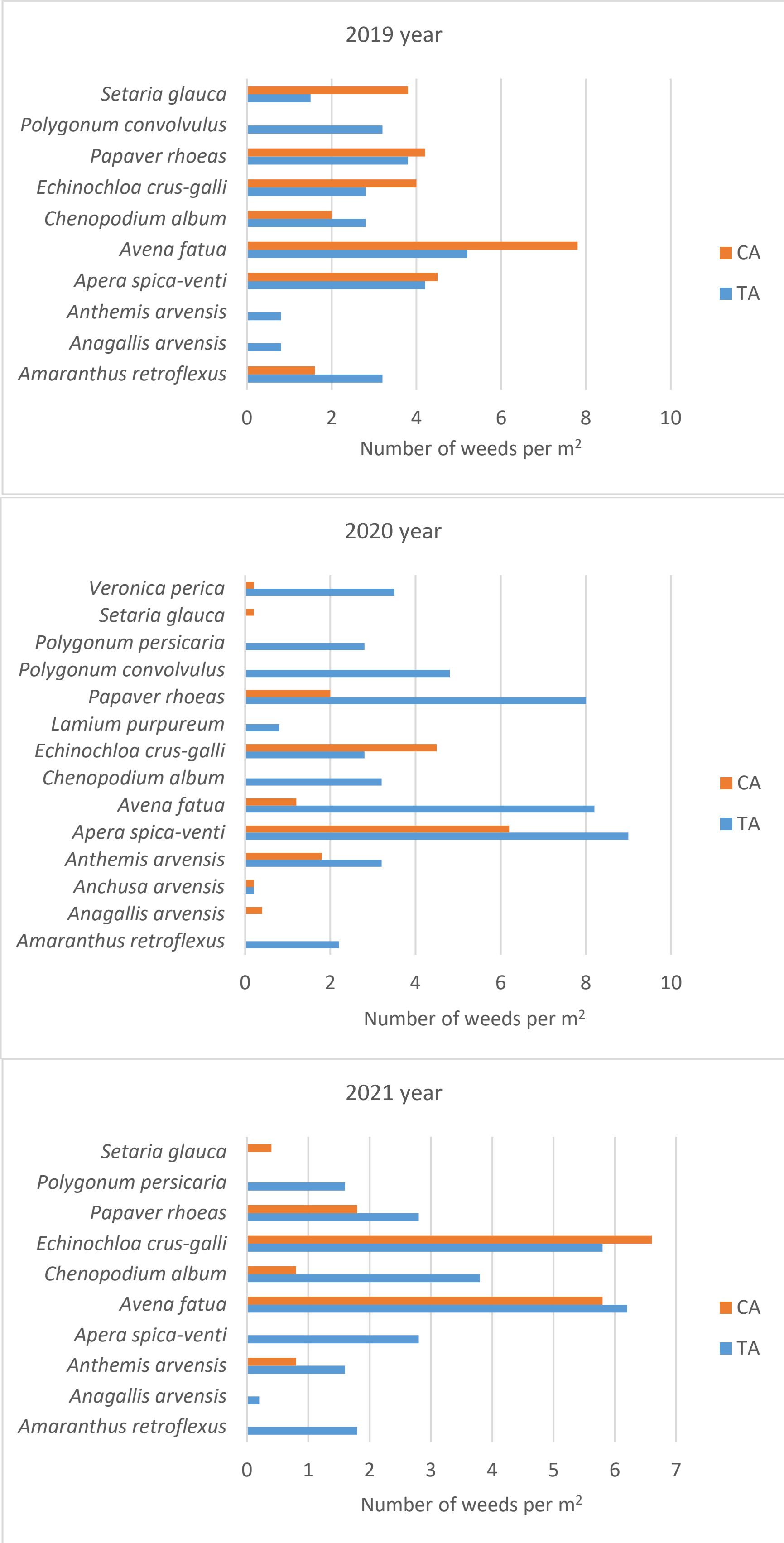

Fig. 2. Species composition of weeds in pea crop (75–76 BBCH). CA – conservation agriculture, TA – conventional agriculture

At the flat pea pod stage (75–76 BBCH), the weed community observed in 2019 on TA plots was predominated by: *A. fatua*, *A. spica-venti*, *P. rhoeas*, and *C. regalis*, whereas that observed on CA plots by: *A. fatua*, *A. spica-venti*, *P. rhoeas*, and *Echinochloa crus-galli* (Fig. 2). In 2020, the species prevailing in the TA system included: *A. fatua*, *P. rhoeas*, and *P. convolvulus*, whereas those prevailing in the CA system included: *A. spica-venti*, *E. crus-galli*, *P. rhoeas*, and *A. arvensis*. In 2021, the TA plots were most populated by: *A. fatua*, *E. crus-galli*, *Ch. album*, *A. spica-venti*, and *P. rhoeas*, whereas the CA plots by: *E. crus-galli*, *A. fatua*, and *P. rhoeas*.

The agricultural systems and study years were also drivers of differences in the number of weed species in pea crops (Fig. 3). In all study years, a higher number of weed species was observed on TA than CA plots. At the third pea leaf stage (13–14 BBCH), from 10 to 13 weed species were identified in the conventional agriculture system, and from 7 to 11 weed species in the conservation agriculture system. At the flat pod stage (75–76 BBCH), from 9 to 12 weed species were identified on TA plots, and from 6 to 8 weed species on CA plots.

Soil properties

The organic C content in the soil was higher by 15.8% on CA than on TA plots (Tab. 7). Also the total N content was affected only by the agricultural systems. It was 24.7% higher in the soil from CA than

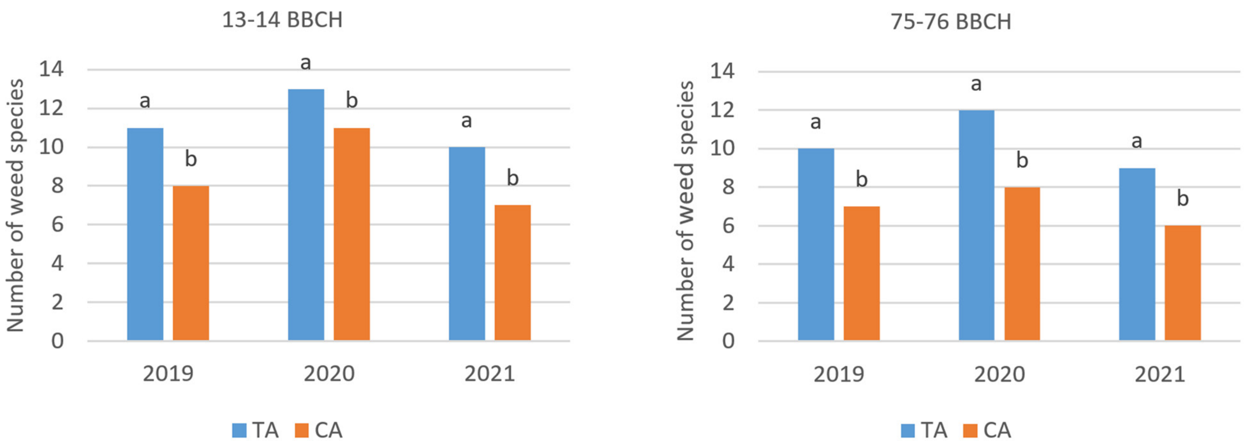

Fig. 3. Number of weed species per m^2. TA – conventional agriculture, CA – conservation agriculture. Mean values denoted with the same letters do not differ significantly, $p < 0.05$

Table 8. Effect of agricultural systems (AS) and study years (Y) on soil properties and number of earthworms

Specification	Value	AS	Y	AS × Y
Organic C content (g kg^{-1})	*F*	460.91	2.63	3.31
	p	<0.01	ns	ns
Total N content (g kg^{-1})	*F*	43.25	3.20	1.10
	p	<0.05	ns	ns
Number of earthworms per m^2	*F*	55.73	2.28	3.26
	p	<0.05	ns	ns

ns – not significant

from TA plots. Also the number of earthworms per m^2 was significantly higher (by 30.8%) in the CA than TA system. The ANOVA results indicate that the study years had only a negligible effect on the values of the above-discussed features (Tab. 8).

DISCUSSION

A feature of modern agriculture is the pursuit of high plant productivity and yield stability as well as alleviation of the adverse impact of agriculture on the natural environment [Jones et al. 2006, Kertész and Madarász 2014, Faligowska et al. 2022]. Such conditions are met by conservation agriculture that is based on crop rotation involving legume inclusion, no-till cultivation and crop residues left on the field surface [Döring et al. 2005, Herridge et al. 2008]. The conducted field experiment corroborated the beneficial effect of conservation agriculture on the produced pea seed yield, as well as its significant impact on the chemical and biological properties of the soil. The contents of organic C and total N, and the number of earthworms in the soil were significantly higher in the conservation than in the conventional agriculture system. As Peoples et al. [2009] and Woźniak [2021] report, the inclusion of legumes into the crop sequence improves the efficiency of crop rotation. This is related to the improvement of nitrogen availability in the soil and a beneficial effect on soil properties. According to Byerlee and White [2000], legumes are characterized by high variability of yields, as well as seasonal and annual price fluctuations, both on domestic and international markets. In our research, the variability of pea seed yields was influenced by study years. The greatest decrease in the seed yield was found in 2020, when pea crops were infested by the highest number of weeds which produced the highest biomass, compared to the other study years. In turn, the TA and CA systems did not differentiate the seed yield and its components. Many studies show that on soils deficient in water, plants yield better in the no-till than in the conventional ploughing system [López-Bellido et al. 1996, Knight 2004, De Vita et al. 2007, Morris et al. 2010], whereas on moderately moist soils – in the conventional tillage system [Woźniak and Gawęda 2019]. In my previous study [Woźniak 2013] conducted on moderately moist soil, over 40% higher yields of pea seeds were obtained in the conventional than no-till system. The conservation agriculture enables better control of weed infestation of crops [Siddique et al. 2012]. According to Lu et al. [2000], in this system, plant residues left on the field surface reduce weed density and lower the biomass produced by weeds. Also, in the conducted experiment, a significantly lower density of weeds and the biomass produced by them as well as a lower number of weed species were found in the conservation agriculture system than in the conventional system.

CONCLUSIONS

The agricultural systems tested had no significant effect on pea seed yield. In contrast, this trait was differentiated by study year. A higher number and biomass of weeds, and a higher weed species number were demonstrated in the conventional than conservation agricultural system. Also, a higher number and air-dry weight of weeds were recorded in 2020 than in the other study years. Contents of organic C and total N in the soil and the number of earthworms were higher in the conservation than conventional agricultural system.

SOURCE OF FUNDING

Research supported by Poland's Ministry of Science and Higher Education as part of the statutory activities of the Department of Herbology and Plant Cultivation Techniques, University of Life Sciences in Lublin.

REFERENCES

Bàrberi, P., Bonari, E., Mazzoncini, M., García-Torres, L., Benites, J., Martínez-Vilela, A. (2001). Weed density and composition in winter wheat as influenced by tillage systems. Conservation agriculture, a worldwide challenge. In: Proceedings of the First World Congress on Conservation Agriculture, Madrid, Spain, pp. 451–455.

Bilalis, D., Efthimiadis, P., Sidiras N. (2001). Effect of three tillage systems on weed flora in a 3-year rotation with four crops. J. Agron. Crop Sci., 186, 135–141.

Buhler, D.D., Kohler, K.A., Thompson, R.L. (2001). Weed seed bank dynamics during a five-year crop rotation. Weed Technol., 15, 170–176.

Byerlee, D., White, R. (2000). Agricultural systems intensification and diversification through food legumes: technological and policy options. In: Linking research and marketing opportunities for pulses in the 21st century, Knight R. (ed.). Current Plant Science and Biotechnology in Agriculture, 34. Springer, Dordrecht.

Cardina, J., Sparrow, D.H. (1996). A comparison of methods to predict weed seedling populations from the soil seedbank. Weed Sci., 44, 46–51. http://dx.doi.org/10.1017/S004317450009 353X

Davis, A.S., Renner, K.A., Gross, K.L. (2005). Weed seedbank community shifts in a long-term cropping experiment. Weed Sci., 53, 296–306. http://dx.doi.org/10.1614/WS-04-182

De Vita, P., Di Paolo, E., Fecondo, G., Di Fonzo, N., Pisante, M. (2007). No-tillage and conventional tillage effects on durum wheat yield, grain quality and soil moisture content in southern Italy. Soil Till. Res. 92, 69–78.

Döring, T.F., Brandt, M., Heß, J., Maria, R., Finckh, M.R., Saucke, H. (2005). Effects of straw mulch on soil nitrate dynamics, weeds, yield and soil erosion in organically grown potatoes. Field Crops Res., 94, 238–249. http://dx.doi.org/10.1016/j.fcr.2005.01.006

Faligowska, A., Kalembasa, S., Kalembasa, D., Panasiewicz, K., Szymańska, G., Ratajczak, K., Skrzypczak, G. (2022). The nitrogen fixation and yielding of pea in different soil tillage systems. Agronomy, 12, 352. https://doi.org/10.3390/agronomy12020352

Feledyn-Szewczyk, B., Smagacz, J., Kwiatkowski, C.K., Harasim, E., Woźniak, A. (2020). Weed flora and soil seed bank composition as affected by tillage system in three-year crop rotation. Agriculture, 10, 186. http://dx.doi.org/10.3390/agriculture10050186

Fracchiolla, M., Stellacci, A.M., Cazzato, E., Tedone, L., Alhajj Ali, S., De Mastro, G. (2018). Effects of conservative tillage and nitrogen management on weed seed bank after a seven-year durum wheat-faba bean rotation. Plants, 7, 82. http://dx.doi.org/10.3390/plants 7040082

Fykse, H., Waernhus, K. (1999). Weed development in cereals under different growth conditions and control intensities. Acta Agric. Scand., sec. B, Soil Plant Sci., 49, 134–142. http://dx.doi.org/10.1080/09064719909362509

Gruber, S., Pekrun, C., Möhring, J., Claupein, W. (2012). Long-term yield and weed response to conservation and stubble tillage in SW Germany. Soil Till. Res., 121, 49–56. http://dx.doi.org/10.1016/j.still.2012.01.015

Gruber, S., Claupein, W. (2009). Effect of tillage intensity on weed infestation in organic farming. Soil Till. Res., 105, 104–111. http://dx.doi.org/10.1016/j.still.2009.06.001

Herridge, D.F., Peoples, M.B., Boddey, R.M. (2008). Global inputs of biological nitrogen fixation in agricultural systems. Plant Soil, 311, 1–18. http://dx.doi.org/10.1007/s11104-008-9668-3

Hoffman, M.L., Owen, M.D., Buhler, D.D. (1998). Effects of crop and weed management on density and vertical distribution of weed seeds in soil. Agron. J., 90, 793–799.

IUSS Working Group WRB. (2015). World Reference Base for Soil Resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.

Javůrek, M., Hůla, J., Vach, M., Kroulík, M. (2008). Impact of different soil tillage technologies on soil erosion effect mitigation. Sci. Agric. Bohem., 39, 218–223.

Jones, C.A., Basch, G., Baylis, A.D., Bazzoni, D., Bigs, J., Bradbury, R.B., Chaney, K., Deeks, L.K., Field, R., Gomez, J.A., Jones, R.J.A., Jordan, V., Lane, M.C.G., Leake, A., Livermore, M., Owens, P.N., Ritz, K., Sturny, W.G., Thomas, F. (2006). Conservation agriculture in Europe: an approach to sustainable crop production by protecting soil and water? SOWAP, Jealott's Hill, Bracknell, UK.

Kertész, Á., Madarász, B., Bádonyi, K., Csepinszky, B., Mika, J. (2011). Conservation tillage for rational water management and soil conservation. Hung. Geogr. Bull., 60, 117–133.

Kertész, Á., Madarász, B. (2014). Conservation Agriculture in Europe. Int. Soil Water Conserv. Res., 2, 91–96. http://dx.doi.org/10.1016/S2095-6339(15)30016-2

Knight, S.M. (2004). Plough, minimal till or direct drill? Establishment method and production efficiency. In: HGCA Conference 2004. Managing Soil and Roots for Profitab. Production. London, Home Grown Cereals Authority.

Li, C., Moore-Kucera, J., Lee, J., Corbin, A., Brodhagen, M., Miles, C., Inglis, D. (2014). Effects of biodegradable mulch on soil quality. Appl. Soil Ecol., 79, 59–69. http://dx.doi.org/10.1016/j.apsoil.2014.02.012

López-Bellido, L., Fuentes, M., Castillo, J.E., López-Garrido, F.J., Fernández, E.J. (1996). Long-term tillage, crop rotation, and nitrogen fertilizer effects on wheat yield under rainfed Mediterranean conditions. Agron. J., 88, 783–791. http://dx.doi.org/10.2134/ agronj1996.000219 62008800050016x

Lu, J.C., Watkins, K.B., Teasdale, J.R., Abdul-Baki, A.A. (2000). Cover crops in sustainable food production. Food Rev. Int., 16, 121–157. http://dx.doi.org/10.1081/FRI-100100285

Meena, R.S., Lal, R. (2018). Legumes and sustainable use of soils. In: Legumes for soil health and sustainable management, Meena, R., Das, A., Yadav, G., Lal, R. (eds.). Springer, Singapore. http://dx.doi.org/10.1007/978-981-13-0253-4_1

Meier, U. (ed.). (2001). Growth stages of mono- and dicotyledonous plants. Federal Biological Research Centre for Agriculture and Forestry. Available: https://www.politicheagricole.it/flex/AppData/WebLive/Agrometeo/MIEPFY800/BBCHengl2001.pdf

Morris, N.L., Miller, P.C.H., Orson, J.H., Froud-Williams, R.J. (2010). The adoption of non-inversion tillage systems in the United Kingdom and the agronomic impact on soil, crops and the environment – a review. Soil Till. Res., 108, 1–15. http://dx.doi.org/ 10.1016/j.still.2010.03.004

Peigné, J., Ball, B.C., Roger-Estrade, J., David, C. (2007). Is conservation tillage suitable for organic farming? A review. Soil Use Manage. 23, 129–144.

Peoples, M.B., Brockwell, J., Herridge, D.F., Rochester, I.J., Alves, B.J.R., Urquiaga, S., Boddey, R.M., Dakora, F.D., Bhattarai, S., Maskey, S.L., Sampet, C., Rerkasem, B., Khans, D.F., Hauggaard-Nielsen, H., Jensen, B.S. (2009). The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. Symbiosis, 48, 1–17. http://dx.doi.org/10.1007/BF03179980

Pranagal, J., Woźniak, A. (2021). 30 years of wheat monoculture and reduced tillage and physical condition of Rendzic Phaeozem. Agric. Water Manag., 243, 106408. http://dx.doi.org/10.1016/j.agwat.2020.106408

Rasmussen, K.J. (1999). Impact of plough less soil tillage on yield and soil quality: a Scandinavian review. Soil Till. Res., 53, 3–14.

Siddique, K.H.M., Johansen, C., Turner, N.C., Jeuffory, M.E., Hashem, A., Saker, D., Gan, Y., Alghamdi, S.S. (2012). Innovations in agronomy for food legumes. A review. Agron. Sustain. Dev., 32, 45–64. http://dx.doi.org/10.1007/s13593-011-0021-5

Smith, P., Powlson, D.S., Glendining, M.J., Smith, J.U. (1998). Preliminary estimates of the potential for carbon mitigation in European soils through no-till farming. Global Change Biol., 4, 679–685. http://dx.doi.org/10.1046/j.1365-2486.1998.00185.x

Soane, B.D., Ball, B.C., Arvidsson, J., Basch, G., Moreno, F., Roger-Estrade, J. (2012). No-till in northern, western and south-western Europe: a review of problems and opportunities for crop production and the environment. Soil Till. Res., 118, 66–87. http://dx.doi.org/10.1016/j.still.2011.10.015

Tørresen, K.S., Skuterud, R. (2002). Plant protection in spring cereal production with reduced tillage. IV. Changes in the weed flora and weed seedbank. Crop Prot., 21, 179–193.

Vanasse, A., Leroux, G.D. (2000). Floristic diversity, size and vertical distribution of the weed seedbank in ridge and conventional tillage systems. Weed Sci., 48, 454–460. http://dx.doi.org/10.1614/0043-1745(2000)048%5B0454:FDSAVD%5D2.0.CO;2

Wang, X., Fan, J., Xing, Y., Xu, G., Wang, H., Deng, J., Wang, Y., Zhang, F., Li, P., Li, Z. (2019). Chapter three – the effects of mulch and nitrogen fertilizer on the soil environment of crop plants. Adv. Agron., 153, 121–173.

Woźniak, A. (2013). The yielding of pea (*Pisum sativum* L.) under different tillage conditions. Acta Sci. Pol. Hortorum Cultus, 12, 133–141.

Woźniak, A. (2018). Effect of tillage system on the structure of weed infestation of winter wheat. Span. J. Agric. Res., 16, e1009. http://dx.doi.org/10.5424/sjar/2018164-12531

Woźniak, A., Rachoń, L. (2019). Effect of tillage systems on pea crop infestation with weeds. Arch. Agron. Soil Sci., 65, 877–885. http://dx.doi.org/10.1080/03650340.2018.1533956

Woźniak, A., Gawęda, D. (2019). Tillage management effects on pea yield and chemical composition of pea seeds. Acta Sci. Pol., Hortorum Cultus, 18(1), 151–160. http://dx.doi.org/10.24326/asphc.2019.1.15

Woźniak, A. (2021). Production efficiency of different crop rotations and tillage systems. Span. J. Agric. Res., 19 (4), e0907. http://doi.org/10.5424/sjar/2021194-17023