AGRONOMY SCIENCE
wcześniej – formerly
Annales UMCS sectio E Agricultura

VOL. LXXVII (3) 2022

http://doi.org/10.24326/as.2022.3.12

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

e-mail: andrzej.wozniak@up.lublin.pl

ANDRZEJ WOŹNIAK

The influence of agricultural practices on yield and weed infestation of winter triticale

Wpływ praktyki rolniczej na plonowanie i zachwaszczenie pszenżyta ozimego

Summary. This study aimed to evaluate grain yield and weed infestation of winter triticale grown in various cropping and tillage systems. The first order factor studied was the cropping systems (CS): (1) crop rotation A (CR-A): peas – winter barley – winter triticale; (2) crop rotation B (CR-B): lupin – winter wheat – winter triticale; and (3) winter triticale monoculture (MON). The second order factor included tillage systems (TS): (a) conventional (CT); (b) reduced (RT); and (c) no-tillage (NT). A significantly higher triticale grain yield was recorded in CR-A and CR-B than in MON, and also in CT than in RT and NT, due to higher spike number per 1 m^2, grain weight per spike, and 1000 grain weight. The weed community formed in triticale crop was mainly represented by short-lived species. A higher weed number per 1 m^2 was determined in CR-A and MON than in CR-B as well as in RT than in CT and NT. In turn, weeds produced a higher air-dry weight of weeds in MON than in CR-A and CR-B, and also in RT than in CT and NT. The tillage system affected the weed contribution in particular levels of winter triticale crop, with the lower-level and middle-level species prevailing in CT and RT, and the middle-level and upper-level ones in NT.

Key words: crop rotation, monoculture, tillage system, grain yield, weeds

INTRODUCTION

The contemporary agriculture is mainly based on crop rotation consisting of 2–3 plant species and no-tillage system. However, crop productivities obtained under these conditions vary extremely and depend on the climate, soil fertility, and the level of agrotechnical measures applied [Adeux et al. 2019, MacLaren et al. 2020, Bobryk-Mamczarz et al. 2022]. According to Panasiewicz et al. [2020] and Feledyn-Szewczyk et al. [2020], the performance of crops in the conventional and no-tillage systems is determined by many co-interacting and unpredictable factors. Nevertheless, in general, cereals grown in the no-till system produce lower yields than those cultivated in the conventional system [Gruber and Claupein 2009, Woźniak and Soroka 2014, Sanginés de Cárcer et al. 2019]. As reported by Woźniak [2020], the no-tillage cultivation system as well as the simplified crop rotations increase weed infestation, which in turn leads to grain yield reduction [Skuodiene and Repšienė 2009]. Cereal crop stands are infested by weed communities formed mainly by short-lived species, including annual and biennial ones, whereas perennial species, including the ruderal ones, can also be found on the fields exposed to few agricultural measures. In cereal crops, the weed communities are formed by species belonging to the *Stellarietea mediae* class, while the associations representing this class are formed upon the influence of habitat conditions and agrotechnology level [Skuodiene et al. 2018]. As reported by Woźniak and Soroka [2015], a 24-year cereal monoculture was predominated by weeds representing the *Apero spica-venti-Papaveretum rhoeadis* association and ruderal weeds from the *Artemisietea vulgaris* class. In turn, weeds representing the *Polygono-Chenopodietalia* order were found in the crop rotation including root crops, legumes, and cereals.

The structure of cereal crop weed infestation is significantly determined by the tillage system [Woźniak and Soroka 2017, Feledyn-Szewczyk et al. 2020]. In general, greater weed diversity can be found in the conventional tillage than in the no-tillage system, because in the CT system, weed seeds are distributed throughout the arable soil layer and germinate in various seasons of the year [Santín-Montanyá et al. 2016, Schwartz-Lazaro and Copes 2019], while in the no-tillage system, they remain in the topsoil and emerge in the same time, which facilitates their effective eradication. According to Feledyn-Szewczyk et al. [2020] from 60% to 90% of weed seeds are deposited on the soil surface in the no-tillage system and represent the main source of crop stand infestation [Santín-Montanyá et al. 2016, Fracchiolla et al. 2018].

Given the above, this study aimed to evaluate grain yield and weed infestation of winter triticale grown in various cropping and tillage systems.

MATERIALS AND METHODS

Experimental location and description

The experiment was performed in the years 2017–2019 at the Uhrusk Experimental Station belonging to the University of Life Sciences in Lublin (south-eastern Poland; 51°18'N, 23°36'E). The experimental field was located at an altitude of 170 m a.s.l. Its aim was to evaluate grain yield and weed infestation of winter triticale (*Triticosecale* Wittamck), Porto cultivar, as affected by cropping and tillage systems. It was established in the system of randomized sub-blocks (25 m × 6 m), in three replications. The first order factor studied was the cropping systems (CS): (1) crop rotation A (CR-A): spring peas – winter barley – winter triticale; (2) crop rotation B (CR-B): yellow lupine – winter wheat – winter triticale; and (3) winter triticale monoculture (MON) (has been conducted since 2010). All crop rotations are carried out every year. The second order factor included tillage systems (TS): (a) conventional (CT); (b) reduced (RT); and (c) no-tillage (NT). In the CT system, shallow ploughing (at a depth of 10–12 cm from the topsoil) was performed after previous crop harvest, and pre-sow ploughing (at a depth of 18–22 cm) in the second week of September. In the RT system, the shallow ploughing was replaced by field cultivation at a depth of 10–12 cm, whereas the pre-sow ploughing – be a tillage unit composed of a cultivator, a string roller, and a harrow. In the NT system, a herbicide treatment with glyphosate (4 dm^3 ha^{-1}, 360 g dm^{-3}) was used instead of the ploughing measures, whereas a tillage unit was used before sowing.

Triticale was sown in the last week of September, in the amount of 450 seeds per 1 m^2. Before sowing, the soil was fertilized with 20 kg ha^{-1} N, 30 kg ha^{-1} P and 85 kg ha^{-1} K. After vegetation renewal in the spring, nitrogen fertilization was performed in the following doses and terms: 1) 50 kg ha^{-1} at the tillering stage (22–23 BBCH) [Meier 2001]; 2) 30 kg ha^{-1} at the shooting stage (32–33 BBCH); and 3) 20 kg ha^{-1} at the onset of the ear formation stage (52–53 BBCH).

Habitat condition

The experiment was established on the soil classified as *Rendzic Phaeozem* [FAO 2015] with the following mineral fraction composition in the arable layer: 2.0–0.05 mm 52% (sand); 0.05–0.002 mm 25% (silt), and <0.002 mm 23% (clay). The soil was sandy clay with particle density of 2.64 Mg m^{-3}, total organic carbon content of 11.67 g kg^{-1}, pH_{KCl} = 7.1, and $CaCO_3$ = 154 g kg^{-1}. Its available macroelements accounted for: total N 0.70 g kg^{-1}, P 120 mg kg^{-1}, K 200 mg kg^{-1} and Mg 70 mg kg^{-1}.

Table 1. Monthly sums of precipitation (mm) at the Uhrusk Experimental Station

Month	Years			Mean from 1989–2015
	2016–2017	2017–2018	2018–2019	
September	11.0	105.0	44.1	60.8
October	120.7	110.9	26.3	44.5
November	17.0	34.8	40.7	38.9
December	15.3	33.5	26.4	25.3
January	6.0	15.4	13.8	31.5
February	42.8	9.3	11.0	29.1
March	30.9	27.5	11.0	37.0
April	59.5	26.4	26.5	44.8
May	71.6	55.1	83.1	68.7
June	27.0	62.4	28.1	72.2
July	99.5	31.1	72.5	82.6
August	39.3	44.6	67.4	70.8
Sum of precipitation	540.6	556.3	452.4	606.4

At the study area, the growing season spanned for 210–215 days and began in the second half of March. The sums of precipitation since triticale sowing to harvest were at 540 mm in the 2016–2017 growing season, 556 mm in 2017–2018, and 452 mm in 2018–2019 (Tab. 1). The highest monthly sums of precipitation were recorded in the spring-summer months, i.e., 69 mm on average in May, 72 mm in June, and 83 mm in July; whereas the lowest ones – in the winter months, i.e., 25 mm in December, 32 mm in January, and 29 mm in February. The highest air temperatures were recorded since June till August, and the lowest ones since December till February (Tab. 2).

Table 2. Average air temperatures (°C) at the Uhrusk Experimental Station

Month	Years			Mean from 1989–2015
	2016–2017	2017–2018	2018–2019	
September	15.0	13.6	15.5	13.3
October	6.8	9.3	10.0	8.0
November	2.3	3.7	3.1	2.6
December	–0.1	1.9	0.1	–1.2
January	–5.2	–0.3	–3.5	–2.1
February	–1.7	–4.3	2.1	–1.6
March	5.8	–0.5	5.0	2.3
April	7.4	13.5	9.4	8.5
May	14.2	17.2	13.5	13.9
June	17.9	18.9	21.7	17.1
July	20.1	20.4	18.9	19.4
August	20.1	20.8	20.0	18.4
Mean temperature	8.6	9.5	9.7	8.2

Production traits

Analyses were carried out to determine winter triticale grain yield and its biometric traits (plant number after germination per 1 m^2, spike number per 1 m^2, grain weight per spike, and 1000 grain weight) as well as indices of triticale crop infestation by weeds at the maturation stage (90–92 BBCH). Plant number after germination (12–13 BBCH) and spike number per 1 m^2 were counted on the area of m^2 of each plot. The grain number per spike and grain weight per spike was measured using 30 spikes selected at random, whereas the 1000 grain weight – by counting 2 × 500 grains and weighing them. Winter triticale grain was harvested using a plot harvester, when its moisture content had reached 14%. Weed infestation was evaluated on a randomly selected area of 1 m^2 of each plot. It involved the determination of the species composition, weed plant number in the crop, and weed species distribution in crop levels. The upper-level weeds were represented by species higher than triticale, the middle-level weeds – by species reaching the height from half to the total height of the triticale crop, the lower-level weeds – by species reaching half height of the triticale crop, and the ground-level weeds – by creeping species and these reaching 10 cm in height. Weeds collected from the selected areas were placed on openwork shelves in a well-ventilated and dry room and left therein till they reached the constant air-dry weight.

Statistical analysis

Results obtained were subjected to the analysis of variance (ANOVA), whereas the significance of differences between mean values for cropping systems (CS) and tillage systems (TS) was determined with Tukey's HSD test, $P < 0.05$. For the grain yield, the coefficients of variation (CV%) were also calculated.

RESULTS

Grain yield and its components

The grain yield produced by winter triticale in CR-A and CR-B was higher by 44.7% and 39.3%, respectively, compared to MON. The higher grain yields were also recorded in the CT system than in the RT and NT systems, i.e., by 18.3% and 27.5%, respectively (Tab. 3). The differences in grain yield were also influenced by CS × TS interactions. In the CR-A system, the grain yield was higher in CT than in RT (by 25.6%) and NT (by 30%), whereas in the CR-B system, the respective differences were by 16.5% and 21.6%. In the monoculture, triticale also produced a higher grain yield in CT than in RT and NT; however, the differences observed were statistically insignificant. Grain yield variability (CV%) was affected to a greater extent by the cropping systems than by tillage systems (Tab. 4).

The cropping and tillage systems influenced triticale plant density after germination (Tab. 5), which was significantly higher in the crop rotations CR-A and CR-B than in MON (by 22.6–23.9%). A higher plant number was also recorded in the RT and CT systems compared to the NT system, by 12% and 21.1%, respectively. This yield trait was also differentiated by CS × TS interactions. In the CR-A system, plant density was significantly higher in CT (by 26.9%) than in NT. In the CR-B system the respective difference between CT and NT was 21.5%, while no significant differences were determined in MON. Similar observations were made for triticale spike number. It was higher in CR-A and CR-B than in MON (by 13.9–18.2%), and also in the CT and RT systems compared to the NT system (by 10.9–16.3%).

Table 3. Winter triticale grain yield in t ha^{-1} (average of the years 2017–2019)

Cropping systems (CS)	Tillage systems (TS)			Mean
	CT	RT	NT	
Crop rotation A (CR-A)	7.80	6.21	6.00	6.67
Crop rotation B (CR-B)	7.19	6.17	5.91	6.42
Monoculture (MON)	5.20	4.69	3.93	4.61
Mean	6.73	5.69	5.28	–
$HSD_{0.05}$ for CS = 0.82, TS = 0.82, CS × TS = 1.33				

CT – conventional tillage, RT – reduced tillage, NT – no-tillage

Table 4. Coefficients of variation (CV%) determined for winter triticale grain yield (average of the years 2017–2019)

Specification	Coefficient of variation (CV%)
Cropping systems	24.3
Tillage systems	11.2

Table 5. Components of winter triticale grain yield (average of the years 2017–2019)

Cropping systems (CS)	Tillage systems (TS)			Mean
	CT	RT	NT	
Plant number after germination per 1 m^2				
Crop rotation A (CR-A)	420	382	331	378
Crop rotation B (CR-B)	413	370	340	374
Monoculture (MON)	320	313	281	305
Mean	384	355	317	–
$HSD_{0.05}$ for CS = 26; TS = 26; CS × TS = 47				
Spike number per 1 m^2				
Crop rotation A (CR-A)	500	455	394	449
Crop rotation B (CR-B)	454	440	405	433
Monoculture (MON)	394	388	359	380
Mean	449	428	386	–
$HSD_{0.05}$ for CS = 32; TS = 32; CS × TS = 55				
Grain weight per spike in g				
Crop rotation A (CR-A)	1.56	1.36	1.52	1.48
Crop rotation B (CR-B)	1.58	1.40	1.46	1.48
Monoculture (MON)	1.32	1.21	1.09	1.21
Mean	1.49	1.32	1.36	–
$HSD_{0.05}$ for CS = 0.11; TS = 0.11; CS × TS = ns				
1000 grain weight in g				
Crop rotation A (CR-A)	51.2	50.9	44.3	48.8
Crop rotation B (CR-B)	52.0	49.9	42.1	48.0
Monoculture (MON)	47.0	44.5	42.0	44.5
Mean	50.1	48.4	42.8	–
$HSD_{0.05}$ for CS = 2.2; TS = 2.2; CS × TS = ns				

CT – conventional tillage, RT – reduced tillage, NT – no-tillage, ns – not significant

In the CR-A system, the spike number was additionally affected by CS × TS interactions, i.e., it was higher by 26.9% and 15.5% in CT and RT than in NT. The grain weight per triticale spike was higher in crop rotations CR-A and CR-B than in MON as well as in the CT system compared to RT and NT systems. Likewise, the 1000 grain weight was higher in CR-A and CR-B than in MON as well as in CT and RT than in NT. The components of the variance analysis allowed concluding that the grain yield, plant number after germination, and spike number were affected to a greater extent by CS than by TS, while the grain weight per spike and 1000 grain weight were more strongly affected by TS than by CS (Tab. 6).

Table 6. Analysis of variance for grain yield and its components

Specification	Value	CS	TS	CS × TS
Grain yield in t ha^{-1}	*F* *P*	298.9 **	110.2 *	98.0 *
Plant number after germination per 1 m^2	*F* *P*	378.3 **	224.2 *	267.3 *
Spike number per 1 m^2	*F* *P*	242.2 **	98.2 *	111.0 *
Grain weight per spike in g	*F* *P*	47.0 *	84.0 *	8.9 ns
1000 grain weight in g	*F* *P*	33.2 *	72.0 *	11.7 ns

CS – cropping systems, TS – tillage systems, * – $P < 0.05$, ** – $P < 0.01$, ns – not significant

Weed infestation structure

A higher number of weeds per 1 m^2 was determined in CR-A and MON than in CR-B as well as in the RT system than in the CT and NT systems (Tab. 7). In CR-B and MON, it was additionally affected by CS × TS interactions, which contributed to higher weed infestation in the RT than in the CT and NT systems. In turn, the air-dry weight of weeds was significantly higher in MON than in CR-A and CR-B, and also in the RT system compared to the CT and NT systems. The variance component analysis demonstrated that the weed number was more strongly influenced by TS than by CS, and that the air-dry weight of weeds was similarly affected by CS, TS and CS × TS interactions (Tab. 8).

Table 7. Number and air-dry weight of weeds per 1 m^2 of winter triticale crop (average of the years 2017–2019)

Cropping systems (CS)	Tillage systems (TS)			Mean
	CT	RT	NT	
Number of weeds per 1 m^2				
Crop rotation A (CR-A)	25.9	27.7	32.3	28.6
Crop rotation B (CR-B)	13.3	22.1	17.0	17.5
Monoculture (MON)	16.8	32.4	22.1	23.8
Mean	18.7	27.4	23.8	–
$HSD_{0.05}$ for CS = 3.8. TS = 3.8. CS × TS = 5.4				
Air-dry weight in g m^{-2}				
Crop rotation A (CR-A)	26.9	51.2	40.3	39.5
Crop rotation B (CR-B)	30.0	48.4	42.1	40.2
Monoculture (MON)	53.1	68.0	51.2	57.4
Mean	36.7	55.9	44.5	–
$HSD_{0.05}$ for CS = 4.2; TS = 4.2; CS × TS = 6.0				

CT – conventional tillage, RT – reduced tillage, NT – no-tillage

Table 8. Analysis of variance for the number and air-dry weight of weeds

Specification	Value	CS	TS	CS × TS
Number of weeds	*F*	90.2	190.2	88.0
	P	*	**	*
Air-dry weight	*F*	78.3	69.2	67.3
	P	*	*	*

CS – cropping systems, TS – tillage systems; * – $P < 0.05$, ** – $P<0.01$, ns – not significant

In the crop rotation CR-A, the weed community was composed of 11–13 species, with *Stellaria media* and *Papaver rhoeas* prevailing in CT, *Fallopia convolvulus* and *Stellaria media* in RT, as well as *Apera spica-venti* and *Papaver rhoeas* in NT. In turn, 7–8 species were identified in the crop rotation CR-B, with *Consolida regalis* predominating in all tillage systems. In the case of MON, the weed community was formed by 8–9 species, with *Papaver rhoeas, Galeopsis tetrahit*, and *Polygonum aviculare* prevailing in CT; *Consolida regalis, Apera spica-venti*, and *Papaver rhoeas* in RT, whereas *Consolida regalis*, *Papaver rhoeas*, and *Fallopia convolvulus* in NT (Fig. 1).

The crop rotation and tillage systems influenced weed species distribution in particular levels of winter triticale crop (Fig. 2). In the crop rotation CR-A, the lower-level and middle-level species prevailed in the CT system, the upper-level and lower-level ones in the RT system, whereas the lower-level, upper-level, and ground-level ones in the NT system. In the CR-B rotation, the middle-level and lower-level weed species predominated in the CT system, the upper-level and middle-level ones in the RT system, and the lower--level and middle level ones in the NT system. Finally, in the monoculture, the prevailing weed species in CT were these from the middle level followed by these from the upper and lower levels. Triticale crop in the RT system was predominated by the ground-level and middle-level weed species, while in the NT system – by weed species from the upper and ground levels.

DISCUSSION

The contemporary agricultural production is based on replacing the conventional tillage with reduced or no-till systems and neglecting the crop rotation with root crops, legumes, and inter-crops in favor of the monoculture [Sanginés de Cárcer et al. 2019, Pranagal and Woźniak 2021]. However, these solutions do not always prove effective, given the effects of climatic, soil, and agrotechnological conditions [Woźniak and Soroka 2014, Rachoń et al. 2022]. Crop yields in the conventional and no-tillage systems are determined by many inter-dependent and hardly predictable factors; with lower grain yields usually produced in the no-tillage system [Dębska et al. 2020, Feledyn-Szewczyk et al. 2020]. Also in our experiment, a higher by 18.3–27.5% grain yield was achieved in the CT than in the RT and NT systems, and also by 39.3–44.7% in the crop rotations CR-A and CR-B than in the monoculture. In the study by Woźniak and Soroka [2014], the difference in spring triticale grain yield between the CT system and the RT and NT systems ranged from 28.2% to 45.3%.

In the no-tillage cultivation systems, weeds are eradicated mainly by the herbicide treatment [Hernández Plaza et al. 2015, Westwood et al. 2018, Kumar et al. 2020]. However, under certain conditions, the continuous use of the same substances can make the weeds resistant to them [Heap and Duke 2018, Koning et al. 2019]. An example in this case can be grassy weeds *Alopecurus myosuroides* and *Apera spica-venti* that are widespread in many regions and little susceptible to sulfonylurea herbicides. This threat of resistance development by weeds can be avoided in the crop rotation system involving integrated weed control [Heap and Duke 2018]. In the present study, weed communities were formed in the CR-A and CR-B systems by species typical of the root crops and legumes, hence little competitive to winter cereals.

In contrast, MON crops were heavily infested by weed species sharing similar growth and development dynamics with triticale. Their presence was intensified by the no-tillage systems (RT and NT), which is consistent with findings reported by Fracchiolla et al. [2018]. In the present study, a higher weed number per m^2 was determined in CR-A and MON than in CR-B as well as in the RT than in the CT and NT systems. In turn, the weeds produced a higher air-dry weight in MON than in CR-A and CR-B, and also in RT than in CT and NT. In the CR-A rotation, they were represented by spring weeds at the juvenile developmental stages which contributed to the secondary infestations, whereas in MON – by grown winter weeds of the upper and middle levels. Therefore, the air-dry weight of weeds in MON was significantly higher than in both crop rotations.

The cropping and tillage systems also influenced weed distribution in triticale crop. The predominating weed species were these from the lower and middle levels; however, the upper-level species were also abundant in the RT and NT systems. In my previous research [Woźniak 2018], the ground-level and lower-level weed species prevailed in CT, whereas the ground-level and middle-level ones in the no-tillage systems (RT and NT).

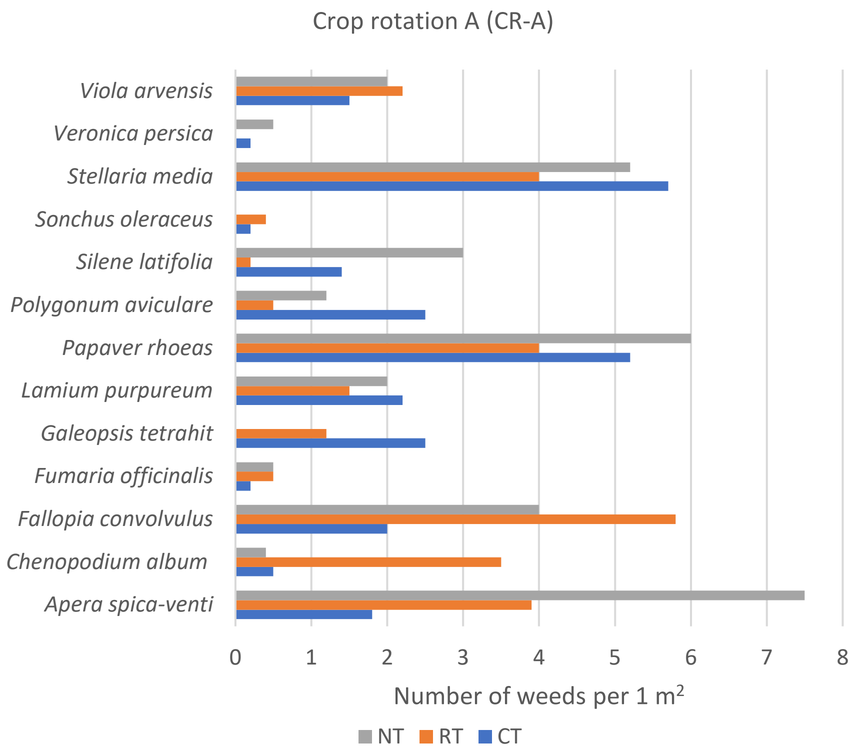
In the present study, the weeds produced the highest air-dry weight in the NT system. This was due to the abundance of silky bent grass (*Apera spica-venti*), highly-branched field poppy (*Papaver rhoeas*) and field larkspur (*Consolida regalis*) on NT plots. Also, other authors [Woźniak and Soroka 2017, Feledyn-Szewczyk et al. 2020] confirmed a higher air-dry weight produced by weeds in various variants of no-tillage cultivation compared to the conventional tillage.

CONCLUSIONS

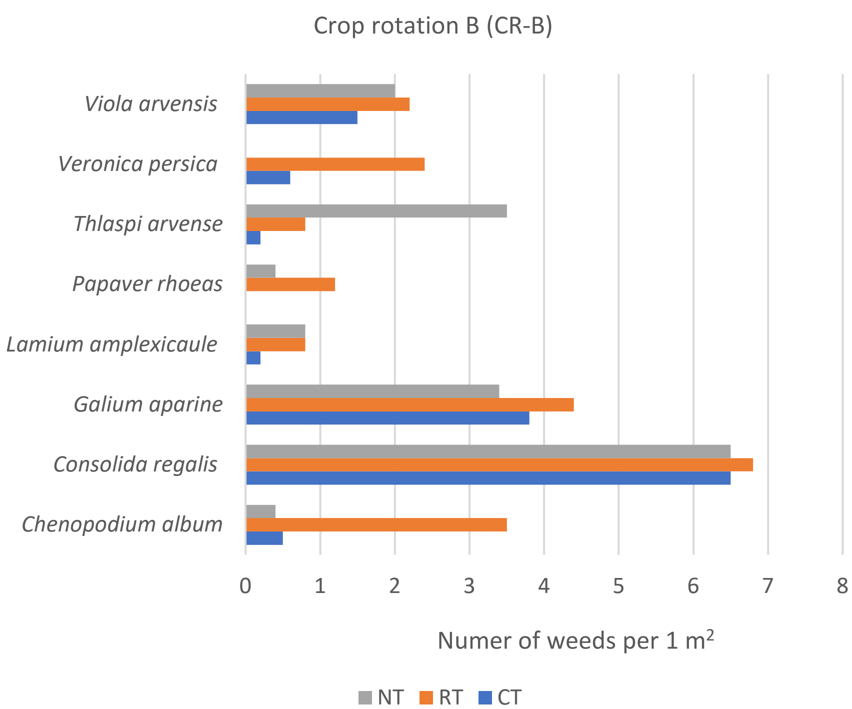
A significantly higher winter triticale grain yield was recorded in crop rotations A and B than in monoculture, and also in conventional tillage system than in reduced tillage and no tillage due to higher spike number per 1 m^2, grain weight per spike, and 1000 grain weight.

The weed community in triticale crop was formed by short-term species. In the crop rotations A and B the prevailing weed species were these typical of the root crops and legumes, whereas in the monoculture – these typical of cereals. A higher weed number per 1 m^2 was determined in crop rotation A and monoculture than in crop rotation B as well as in reduced tillage system than in conventional tillage and no-tillage. In turn, higher air-dry weight of weeds was produced in the monoculture than in crop rotations A and B, and also in reduced tillage than in conventional tillage and no-tillage.

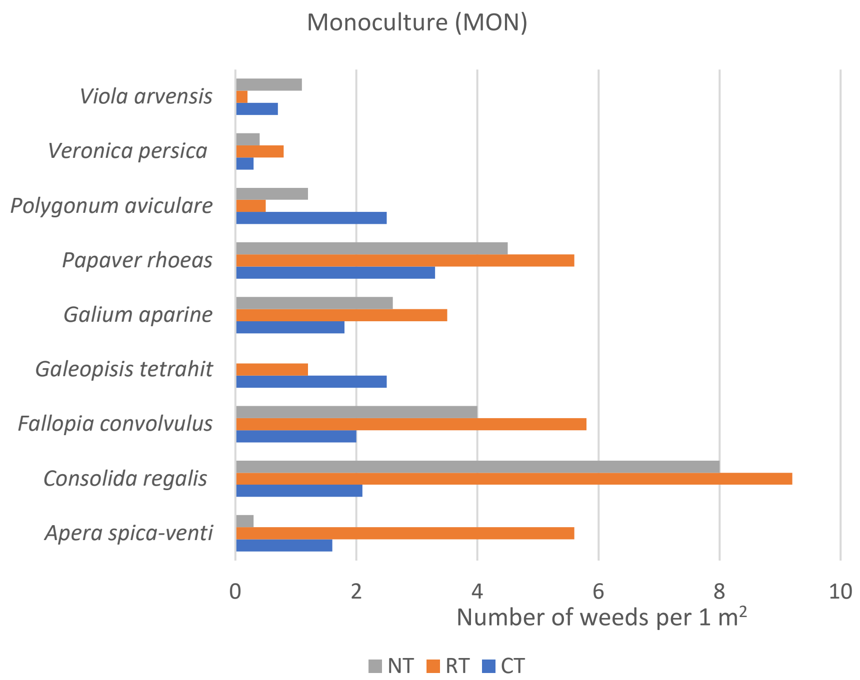
The crop succession in the crop rotation and tillage system affected the weed contribution in particular levels of winter triticale crop, with the lower-level and middle-level



Crop rotation A (CR-A)
Viola arvensis
Veronica persica
Stellaria media
Sonchus oleraceus
Silene latifolia
Polygonum aviculare
Papaver rhoeas
Lamium purpureum
Galeopsis tetrahit
Fumaria officinalis
Fallopia convolvulus
Chenopodium album
Apera spica-venti
0 1 2 3 4 5 6 7 8
Number of weeds per 1 m2
NT RT CT

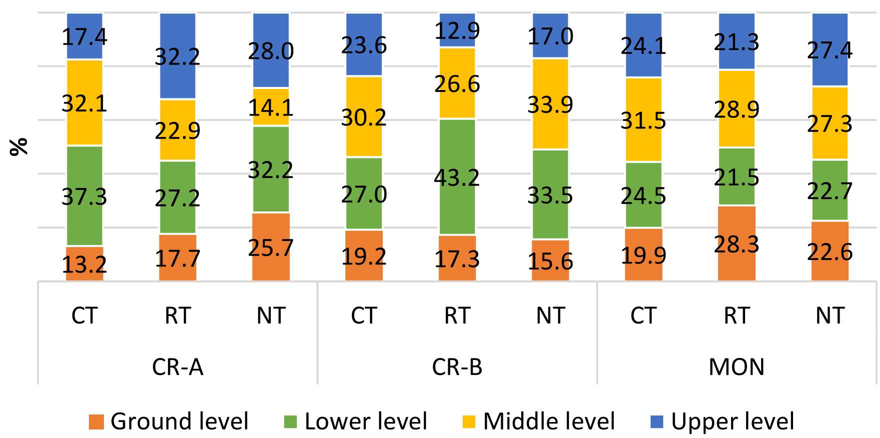


Crop rotation B (CR-B)
Viola arvensis
Veronica persica
Thlaspi arvense
Papaver rhoeas
Lamium amplexicaule
Galium aparine
Consolida regalis
Chenopodium album
0 1 2 3 4 5 6 7 8
Numer of weeds per 1 m2
NT RT CT



CT – conventional tillage, RT – reduced tillage, NT – no-tillage

Figure 1. Species composition and weed number per 1 m^2 of winter triticale crop (average of the years 2017–2019)



CT – conventional tillage; RT – reduced tillage; NT – no-tillage

Figure 2. Percentage contribution of weed species in particular levels of winter triticale crop (average of the years 2017–2019)

species prevailing in conventional tillage and reduced tillage, and the middle-level and upper-level ones in no-tillage. In the crop rotations A and B the number and air-dry weight of weeds were similar in all tillage systems, whereas in monoculture – they were higher in reduced tillage and no-tillage than in conventional tillage.

REFERENCES

Adeux G., Vieren E., Carlesi S., Bàrberi P., Munier-Jolain N., Cordeau S., 2019. Mitigating crop yield losses through weed diversity. Nat. Sustain. 2, 1018–1026. http://dx.doi.org/10.1038/s41893-019-0415-y

Bobryk-Mamczarz A., Rachoń L., Kiełtyka-Dadasiewicz A., Szydłowska-Tutaj M., Lewko P., Woźniak A., 2022. Plonowanie i jakość wybranych gatunków i odmian pszenicy makaronowej. Cz. II. Wartość technologiczna ziarna [Yielding and quality of selected species and cultivars of pasta wheat. Part. II. Technological value of grain]. Agron. Sci. 77(1), 65–78. http://dx.doi.org/10.24326/as.2022.1.6

Dębska B., Jaskulska I., Jaskulski D., 2020. Method of tillage with the factor determining the quality of organic matter. Agronomy 10(9), 1250. http://dx.doi.org/10.3390/agronomy10091250

FAO, 2015. World reference base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps. Update 2015. World Soil Resources Reports 106. FAO, Rome. https://www.fao.org/3/i3794en/I3794en.pdf [date of access: 10.12.2015].

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(5), 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(4), 82. http://dx.doi.org/10.3390/plants7040082

Gruber S., Claupein W., 2009. Effect of tillage intensity on weed infestation in organic farming. Soil Till. Res. 105(1), 104–111. http://dx.doi.org/10.1016/j.still.2009.06.001

Heap I., Duke S.O., 2018. Overview of glyphosate-resistant weeds worldwide. Pest Manag. Sci. 74, 1040–1049. http://dx.doi.org/10.1002/ps.4760

Hernández Plaza E., Navarrete L., González-Andújar J.L., 2015. Intensity of soil disturbance shapes response trait diversity of weed communities: The long-term effects of different tillage systems. Agric. Ecosyst. Environ. 207, 101–108. http://dx.doi.org/10.1016/j.agee.2015.03.031

Koning L.A., de Mol F., Gerowitt B., 2019. Effects of management by glyphosate or tillage on the weed vegetation in a field experiment. Soil Till. Res. 186, 79–86. http://dx.doi.org/10.1016/j.still.2018.10.012

Kumar V., Mahajan G., Dahiya S., Chauhan B.S., 2020. Challenges and opportunities for weed management in no-till farming systems. In: Y. Dang, R.C. Dalal, N.W. Menzies (eds.), No-till farming systems for sustainable agriculture. Springer, Cham, 107–125. https://doi.org/10.1007/978-3-030-46409-7_7

MacLaren C., Storkey J., Menegast A., Metcalfe H., Dehnen-Schmutz K., 2020. An ecological future for weed science to sustain crop production and the environment. A review. Agron. Sustain. Dev. 40, 24. http://dx.doi.org/10.1007/s13593-020-00631-6

Meier U. (ed.), 2001. Growth stages of mono-and dicotyledonous plants, 2nd. ed. Federal Biological Research Centre for Agriculture and Forestry. https://www.politicheagricole.it/flex/AppData/WebLive/Agrometeo/MIEPFY800/BBCHengl2001.pdf [date of access: 15.01.2016].

Panasiewicz K., Faligowska A., Szymańska G., Szukała J., Ratajczak K., Sulewska H., 2020. The effect of various tillage systems on productivity of narrow-leaved lupin-winter wheat-winter triticale-winter barley rotation. Agronomy 10(2), 304. https://doi.org/10.3390/agronomy10020304

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

Rachoń L., Bobryk-Mamczarz A., Kiełtyka-Dadasiewicz A., Woźniak A., Stojek Z., Zajdel-Stępień P., 2022. Plonowanie i jakość wybranych gatunków i odmian pszenicy makaronowej. Cz. I. Plonowanie [Yielding and quality of selected speciesand cultivarsof pasta wheat. Part I. Yielding]. Agron. Sci. 77, 53–63. http://dx.doi.org/10.24326/as.2022.1.5

Sanginés de Cárcer P., Sinaj S., Santonja M., Fossati D., Jeangros B., 2019. Long-term effects of crop succession, soil tillage and climate on wheat yield and soil properties. Soil Till. Res. 190, 209–219. https://doi.org/10.1016/j.still.2019.01.012

Santín-Montanyá M.I., Martín-Lammerding D., Zambranab E., Tenorio J.L., 2016. Management of weed emergence and weed seed bank in response to different tillage, cropping systems and selected soil properties. Soil Till. Res. 161, 38–46. http://dx.doi.org/10.1016/j.still.2016.03.007

Schwartz-Lazaro L.M., Copes J.T., 2019. A review of the soil seedbank from a weed scientists perspective. Agronomy 9, 369. https://doi.org/10.3390/agronomy9070369

Skuodiene R., Repšienė R., 2009. The effects of organic fertilisers and liming on segetal flora in a sustainable crop rotation on an acid soil. Zemdirbyste, 96, 154–169.

Skuodiene R., Karcauskiene D., Repsiene R., Gintares S., 2018. Changes in the weed communities as affected by different primary soil tillage and deep loosening. Acta Agric. Scand. B Soil Plant Sci. 68, 643–648. http://dx.doi.org/10.1080/09064710.2018.1455219

Westwood J.H., Charudattan R., Duke S.O., Fennimore S.A., Marrone P., Slaughter D.C., Swanton C., Zollinger R., 2018. Weed management in 2050: Perspectives on the future of weed science. Weed Sci. 66, 275–285. http://dx.doi.org/10.1017/wsc.2017.78

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., 2020. Effect of various systems of tillage on winter barley yield, weed infestation and soil properties. Appl. Ecol. Environ. Res. 18, 3483–3496. http://dx.doi.org/10.15666/aeer/1802_34833496

Woźniak A., Soroka M., 2014. Effects of a 3-years reduced tillage on the yield and quality of grain and weed infestation of spring triticale (*Triticosecale* Wittmack). Int. J. Plant Prod. 8, 231–242. http://dx.doi.org/10.22069/IJPP.2014.1526

Woźniak A., Soroka M., 2015. Structure of weed communities occurring in crop rotation and monoculture of cereals. Int. J. Plant Prod. 9, 487–506. http://dx.doi.org/10.22069/IJPP.2015.2227

Woźniak A., Soroka M., 2017. Effect of tillage systems on weed infestation of durum wheat. Int. J. Plant Prod. 11, 453–460. http://dx.doi.org/10.22069/ijpp.2017.3551

The 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.

Received: 26.08.2022
Accepted: 10.10.2022