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Impact of cropping and tillage system on take-all disease of winter wheat (*Gaeumannomyces graminis* var. *tritici*)

Wpływ następstwa roślin i systemów uprawy roli na choroby podsuszkowe pszenicy ozimej (*Gaeumannomyces graminis* var. *tritici*)

Summary. Diseases induced by *Gaeumannomyces graminis* var. *tritici (G. g. tritici)* are the most important wheat root diseases in all cropping areas around the world and significantly reduces yield and quality of wheat grain. A multi-year field experiment was used to evaluate infestation of winter wheat roots by *G. g. tritici.* The experimental factors included: I. cropping system (CS): 1) crop rotation (CR): pea – winter wheat – spring barley; 2) monoculture of winter wheat (MON); and II. tillage system (TS): 1) CT – conventional tillage, 2) RT – reduced tillage, and 3) NT – no-tillage. The following cultivation treatment were applied: a shallow ploughing after previous harvest and pre-sowing ploughing in the CT system; double cultivation instead of both aforementioned ploughing treatments in the RT system; and glyphosate in NT system. A cultivation set, consisting of a cultivator, a string roller, and a harrow, was used before wheat sowing. The value of the index of winter wheat roots infestation by *G. g. tritici* was significantly higher in the monoculture than in crop rotation. The value was also higher in NT than in CT system. In wheat monoculture with NT system, the percentage of highly and severely infested plants was higher than in crop rotation with CT system.

Key words: crop rotation, monoculture, tillage systems, index of root infestation

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INTRODUCTION

A characteristic feature of today's agriculture are crop rotations consisting of 2–3 species of commodity plants and no-tillage system. This is due to economic considerations that result from the high demand for cereal grains and seeds of oil-bearing plants and legumes as well as from low production costs, especially in the no-tillage system [Haliniarz et al. 2018, Woźniak et al. 2019]. Another priority concern is expressed over the successively decreasing soil fertility and prolonged periods of soil water deficit. They can be countered by growing crops in multispecies crop rotations and by adapting cultivation treatments to existing environmental conditions. Investigations conducted by Lal [2009], Woźniak and Gos [2014], and by Liu et al. [2016] have indicated that the no-tillage system reduces water evaporation from the soil, improves organic carbon balance in the soil, improves soil biological and enzymatic activity, and prevents erosion. However, a drawback of this system is the increase in weed infestation, as well as the compensation of troublesome weed species (especially *Apera spica-venti* (L.) P. Beauv.) [Woźniak 2018]. Their eradication requires increased amounts of non-selective herbicides, which additionally increases the likelihood of weeds becoming resistant to these agents [Koning et al. 2019].

Wheat grain yield and quality are affected by stem base and root diseases, however the range of yield variability is very large [Sieling et al. 2005, Janvier et al. 2007, Ramanauskienė et al. 2019]. The high infestation with these pathogens is observed in fields where wheat, triticale, and barley are constantly sown in succession [Andrade et al. 2011]. According to Freeman and Ward [2004], diseases induced by *G. g. tritici* are the most important wheat root diseases. The first signs of infestation are noticeable on wheat germ roots, while as the root system develops, infection appears on adventitious roots [Augustin et al. 1997, Bailey and Gilligan 1999, Bailey et al. 2009]. The infested plants die prematurely or produce small and poorly developed grains. This fungus can survive on straw residues for 2–3 years. A study conducted by Kurowski and Adamiak [2007] has shown that cereals cultivated in the monoculture were most often infested by *Fusarium* spp., less often by *Tapesia yallundae* (*Oculimacula yallundae*) and incidentally by *G. g. tritici* and *Rhizoctonia cerealis*.

This study aimed to evaluate the effect of cropping system and tillage systems on winter wheat roots infestation by *G. g. tritici*.

MATERIALS AND METHODS

Localization of the experiment, soil and weather conditions

A field experiment was established in 1988 at the Uhrusk Experimental Station of the University of Life Sciences in Lublin (south-eastern Poland, 51°18'N, 23°36'E), and results presented in this work were collected in the years 2016–2018. The experiment was established on Rendzic Phaeozem composed of sandy clay with 24% of silty fraction and 13% of dust fraction; characterized by basic pH (pH_{KCl} = 7.3) and medium contents of available phosphorus (114 mg P kg^{-1} d.m.) with the Egner-Riehm's method, potassium (212 mg K kg^{-1} d.m.) with the Egner-Riehm's method, and magnesium (59 mg Mg kg^{-1} d.m.) with the Schachtschabel's method.

The growing season (the number of days with an average daily temperature above + 5°C) begins on the study area in the third week of March and spans for 210 days on average (Fig. 1). From May until October, average annual of precipitation in the multi-year period of 1988–2015 was at 400 mm, whereas since November till April the total was 207 mm. The average daily air temperature from May until October was 15°C, whereas from November until April it was 1.4°C. The highest sums of precipitation were recorded in June (72 mm on average) and July (83 mm), while the highest air temperatures in July (19.4°C on average) and August (18.4°C). In the study years (2016–2018), the

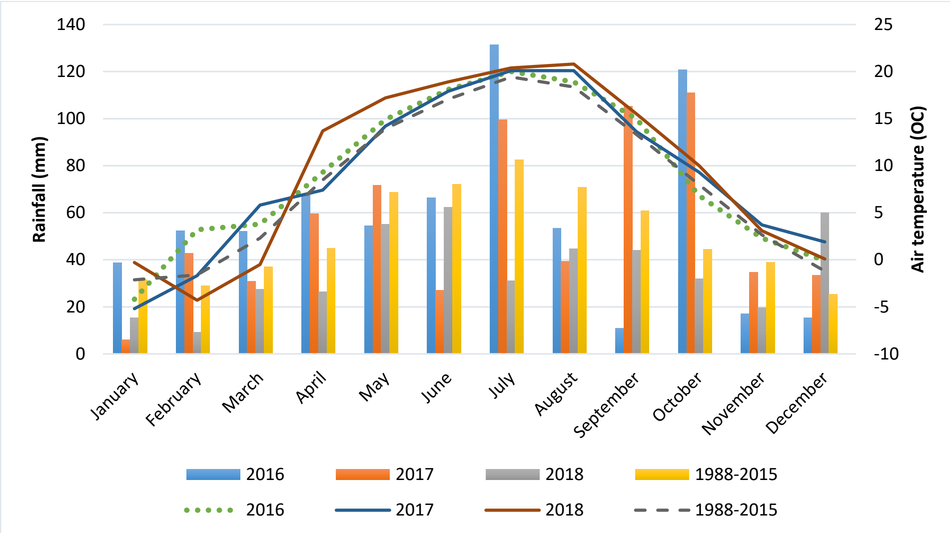


Fig. 1. Monthly sums of precipitation and average air temperatures at the Uhrusk Experimental Station

sum of precipitation recorded from May until October reached 438 mm (2016), 454 mm (2017), and 269 mm (2018); whereas in the months from November until April it reached 243 mm, 208 mm, and 158 mm, respectively. The average air temperature in the warm half-year (from May until October) was at 15.6°C (2016), 15.9°C (2017), and 17.1°C (2018), whereas in the cold half-year (from November until April) it was at 2.4°C (2016) and 2.0°C (in 2017 and 2018).

Experiment design

The experiment was established with a split-block design (6 m × 25 m) in 3 replications. The following experimental factors were considered: I) cropping system (CS): 1) crop rotation (CR): pea – winter wheat – spring barley, 2) monoculture of winter wheat (MON); and II) tillage systems (TS): 1) CT – conventional tillage, 2) RT – reduced tillage, and 3) NT – no-tillage. The following cultivation treatment was applied: a shallow ploughing (mouldboard plough at a depth of 10 cm) and pre-sowing ploughing (20 cm) in the CT system; double cultivation instead of both aforementioned ploughing treatments in the RT system; and glyphosate (Roundup 360 PLUS) used in doses of 360 g dm^{-3} and 4 L ha^{-1} in NT system. A cultivation set, consisting of a cultivator, a string roller, and a harrow, was used before wheat sowing.

The same NPK fertilization was applied on all plots, i.e. in the autumn before sowing: 20 kg N ha^{-1}, 30 kg P ha^{-1}, 85 kg K ha^{-1}; and in the springtime: 70 kg N ha^{-1} at the tillering stage (22–33 in BBCH scale), 40 kg N ha^{-1} at the shooting stage (32–33 BBCH), and 20 kg N ha^{-1} at the ear formation stage (52–54 BBCH) [Meier 2018]. The applied doses of fertilizers were computed based on the chemical analysis of soil. Winter wheat of Skagen cultivar was sown each year at the optimal time for the study region, i.e. between 25 September and 5 October, in the amount of 450 seeds m^{-2}. Flusilazole + carbendazime (1 dm^3 ha^{-1}) applied at the shooting stage (33–34 BBCH) and propiconazole + fenopropidin (1 dm^3 ha^{-1}) applied at the stage of flag leaf sheath booting (43–44 BBCH) were used as plant protection agents against fungal diseases. Weed infestation was controlled at the tillering stage (23–24 BBCH) with a herbicides containing MCPA + mecoprop + dicamba (1.5 dm^3 ha^{-1}) and fenoxaprop-P-ethyl (1 dm^3 ha^{-1}).

Analyzed traits and statistical analysis

This experiment aimed to evaluate infestation of winter wheat roots by *G. g. tritici* at the tillering (24–25 BBCH) and milk maturity (74–75 BBCH) stages of growth. Disease assessment were done according to the method proposed by Kurowski and Adamiak [2007]. The evaluation consisted of digging out 40 plants from each plot; washing their root system; counting healthy plants and rating the severity of plant infection to a lightly, medium, high, and severe extent; and calculating the root infestation index according to the following formula:

$$Ip = [(a \times 0) + (b \times 10) + (c \times 30) + (d \times 60) + (e \times 100)] / n,$$

where: a – number of healthy plants, b – number of lightly infested plants (1–10%); c – number of medium infested plants (11–30%), d – number of highly infested plants (31–60%), e – number of severely infested plants (61–100%), and n = (a + b + c + d + e) – total number of evaluated plants.

Results obtained were processed statistically using the analysis of variance (ANOVA) method (using Statistica PL software), where the significance of differences between mean values for cropping system (CS), tillage systems (TS), growth stages of wheat (GS), and effects of their interactions was estimated with the Tukey's HSD test, $P < 0.05$.

RESULTS

At the tillering stage of winter wheat (24–25 stage in the BBCH scale), the index of root infestation by *G. g. tritici* was over 2-fold higher in wheat monoculture (MON) than in crop rotation (CR) – Table. 1. Higher disease was also demonstrated in the no-tillage (NT) than in the conventional tillage (CT) system. Likewise, at the milk maturity stage of wheat (74–75 BBCH), the value of the root infestation index was higher in MON than in CR as well as in NT than in CT (Tab. 2). At both growth stages of wheat, the highest value of the root infestation index was determined in the monoculture with NT system, whereas the lower one – in crop rotation with CT system. Variance analysis components (ANOVA) indicate that wheat roots infestation by *G. g. tritici* was affected to a greater extent by CS than by TS (Tab. 3).

Values of the wheat infestation index were also differentiated by study year (Y) and growth stage (GS) of plants (Tab. 4). A higher value of the index was determined in 2018, compared to the other years analyzed, and also at the 74–75 BBCH than at the 24–25 BBCH stage of plant growth. Variance analysis components indicate that values of the root infestation index depended to a larger extent on Y than on GS (Tab. 5). In addition, significant differences were noted between study years in CS (Fig. 2) and in TS (Fig. 3).

Cropping system differentiated also affected the percentage of wheat roots infestation (Fig. 4). At the 24–25 BBCH stage, healthy plants with no symptoms of root infestation by *G. g. tritici* accounted for 91%, whereas the little infested and the medium infested ones accounted for 6.5% and 2.5%, respectively, of all plants in CR. In the case of MON, healthy plants represented 84.2% of all plants, whereas the remaining plants were infested to a lightly (10%), medium (4.2%), and high (1.6%) extent. At the 74–75 BBCH stage, healthy plants with no symptoms of infestation accounted for 94.4%, whereas these with the low, medium and high degree of infestation accounted for 2.3%, 2.5%, and 0.8% of all plants in CR. In MON, healthy plants represented 87.5%, whereas the other plants showed symptoms of lightly (5%), medium (2.5%), high (3.3%), and severely (1.7%) infestation.

The percentage of infested winter wheat roots was also influenced by tillage systems (Fig. 5). At the tillering stage (24–25 BBCH), in the CT system, the plants with no symptoms of infestation represented 90%, whereas these showing symptoms of low and medium infestation constituted 7.6% and 2.4%, respectively. In the RT system, healthy plants accounted for 87.5%, whereas the lightly infested ones for 7.5% and the medium infested ones for 5%. In the NT system, healthy plants accounted for 87%, whereas plants with symptoms of low and medium infestation for 5%, and the highly infested ones for 3%. At the milk maturity stage of wheat (74–75 BBCH), in the CT system, the plants with no symptoms of infestation represented 87.5%, whereas these with symptoms of low, medium and high infestation accounted for 5%, 6% and 1.5%, respectively. In the RT system, the percentage of healthy plants was at 86%, whereas lightly, medium, highly and severely infested plants represented 7.3%, 3.2%, 1.5% and 2%. In the NT system, healthy plants represented 78.3%, whereas these with low, medium, high, and severe extent of infestation constituted 15%, 2.4%, 2.5% 1.8% of all plants in this system.

Table 1. Index of winter wheat root infestation by *Gaeumannomyces graminis* var. *tritici* at the tillering stage (24–25 BBCH; average of 2016–2018)

Cropping system (CS)	Tillage systems (TS)			Mean
	CT[a]	RT	NT	
Crop rotation (CR)	0.59	1.38	2.44	1.47
Monoculture (MON)	2.45	2.88	4.30	3.21
Mean	1.52	2.13	3.37	–
$HSD_{0.05}$ for CS – 1.08 $HSD_{0.05}$ for TS – 1.54 $HSD_{0.05}$ for CS × TS – ns				

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

Table 2. Index of winter wheat root infestation by *Gaeumannomyces graminis* var. *tritici* at the milk maturity stage (74–75 BBCH; average of 2016–2018)

Cropping system (CS)	Tillage systems (TS)			Mean
	CT[a]	RT	NT	
Crop rotation (CR)	0.99	2.12	3.16	2.09
Monoculture (MON)	3.11	3.83	4.80	3.92
Mean	2.05	2.98	3.98	–
$HSD_{0.05}$ for CS – 1.05 $HSD_{0.05}$ for TS – 1.49 $HSD_{0.05}$ for CS × TS – ns				

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

Table 3. Variance analysis for indices of winter wheat root infestation by *Gaeumannomyces graminis* var. *tritici* (average of 2016–2018)

Growth stage	Value	CS[a]	TS	CS × TS
24–25 BBCH	*F*	32.88	12.83	0.16
	P	**	**	ns
74–75 BBCH	*F*	38.66	14.37	0.26
	P	**	**	ns

CS[a] – cropping system, TS – tillage systems, $^{**}P < 0.01$, ns – not significant

Table 4. Effect of study year and growth stage on the index of winter wheat root infestation by *Gaeumannomyces graminis* var. *tritici*

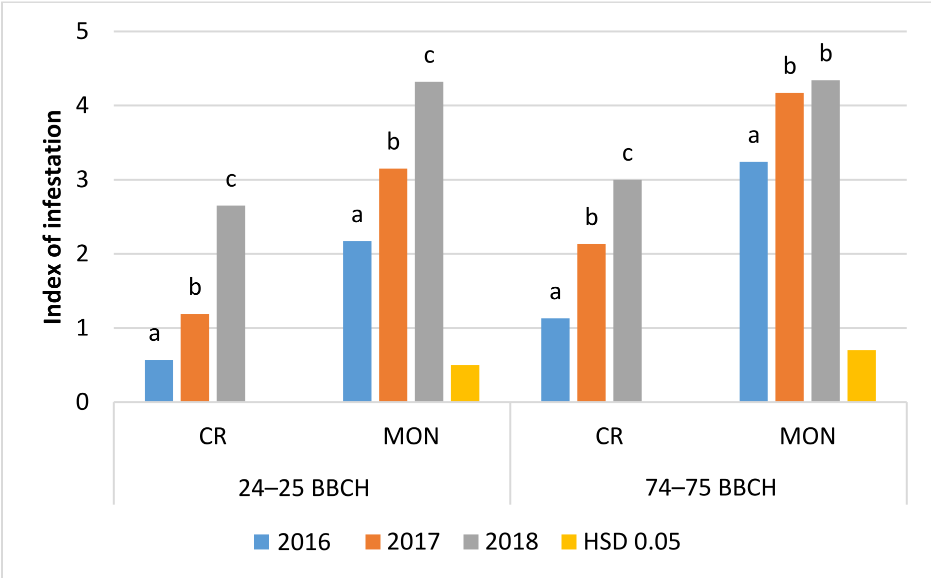
Year (Y)	Growth stage (GS)		Mean
	24–25 BBCH	74–75 BBCH	
2016	1.37	2.18	1.78
2017	2.17	3.15	2.66
2018	3.48	3.67	3.58
Mean	2.34	3.00	–
$HSD_{0.05}$ for Y – 0.71 $HSD_{0.05}$ for GS – 0.55 $HSD_{0.05}$ for Y × GS – ns			

ns – not significant

Table 5. Effect of study year and growth stage on results of variance analysis for indices of winter wheat root infestation by *Gaeumannomyces graminis* var. *tritici*

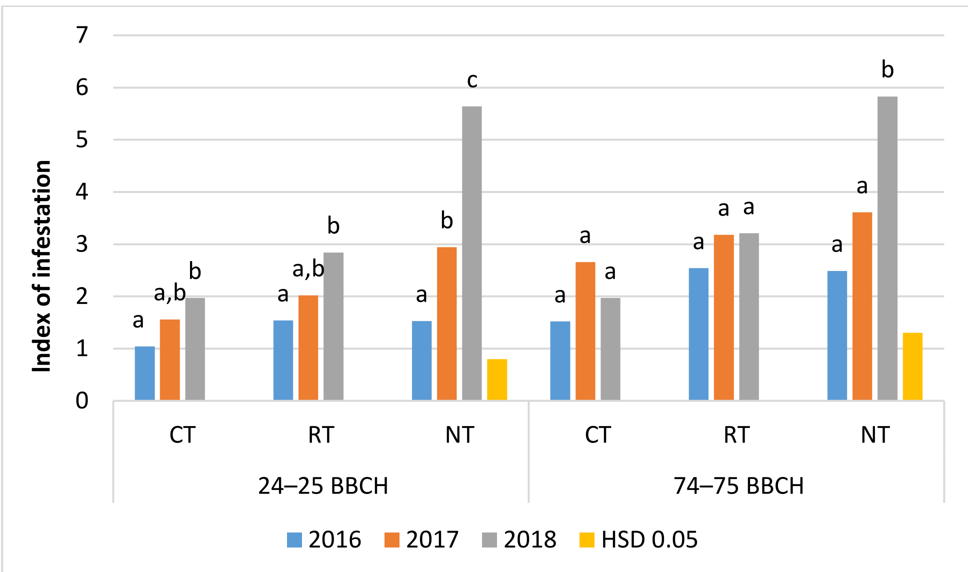
Specification	Value	Y[a]	GS	Y × GS
Ip index	*F*	20.35	15.88	2.75
	P	**	**	ns

Y[a] – year, GS – growth stage, $^{**}P < 0.01$



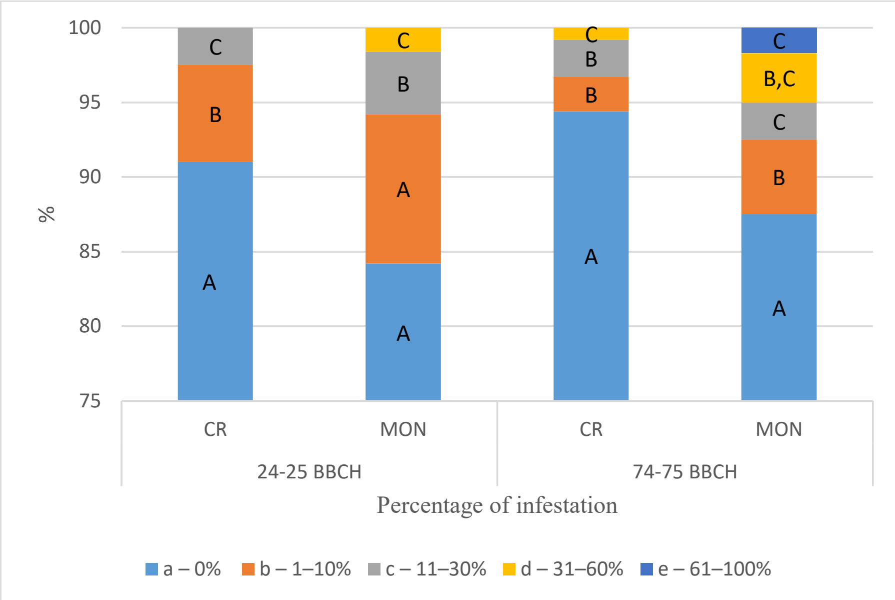
a, b, c – means denoted with the same letters do not differ significantly, $P < 0.05$

Fig. 2. Index of winter wheat root infestation by *Gaeumannomyces graminis* var. *tritici* in crop rotation (CR) and monoculture (MON) in the years of research and in various growth stages



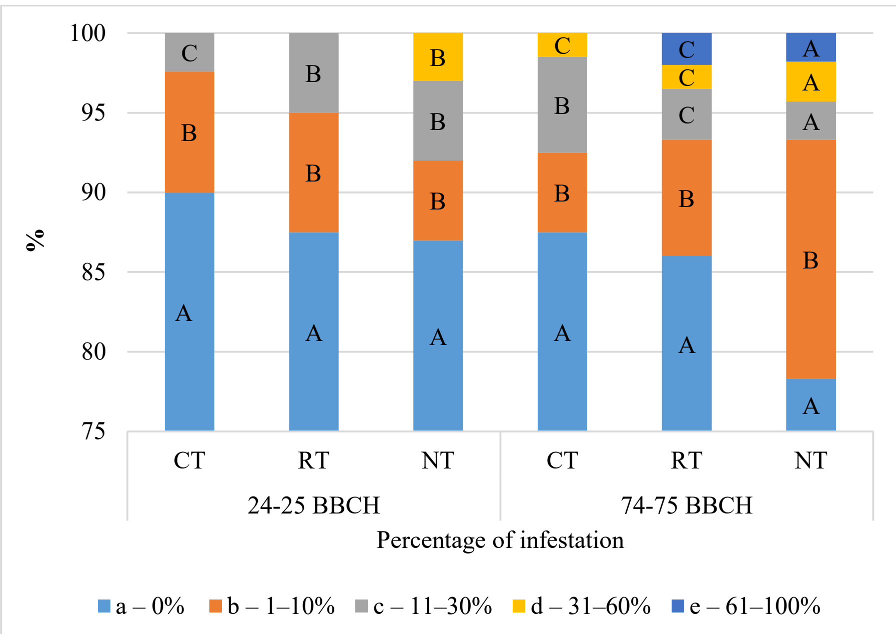
CT – conventional tillage, RT – reduced tillage, NT – no-tillage
a, b, c – means denoted with the same letters do not differ significantly, $P < 0.05$

Fig. 3. Effect of tillage system on the index of winter wheat root infestation by *Gaeumannomyces graminis* var. *tritici* in the years of research and in various growth stages



A, B, C – means denoted with the same letters do not differ significantly, $P < 0.05$

Fig. 4. Percentage of winter wheat root infestation by *Gaeumannomyces graminis* var. *tritici* in crop rotation (CR) and monoculture (MON) in various growth stages



CT – conventional tillage, RT – reduced tillage, NT – no-tillage;
A, B, C – means denoted with the same letters do not differ significantly, $P < 0.05$

Fig. 5. Effect of tillage system on the percentage of winter wheat root infestation by *Gaeumannomyces graminis* var. *tritici* in various growth stages

DISCUSSION

Wheat cultivation in the monoculture leads to increased weed infestation [Woźniak 2019], development of root diseases [Gutteridge and Hornby 2003, Bailey et al. 2009, Ramanauskienė et al. 2018] and to abundance of monophagous and oligophagous pests [Andow 1983]. This results in a significant decline in grain yield and quality [Haliniarz et al. 2018, Woźniak et al. 2019]. Diseases induced by *G. g. tritici* are the most important diseases of wheat roots [Freeman and Ward 2004]. In the conducted experiment, during years 27–30 of a long-term experiment, infestation of winter wheat roots by *G. g. tritici* was twofold greater in MON than in CR. Significantly greater root infestation occurred also in NT than in CT, and its especially high percentage was demonstrated in the monoculture with NT system. It is likely to be due to *G. g. tritici* present on the stubble field and in straw left after wheat harvest in the NT system, which caused the infection of plants sown therein Ramanauskienė et al. [2019]. In the study conducted by Jenkyn et al. [2014], early cultivation of stubble field after cereal harvest was effective in alleviating wheat infestation in the upcoming year. Gosme et al. [2007] demonstrated that in the case of soil-borne diseases, the mechanical cultivation of soil caused 'inoculum dilution' in the arable layer and, thereby, lesser plant infestation in the successive growing season. Gutteridge et al. [2006] showed that also the presence of certain grass species (*Bromus secalinus, Anisantha sterilis*) in wheat crops promotes development of stem base and root diseases to a greater extent than the wheat sown after itself. Bithell et al. [2009], Gutteridge and Hornby [2003] as well as Werker et al. [1990] proved that early sowing increased plant infestation by *G. g. tritici*. In the discussed experiment, plants were sown at the ideal time for the region, but perhaps a delay in winter wheat sowing should be considered in the NT system. Cropping system differentiated also affected the percentage of wheat plants infested by *G. g. tritici*. In crop rotation, plants without symptoms of infestation accounted for 91–94.4%, whereas in monoculture for 84.2–87.5%. In the CT system, the percentage of healthy plants was at 87.5–90%, in the RT system at 86–87.5%, and in the NT system at 78.3–87%. Ennaifar et al. [2007], Bithell et al. [2012], Yang et al. [2018], Ramanauskienė et al. [2019], and Rachoń et al. [2022] reported the percentage of plants infested by *G. g. tritici* was also influenced by varietal traits of wheat, weather course, and soil conditions.

CONCLUSIONS

The index of winter wheat root infestation by *Gaeumannomyces graminis* var. *tritici* was significantly higher in the monoculture (MON) than in the crop rotation (CR). Its higher value was also demonstrated in the no-tillage (NT) than in the conventional tillage (CT) system. Infestation of winter wheat turned out to be more dependent on the cropping system (CS) than on the tillage systems (TS). Cropping system (CS) and tillage systems (TS) affected also the percentage of winter wheat infestation by *Gaeumannomyces graminis* var. *tritici*. In the monoculture with NT system, the percentage of highly and severely infested plants was higher than in the crop rotation with CT system.

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