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Full Length Article

Take-All Disease and Performance of Winter Wheat Cultivars as Influenced by Different Forecrops in Two Crop Rotations

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Abstract

Wheat is often planted in short rotations or consecutively for several years on same field in absence of any break crops, which results in the build-up of soil-borne fungal pathogens. The *Gaeumanoomyces graminis* var. *tritici* (Ggt) is the most destructive fungal pathogen causing root rot, commonly known as "take-all" disease in wheat in Poland; however different wheat cultivars behaved differently in this regard. Therefore, in this study, five winter wheat cultivars *viz*., Akteur, Muszelka, Mulan, Meteor and Satyna were sown in two rotations: i) A mixed rotation with potato-winter wheat-maize-winter wheat (A) and ii) cereal rotation with oat-winter wheat-winter rye-winter wheat (D) for three consecutive years. Analyzed data disclosed that all tested winter wheat cultivars grown after rye as a forecrop observed higher infestation of their roots by take all fungus (*Ggt*) coupled with the lowest grain yield (5.5 to 6.2 t ha^{-1} in different cultivars) due to notable reduction in number of ears and 1000-grain weight. Moreover, the highest grain yield (7.3–8.5 t ha^{-1}; averaged for 3 years) was harvested when tested wheat cultivars were sown after potato as a preceding crop. Among the tested wheat cultivars, Mulan sown after rye observed the lowest take-all index along with higher grain yield compared with other cultivars. In conclusion, wheat sown after non cereal (*e.g*., potato) crops harvested more yield. Moreover, wheat cultivar Mulan should be sown to get higher wheat yield in Poland if wheat is planted after cereals like rye.

Keywords: Crop rotation; Forecrop; Winter wheat; Cultivar; Take-all; Grain yield

Introduction

Wheat (*Triticum eastivum* L.) is one of the most commonly grown crops by farmers in many regions the world due to its grain versatility as food and feed, profitability as cash crop and suitability to grow at various latitudes (Leff *et al*. 2004; Mazzilli *et al*. 2016; Nadeem *et al*., 2018). Sustainable approaches to agricultural production and integrated crop protection practices are needed to grow agricultural plants in diversified crop rotations. Such rotations reduce pressure of weeds and fungal diseases, deliver more heterogeneous plant residues and stimulate biological activity in soils (Martyniuk *et al*. 2001; Eerd *et al*. 2014). However, some important crops such as wheat or maize (*Zea mays* L.) are often planted in short rotations or consecutively for several years on the same field and under these conditions wheat yields are usually decreased by 10–30% (Sieling *et al*. 2005; Anderson 2008; Smagacz and Kus 2010). These yield losses occur mainly due to the absence of break crops, particularly broad-leaf preceding crops, which have been shown to prevent inoculum build-up of soil-borne fungal pathogens of cereals and to have many other beneficial effects on soil quality (Kirkegaard *et al*. 2008; Baculicova 2014). Amongst cereals, oat (*Avena sativa* L.) has also been shown to be an effective break crop for winter wheat rotations as oat roots containing antifungal saponins (avenacines) are resistant to *Gaeumanoomyces graminis* var. *tritici (Ggt)*. The *Ggt* is considered as the most destructive fungal pathogen causing root rot and often premature death (white heads) of continuously grown winter wheat, and this disease is commonly known as "take-all" (Trojanowska and Threlfall 1999; Kwak and Weller 2013). Contrary to oat, rye (*Secale cereale* L.) roots can be infected by the take-all fungus, although this crop is generally less susceptible to *Ggt* than wheat (Bithell *et al*. 2011).

A long-term assessment of winter wheat performance as influenced by preceding crops, including oat and rye, was also one of the goals of a field experiment established in 1969 at Grabow Experimental Station (Poland) on a light loamy soil. Cultivation of winter wheat in rotation with other cereals has some advantages, *e.g*., similar technologies and machinery. However, some earlier findings highlighted that in the cereal rotation (oat - winter wheat – rye – winter wheat) the grain yields of winter wheat were on average 10–20% lower than those obtained in a rotation in which winter wheat was grown in rotation with potato (*Solanum tuberosum* L.) and maize (Smagacz and Kus 2010). One of the ways which would help to reduce yield losses of winter wheat when this crop is grown after unfavorable forecrops would be the selection of wheat cultivars showing an advantageous performance under these conditions. So far, one winter wheat cultivar had been grown in the experiment mentioned above. Therefore, this study was designed to evaluate the response of different winter wheat cultivars sown under different crop rotations with respect to take-all disease and wheat productivity.

Materials and Methods

This study was based on a long-term field experiment established in 1969, at the Grabów Experimental Station (51°21'N, 21°40'E and 167 m a.s.l.) belonging to the Institute of Soil Science and Plant Cultivation in Puławy. The soil of experimental field was typical soil in Poland, classified as light loam (Haplic Cambisol) containing 26% of silt (0.05–0.002 mm) and 6% of clay (<0.002 mm). The main characteristics of weather conditions at this site are presented in Table 1. In the experiment, winter wheat is being grown in 4-years crop rotations with 50% share of this crop. For the purpose of this study, two crop rotations (A and D) were used. In the crop rotation A (mixed rotation), wheat follows potato and maize (for silage) in the following order: potato – winter wheat – maize – winter wheat. In the crop rotation D (cereal rotation) winter wheat followed oat and winter rye in the following order: oat – winter wheat – rye – winter wheat.

All crops of both rotations were grown each year with four replications arranged in a split-plot design. In both rotations cereal straw is removed but 30 t ha^{-1} of farm yard manure is applied every 4 years under potato or oat in crop rotation A and D, respectively. Conventional soil tillage (plowing) and crop management systems were used in this experiment. In each growing season winter wheat in both rotations was fertilized with a fall-applied complex mineral fertilizer “Polifoska” to give 18, 60 and 90 kg ha^{-1} of N, P_2O_5 and K_2O, respectively. Spring mineral N (NH_4NO_3) fertilization of wheat at the rate of 120 kg N ha^{-1} was applied in 3 doses: 60 kg ha^{-1} – at the beginning of spring growth, 36 kg ha^{-1} – at stem elongation (BBCH 31-32) and 24 kg ha^{-1} at heading (BBCH 58-59). Originally winter wheat plots were planted to one cultivar of this crop, however currently winter wheat plots have been divided into smaller plots (17 m^2 of harvesting area) to grow five different cultivars of this cereal. In the years 2009–2013, the following winter wheat cultivars were grown: Akteur, Muszelka, Mulan, Meteor and Satyna. Since cultivars differing with respect to their resistance to *Ggt* and other stem-base diseases are not available, we selected the cultivars which were registered in Poland in 2007–2008. In each growing season, winter wheat was planted in the fall (the first decade of September of 2009, 2010 and 2012) at the rate of 4.5 million seeds ha^{-1} and harvested in the last decade of July 2010, 2011 and 2013. Before sowing, seeds were treated with a chemical seed protectant to control seed-borne fungal diseases. Due to a dry autumn in 2011 (Table 1) and frosty and snowless winter, particularly in January of 2012, a severe killing of winter wheat seedlings occurred and thus this growing season has not been included in the present study. To control foliar fungal pathogens two fungicidal sprays were applied (at plant tillering and heading).

Observations recorded

In June when wheat plants were at the late milk stage (BBCH 77), 15 plants were dug out from each replicated plot to assess root systems infestation by the take all fungus *G.aeumannomyces graminis* var. *tritici* (*Ggt*). Take-all severity was assessed and expressed as TAI (take-all index) according to Beale *et al*. (1998). At full ripeness all cultivars were harvested to measure grain yield and some yield components (ears m^{-2} and 1000-grain weight). Numbers of ears were counted on the area of one square meter and grain characteristics were done after drying to 14% moisture contents.

Statistical analysis

Collected data were subjected to analysis of variance (ANOVA) with significance of differences assessed at $P \leq 0.05$, using the FR-ANALWAR software based on Microsoft Excel.

Results

Forecrops had significant while tested wheat cultivars and interaction between forecrops and wheat cultivars had non-significant effect on the infestation of wheat roots by the take-all fungus *Gaeumannomyces graminis* var. *tritici* (*Ggt*) and number of ears of winter wheat (Table 2). Wheat sown after rye had significantly higher *Ggt* infestation (take-all index 10.9 – 18.2) while wheat sown after other forecrops (potato, maize and oat) recorded the minimum *Ggt* infestation, ranging from 2.7 to 6.2 (Table 2). Winter wheat observed the maximum number of ears (474 – 518 ears m^{-2}) when grown after potato and the lowest numbers of ears per unit area were found for all wheat cultivars grown after winter rye (375 – 429 ears m^{-2}) (Table 2).

Grain size *i.e.*, 1000-grain weight was significantly influenced both by cultivars and forecrops, but not by interaction between these factors (Table 3). Wheat cultivar Mulan recorded higher 1000-grain weight (45.0 g) compared with all other cultivars tested (Table 3).

Table 1: Quarterly mean air temperature and total precipitation at Grabów Experimental Station during 2009–2013 growing seasons

Months	Temperature (°C)				Precipitation (mm)			
	2009/2010	2010/2011	2011/2012	2012/2013	2009/2010	2010/2011	2011/2012	2012/2013
Autumn	9.0	7.8	8.3	9.3	195	202	25	135
Winter	-4.0	-3.3	-5.4	-2.7	103	84	105	110
Spring	8.6	9.0	9.9	7.2	160	128	95	183
Summer	19.7	18.6	19.1	19.2	259	387	200	149

Table 2: Effect of forecrops on mean (2010–2013) take-all index on roots and on mean numbers of ears m^{-2} of five winter wheat cultivars grown in two long-term crop rotations

Crop rotation/forecrop	Cultivar					Means
	Akteur	Meteor	Mulan	Muszelka	Satyna	
Take-all index						
A – potato	2.7^{NS}	3.7	3.4	3.1	4.7	3.5 a
A – fodder crops	2.8	3.2	3.0	3.8	4.3	3.4 a
D – oat	6.2	3.4	4.5	4.9	4.7	4.7 a
D – winter rye	18.2	18.0	10.9	15.2	13.0	15.1 b
Means	7.5^{NS}	7.1	5.5	6.8	6.7	
Ear number (m^{-2})						
A – potato	472^{NS}	474	518	496	485	489 b
A – fodder crops	500	426	508	473	470	475 b
D – oat	457	441	484	437	458	455 b
D – winter rye	420	396	429	375	407	405 a
Means	462^{NS}	434	485	445	455	

Means sharing the same letter within a column, for each trait, did not differ significantly at $P \leq 0.05$
LSD value at 5% of forecrops for Take-all index = 3.7 and for ear number = 45.0; NS = Non-significant

Table 3: Effect of forecrops on mean (2010-2013) 1000-grain weight and grain yield of five winter wheat cultivars grown in two long-term crop rotations

Crop rotation/forecrop	Cultivar					Means
	Akteur	Meteor	Mulan	Muszelka	Satyna	
1000-grain weight (g)						
A – potato	45.2^{NS}	44.2	45.5	43.7	45.8	44.9 c
A – fodder crops	41.4	44.6	44.6	41.9	43.3	43.1 ab
D – oat	45.3	42.4	45.2	43.2	46.3	44.5 bc
D – winter rye	41.7	41.8	44.8	41.7	41.4	42.3 a
Means	43.4 a	43.0 a	45.0 b	42.6 a	44.2 a	
Grain yield (t ha^{-1})						
A – potato	7.5	8.3	7.3	8.5	7.94	7.9 c
A – fodder crops	6.6	7.3	7.0	7.8	7.18	7.2 b
D – oat	6.8	7.1	6.8	7.3	7.04	7.0 b
D – winter rye	5.5	6.0	6.2	6.1	6.00	6.0 a
Means	6.6 a	7.2 b	6.8 b	7.4 b	7.04 b	

Means sharing the same letter within a column, for each trait, did not differ significantly at $P \leq 0.05$
LSD value at 5% for 1000-grain weight and grain yield of forecrops = 1.7 and 0.56 and for cultivars = 2.0 and 0.66; NS = Non-significant

Likewise, the lowest and highest 1000-grain weight was recorded when wheat cultivars were grown after rye and potato, respectively (Table 3). Forecrops and wheat cultivars had significant effects on grain yields, but interactions between these factors were non-significant. All winter wheat varieties cultivated after potato harvested the maximum grain yields (7.50 – 8.48 t ha^{-1}) and the minimal yields were observed when these cultivars followed rye (5.54 – 6.16 t ha^{-1}) (Table 3). The cultivar Akteur recorded the lowest mean grain yield 6.62 t ha^{-1} while cultivar Muszelka out yielded the all other cultivars (Table 3).

Discussion

In this study winter wheat was grown in two crop rotations with the same share (50%) of this crop; however, these rotations differed markedly with respect to forecrops of winter wheat. In the mixed rotations (A) winter wheat was grown after potato and maize and in the cereal rotations (D) the preceding crops for winter wheat were oat and rye. Results disclosed that all winter wheat cultivars grown after potato, maize or oat as forecrops had low disease infestation (take-all index 2.7 – 6.2) of their roots by the take-all fungus *G. graminis* var. *tritici* (*Ggt*), but when planted after rye the infestation of their roots by *Ggt* was significantly stronger, ranging from 10.9 to 18.2, than after other forecrops mentioned above. These results are in accordance with those of other reports showing that crops not transmitting *Ggt*, such as potato, rape or oat, are favorable forecrops for winter wheat, both with respect to disease suppression and other beneficial effects on grain yields (Kirkegaard *et al*. 2008; Mazzilli *et al*. 2016). However, when preceding crops are susceptible to *Ggt* roots and stem bases of winter wheat following these crops are usually severely affected by this pathogen, particularly when wheat is planted after wheat or other susceptible cereals (Sieling *et al*. 2005; Anderson 2008; Smagacz and Kus 2010). These effects have been clearly shown by Rothrock and Cunfer (1991), who found that wheat grown after two successive crops of susceptible cereals (wheat, triticale, barley or rye) was severely infected by *Ggt*, including numerous white heads, while wheat following oat had low take-all index. In our study, wheat following rye had the highest take-all scores, although the disease severity was rather mild and no white heads were observed (Table 2). This mild take-all on winter wheat grown in the cereal rotation (rotation D) indicates that soil in this rotation has developed a certain degree of suppressiveness against the take-all fungus due to a long-term cultivation in this rotation of three cereals susceptible to this pathogen. The take-all decline phenomenon occurring in long-term monocultures of winter wheat is well documented and it was proved that this phenomenon evolves primarily from the dynamic interactions between pathogen, plant and soil microorganisms leading to a bulid-up of microorganisms suppressive or antagonistic to the take all fungus (Bailey *et al.* 2009; Kwak and Weller 2013). Our study also shows that, of the tested cultivars grown after rye, the cultivar Mulan had relatively weakest roots infestation by *Ggt* (take-all index 10.9) compared to the other cultivars (take-all index 13.0 – 18.2), although the differences were not statistically significant.

The highest take-all infestation of all winter wheat cultivars grown after rye was accompanied by the lowest number of ears m^{-2} and 1000-grain weight values and these effects caused that winter wheat cultivated after rye gave the minimal grain yields (5.54 – 6.16 t ha^{-1}). These yields were significantly lower than those obtained after other forecrops (6.59 – 8.48 t/ha) used in this experiment. All the cultivars included in this experiment yielded the best (7.25–8.48 t ha^{-1}) when grown after potato as the preceding crop. Potato is well known as a beneficial forecrop for various cereals, as this crop is an effective break crop helping to control soil-borne fungal diseases of cereals (Kirkegaard *et al.* 2008). Moreover, cultivation of potato, particularly when farm-yard manure is included in the fertilization system of this crop, was shown to improve soil structure and nutrients uptake by other plants in crop rotations (Rahimizadeh *et al.* 2010).

In this study the average grain yield of the cultivar Mulan (6.81 t ha^{-1}) was slightly lower than those of Muszelka, Meteor and Satyna, however this cultivar yielded the best when grown under less favorable conditions (after rye). Moreover, under these conditions, the cultivar Mulan had the lowest take-all index and produced the bold grains as indicated by the highest 1000-grain weight, proving that this cultivar would be the preferred choice to grow after unfavorable preceding crops.

Conclusion

Winter wheat cultivars used in this study have not been breed for their resistance or tolerance to soil-borne fungal disease. However, the results obtained in this work indicate that wheat cultivars differ substantially in their response to less favorable forecrops (cereal rotation) and that, of the tested varieties, the cultivar Mulan showed the most advantageous performance under such conditions.

References

Anderson RL (2008). Growth and yield of winter wheat as affected by preceding crop and crop management. *Agron J* 100:977–980

Baculicova M (2014). The influence of fertilization and crop rotation on the winter wheat production. *Plant Soil Environ* 60:297–302

Bailey DJ, N Paveley, J Spink, P Lucas, CA Gillian (2009). Epidemiological analysis of take-all decline in winter wheat. *Phytopathology* 99:861–868

Beale RE, DP Phillion, JM Headrick, P O'Reilly, J Cox (1998). MON65500: A unique fungicide for the control of take-all in wheat. *Proceedings of the 1986 British Crop Protection Conference — Pestsand Diseases. Farnham, British* Crop Protection Council, UK, pp: 343 –350

Bithell SL, RC Butler, S Harrow, MG Cromey (2011). Susceptibility to take-all of cereals and grass species, and their effects on pathogen inoculums. *Ann Appl Biol* 159:252–266

Eerd LLV, KA Congreves, A Hayes, A Verhallen, DC Hooker (2014). Long-term tillage and crop rotation effects on soil quality, organic carbon, and total nitrogen. *Can J Soil Sci* 94:303–315

Kirkegaard J, O Christen, J Krupinsky, D Layzell (2008). Break crop benefits in temperate wheat production. *Field Crop Res* 107:185–195

Kwak YS, DM Weller (2013). Take-all of wheat and natural disease suppression: a review. *Plant Pathol J* 29:125–135

Leff B, N Ramankutty, JA Foley (2004). Geographic distribution of major crops across the world. *Glob Biogeochem Cycl* 18:1–33

Martyniuk S, A Gajda, J Kus (2001). Microbiological and biochemical properties of soils under cereals grown in the ecological, conventional and integrated systems. *Acta Agrophys* 52:185–192

Mazzilli SR, OR Ernst, VPD Mell, CA Perez (2016). Yield losses on wheat crops associated to the previous winter crop: impact of agronomic practices based on on-farm analysis. *Eur J Agron* 75:99–104

Nadeem MK, SJ Rasool, M Ikram, A Jahanzab, MF Maqbool, H Ahmad, R Habib (2018). Management of wheat production in saline soils through multi-strain bacterial inoculation. *J Glob Innov Agric Soc Sci* 6:135-142

Rahimizadeh M, A Kashani, A Zare-Feizadadi, AR Koocheki, M Nassiri-Mahallati (2010). Nitrogen use efficiency of wheat as affected by preceding crop, application rate of nitrogen and crop residues. *Aust J Crop Sci* 4:363–368

Rothrock CS, BM Cunfer (1991). Influence of small grain rotations on take-all in a subsequent wheat crop. *Plant Dis* 175:1050–1052

Sieling K, C Stahl, C Winkelmann, O Christen (2005). Growth and yield of winter wheat in the first 3 years of a monoculture under varying N fertilization in NW Germany. *Eur J Agron* 22:71–84

Smagacz J, J Kus (2010). Influence of cereal crop rotation on yielding of cereals and selected chemical soil properties. *Fragm Agron* 27:119–134.

Trojanowska MR, DR Threlfall (1999). Regulation of saponin biosynthesis in primary roots of oat. *Acta Bot Gall* 146:101–104.