Acta Sci. Pol. Agricultura 16(4) 2017, 199–206
www.agricultura.acta.utp.edu.pl pISSN 1644-0625 eISSN 2300-8504

ORIGINAL PAPER

Received: 17.08.2017
Received in revised form: 11.09.2017
Accepted: 27.11.2017

THE EFFECT OF PRODUCTION SYSTEM INTENSITY ON THE YIELD OF WINTER TRITICALE (x *Triticosecale* Wittm. ex A. Camus) CULTIVAR ALEKTO

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ABSTRACT

Background. New production systems have to be designed to fully harness the potential of new triticale varieties. This requires determination of their responses to the major agricultural inputs such as nitrogen fertilization and pesticide use.

Material and methods. A three-year field experiment was conducted in 2008–2011 in the Production and Experimental Station in Bałcyny (53°40’ N; 19°50’ E) owned by the University of Warmia and Mazury in Olsztyn. The aim of this study was to determine the effects of different levels of nitrogen fertilization and fungicide protection on the productivity of winter triticale cv. Alekto, and on the severity of foliar and ear diseases. The response of the semi-dwarf morphotype of winter triticale cv. Alekto to different rates of nitrogen fertilizer (90, 90 (60 + 30), 120 (60 + 60) and 150 (90 + 60) kg N·ha^{-1}) applied at different stages, and to different fungicide treatments was tested in the study.

Results. The average grain yield determined for three years was significantly higher in the second highest input production system (120 kg N·ha^{-1}, applied at stages BBCH 27 (50%) and BBCH 32 (50%) with seed dressing and two foliar fungicide treatments at stages BBCH 31 and 39). The second highest input system was characterized by the most desirable yield components and the highest disease resistance. The lowest yield (decrease by 9–19%, three-year average) was noted in the low-input system with a single rate of nitrogen fertilizer (90 kg N·ha^{-1}) and only antifungal seed dressing.

Conclusion. A nitrogen fertilizer rate of 120 kg N·ha^{-1} combined with two foliar fungicide treatments exerted the most beneficial influence on the yield and disease resistance of semi-dwarf winter triticale.

Key words: agricultural treatments, application date, hydrothermal conditions, pathogen infections

INTRODUCTION

In Europe, the area under triticale has increased by 17% in the last decade (FAOSTAT, 2016), which points to an increase in this cereal’s economic significance (McGoverin *et al*., 2011; Nogalska *et al*., 2012; Pattison and Trethowan, 2013). Triticale is characterized by high yield potential (Brzozowska and Brzozowski, 2013) and high nutritional value (Arendt and Zannini, 2013). The species is highly resistant to abiotic and biotic stress, which makes it suitable for cultivation in areas that are less favorable for the production of other cereals (Estrada-Campuzano *et al*., 2012). Varietal improvements have contributed to increased grain yield and quality (Wicki, 2008). Long-stemmed (traditional) and semi-dwarf varieties of winter triticale are presently cultivated (Jaśkiewicz, 2007). Semi-dwarf morphotypes are characterized by shorter, thicker and more flexible stems as well ashigher resistance to lodging,

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which makes them suitable for cultivation in high-input systems with high and stable grain yields (Jaśkiewicz, 2009b). New production systems have to be designed to fully harness the potential of new triticale varieties. This requires determination of their responses to the major agricultural inputs such as nitrogen fertilization and pesticide use (Jaśkiewicz, 2009a, b). Plant protection is one of the most important challenges in agricultural production, as it can largely contribute to an improvement in production efficiency (Jaśkiewicz, 2007). Effective use of nitrogen fertilizers is dependent upon the appropriate rate and the timing of application (Jaśkiewicz, 2006). We postulated the hypothesis that the grain yield of winter triticale can be increased at higher nitrogen fertilization levels combined with adequate control of fungal pathogens.

The objective of this study was to determine the effects of different levels of nitrogen fertilization and fungicide protection on the productivity of winter triticale cv. Alekto and on the severity of foliar and ear diseases.

MATERIAL AND METHODS

Study site and experimental design

In 2008–2011, a field experiment with a split-plot design was conducted in the Production and Experimental Station in Bałcyny (north-eastern Poland, 53°40' N; 19°50' E) owned by the University of Warmia and Mazury in Olsztyn. The experiment was established on soil belonging to the order of podzolic-earths, type – podzolic, subtype – sandy podzolic, of good wheat complex, quality class IIIa (Marcinek and Komisarek, 2011). The arable layer (0-30 cm) was slightly acidic (pH in 1 M KCl – 6.2–6.5), and it was characterized by a high content of available phosphorus and magnesium, and moderate potassium content.

The response of the semi-dwarf morphotype of winter triticale cv. Alekto to different rates and methods of nitrogen fertilizer application, and different fungicide treatments was tested in the study. The experiment involved four levels of nitrogen fertilization combined with different fungal infection control methods: treatment A – 90 kg N·ha^{-1} applied in a single dose at stage BBCH 27, and seed dressing; treatment B – 90 kg N·ha^{-1} applied in two doses: 60 kg N at stage BBCH 27 + 30 kg N at stage BBCH 32, seed dressing and a single fungicide application at stage BBCH 39; treatment C – 120 kg N·ha^{-1} applied in two equal doses: 60 kg N at stage BBCH 27 + 60 kg N at stage BBCH 32, seed dressing and two fungicide applications at stages BBCH 31 and 39; treatment D – 150 kg N·ha^{-1} applied in two doses: 90 kg N at stage BBCH 27 + 60 kg N at stage BBCH 32, seed dressing and a single fungicide application at stage BBCH 31 (Table 1).

Table 1. Nitrogen fertilizer application and fungicide protection

Treatment/date		Rate and application of nitrogen fertilizer			
		A	B	C	D
N fertilization, kg·ha^{-1}	27 BBCH	90	60	60	90
	32 BBCH	–	30	60	60
Disease control	seed dressing	Raxil Extra 515 FS (thiuram, tebuconazole) at 200 ml per 100 kg of grain			
	31 BBCH	–	–	Alert 375 SC (flusilazole, carbendazim) at 1.0 dm^3·ha^{-1}	Alert 375 SC (flusilazole, carbendazim) at dm^3·ha^{-1}
	39 BBCH	–	Amistar 250 SC (azoxystrobin) at 1.0 dm^3·ha^{-1}	Impact 125 SC (flutriafol) at 0.6 dm^3·ha^{-1} + Soprano 125 SC (epoxiconazole) at 0.6 dm^3·ha^{-1}	–

In each year of the study, winter triticale was sown in the last 10 days of September at 400 kernels per m^2. Winter oilseed rape was the preceding crop. The experimental plots had an area of 15 m^2 each. Crops were grown in a conventional tillage system. Phosphorus and potassium fertilizers were applied before sowing at 30 kg $P \cdot ha^{-1}$ and 83 kg $K \cdot ha^{-1}$, respectively, in the form of granular triple superphosphate (46%) and potash salt (60%). Nitrogen was applied as ammonium nitrate (34%). Herbicides (Boxer 800 EC – *prosulfocarb* at 2 $dm^3 \cdot ha^{-1}$ + Legato Plus 600 SC – *diflufenican* at 0.5 $dm^3 \cdot ha^{-1}$ + Glean 75 WG – *chlorsulfuron* at 5 $g \cdot ha^{-1}$) and growth regulators (Cerone 480 SL – *ethephon* at 1.0 $dm^3 \cdot ha^{-1}$) were applied at stage BBCH 31. Triticale was harvested at physiological maturity with a small-plot harvester.

The following parameters were determined: severity of infection (on a 9-point scale, where 1 – high susceptibility, and 9 – full resistance, no symptoms of disease) at stage BBCH 75, number of productive spikes per m^2 before harvest, number of kernels per spike, 1000 kernel weight, and grain yield per ha at 15% moisture content.

Statistical analysis

The results were processed statistically by ANOVA in the Statistica 10.0 PL program. Homogeneous groups were identified in Tukey's HSD test. Differences between groups were estimated at a significance level of $P < 0.05$.

Weather conditions

Weather conditions were analyzed with the use of Syelaninov's hydrothermal index (Bac *et al*., 1998). The examined growing seasons were characterized by varied hydrothermal conditions (Table 2). Dry spells were noted in September 2008 and 2009, and precipitation levels were very low in October 2011. The remaining seasons, until growth inhibition in autumn, were characterized by high or very high precipitation levels in all experimental years. High and very high precipitation levels were observed in March and July of all the analyzed years. Dry spells were noted in April 2009 and 2010, and precipitation levels were very low in May 2011.

Table 2. Weather conditions measured by the meteorological station in Bałcyny (Syelaninov's hydrothermal index, K)

Years	Month											
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	Apr.	May	June	July	Aug.
2008–2009	0.48	3.89	3.34	–	–	–	11.12	0.12	2.35	3.00	1.39	0.44
2009–2010	0.35	3.16	2.58	–	–	–	3.70	0.39	2.83	1.56	1.36	1.65
2010–2011	1.23	0.68	8.45	–	–	–	1.35	1.15	0.98	1.07	3.07	1.49

K: up to 0.5 – severe drought, 0.51–0.69 – drought, 0.70–0.99 – mild drought, ≥1 – incipient drought (Bac *et al*., 1998)

RESULTS AND DISCUSSION

Grain yield and yield components were influenced by weather conditions in all experimental years (Table 3). The grain yield of the semi-dwarf variety of winter triticale was significantly lowest in the growing season of 2008–2009 (dry April and August) when the number of kernels per spike and 1000 kernel weight were significantly lowest (Table 3). Compared with the growing season of 2008–2009, grain yield was significantly higher in the growing season of 2010–2011 when the number of kernels per spike and 1000 kernel weight were highest, while the 2009–2010 growing season (high precipitation in June, July and August) was characterized by the significantly highest grain yield and the highest number of spikes per unit area. The difference in grain yield between the most favorable (2009–2010) and the least favorable (2008–2009) growing season was 14%. Strong correlations between weather conditions and triticale grain yield have also been reported by other authors (Alaru *et al*., 2009; Brzozowska and Brzozowski, 2013). However, in a study by Koziara *et al*. (2015), weather conditions did not exert a significant influence on the grain yield of the semi-dwarf triticale var. Gniewko.

Differences in triticale grain yield were noted in systems with varied intensities of agricultural inputs (Table 3). In all experimental years, the highest grain yield was observed in the second highest input system with a N fertilizer rate of 120 kg N·ha^{-1} (60 kg at BBCH 27 and 60 kg at BBCH 32) and two fungicide treatments (Alert 375 SC at BBCH 31 and Impact 125 SC + Soprano 125 SC at BBCH 39). In the above technology grain yield was determined by the number of kernels per spike and the 1000 kernel weight (2008–2009) or by all yield components (2009–2010 and 2010–2011) (Table 3). In technology C, the increase in grain yield relative to the lower-input technologies (technology A with a single rate of N fertilizer at 90 kg N·ha^{-1} and seed dressing; technology B with two applications of N fertilizer at 60 kg N·ha^{-1} and 30 kg N·ha^{-1} each seed dressing and Amistar 250 SC fungicide treatment at BBCH 39) ranged from 200 to 2130 kg·ha^{-1} and was statistically significant. In technology D, where the rate of N fertilizer was increased to 150 kg N·ha^{-1} and where one fungicide treatment was abandoned (Impact 125 SC + Soprano 125 SC at BBCH 39), grain yield decreased significantly (2009/2010) or was similar (2008–2009 and 2010–2011) to that noted in the most productive technology (technology C). Our findings are consistent with the results reported in other studies where semi-dwarf (Jaśkiewicz, 2007) and long-stemmed (Saglam and Ustunalp, 2014) winter triticale varieties were characterized by the highest grain yield in response to a N fertilizer rate of 120 kg N·ha^{-1}. However, significantly highest grain yields have been reported by Prusiński *et al*. (2016) in treatments fertilized with 60 kg N·ha^{-1}, by Alaru *et al*. (2004) in treatments fertilized with 90 kg N·ha^{-1}, and by Jaśkiewicz (2008) in semi-dwarf winter triticale treatments fertilized with 100 kg N·ha^{-1}, while in the work of Koziara *et al*. (2015) and Mut *et al*. (2005), grain yields were highest when N fertilizer was applied at 150-180 kg N·ha^{-1}. Additionally, in several studies (Jaśkiewicz, 2007; 2011) winter triticale yields improved in response to fungicide application, which is consistent with our findings.

Table 3. Grain yield and yield components of semi-dwarf winter triticale

Parameter	Rate and application of nitrogen fertilizer*				Mean
	A	B	C	D	
	Growing season of 2008–2009				
Number of spikes per m^2	599^{a}**	581^{b}	553^{c}	591^{a}	581^{b}
Kernels per spike, kernels	36.0^{c}	38.3^{b}	40.4^{a}	39.3^{ab}	38.5^{c}
1000 kernel weight, g	38.3^{b}	40.9^{a}	41.6^{a}	40.7^{a}	40.4^{c}
Grain yield, Mg·ha^{-1} 85% DM	8.28^{c}	9.10^{b}	9.30^{a}	9.47^{a}	9.04^{c}
	Growing season of 2009–2010				
Number of spikes per m^2	607^{d}	614^{bc}	633^{a}	609^{cd}	616^{a}
Kernels per spike, kernels	38.6^{c}	39.8^{b}	41.8^{a}	41.4^{a}	40.4^{b}
1000 kernel weight, g	39.6^{c}	42.7^{a}	42.9^{a}	40.7^{b}	41.8^{b}
Grain yield, Mg·ha^{-1} 85% DM	9.18^{d}	10.46^{b}	11.31^{a}	10.31^{c}	10.32^{a}
	Growing season of 2010–2011				
Number of spikes per m^2	445^{b}	436^{b}	469^{a}	482^{a}	458^{c}
Kernels per spike, kernels	42.3^{b}	43.5^{a}	43.6^{a}	43.9^{a}	43.5^{a}
1000 kernel weight, g	49.7^{ab}	50.6^{a}	50.8^{a}	49.0^{b}	50.0^{a}
Grain yield, Mg·ha^{-1} 85% DM	9.41^{b}	9.55^{b}	10.35^{a}	10.28^{a}	9.90^{b}

* description in the Materials and Methods section
** a, b, c, d – homogeneous groups ($P < 0.05$)

According to recent research, triticale is highly resistant to powdery mildew and brown rust, and highly susceptible to Septoria glume blotch (Kramek and Kociuba, 2014). In our study, winter triticale was weakly colonized by fungal pathogens, and on average only up to 2% of leaf or spike area was infected (Table 4). In all years of the study (Table 4), Septoria leaf blotch (*Septoria tritici*), tan spot (*Pyrenophora tritici repentis* Died.), brown rust (*Puccinia recondita* Dietel&Holw) and scald (*Rhynchosporium secalis* ondem) were observed on flag leaves, while symptoms of glume blotch (*Stagonospora nodorum* (E. Müller) and Fusarium head blight (*Fusarium* spp.) were noted on spikes. Disease incidence was influenced by weather conditions across the experimental years (Table 4).

Table 4. Colonization of semi-dwarf winter triticale plants by pathogens (on a scale of 1–9 points)

Pathogen	Rate and application of nitrogen fertilizer*				Mean
	A	B	C	D	
	Growing season of 2008–2009				
Pyrenophora tritici-repentis	8.0	8.3	8.2	8.4	8.2[ab**]
Puccinia recondite	8.8	8.7	8.8	8.7	8.7[b]
Rhynchosporium secalis	8.5	8.6	8.7	8.8	8.6
Septoria tritici	7.6	8.0	8.0	8.1	7.9[b]
Stagonospora nodorum	8.5	8.2	8.4	8.2	8.3[b]
Fussarium ssp.	7.8	7.9	7.9	7.8	7.8[c]
	Growing season of 2009–2010				
Pyrenophora tritici-repentis	8.3	7.9	8.1	8.1	8.1[b]
Puccinia recondite	8.1[b]	8.8[a]	9.0[a]	8.5[ab]	8.6[b]
Rhynchosporium secalis	8.8	8.8	8.9	8.8	8.8
Septoria tritici	8.6	8.7	8.8	8.8	8.7[a]
Stagonospora nodorum	7.8[b]	8.0[b]	9.0[a]	8.0[b]	8.2[b]
Fussarium ssp.	9.0	9.0	9.0	9.0	9.0[a]
	Growing season of 2010–2011				
Pyrenophora tritici-repentis	8.3	8.8	9.0	8.3	8.6[a]
Puccinia recondite	9.0	9.0	9.0	9.0	9.0[a]
Rhynchosporium secalis	8.3	8.8	8.8	8.5	8.6
Septoria tritici	9.0	9.0	9.0	9.0	9.0[a]
Stagonospora nodorum	9.0	9.0	8.8	8.7	8.9[a]
Fussarium ssp.	8.5	8.3	8.8	8.3	8.4[b]

* description in the Materials and Methods section
** a, b, c – homogeneous groups ($P < 0.05$)

The lowest rates of infections caused by fungi of the genera *Pyrenophora tritici repentis* Died., *Puccinia recondita* Dietel&Holw, *Septoria tritici* and *Stagonospora nodorum* (E. Müller) were observed in the growing season of 2010/2011 which was characterized by warm weather and optimal precipitation levels in April, May and June. Fusarium head blight (*Fussarium* ssp.) was most prevalent in the growing season of 2008/2009 that had high precipitation levels and a moderate temperature (around 15°C) in the inflorescence stage (June of 2009). Only the severity of leaf scald caused by *Rhynchosporium secalis* ondem was not affected by weather (Table 4). In other studies, the incidence and severity of fungal diseases in winter triticale plants were also correlated with weather conditions (Nieróbca, 2011; Panasiewicz *et al*., 2012).

The different levels of nitrogen fertilization and different methods of fungal disease control, evaluated in the present study, had no significant effects on the severity of tan spot, scald, septoria leaf spot or Fusarium head blight (Table 4). The severity of brown rust and septoria glume blotch differed across the analyzed production systems only in the growing season of 2009/2010 (Table 4). The severity of diseases caused by fungi of the genera *Puccinia recondita* Dietel&Holw and *Stagonospora nodorum* (E. Müller) was highest in the technology where seed dressing (Raxil Extra 515 FS) was the only protective treatment and where winter triticale plants were fertilized with a single rate of N fertilizer at 90 kg $N \cdot ha^{-1}$ (technology A), and it was lowest in the technology with seed dressing, two fungicide treatments (Alert 375 SC at BBCH 31 and Impact 125 SC + Soprano 125 SC at BBCH 39) and N fertilizer rate of 120 kg $N \cdot ha^{-1}$ (technology C). In the growing season of 2009–2010, the significantly highest grain yield was noted for technology C relative to the results obtained for all technologies in all years of the study (Table 3). In other studies (Panasewicz *et al*., 2012; Koziara *et al*., 2015), triticale also responded to intensive fungicide protection, which improves the health status of plants.

CONCLUSIONS

1. Semi-dwarf winter triticale cv. Alekto responded positively to an increase in the nitrogen fertilizer rate from 90 to 120 kg $N \cdot ha^{-1}$. A further increase in the nitrogen application rate (to 150 kg $N \cdot ha^{-1}$) had no influence on grain yield.
2. The number of productive spikes, the number of kernels per spike and 1000 kernel weight were highest when winter triticale was fertilized with nitrogen at 120 kg $N \cdot ha^{-1}$ applied in two equal doses (60 + 60), combined with two fungicide treatments.
3. Significant differences in the severity of brown rust (*Puccinia recondita*) on flag leaves and glume blotch (*Stagonospora nodorum*) on spikes in response to different rates and methods of nitrogen fertilizer application and to different fungicide treatments were noted only in the second year of the study.
4. Variable weather conditions had a significant influence on the grain yield, yield components and health status of winter triticale.

ACKNOWLEDGEMENTS

This study was financed by the University of Warmia and Mazury in Olsztyn as part of statutory research grant No. 20.610.020-300.

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PLONOWANIE PSZENŻYTA OZIMEGO (x *Triticosecale* Wittm. ex A. Camus) ODMIANY ALEKTO W ZALEŻNOŚCI OD INTENSYWNOŚCI TECHNOLOGII PRODUKCJI

Streszczenie

Wykorzystanie potencjału nowych odmian pszenżyta ozimego jest możliwe tylko w warunkach ustalenia odpowiedniej technologii produkcji, dlatego istnieje konieczność określenia ich reakcji na intensywność zastosowania podstawowych czynników agrotechnicznych, do których należy nawożenie azotem i ochrona przed chorobami. Celem badań było określenie produkcyjności oraz nasilenia występowania chorób liści i kłosa pszenżyta ozimego odmiany Alekto w zależności od poziomu nawożenia azotem, w warunkach zróżnicowanej ochrony fungicydowej. Trzyletnie ścisłe badania polowe prowadzono w latach 2008–2011 na polach Zakładu Produkcyjno-Doświadczalnego w Bałcynach (NE Polska, 53°40' N; 19°50' E), należącego do Uniwersytetu Warmińsko-Mazurskiego w Olsztynie. W badaniach testowano reakcję półkarłowego morfotypu pszenżyta ozimego odmiany Alekto na wielkość dawki nawożenia azotem (90; 90 (60 + 30); 120 (60 + 60) i 150 (90 + 60) kg N·ha^{-1}) i sposobu jej aplikacji (w stadium BBCH 27 i BBCH 32) przy różnej ochronie fungicydowej (w stadium BBCH 31 i BBCH 39). Półkarłowy morfotyp pszenżyta ozimego reagował istotną zwyżką plonu ziarna pod wpływem intensyfikacji technologii produkcji (120 kg N·ha^{-1}, z podziałem 50% (BBCH 27) i 50% (BBCH 32) i ochrony z użyciem zaprawy nasiennej + dwa zabiegi fungicydowe nalistne (BBCH 31 i 39). Taka technologia sprzyjała uzyskaniu najkorzystniejszych wartości elementów struktury plonu i największej odporności pszenżyta ozimego na choroby. Najmniej korzystna dla plonowania była niskonakładowa technologia produkcji, w której zastosowano nawożenie azotem jednorazowo w dawce 90 kg N·ha^{-1} i ograniczano nasilenie grzybów patogenicznych zaprawą nasienną (spadek plonu o 9–19%). Korzystny wpływ azotu aplikowanego w dawce 120 kg N·ha^{-1} z podziałem 60 kg N w stadium BBCH 27 i 60 kg N w stadium BBCH 32, przy dwukrotnej nalistnej ochronie fungicydowej w stadium BBCH 31 i BBCH 39, uzasadnia ich stosowanie w uprawie półkarłowej formy pszenżyta ozimego.

Słowa kluczowe: operacja technologiczna, porażenie przez patogeny, termin aplikacji, warunki hydrotermiczne