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THE IMPACT OF WEATHER CONDITIONS ON THE YIELD OF WINTER TRITICALE AND CONTENT OF MACROELEMENTS IN GRAIN

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Abstract

The purpose of this work was to determine the impact of weather conditions during the spring and summer growth of winter triticale on the yield and content of nutrients in its grain. The research results were achieved from a controlled field experiment carried out at the Experimental Station of the University of Warmia and Mazury in Olsztyn, located in Tomaszkowo near Olsztyn (53°42′ N; 20°26′ E). The impact of weather factors during the spring and summer growth of winter triticale on the yield and content of nutrients in its grain was explained by correlation and multiple regression analyses. The duration of the spring and summer growing season ($b' = 0.929^{**}$) and the average daily temperatures during the plant growth ($b' = 0.409^{*}$) had the strongest, significantly positive impact on winter triticale yield. A significant linear correlation was found only between the content of nitrogen and potassium in winter triticale grain and the selected weather parameters. The nitrogen content depended on the number of plant growing days and average minimum daily temperature, while the potassium content was affected by the number of spring and summer growing days, average daily temperature, total precipitation volume and the number of days with precipitation. Considering the cumulative impact of the examined weather parameters on the content of macroelements in triticale grain, a significant effect was found for phosphorus and potassium, whose levels depended, to the largest extent, on the precipitation volume and number of days without precipitation ≥10 days, respectively. The content of phosphorus and nitrogen in grain was significantly negatively correlated with the yields of winter triticale.

Keywords: temperature, precipitation, winter triticale, yield, macroelements.

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INTRODUCTION

Plant feeds are a primary source of mineral nutrients for monogastric animals, hence the importance of the content of nutrients in cereal grain. Among fodder grains grown in Poland, winter triticale evokes much interest and has become especially popular in areas with highly intensive animal production. Macroelements are essential for the growth and development of animals, as they improve the feed conversion ratio by animals, fulfil structural functions, constitute an integral part of enzymes and control enzymatic processes. As regards the feed value, both deficiency and excess of macroelements in grain may reduce the biological value of feed and impair the animal's metabolism (Brzóska, Śliwiński 2011). The content of macroelements in cereal grain may vary, depending on many factors, e.g. cereal species, its form and variety, content of bioavailable nutrients in soil, agricultural practice, etc. (Brzozowski et al. 2008, Filipek-Mazur et al. 2010, Knapowski et al. 2010, Woźniak, Makarski 2012, Dekić et al. 2014, Małecka et al. 2004, Wojtkowiak et al. 2014). Many authors also focus on the relationship between the volume of cereal yield or the chemical composition of grain versus the weather parameters, especially precipitation and temperature during the plant growing season (Erekul, Kohn 2006, Bassu et al. 2011, Jaskulski et al. 2011). The aforementioned weather parameters are rather unstable in Poland, which may have an adverse effect on the yield volume and quality (Dmowski et al. 2001, Kalbarczyk 2005, Brzozowski et al. 2008, Jaczewska-Kalicka 2008, Jaskulski et al. 2011, Mizak et al. 2011, Rymuza et al. 2012, Radzka 2014). There are reports in the literature indicating higher variability of the chemical composition in winter triticale than in other cereals under the influence of environmental factors (Stankiewicz et al. 2003). This justifies studies on the influence of weather conditions regarding their impact on the chemical composition of winter triticale grain. The aim of this research has been to determine the effect of weather conditions during spring and summer growth of winter triticale on the yield and nutrient content in grain.

MATERIAL AND METHODS

Data analysed in the study were obtained from a controlled field experiment on winter triticale, carried out in 1994-2013, at the Experimental Station in Tomaszkowo (53°42′ N; 20°26′ E), which belongs to the University of Warmia and Mazury in Olsztyn. The field trials were conducted on proper medium and heavy brown soil, classified into a very good and good rye complex. A series of long-term experiments, with either fertilising or fertilising plus plant protection treatments, was carried out in a split-plot randomized block design with 4 replicates. The winter triticale variety, recommended for cultivation in Warmia and Mazury, was replaced every few years during the experiment (Malno in 1994-1996, Bogo in 1997-2003, Woltario in 2004-2006 and Grenado in 2007-2013). Grain yields from plots fertilised with comparable levels of nitrogen (*ca* 120 kg N ha^{-1}), phosphorus (*ca* 35 kg P ha^{-1}) and potassium (*ca* 90 kg K ha^{-1}) and protected every year with suitable herbicides to control dicotyledonous weeds, were analysed. Grain for analyses of the content of macroelements (N, P, K, Mg, Ca) was sampled at harvest. The analyses were carried out at the Chemical and Agricultural Station in Olsztyn for nitrogen (potentiometric method), phosphorus (vanadium-molybdenum method on a Spectrocolorimeter Specol 11), phosphorus (spectrometric method according to PN-ISO 6491 (2000), magnesium (atomic absorption spectrometry, AAS1), potassium and calcium (flame photometric method, Flavo 4). The tests were performed in an accredited laboratory (accreditation certificate No. AB 277, issued by the Polish Centre for Accreditation) to ensure that the requirements of the PN-EN ISO/IEC 17025:2005 standard were satisfied. Meteorological data obtained from the Meteorological Station in Tomaszkowo, near Olsztyn, were analysed. It was assumed that the plant growth was resumed in the spring after five consecutive days with a mean daily air temperature value ≥5.0°C.

Statistical analyses

The impact of the analysed weather conditions during the spring and summer growing season of winter triticale on yield (Y) in 1994-2013, and on the N, P, K, Mg, Ca content in grain (1994-2009) as Y_1, Y_2, Y_3, Y_4, Y_5, respectively, was determined. The following independent variables were considered: x_1 – number of plant growing days, x_2 – average daily temperature, x_3 – average minimum daily temperature, x_4 – total precipitation volume, x_5 – number of days with precipitation, x_6 – number of days with precipitation lasting 10 days or more. Standard deviation *(σ)* and the coefficient of variation (*V*%) were calculated for the number of triticale growing days and the analysed weather parameters. The relationships between the number of triticale growing days and the analysed meteorological parameters were expressed by the linear correlation coefficient (*r*). Interactions between the variables were assessed through simple correlation and multiple regression analysis (StatSoft, Inc., 2010).

RESULTS AND DISCUSSION

The analysed period (1994-2013) was characterised by high variability of the weather conditions (Table 1) during the spring and summer growing season of winter triticale and of yield volumes in individual years of the research (Figure 1). During the analysed years, the number of triticale growing days ranged from 92 in 2012 to 143 in 2004, and the corresponding coeffi-

Table 1

Number of plant growing days and selected weather parameters in the spring and summer growing seasons of winter triticale in 1994-2013

Year	Number of growing days	Average daily tempera-ture	Average minimum daily tempera-ture	Precipita-tion volume	Number of days with precipita-tion	Number of days without precipita-tion ≥10 days
	x_1	x_2	x_3	x_4	x_5	x_6
1994	114	14.2	7.5	117	31	22
1995	97	14.9	9.0	202	44	-
1996	119	13.5	7.7	204	54	23
1997	95	15.0	9.8	324	45	-
1998	120	14.1	8.9	279	58	25
1999	119	13.5	7.7	366	56	11
2000	105	14.8	8.0	188	49	25
2001	117	13.4	9.0	304	57	18
2002	109	14.3	8.4	205	52	-
2003	108	15.7	8.5	207	33	-
2004	143	11.9	7.6	356	75	10
2005	114	13.2	7.3	140	36	12
2006	118	13.7	8.3	227	38	11
2007	126	13.5	8.1	372	52	13
2008	119	15.2	8.4	159	49	27
2009	115	14.1	8.1	243	40	12
2010	130	14.3	9.2	319	59	-
2011	116	14.1	9.4	340	48	-
2012	92	15.2	10.2	294	40	13
2013	105	15.1	10.1	247	37	14
Average	114	14.2	8.6	255n	48	12
Standard deviation	11.70	0.87	0.84	75.49	10.48	-
Coefficient of variation (%)	10.27	6.15	9.79	29.60	21.82	-

cient of variation was estimated at 10.27%. The number of winter triticale growing days increased with a decrease in average and minimum daily temperatures ($r_{0.05}$ = -0.748 and -0.526) and an increase in the number of days with precipitation ($r_{0.05}$ = 0.645). The most stable meteorological parameters

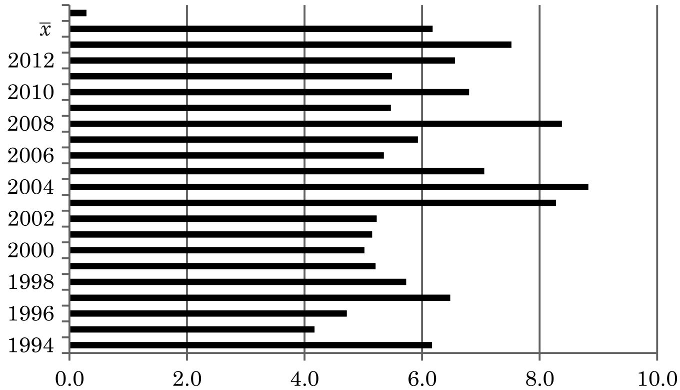

Fig. 1. Winter triticale yields in 1994-2013 (Mg ha^{-1})

were the average daily temperature (V = 6.15%) and minimum daily temperature (V = 9.79%), while the highest variation was found for the total precipitation volume (V = 29.6%) and the number of days with precipitation (V = 21.8%). The highest yields were reached in 2003, 2004 and 2008: 8.28, 8.83 and 8.38 t ha^{-1}, respectively. The selected meteorological parameters in the spring and summer growing seasons in those years were considerably diverse. The year 2004 was characterised by the longest spring and summer growing season for winter triticale (143 days), relatively low average daily air temperature (11.9°C), and high (356 mm) and frequent precipitation (75 days with precipitation, without torrential rains). Then, in 2003 and 2008, the spring and summer growing seasons were distinctly shorter (108 and 119 days, respectively). In 2003, there were no periods without precipitation lasting 10 or more days; in 2004, there was one 10-day period without precipitation, and in 2008 there were 2 periods without precipitation of a total duration of 27 days. The lowest yield was obtained in 1995 (4.17 Mg ha^{-1}), with very short spring and summer growing seasons, precipitation volume below average and more than average daily and minimum temperatures.

While considering coefficients of linear correlation between the analysed random variables (x_1, x_2, x_3, x_4, x_5, x_6) and yield, no significant impact of any of the variables on triticale yield was observed. The average content of mineral elements in winter triticale grain in 1994-2009 was as follows (in g kg^{-1} d.m.): nitrogen – 17.50, phosphorus – 4.03, potassium – 5.01, magnesium – 1.27, and calcium – 0.57 (Figure 2). Triticale grain harvested in 1997, 2002 and 2009 was the richest in mineral elements (average yields in those years were 6.48, 5.23 and 5.47 Mg ha^{-1}, respectively). Our analysis of the relationships between each random variable and the content of macroelements, disregarding the impact of the other variables in the model, revealed a significant negative correlation between the nitrogen content and the number of plant growing days ($r_{0.05}$ = -0.469). The potassium content in grain was positively correlated with the number of plant growing days ($r_{0.05}$ = 0.602), total

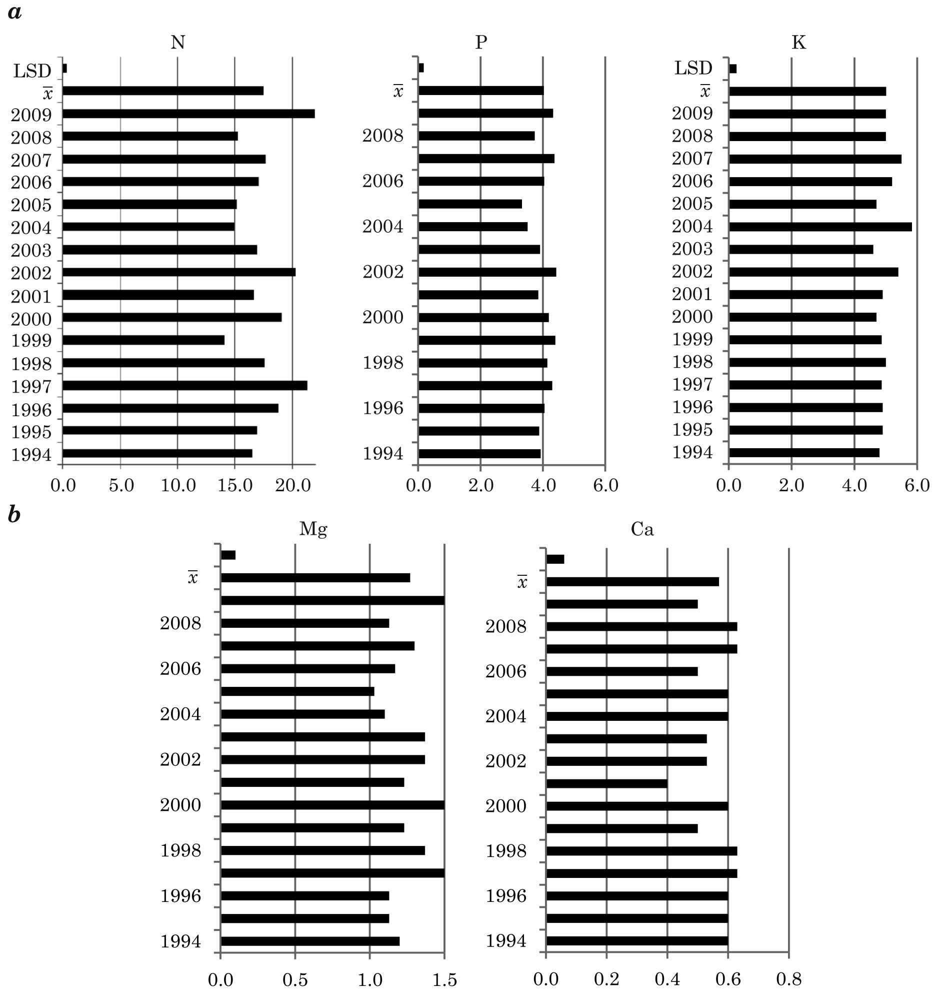

Fig. 2. Content of selected macroelements in winter triticale grain in 1994-2009 (g kg^{-1} d.m): *a* – nitrogen, phosphorus, potassium, *b* – magnesium, calcium

precipitation volume ($r_{0.05}$=0.599) and the number of days with precipitation ($r_{0.05}$ = 0.697). This means that the potassium content in grain increased as the values of these parameters were higher, contrary to average daily temperature ($r_{0.05}$ = -0.547), an increase of which was followed by a reduction in the content of this element.

The analysed coefficients of linear correlations between the content of macroelements (N, P, K, Mg, Ca) and triticale yield revealed a significant negative correlation ($r_{0.05}$ = -0.631) only for phosphorus. The nitrogen content decreased with an increasing triticale yield (r = -0.377).

The analysis of the total impact of the examined meteorological parameters on a dependent variable (“uneven scale effect” eliminated) demonstrated a significant positive influence of spring and summer growing season duration (number of days) ($b'_{0.05}$= 0.929), as well as the average daily temperature ($b'_{0.1}$= 0.409) on triticale yield (Table 2).

The total impact of random variables (x_1, x_2, $x_{3,}$ x_4, $x_{5,}$ x_6) on dependent variables (N, P, K, Mg, Ca) was estimated using multiple regression equations (Table 2). The analysed equations indicated that these regression

Table 2

Total impact of the weather parameters during the spring and summer growing seasons on yields and macroelement content in winter triticale grain

Parameter	Number of spring and summer plant growing days	Average daily tempera-ture	Average minimum daily tempera-ture	Precipita-tion volume	Number of days with precipita-tion	Number of days without precipita-tion ≥10 days
	x_1	x_2	x_3	x_4	x_5	x_6
Grain yield	Y=-16.665.+0.106x_1+0.642x_2-0.420x_3-0.003x_4-0.023x_5-0.011 $x_{6;}$ R^2 = 0.322					
Standardised regression coefficient (b')	0.929**	0.409	0.293	-0.141	-0.213	-0.058
N (g kg^{-1} d.m.)	Y_1=25.757-0.094x_1-0.277x_2+0.741x_3+0.003x_4-0.010x_5+0.012$x_{6;}$ R^2= 0.266					
Standardised regression coefficient (b')	-0.460	-0.110	0.217	0.091	-0.050	0.052
P (g kg^{-1}d.m.)	Y_2= 4.862-0.021x_1+0.171x_2-0.233x_3+0.004x_4+0.004x_5-0.004x_6; R^2= 0.554 **					
Standardised regression coefficient (b')	-0.725	0.480	-0.465	0.897**	0.139	0.120
K (g kg^{-1}d.m.)	Y_3= 1.253+0.021x_1-0.008x_2+0.132x_3-0.001x_4+0.014x_5-0.017$x_{6;}$ R^2=0.750**					
Standardised regression coefficient (b')	0.689	-0.020	0.250	-0.127	0.436	-0.479**
Mg (g kg^{-1} d.m.)	Y_4= 0.468-0.004x_1+0.110x_2-0.081x_3+0.001x_4+0.002x_5+0.003$x_{6;}$ R^2= 0.480					
Standardised regression coefficient (b')	-0.251	0.563	-0.295	0.528	0.143	0.147
Ca (g kg^{-1} d.m.)	Y_5= 0.685-0.001x_1+0.013x_2-0.029x_3-0.0001x_4+0.002x_5+0.001 x_6; R^2= 0.137					
Standardised regression coefficient (b')	-0.220	0.188	-0.312	-0.153	0.350	0.147

** $p < 0.05$

models were best explained only in the case of phosphorus and potassium (coefficient of determination $R^2_{0.05}$ = 0.554 and 0.750, respectively). In the other equations, R^2 was below 0.500. Frequently, the opposing impact (positive or negative) of random variables on the dependent variable in regression models results in low *ratio*s of the *explained* variation.

The analysis of normalised regression coefficients ("uneven scale effect" eliminated) demonstrated a significant positive impact of the total precipitation volume during the spring and summer growing seasons ($b'_{0.05}$= 0.897) on the phosphorus content in triticale grain, and a significant negative impact of the number of days without precipitation ≥10 days ($b'_{0.05}$=-0.479) on the potassium content. For the other macroelements (nitrogen, magnesium and calcium), multiple regression equations indicated a lack of significant impact of the analysed weather parameters on the content of these nutrients in grain (Table 2).

Climatic conditions in Poland have a considerable impact on cereal yield volume and quality (Jaczewska-Kalicka 2008, Gąsiorowska et al. 2011). A significant negative effect on yield is produced by severe precipitation surplus or deficiency, and high temperature amplitudes (Mizak et al. 2011). In Poland, greater significance is attributed to precipitation, which seems to fluctuate more in successive years. Wielgosz et al. (2005) emphasise that what matters in this regard is not only total precipitation but also its distribution during the growing season and in individual phenological phases. According to Gąsiorowska et al. (2011), higher precipitation volume is necessary at the stem elongation and flowering phases. Jaczewska-Kalicka (2008) shows that warm and sunny weather is most favourable at the stem elongation phase, while moderate temperature and good insolation are best in the grain filling period. Other authors focus on the fact that winter triticale grain yield largely depends on weather conditions during the autumn growth and in wintertime (Gąsiorowska et al. 2011, Rymuza et al. 2012). It is rather difficult to determine the impact of weather parameters on plant yield and crop quality, especially in the absence of weather anomalies, since these are also affected by other factors, including soil type and condition, variety, fertilisation, plant protection and other agrotechnical determinants (Brzozowski et al. 2008, Woźniak, Makarski 2012, Dekić et al. 2014, Wojtkowiak et al. 2014). In the analysed research, taking into account the strength and direction of the relationship between variables (linear correlation coefficient), only the nitrogen and potassium content was dependent on the examined weather parameters. Considering the total impact of the examined weather parameters on the content of macroelements in grain, precipitation volume was most important for phosphorus, and the number of days without precipitation ≥10 days for potassium. Also, many authors have pointed out the considerable impact of habitat conditions, including weather conditions, on the chemical composition of grain (Pisulewska et al. 1998, Erekul, Kohn 2006, Jaczewska-Kalicka 2008, Kraska, Pałys 2009, Bassu et al. 2011). Kraska, Pałys (2009) reported the lowest content of potassium, magnesium and total protein in winter wheat grain in chilly 2004, and phosphorus and calcium content in the warmest year, 2003. Some researchers also claim that nitrogen transformations in winter triticale grain depend primarily on a plant variety and less on weather conditions (Alaru et al. 2003). Moreover, some studies revealed a strong negative correlation between the nitrogen content and crop yield. Pisulewska et al. (1998) suggest that weather conditions during the growing season of cereals, including winter triticale, are closely correlated with nitrogen fertilisation, which affects potassium, calcium and magnesium content in grain. Jaskulski et al. (2011) reported that the efficiency of nitrogen uptake by plants depends on a calcium concentration, and the protein content in triticale grain increases with a decreasing calcium content. Moreover, they observed an increasing protein content in grain due to a lower precipitation volume in April and May, and higher in June and July.

CONCLUSIONS

1. The duration of the spring and summer growing seasons, and the average daily temperature during the plant growth had the strongest statistically significant positive impact on winter triticale yield volume.

2. A significant correlation was found only between the content of nitrogen and potassium in winter triticale grain and the selected weather parameters. The nitrogen content depended on the number of plant growing days and average minimum daily temperature, while the potassium content was affected by the number of spring and summer plant growing days, average daily temperature, total precipitation volume, and the number of days with precipitation.

3. Considering the total impact of selected weather parameters on the content of macroelements in grain, precipitation volume was the most important parameter for phosphorus, and the number of days without precipitation ≥10 days most strongly affected potassium.

4. A significant negative correlation was found between the content of phosphorus and nitrogen in grain, and yields of winter triticale.

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