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ORIGINAL PAPER

EFFECT OF WEATHER CONDITIONS ON SPRING TRITICALE YIELD AND CONTENT OF MACROELEMENTS IN GRAIN*

Irena Brzozowska[1], Jan Brzozowski[1], Iwona Cymes[2]

[1]Department of Agroecosystems
[2]Department of Water Resources, Climatology and Environmental Management
University of Warmia and Mazury in Olsztyn, Poland

Abstract

The chemical composition of cereal grains depends on the natural conditions and applied agronomic practices. Our objective has been to determine the influence of meteorological factors, especially precipitation and temperature during the growth and development of spring triticale, on the yields and content of nutrients in grain. The strongest, significantly positive effect on the volume of yields produced by spring triticale was exerted by the plant growing period duration, whereas the average and minimum daily temperatures had a significantly negative influence on the analysed characteristics of spring triticale. The highest levels of the analyzed minerals were determined in the grain of triticale grown in the years 2007 and 2008, when the yields were the lowest over the research period. The least abundant in minerals was triticale grain from the 2005 and 2011 seasons. The accumulation of nitrogen, phosphorus and potassium in spring triticale grain depended significantly (positively or negatively) on the examined meteorological factors, except phosphorus being unaffected by total rainfall during the plant growing period. In general, the accumulation of magnesium and calcium in triticale grain was independent from the tested weather conditions, except total precipitation during the plant growing period, which significantly limited the content of calcium in triticale grain. Significant correlations were found between the grain content of the following macronutrients: nitrogen versus phosphorus and magnesium (positive correlations), and potassium versus nitrogen, phosphorus and magnesium (negative correlations).

Keywords: temperature, rainfalls, spring cereal, crops, mineral composition of the grain.

Irena Brzozowska, PhD DSc, Department of Agroecosystems of University of Warmia and Mazury in Olsztyn, pl. Łódzki 3, 10-718 Olsztyn, Poland, e-mail: irena.brzozowska@uwm.edu.pl
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INTRODUCTION

Spring triticale grain is mostly used in animal nutrition (Peña 2004, Bruckner et al. 2013, Bona et al. 2014). According to Myer and Lozano del Rio (2004), the availability and digestibility of some mineral components are better in spring triticale grain than in corn. As a result, less triticale grain needs to be added to supplement animal feeds, which generates economic profits. Hence, the content of macronutrients in cereal grains is an essential characteristic and an important consideration when designing various feed mixtures and regimes. Both excess and deficit of nutrients can upset the metabolism of animals (Brzóska, Śliwiński 2011). The concentration of minerals in cereal grains is affected by a number of factors, including the type of soil, its richness in minerals, applied agronomic practices and, last but not least, the course of weather conditions during the crop growing season and at harvest, particularly rainfalls and temperatures (Erekul, Kohn 2006, Jaskulski et al. 2011, Dekić et al. 2014, Klikocka et al. 2015, Brzozowska, Brzozowski 2016, Gill, Omokanye 2016). Stankiewicz (2005) demonstrated that the variability of grain mineral composition induced by habitat-specific and agrotechnical conditions was higher in spring triticale than in other cereal crops. Our research hypothesis stated that the chemical composition of cereal grain depends on the natural conditions and applied agronomic practices. This hypothesis was verified in an experiment whose aim was to determine the influence of atmospheric conditions on the yield and content of nutrients (N, P, K, Mg, Ca) in grain of spring triticale.

MATERIAL AND METHODS

The research included results of controlled field experiments with spring triticale, carried out in 2003-2012, at the Research Station in Tomaszkowo near Olsztyn (53°42′ N; 20°26′ E), affiliated to the University of Warmia and Mazury in Olsztyn, Poland. The experiments were set up on medium and heavy-textured cambisol (IUSS Working Group WRB 2015) , classified as very good and good rye complex. Series of experiments, each lasting for a few years, were designed to test fertilisation as well as fertilisation and plant protection treatments. The experiments were set up in line with the method of randomised subblocks in dynamic arrangement, with 3 replications. After seven years, a new triticale variety was chosen according to the then current recommendations for the Region of Warmia and Mazury (cv. Wanad, which was grown in 2003-2009, was replaced with cv. Milewo, cultivated in 2010-2012). This paper includes data of grain yields from triticale grown in objects comparable with respect to nitorgen (120 kg ha^{-1}), phosphorus (35 kg ha^{-1}) and potassium (90 kg ha^{-1}) fertilisation, and protected each year with appropriate herbicides to prevent dicotyledonous weeds. Grain samples for analyses of the content of macronutrients (N, P, K, Mg, Ca) were collected at harvest done with a combine harvester. The content of the macronutrients was determined at the Regional Chemical and Agricultural Station in Olsztyn, using the following methods: nitrogen by potentiometry, phosphorus with the vanadate-molybdate method in a Specol 11 spectrocolometer, spectrometric method in line with the standard PN-ISO 6491 (2000), magnesium – in a Flavo 4 apparatus. The chemical analyses were performed in an accredited laboratory (accreditation certificate no AB 277, issued by the Polish Accreditation Centre), which satisfies the requirements set in the standard PN-EN ISO/IEC 17025: 2005.

Meteorological data from the Meteorological Station in Tomaszkowo near Olsztyn collected during the analysed spring triticale growing seasons were taken into account. The coefficient of variation (CV in %) was calculated for the number of days of a triticale growing season, analysed meteorological factors and content of macronutrients in triticale grain, using Microsoft Office Excel 2007.

Statistical analyses

Simple correlation and multiple regression analyses (StatSoft, Inc., 2010) were applied to assess the impact of the examined meteorological factors (x_1 – number of days of the plant growing season, x_2 – average daily temperature, x_3 – average daily minimum temperature, x_4 – sum of precipitations, x_5 – number of days with precipitations, x_6 – number of days in periods without precipitation, lasting at least 10 days) during the spring triticale growing season on the volume of yields (Y), and content of N, P, K, Mg, Ca in triticale grain (Y_N, Y_P, Y_K,Y_{Mg}, Y_{Ca}).

RESULTS AND DISCUSSION

In the time period covered by the study (2003-2012), the weather conditions varied (Table 1) for each growing season of spring triticale, which resulted in different grain yields harvested in individual years (Figure 1). Over the years, the duration of the triticale vegetative period ranged from 117 days in 2008 to 135 days in 2004, at a low coefficient of variation CV = 3.9%. The most stable meteorological factors were: average daily temperature and minimum daily temperature, whereas sum of precipitations and number of days with precipitation were the two most variable factors.

The highest yields were harvested in 2004 and 2005 , which were 6.29 and 7.24 t ha^{-1}, respectively, at the longest vegetative periods (135 and 127 days) and the lowest average daily air temperature (14.3 and 14.2°C) – Figure 1. The spring triticale growing period for in 2004 was also distin-

Table 1

Length of the plant growing period and selected weather parameters in the spring triticale growing seasons of 2003-2012

Years	Number of growing days	Average daily tempera-ture (°C)	Average minimum daily tempera-ture (°C)	Precipita-tion volume (mm)	Number of days with precipita-tion	Number of days in periods without precipi-tation, lasting at least 10 days
	x_1	x_2	x_3	x_4	x_5	x_6
2003	121	16.3	10.4	207.5	52	0
2004	135	14.3	9.5	375.7	69	10
2005	127	14.2	8.4	206.5	44	23
2006	120	15.4	10.0	267.7	43	22
2007	124	14.7	9.5	384.5	56	11
2008	117	15.2	9.2	162.3	40	43
2009	125	14.7	8.7	246.8	44	21
2010	123	15.7	10.6	337.1	61	0
2011	125	15.2	10.4	371.8	53	0
2012	127	15.2	10.3	361.8	53	13
Average	124	15.1	9.7	292.2	51	14
Coefficient of variation (%)	3.9	4.2	7.9	28.6	17.6	94.6

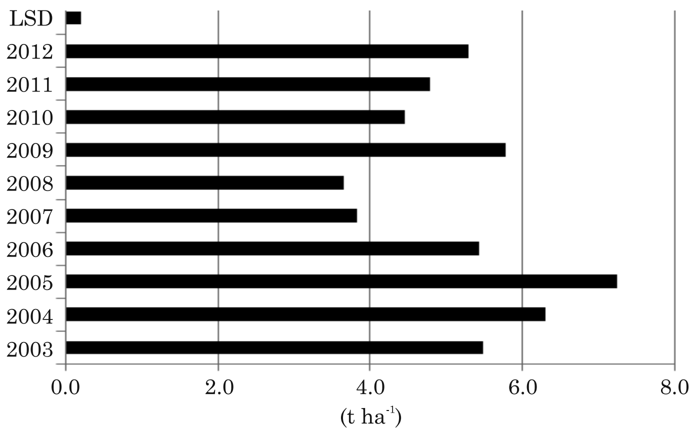

Fig. 1. Spring triticale yields in 2003-2012 (t ha^{-1})

guished by high (375.7 mm) and frequent (69 days with precipitation) rainfalls. In contrast, 2005 was a much drier year, with the total rainfall of 206.5 mm and fewer days with rainfalls (44 days). The lowest harvest was obtained in 2007 and 2008 (3.86 and 3.66 t ha^{-1}, respectively), that were the years with the shortest vegetative periods (117 days in 2008 and 7 days longer in 2007). Results from these two years provided evidence that both rainfall deficit and surplus strongly affect crop yields. In 2007, the rainfalls were the highest in the whole decade analysed (384.5 mm), while the lowest in 2008 (162.3 mm, i.e. 42.2% of the previous year's precipitation). The triticale grain harvested in 2007 and 2008, which were the years when the average yields were the lowest in the analysed period, was the richest in minerals. The lowest concentrations of mineral nutrients was found in the grain obtained in 2005 and 2011 (Table 2).

Table 2

Content of selected macronutrients in spring triticale grain (g kg^{-1} d.m.)

Years	N	P	K	Mg	Ca
	(g kg^{-1}d.m.)				
2003	21.3	4.33	4.61	1.41	0.44
2004	20.8	4.41	4.68	1.30	0.59
2005	19.4	4.10	4.71	1.47	0.46
2006	20.6	4.39	4.62	1.47	0.44
2007	23.7	4.68	4.40	1.50	0.32
2008	25.8	4.32	4.31	1.49	0.47
2009	20.3	4.33	4.60	1.32	0.46
2010	21.0	4.37	4.70	1.22	0.33
2011	19.3	4.22	4.73	1.20	0.44
2012	20.9	4.42	4.70	1.30	0.33
Average	21.3	4.36	4.61	1.37	0.43
Coefficient of variation (%)	8.98	3.36	3.03	8.33	19.32

When analysing linear correlation coefficients between the selected meteorological factors (random variables x_1, x_2, x_3, x_4, x_5, x_6) and triticale yields, it was observed that the number of days of the triticale vegetative period, average daily temperature and average minimum daily temperature affected significantly the triticale yielding (Table 3). Negative correlations between spring triticale yields and the temperature during the vegetative period were reported by Koziara (1996). Considering the relationships between an effect produced by each meteorological factor on the content of minerals, and discarding the other variables in the model, significant positive correlations were determined between the content of phosphorus and the total precipitation as well as the number of days with rainfalls, the content of potassium and the number of days of the triticale growing season, and the content of nitrogen and magnesium versus the number of days without rain-

Table 3

Linear correlation coefficients (r) between the selected meteorological parameters (x_1, x_2, x_3, x_4, x_5, x_6) and grain yield and content of macroelements in spring triticale grain

Specification	Number of vegetation days	Average daily temperature (°C)	Average minimum daily temperature (°C)	Amount of precipitation (mm)	Number of days with precipitation	Number of days in periods without precipita-tion, lasting at least 10 days
	x_1	x_2	x_3	x_4	x_5	x_6
Grain yield	0.586**	-0.414*	-0.405*	-0.154	0.019	-0.065
N	-0.499**	0.115	-0.091	-0.246	-0.174	0.529**
P	0.012	0.042	0.233	0.509**	0.379*	-0.130
K	0.547**	-0.010	0.285	0.342	0.358	-0.599**
Mg	-0.408*	-0.139	-0.486**	-0.529**	-0.524**	0.612**
Ca	0.336	-0.342	-0.397*	-0.290	0.014	0.262

* $p \leq 0.05$, ** $p \leq 0.01$

falls equal or longer than 10 days (Table 3). On the other hand, longer triticale growing periods limited the concentration of nitrogen and magnesium. Lower minimum daily temperature during the crop growing season reduced the accumulation of magnesium (and calcium). As for calcium, the sum of precipitation as well as a higher number of days with rainfalls reduced the accumulation of this element in triticale grain, in contrast to the accumulation of potassium, whose content decreased as the total time period without rainfall ≥10 days was longer.

Our analysis of the linear correlation coefficients between the content of macronutrients (N, P, K, Mg, Ca) and the yield of triticale revealed the highest negative correlations for nitrogen and phosphorus, while positive correlations were found for potassium and calcium (Table 4). Regarding the content

Table 4

Linear correlation coefficients (r) between the grain yield and content of macronutrients in spring triticale grain

Specificaton	Grain yield	N	P	K	Mg	Ca
Grain yield	1.000					
N	-0.733**	1.000				
P	-0.538**	0.487**	1.000			
K	0.649**	-0.925**	-0.441*	1.000		
Mg	-0.053	0.515**	0.174	-0.649**	1.000	
Ca	0.471**	-0.133	-0.353	0.061	0.082	1.000

* $p \leq 0.05$, ** $p \leq 0.01$

of macronutrients, significant positive correlations were determined between nitrogen versus phosphorus as well as magnesium, while significant negative correlations occurred between potassium versus nitrogen, phosphorus and magnesium.

Considering the extent of the aggregated impact of all explanatory variables (x_1, x_2, x_3, x_4, x_5, x_6) on the explained variable, i.e. the yield of triticale, while abolishing 'the unequal scale effect', the highest positive effect on triticale yields was demonstrated to have been produced by the number of days in the growing season (Table 5). The longer the growing season was, the higher the yields of spring triticale were, a finding also reported by KALBARCZYK (2010*b*) and PANASIEWICZ (2013). On the other hand, the weather factors which most distinctly limited the yielding of triticale were: sum of precipitation, number of days with precipitation and number of days without precipitation lasting ≥10 days. Excessively high and frequent rainfalls depressed the yield of spring triticale, same as prolonged time periods without any rainfall (≥10 days). According to KALBARCZYK (2010*a*,*b*), the biggest decrease in spring triticale grain yields is due to very dry or extremely dry weather conditions during the growing season. In KALBARCZYK'S (2010*a*) research, the strongest influence on spring triticale yields is produced by the course of weather conditions during the periods from the heading to the dough stage and then in the last month before sowing and from the full ripeness to harvest. Research into relationships between the volume and distribution of rainfalls as well as rainless periods versus yields of cereal crops has been conducted by other authors as well (GĄSIOROWSKA et al. 2011, JANUŠAUSKAITĖ 2013). According to RADZKA and JANKOWSKA (2015), differences in precipitation, its volume and intensity as well as distribution over the plant growing season, could be one of the major factors contributing to fluctuations in cereal yields. MIZAK et al. (2011) claim that cereal yields are particularly badly affected by excessive surplus or deficit of rains and by large temperature amplitudes. These authors conclude that the most severe decline in spring triticale grain yields, compared to a long-term average yield, is caused by extremely dry conditions from the heading stage to full ripeness, or over the whole plant growing period. In addition, MARENYCH et al. (2014) has suggested that the yields of cereal crops in Ukraine where agricultural practice is less advanced, are more dependent on the quality of soil and climatic conditions.

The total effect of random variables (x_1, x_2, x_3, x_4, x_5, x_6) on dependent variable (N, P, K, Mg, Ca) is illustrated by multiple regression equations (Table 5). The equations show that among the analysed elements, nitrogen, phosphorus and potassium achieved a high degree of explanation for these regression models, which is confirmed by the determination coefficient R^2 values reaching. For the other equations, concerning magnesium and calcium, the values of R^2 were less than 0.500.

Our analysis of normalised regression coefficients (b') in the models, regardless of the measurement units of variables, showed that significantly

Table 5

Total impact of the meteorological parameters ($x_1.x_2.x_3.x_4.x_5.x_6$) on yields and the content of macronutrients in spring triticale grain

Parameter	Number of vegetation days	Average daily temperature (°C)	Average minimum daily temperature (°C)	Amount of precipitation (mm)	Number of days with precipitation	Number of days in periods without precipitation, lasting at least 10 days
	x_1	x_2	x_3	x_4	x_5	x_6
Grain yield (t ha^{-1})	Y=-16.38+0.2857x_1-0.844x_2+0.8247x_3-0.013x_4-0.090x_5-0.046 x_6; R^2 = 0.868					
Standardised regression coefficient (b')	1.272*	-0.493	0.575	-1.021*	-0.745*	-0.563*
N (g kg^{-1}d.m.)	Y_N=30.32-0.3745x_1+2.789x_2-2.595x_3+0.016x_4+0.264x_5+0.0164x_6; R^2= 0.878					
Standardised regression coefficient (b')	-0.922*	0.901*	-1.001*	0.678*	1.207*	1.121*
P (g kg^{-1}d.m.)	Y_P= -1.62-0.005x_1+0.623x_2-0.486x_3+0.004x_4+0.011x_5+0.011x_6; R^2= 0.786					
Standardised regression coefficient (b')	-0.165	2.625*	-2.447*	2.315*	0.638*	0.991*
K (g kg^{-1}d.m.)	Y_K= 3.28+0.029x_1-0.243x_2+0.283x_3-0.002x_4-0.014x_5-0.009x_6; R^2=0.792					
Standardised regression coefficient (b')	0.970*	-1.072*	1.496*	-0.927*	-0.899*	-0.844*
Mg (g kg^{-1}d.m.)	Y_{Mg}= 4.07-0.016x_1+0.014x_2-0.078x_3-0.001x_4+0.004x_5+0.002x_6; R^2= 0.383					
Standardised regression coefficient (b')	-0.650	0.076	-0.504	-0.055	0.322	0.212
Ca (g kg^{-1}d.m.)	Y_{Ca}= 0.07+0.010x_1-0.1052x_2+0.095x_3-0.001x_4+0.003x_5-0.001 x_6; R^2= 0.413					
Standardised regression coefficient (b')	0.716	-0.783	0.841	-1.252*	0.275	0.160

* $p \leq 0.05$

positive effects on the accumulation of nitrogen were produced by the number of days with precipitation, number of days in periods without precipitation, lasting at least 10 days , average daily temperature and sum of precipitations while the number of days of the triticale vegetative period had a limiting effect. An increase in the content of phosphorus in triticale grain was effected by the average daily temperature, total rainfall, the number of days without rainfalls ≥10 day and the number of days with rainfall. The accumulation of this element was limited by the average minimum daily temperature. In turn, the accumulation of potassium in triticale grain was stimulated by the sum of precipitation during the plant growing season and the average minimum daily temperature; in contrast, it was negatively affected by the total precipitation, the number of days with rainfalls and the number of days without rainfalls lasting ≥10 days. In general, the accumulation of magnesium and calcium in triticale grain was not dependent on the analysed weather conditions, although the content of calcium was limited by higher total rainfalls during the growing season. The high degree of explanation achieved for the nitrogen, phosphorus and potassium regression models, and the values of normalised regression coefficients for some of the meteorological factors prove that the analysed independent variables (x_1, x_2, x_3, x_4, x_5, x_6) have considerable influence on concentrations of the macronutrients in grain.

Understanding the dynamics of nutrient accumulation in cereal grains is necessary for attaining optimal performance of crops as well as high quality of food and feed products. Many reserachers have demonstrated a significant impact of habitat conditions, including meteorological factors, on the chemical composition of cereal grains (Pisulewska et al. 1998, Erekul, Kohn 2006, Kraska, Pałys 2009, Woźniak, Makarski 2012, Dekić et al. 2014, Gill, Omokanye 2016). There are claims that the content of minerals in cereal grain depends mostly on crop cultivars and, to a lesser extent, on the weather conditions (Alaru et al. 2003, Akgun, Altindal 2015). Moreover, in a study by Alaru et al. (2003), as well as in the current experiment, the content of nitrogen and the yielding capacity of plants were strongly negatively correlated. Jaskulski et al. (2011) reported that the level of protein in triticale grain was higher in parallel to the lower grain content of calcium, which suggests that the efficiency of nitrogen management by plants depends on the concentration of calcium. Patil et al. (2010) showed that artificial soil warming did not cause changes in the content of nitrogen in winter wheat grain as compared to the control. According to Pisulewska et al. (1998), weather conditions during a growing season of cereal crops are closely connected with other agronomic factors, e.g. nitrogen fertilization, which influence the content of potassium, calcium and magnesium in grain. In their study, Kraska and Pałys (2009) showed that the content of potassium and magnesium, as well as total protein in winter wheat grain was demonstrably the smallest in the cold year of 2004, while the levels of phosphorus and calcium dropped the lowest in the warmest year 2003. In turn, Stankowski et al. (2015) draw attention to high stability of the content of macro- and micronutrients in grain of the spring triticale variety Nagano.

CONCLUSIONS

1. The biggest, significantly positive effect on the volume of spring triticale yields was produced by the length of the growing season, while a significantly negative effect was caused by the sum of rainfall, which is confirmed by normalised regression coefficients.

2. Among the macronutrients analysed in spring triticale grain, the accumulation of nitrogen, phosphorus and potassium was significantly (positively or negatively) dependent on the meteorological factors examined.

3. In general, the accumulation of magnesium and calcium in triticale grain was not dependent on the analysed meteorological factors, except the total precipitation, which significantly reduced the content of calcium in triticale grain.

4. Significant positive dependences were determined with respect to the triticale grain content of macronutrients, such as between nitrogen phosphorus and magnesium, while negative relationships were found between potassium and nitrogen, phosphorus and magnesium.

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