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EFFECT OF SOME METEOROLOGICAL PARAMETERS ON YIELDS AND THE CONTENT OF MACROELEMENTS IN WINTER WHEAT GRAIN

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Abstract

The volume and quality of cereal yields are largely determined by the course of climatic conditions, mainly air temperature and precipitation. The objective of this paper was to determine the impact of meteorological conditions during the spring and summer growing season of winter wheat on grain yields (in 1993-2012) and on the content of nutrients in grain (in 1994-2009). The study was based on a field experiment conducted at the Research Station located in Tomaszkowo near Olsztyn, which belongs to the University of Warmia and Mazury in Olsztyn. The impact of meteorological parameters during the spring and summer season on winter wheat yields and the content of elements was investigated by correlation analysis and multiple regression analysis. The examined weather conditions in the spring and summer did not produce any significant impact on the yields. However, some tendencies were noted, indicating that the average minimum temperature had the highest negative impact and the number of days with precipitation produced the highest positive impact on winter wheat yielding. Among the tested macroelements (N, P, K, Mg, Ca), the analyzed meteorological parameters significantly affected the content of nitrogen and phosphorus in winter wheat grain. The accumulation of nitrogen was positively influenced by precipitation, yet significantly negatively affected by the minimum temperature during the spring and summer growing season. The mean daily air temperature during that time had a significant negative impact on the concentration of phosphorus in wheat grain, which was significantly positively raised by the average minimum daily air temperature during the growing season.

Keywords: temperature, precipitation, winter wheat, yielding, macroelements.

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WPŁYW WYBRANYCH ELEMENTÓW METEOROLOGICZNYCH NA PLONOWANIE I ZAWARTOŚĆ MAKROELEMENTÓW W ZIARNIE PSZENICY OZIMEJ

Abstrakt

Wielkość i jakość plonu zbóż w znacznym stopniu zależą od przebiegu warunków pogodowych, głównie temperatury powietrza i opadów. Celem pracy było określenie wpływu warunków meteorologicznych w okresie wiosenno-letniej wegetacji pszenicy ozimej na plonowanie (1993-2012) i zawartość składników pokarmowych w ziarnie (1994-2009). W pracy wykorzystano wyniki badań polowych w Ośrodku Dydaktyczno-Doświadczalnym Uniwersytetu Warmińsko-Mazurskiego w Olsztynie, położonym w Tomaszkowie k. Olsztyna. Wpływ elementów meteorologicznych na plonowanie pszenicy ozimej i zawartość pierwiastków w okresie wegetacji wiosenno-letniej wyjaśniano, stosując analizę korelacji i regresji wielokrotnej. Badane elementy meteorologiczne w okresie wiosenno-letniej wegetacji pszenicy ozimej nie wywierały istotnego wpływu na plonowanie. Niemniej jednak zarysowały się pewne tendencje, wskazujące, iż średnia temperatura minimalna miała największy ujemny wpływ na wydajność pszenicy ozimej, a liczba dni z opadem największy wpływ dodatni. Spośród badanych makroelementów (N, P, K, Mg, Ca) w ziarnie pszenicy ozimej, analizowane elementy meteorologiczne wywierały istotny wpływ jedynie na zawartość azotu i fosforu. Na gromadzenie azotu istotnie dodatnio oddziaływała suma opadów, a istotnie ujemny wpływ miała temperatura minimalna w okresie wegetacji wiosenno-letniej. Na zawartość fosforu w ziarnie pszenicy istotnie ujemny wpływ miała średnia dobowa temperatura powietrza w okresie wegetacji wiosenno letniej, a istotnie dodatni – średnia dobowa temperatura minimalna powietrza w okresie wegetacji.

Słowa kluczowe: temperatura, opady, pszenica ozima, plony, makroelementy.

INTRODUCTION

The climatic conditions in Poland are a relatively unstable factor in cereal cultivation and weather anomalies limit the volume and quality of yielding (Pisulewska et al. 1998, Jaczewska-Kalicka 2008, Kraska, Pałys 2009, Orzech et al. 2009). The deficiency or excess of water modifies the growth of plants and the development of yield components, which directly determines the volume of yields (Jaczewska-Kalicka 2008). It is claimed that winter wheat yields depend strongly on meteorological conditions, mainly available water. This cereal is extremely sensitive to water shortage from the shooting till flowering (the so-called "critical period"). The role of air temperature during the spring development of what is less important (Orzech et al. 2009). Some authors believe that in June and in the first half of July relatively cold weather with sufficient precipitation are beneficial (Jaczewska-Kalicka 2008). There are reports on an ambiguous impact of temperature, especially higher temperatures from the head emergence to hard dough stage (Deputat, Marcinkowska 1999, Jaczewska-Kalicka 2008, Rymuza et al. 2007, Orzech et al. 2009). Economically speaking, yield volume is important but other factors, like yield quality, including the content of minerals in grain, must also be considered. In an animal body, minerals ensure a proper course of different metabolic processes, and their role gains

importance when mineral deficiencies occur. Feeds rich in minerals are the simplest way to replenish lacking minerals (STANKIEWICZ et al. 2003). Wheat grain may serve as a natural source of mineral compounds, whose concentrations are determined by numerous factors, such as a plant species, cultivar, soil and weather conditions and agricultural procedures, including fertilization and herbicide application, which in extreme cases may deteriorate the nutritional value of yields (DUCSAY, LOŽEK 2004, MAKARSKA et al. 2010). The content in minerals in grain and investigations into this subject are therefore essential. Presumably, the meteorological conditions have a strong impact on the volume and quality of winter wheat yields. This study has been carried out to verify such assumptions, and to determine the impact of the weather during the spring and summer growing season of winter wheat on the yields and content of nutrients in grain.

MATERIAL AND METHODS

This paper is based on the results of field studies on winter wheat carried out in 1993-2012, at the Research Station in Tomaszkowo near Olsztyn, which belongs to the University of Warmia and Mazury in Olsztyn. They were controlled field experiments set up on medium and heavy typical brown soil classified as good wheat complex. A series of multiannual experiments of with fertilization as well as fertilization and plant protection treatments were carried out in a randomized sub-block design with 4 replications, including dynamic arrangement and change of cultivars, which took place every few years by selecting the then recommended varieties for cultivation in Warmia and Mazury, north-eastern Poland (Almari 1993-1999, Elena 2000-2003, Rysa 2004-2006, Bogatka 2007-2009, Türkis 2010-2012). This paper reports on the grain yields from standard objects with medium nitrogen (app. 130 kg N ha^{-1}), phosphorus (P – app. 35 kg ha^{-1}) and potassium (K – app. 90 kg ha^{-1}) fertilization and application of herbicides against dicotyledonous weeds and fungicides. During the combine harvesting, samples of grain were collected for analyses of macroelements, such as N, P, K, Mg and Ca. The analyses were performed at the Chemical and Agricultural Station in Olsztyn. The following methods were applied: potentiometry (N), vanadium-molybdenum method (P), atomic absorption spectrometry (Mg) and flame photometry (K and Ca).

The spring growth was assumed to begin after the average daily temperature reached ≥5.0°C on five consecutive days. The beginning of this thermal period overlaps with the commencement of the wheat physiological growth. The following independent variables were used to determine the impact of meteorological conditions during the spring and summer growing season of winter wheat on the volume of yields (Y): x_1 – number of vegetative days, x_2 – average daily temperature, x_3 – average minimum daily temperature,

x_4 – volume of precipitation, and x_5 – number of days with precipitation. The values of these meteorological parameters were also used to investigate their impact on the content of N, P, K, Mg, and Ca in grain as Y_1, Y_2, Y_3, Y_4, and Y_5 in 1994-2009, respectively.

The results were evaluated with correlation and linear regression analyses. The calculations were performed with the help of a Statistica software package.

RESULTS AND DISCUSSION

During the twenty years of the field experiment, the weather conditions were highly variable (Table 1). Likewise, the wheat yields harvested in

Table 1

Selected meteorological parameters in the spring and summer growing season of winter wheat

Year	Number of vegetation days	Average daily temperature (°C)	Average minimum daily temperature (°C)	Volume of precipitation (mm)	Number of days with precipitation
	x_1	x_2	x_3	x_4	x_5
1993	99	15.4	9.0	245	43
1994	114	14.2	7.5	117	31
1995	97	14.9	9.0	202	44
1996	124	13.5	7.6	204	54
1997	104	15.2	1.,0	333	50
1998	126	14.2	9.1	283	62
1999	117	13.4	7.6	358	55
2000	106	14.8	8.1	188	49
2001	120	13.6	9.1	114	48
2002	113	14.6	8.8	205	52
2003	107	15.6	9.3	207	33
2004	140	11.8	7.5	356	75
2005	113	13.2	7.2	140	36
2006	114	13.4	8.1	207	38
2007	129	13.7	8.3	375	54
2008	119	15.2	8.4	159	49
2009	115	14.1	8.1	243	40
2010	131	14.3	9.2	319	59
2011	118	14.2	9.5	342	49
2012	96	15.2	10.5	294	48
Average	115	14.2	8.6	245	48

Table 2

Yields and the content of selected macroelements in winter wheat grain

Year	Yield (t ha^{-1})	Macroelements (g kg^{-1} d.m.)				
		N	P	K	Mg	Ca
1993	5.45	-	-	-	-	-
1994	5.85	20.6	3.9	4.3	1.1	0.5
1995	6.38	18.6	3.6	4.4	1.1	0.4
1996	7.34	16.9	4.1	4.6	1.1	0.4
1997	5.61	19.1	3.8	3.7	1.3	0.4
1998	6.33	17.7	4.2	3.6	1.0	0.4
1999	5.65	22.4	4.8	5.3	1.5	0.9
2000	6.40	20.1	4.0	5.5	1.4	0.6
2001	4.11	16.5	3.6	4.7	1.1	0.4
2002	7.39	19.5	3.8	4.2	1.1	0.4
2003	7.27	17.8	3.4	4.4	1.2	0.7
2004	9.04	18.2	4.2	4.0	1.3	0.6
2005	6.13	17.7	3.8	4.2	1.3	0.4
2006	6.84	19.6	4.1	4.6	1.3	0.5
2007	5.68	20.7	4.1	4.5	1.3	0.5
2008	7.42	17.8	3.7	3.8	1.3	0.6
2009	7.68	20.7	4.1	3.8	1.3	0.4
2010	6.80	-	-	-	-	-
2011	5.49	-	-	-	-	-
2012	6.56	-	-	-	-	-
Average	6.47	19.0	4.0	4.4	1.2	0.5

this period varied from year to year (Table 2). The average grain yield was 6.47 t ha^{-1}, ranging from 4.11 t ha^{-1} in 2001 to 9.04 t ha^{-1} in 2004. In 2004, the spring and summer growing season was the longest (140 days), the precipitation was high (356 mm) and frequent (75 days with precipitation, without torrential rains) and the average daily temperature was relatively low (11.8°C). The lowest yield (4.11 t ha^{-1}) was recorded in 2001, a year with a relatively high average daily temperature (13.6°C) and low precipitation (114 mm) occurring in just 48 days.

The average content of macroelements in wheat grain (g kg^{-1} d.m.) was as follows: nitrogen 19.0, phosphorus 4.0, potassium 4.4, magnesium 1.2 and calcium 0.5 (Table 2). The grain harvested in 1999 was the richest in mineral compounds (the average yield of 5.65 t ha^{-1}), containing nitrogen at 22.4 g kg^{-1} d.m., phosphorus at 4.8 g kg^{-1} d.m., potassium at 5.3 g kg^{-1} d.m., magnesium at 1.5 g kg^{-1} d.m., and calcium at 0.9 g kg^{-1} d.m.

The correlation and linear regression analyses indicate absence of any significant impact of the examined meteorological parameters on wheat

Table 3

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

Parameter	Number of vegetation days	Average daily temperature (°C)	Average minimum daily temperature (°C)	Amount of precipitation (mm)	Number of days with precipitation
	x_1	x_2	x_3	x_4	x_5
Grain yield	0.303	-0.212	-0.280	0.103	0.296
N	-0.136	-0.010	-0.260	0.419	-0.102
P	0.461*	-0.564**	0.510**	0.603**	0.477*
K	-0.183	-0.109	-0.314	-0.082	-0.095
Mg	-0.017	-0.166	-0.334	0.402	0.050
Ca	0.084	-0.038	-0.249	0.321	0.102

* $p< 0.10$, ** $p<0.05$

yields (Tables 3, 4). However, some tendencies were observed, such as the highest negative impact of the average minimum daily temperature (b = -0.475) and the highest positive impact of the number of days with precipitation (b = 0.380) during the spring and summer plant growing season.

The effect of the analyzed random variables (x_1, x_2, x_3, x_4, x_5) which define the relationships between the examined meteorological parameters and the content of macroelements (N, P, K, Mg, Ca) in wheat grain is described by linear correlation coefficients and multiple regression equations (Tables 3, 4). The equations demonstrate that a significant degree of the explanation of these regression models was achieved for nitrogen and phosphorus. Among the examined meteorological parameters, standardized regression coefficients indicate that the volume of precipitation (x_4) had a significant positive impact while the average minimum daily temperature in the growing season (x_3) had a significant negative impact on the concentration of nitrogen in wheat grain dry matter. Regarding phosphorus, its accumulation in grain was significantly negatively influenced by the average daily temperature in the spring and summer x_2 (b'= -0.596**, r = -0.564**), and significantly positively affected by the average minimum daily temperature x_3 (b' = 0.592**, r = 0.510**). Moreover, the concentration of phosphorus in wheat grain correlated significantly and positively with the amount of precipitation in the spring and summer growing season (x_4), with the number of vegetative days (x_1) and number of days with precipitation (x_5). It means that as the values of these parameters went up, so did the concentration of phosphorus in grain dry matter. The estimated linear regression equations for phosphorus (Y_2) are as follows: $Y_2 = 0.0144x_1 + 2.2727$; $Y_2 = -0.1926x_2 + 6.6627$; $Y_2 = -0.2109x_3 + 5.7123$; $Y_2 = 0.0023x_4 + 3.4185$; $Y_2 = 0.0139x_5 + 3.2808$.

The calculated multiple regression equations for the other macroele-

ments (potassium, magnesium and calcium) indicate insignificant effects of the analyzed meteorological conditions on the content of these elements in wheat grain (Table 4). However, the amount of rainfall during the spring and summer vegetation season (x_4) had a significant positive impact on the content of magnesium, whereas the average minimum daily temperature (x_3) affected it negatively. Nevertheless, as the standardized regression coefficients (b') for the average minimum daily temperature and the amount of precipitation indicate that the said effects were similar in magnitude but

Table 4

Total impact of the meteorological parameters (x_1, x_2, x_3, x_4, x_5) on yields and the content of macroelements in winter wheat grain

Parameter	Number of vegetation days	Average daily temperature (°C)	Average minimum daily temperature (°C)	Amount of precipitation (mm)	Number of days with precipitation
	x_1	x_2	x_3	x_4	x_5
Grain yield	$Y = 2.716 + 0.009x_1 + 0.392x_2 - 0.564x_3 + 0.0002x_4 + 0.039x_5$; $R^2 = 0.205$				
Standardized regression coefficient (b')	0.101	0.344	-0.475	0.019	0.380
N (g kg^{-1} d.m.)	$Y = 27.493 - 0.048x_1 + 0.482x_2 - 1.344x_3 + 0.017x_4 - 0.049x_5$; $R^2 = 0.428$*				
Standardized regression coefficient (b')	-0.309	0.286	-0.658**	0.892**	-0.343
P (g kg^{-1} d.m.)	$Y = 6.008 - 0.005x_1 - 0.247x_2 + 0.002x_3 - 0.014x_4 + 0.005x_5$; $R^2 = 0.543$**				
Standardized regression coefficient (b')	-0.157	-0.596**	0.592**	-0.040	0.177
K (g kg^{-1} d.m.)	$Y = 11.567 - 0.034x_1 - 0.078x_2 - 0.330x_3 - 0.0001x_4 + 0.014x_5$ $R^2 = 0.267$				
Standardized regression coefficient (b')	-0.678	-0.142	-0.492	-0.0005	0.287
Mg (g kg^{-1} d.m.)	$Y = 2.322 - 0.006x_1 - 0.016x_2 - 0.109x_3 + 0.001x_4 - 0.001x_5$; $R^2 = 0.215$				
Standardized regression coefficient (b')	-0.410	0.114	-0.638*	0.695**	-0.077
Ca (g kg^{-1} d.m.)	$Y = 0.112 + 0.0002x_1 + 0.082x_2 - 0.119x_3 + 0.001x_4 - 0.0001x_5$; $R^2 = 0.310$				
Standardized regression coefficient (b')	0.013	0.553	-0.656	0.516	0.010

* $p < 0.10$, ** $p < 0.05$

Table 5

Linear regression coefficients between the yield (Y) of winter wheat and the selected meorological parameters (x_1, x_2, x_3, x_4, x_5) during the spring and summer vegetative season

Relation of variables	Evaluation of correlation	Number of vegetation days	Average temperature (°C)	Average minimum temperature (°C)	Amount of precipitation (mm)	Number of days with precipitation
		x_1	x_2	x_3	x_4	x_5
Yield (t ha^{-1})	r	0.303	-0.212	-0.280	0.103	0.296
	p	0.194	0.369	0.232	0.666	0.205

opposite (-0.695 and 0.638), the final degree of explanation of the regression model is insignificant.

Numerous authors claim that the course of meteorological conditions in Poland substantially affects the volume and quality of cereal yields (Jaczewska-Kalicka 2008, Orzech et al. 2009, Rachoń, Szumiło 2009, Nogalska et al. 2012, Gaj et al. 2013). In particular, a severe shortage or excess of precipitation as well as highly fluctuating temperatures pose a serious risk to cereal yielding (Mizak et al. 2011). Studies on the response of cereals to the weather conditions during the plant growing season often show that rainfall has had a stronger impact than temperature on the growth and yielding of plants. Koziara (1996) explained it by the higher variability of precipitations than temperature in subsequent years. In addition, according to this author, the low retention capacity of soil explains why the amount and distribution of rainfalls have a decisive impact on the volume of yields. Any precise description of the impact of the weather conditions on yield levels and quality is difficult because of other factors involved, e.g. the type of soil, soil tillage, crop cultivar, fertilization, plant protection treatments and other agronomic factors, whose yield stimulating effects also depend on the course of weather (Orzech et al. 2009). In the research present herein, the average minimum daily temperature in the spring and summer vegetative season had the highest negative impact on the volume of wheat yield. At a higher number of days with precipitation and an average daily temperature during the growing season, the yields of wheat increased. However, these effects were not significant. It may be assumed that, like in the study on winter triticale reported by Rymuza et al. (2012), the grain yield mainly depended on the meteorological conditions during the autumn vegetative and winter resting period. As reported by Jaczewska-Kalicka (2008), the warm and sunny weather is the best at the shooting stage, while moderate temperature and good insolation are favourable at the kernek fillig stage.

Many authors have emphasized the substantial impact of habitat condition, including meteorological conditions, on the chemical composition of grain (Pisulewska et al. 1998, Jaczewska-Kalicka 2008, Kraska, Pałys 2009, Orzech et al. 2009). Pisulewska et al. (1998) believe that the course of me-

teorological conditions during the growing season ofor cereals interacts with nitrogen fertilization and modifies the content of potassium, calcium and magnesium in winter wheat and winter triticale grain. In the analyzed experiment, the concentration of nitrogen in wheat grain increased in response to higher precipitation in the spring and summer, but decreased together with an increase in the average minimum daily temperature. The content of phosphorus declined together with an increase in the average daily temperature in the spring and summer season, whereas the concentration of potassium decreased under higher average minimum daily temperature. The volume of precipitation in the vegetative season exerted a positive impact on the accumulation of magnesium, while the accumulation of calcium was stimulated by a higher average daily temperature. In the study by KRASKI and PAŁYS (2009) conducted near Lublin, the content of total protein, potassium and magnesium in winter wheat grain was the lowest in 2004 (a cold year) and the concentrations of phosphorus and calcium were the lowest in 2003 (the warmest year).

CONCLUSIONS

1. The examined meteorological conditions during the spring and summer growing season of winter wheat did not exert any significant impact on yielding. However, several results indicated that the average minimum daily temperature had the highest negative impact while the number of days with precipitation had the highest positive impact on winter wheat yields. .

2. The analyzed meteorological parameters had a significant impact on the content of nitrogen and phosphorus, but not on the other analyzed elements (K, Mg, Ca) in winter wheat grain.

3. The accumulation of nitrogen in grain was significantly and positively influenced by the amount of precipitation, while being significantly and negatively affected by the average minimum daily temperature in the spring and summer vegetative season.

4. The concentration of phosphorus in grain was significantly and negatively affected by the average daily temperature in the spring and summer. There was a significant positive impact of the average minimum daily temperature during the plant growing season on this parameter.

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