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RESPONSE OF SPRING WHEAT ON AGRICULTURAL MEASURES IN THE REGION WITH LOW RAINFALL

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ABSTRACT

The rationale for applying agricultural measures and practices is their confirmed, favourable effect on the growth, development and yield of plants. Each of them, however, interacts with the environmental conditions, particularly soil quality and precipitation distribution during the growing season. The aim of this study was to find the effect of bioregulators applied at different nitrogen fertilization levels and in years with different amounts and distributions of rainfall on some biometric features, yield components and spring wheat yield. A two-factor field experiment was carried out for 4 years differing in the amount and distribution of rainfall during the growing period of spring wheat (2010-2013). Experimental factors were: A – nitrogen fertilization: N1 – 60 kg N·ha^{-1}, N2 – 120 kg N·ha^{-1}; B – bioregulators: B1 - nitrophenols (NPH), B2 – trinexapac-ethyl (TE), B3 – chlorocholine chloride (CCC), B4 – TE + NPH, B5 – CCC + NPH, B6 – no bioregulators (control). The experiment was established in the randomized split-plot design in four replications. In three of the four years of the study there occurred a significant independent effect of nitrogen fertilization and bioregulators application, as well as a combined effect of those factors on spring wheat grain and straw yields. The effect of bioregulators on the number of grains per spike and on the yields was dependent on the year of the study. In the year with a large rainfall deficit from intensive stem elongation, TE application increased the grain yield, whereas CCC application reduced it, but not significantly. These effects were abolished by the combined use of NPH with growth retardants. Nevertheless, in these site conditions the unfavourable effect of CCC on grain yield was increased by additional fertilization with nitrogen. TE and CCC also decreased the yield when rainfall deficit occurred in May, at tillering.

Key words: chloromequat, nitrophenols, trinexsapac-ethyl, nitrogen dose, precipitation conditions, spring cereal.

INTRODUCTION

The rationale for applying agricultural measures and practices is their confirmed, favourable effect on the growth, development and yield of plants. Each of them, however, interacts with the environmental conditions, particularly soil quality (Stuczyński *et al.*, 2007) and precipitation distribution during the growing season (Szwejkowski *et al.*, 2008). Unfavourable abiotic and biotic factors cause a decrease in plant yield, reducing the effectiveness of agricultural technology. In most part of Poland the amount of rainfall does not cover requirements of crops for water during the growing season, but this is not a local problem but affects many regions of the world (Radzka, 2014). Spring forms of cereals, as opposed to winter ones, have less opportunity to avoid drought stress. They germinate and emerge at higher temperatures, poorly propagate, later cover the soil in interrows, utilize smaller amounts of water supply after winter and reduce the evaporation of water from the surface (Żurek, 2004). Moreover, instead of always winter wheat a rotation winter wheat and facultative/spring wheat may be practiced, if only for reasons of high quality grain (Wenda-Piesik *et al*., 2016). Tolerance to drought stress a genetically controlled mechanism (Saleem *et al.*, 2016). Plants have evolved natural physiological defensive mechanisms against stress factors (Labudda and Azam, 2014). The transpiration of water is decreased through the stomata hence biomass production deceased. Thanks to this, plants are able to survive periods of limited access to water, although this may result in a lower yield, even not covering the outlays, especially at intensive cultivation. As a result of plant selection, cultivars with a well-developed root system and a larger diameter of conductive vessels have been obtained. Such plants can effectively take up water from deeper soil layers maintaining and a high production level in short periods of drought (Vadez *et al.*, 2014). Attempts are also taken to support natural processes of plant adaptation to stress conditions by the application of synthetic or natural substances called biostimulants (Ciepiela *et al.,* 2016). The example can be retardants used in plant production. These substances, affecting different physiological processes of plants, also modify their responses to the environmental conditions (Barányiová and Klem, 2016).

In this study it was hypothesized that the reaction of spring wheat plants on the application of preparations containing physiologically active substances, called bioregulators is different depending on nitrogen fertilization as well as the amount and distribution of precipitation during their growth period. The aim of this study was to learn about the effect of bioregulators applied at different levels of nitrogen fertilization and changing precipitation conditions on chosen biometric features, yield components and yields of spring wheat.

MATERIALS AND METHODS

The source material consisted of the results of a two-factor, repeated, field experiment conducted for 4 successive years differing in the amount and distribution of precipitation during the spring wheat growing period (2010-2013). The study was conducted in northern Poland, in the region with low average annual precipitation amount – about 500 mm, at the Research Station in Mochełek (53°13'N; 17°51'E) owned by the University of Science and Technology in Bydgoszcz. In each year of the study experiments with spring wheat cv.'Bombona' were carried out in a field after winter oilseed rape. The soil of the experimental site was a Luvisol (LV) with a loamy sand texture. The experiment was established in the randomized split-plot design in four replications. The experimental factors were: A – nitrogen fertilization: A1 – 60 kg N·ha^{-1}, A2 -120 kg N·ha^{-1}; B – bioregulators application: B1 – NPH, B2 – TE, B3 – CCC, B4 – TE + NPH, B5 – CCC + NPH, B6 – no bioregulators (control).

The dose and time of application of bioregulators in the field experiment:

- CCC – chlormequat: Cycocel 460SL – 2 l·ha^{-1}, BBCH 31,
- TE – trinexsapac-ethyl: Moddus 250EC – 0.4 l·ha^{-1}, BBCH 31,
- NPH – ortho-nitrophenol sodium salt + para-nitrophenol sodium salt + 5-nitroguaiacol sodium salt: Asahi SL – 3 times 0.6 l·ha^{-1}, BBCH 21, 31, 39.

The experimental units were plots with an area of 12.8 m^2 (1.6 m·8 m) each – 10.4 m^2 (1.3 m·8 m) to harvest, separated from each other with paths 50 cm in width.

Spring wheat was sowed on 31March 2010, 28 March 2011, 26 March 2012, 29 March 2013 and harvested, respectively, on 20 July 2010, 03 August 2011, 06 August 2012, 14 August 2013. The sowing density in each year was 600 grains·m^{-2}. Fertilization with P 35 kg·ha^{-1} and K 100 kg·ha^{-1} was applied prior to sowing. Nitrogen fertilization was applied A1: 60 kg·ha^{-1} BBCH 13; A2: 60 kg·ha^{-1} BBCH 13 + 60 kg·ha^{-1} BBCH 31-33. The plants were protected by chemical control. Herbicide was applied – tritosulfuron + dicamba (Mocarz 75WG, 0.2 kg·ha^{-1}, 21-25 BBCH). Fungicide was applied – epoxiconazole + fenpropimorph + kresoxim-methyl (Juwel TT 483SE, 1.2 l·ha^{-1}, 30-32 BBCH). Insecticide was applied – alfa-cypermethrin (Fastac 100 EC, 0.1 l·ha^{-1}, 39-49 BBCH).

Biometric measurements: The following biometric evaluations and measurements were made: the plant height as the mean length of 60 stems from each plot, spike density from 2 mb of the plant row expressed in pieces from an area of 1 m^2, the number of grain per spike – the mean of 30 spikes per each plot, thousand grain weight from each experimental unit. Harvest was performed with the plot combine harvester 'Winterstaiger', and the straw and grain weight from each plot was determined. The yield was expressed at a water content of 15%.

Statistical analysis of the results: The results were analysed statistically. The two-factor analysis of variance ANOVA was carried out. Results were analysed for each year of the study and on average for the years 2010-2013. Synthesis of the analysis of variance for the long-term period was made in mixed model considering the random nature of the years of the study (random years, constant factors). The significance of difference of means was estimated with Tukey's test at P=0.05. The significance of effect of the factors – nitrogen fertilization, bioregulator application – on spring wheat characters and interacting effect of particular bioregulators at different nitrogen doses. Programs Statistica 12, ANALWAR – 5.2-FR, Excel Microsoft Office 2016 were used to develop the results mathematically and statistically.

RESULTS

In March, the period of sowing spring wheat and for a twenty-day period earlier, in each year of the study precipitation was less than on average in the long-term period (Table 1). A very unfavourable precipitation distribution occurred in 2010. In April and May precipitation was considerably higher than the long-term mean. A period of drought lasted from the stage of intensive stem elongation (BBCH 35) and heading, i.e. from the beginning of June to maturation (BBCH 82) – to the twentieth of July. The 2011 was more favourable in respect of precipitation distribution. Although there was rainfall shortage on the turn of April and May at tillering (BBCH 31-33), June and July were abundant in rain. Precipitation distribution during spring wheat growth in 2012 was similar to that in 2011, and in 2013 like on average in the long-term period. In both years precipitation deficit also occurred at plant tillering, later in the first year and slightly earlier in the other.

The conducted experiment was characterized by a large precision, which is shown by generally small errors of the means, i.e. 0.68-15.80% (Table 2). In spite of the interactive effect of the experimental factors on biometric features, yield component and spring wheat yields in successive years, on average in the whole period they acted independently. This resulted probably from strong but diverse effect of the site conditions on the effect of experimental factors and their interaction in successive years.

On average in the period of the study, the spring wheat plants were lower by 14.4 and 17.0%, respectively, under the influence of TE and CCC than the control plants. Total application of those substances with NPH did not significantly decrease the effect of retardation, although the application of only NPH did not reduce the plant height (Table 3). The plant response to growth regulators CCC and TE in particular years was similar, only in 2010 TE was a stronger retardant than CCC. Nitrogen fertilization in dose of 120 kg $N \cdot ha^{-1}$ caused elongation of spring wheat stems, but it did not affect various effects of particular bioregulators on this feature. Only in 2010 a limited retardation effect of NPH and CCC on the stem length was found under its influence.

In the period of this study, the straw yield was significantly reduced by the application of CCC. Such an effect occurred in two of the four years, i.e. in 2010 and 2011. Moreover, TE caused a smaller straw yield in 2010 (Table 4). In 2010, doubling the nitrogen rate (120kg $N \cdot ha^{-1}$) increased the straw yield of the control plants, but also those treated with NPH and its mixtures with CCC and TE. In 2011 a higher straw yield occurred under an influence of an increased nitrogen fertilization occurred in the case of application of NPH, CCC and NPH + TE.

On average during the period of this study, an effect of nitrogen fertilization was observed and no effect of bioregulators on the spike density of spring wheat, although in three of four years they significantly affected this feature. As compared with the control treatment, a higher spike density was observed as a result of the application of NPH and TE – 2011, CCC – 2012, CCC, CCC + NPH and TE + NPH – 2013 (Table 5). A favourable effect of a double nitrogen rate on spike density occurred after the application of only some bioregulators in 2012 and 2013. These were NPH, TE, CCC + NPH and TE + NPH – 2012 and CCC, TE + NPH – 2013.

All the bioregulators caused a decrease in the thousand grain weight of spring wheat, and CCC to the greatest extent (Table 6). Such an effect of CCC occurred in 2010 and 2011, and in a mixture with NPH also in 2013. NPH, in relation to the plants not treated with bioregulators, had a favourable effect on the thousand grain weight in 2010, and a very unfavourable in 2012. Under the influence of a doubled rate of nitrogen there was an increase in the thousand grain weight of spring wheat in the years 2011 and 2013. In 2010 an increase in the nitrogen rate to 120 kg $N \cdot ha^{-1}$ caused a decrease in the thousand grain weight, except for the plants treated with NPH, TE + NPH, and particularly CCC + NPH.

Application of bioregulators on average in the 4-year period did not have a significant effect on the number of grains per spike as compared with the control plants (Table 7). Nevertheless, a tendency appeared to a favourable effect of NPH and unfavourable effect of CCC on this yield component of spring wheat. In the dry year i.e. 2010 this effect was significant. Moreover, a higher number of grains per spike occurred as affected by TE – 2010, by all the bioregulators – 2011; by NPH, TE, TE + NPH – 2012. Favourable effect of a double nitrogen rate on this feature occurred in all the years, except for 2013. However, increased fertilization with nitrogen did not cause an increase in the number of grains per spike, when at the same time TE, TE + NPH – 2010 and CCC, TE + NPH were applied – 2013.

The effect of particular bioregulators and nitrogen fertilization on spring wheat grain yield was different in the years, hence insignificant on average in the study period (Table 8). Only TE in 2010 had a favourable effect on the yield, whereas NPH in 2011 and 2013 and both retardants TE and CCC in 2012 had an unfavourable effect. Increased nitrogen fertilization to 120 kg $N \cdot ha^{-1}$ in the years 2011-2013 had a favourable effect on the grain yield, although to different extent in plants treated with particular bioregulators. In the dry year i.e. 2010 nitrogen fertilization of 120 $kg \cdot ha^{-1}$ caused a decrease in the grain yield, except for the plants treated with TE + NPH and CCC + NPH.

Table 1. Precipitation during the growth period of spring wheat from the meteorological point (53°13'N; 17°51'E).

Month	Decade	Year 2010	2011	2012	2013	Mean 1996-2013
March	I	6.7	0.0	3.7	1.3	
	II	9.9	8.7	3.5	6.4	
	III	12.0	3.0	8.2	7.0	
	sum	28.6	11.7	15.4	14.7	32.5
April	I	20.3	12.8	11.3	0.5	
	II	2.5	0.7	2.1	11.4	
	III	11.0	0.0	13.1	1.7	
	sum	33.8	13.5	26.5	13.6	28.7
May	I	22.0	7.1	9.9	18.0	
	II	48.2	24.2	15.5	9.1	
	III	22.4	7.1	0.0	64.6	
	sum	92.6	38.4	25.4	91.7	61.1
June	I	9.0	52.0	10.7	5.8	
	II	8.5	17.0	67.7	0.0	
	III	0.6	31.8	55.4	43.5	
	sum	18.1	100.8	133.8	49.3	53.1
July	I	4,8	48.3	35.9	35.0	
	II	2.4	59.6	26.7	20.2	
	III	100.2	24.6	53.0	23.8	
	sum	107.4	132,5	115.6	79.0	87.1

Table 2. Significances in ANOVA of spring wheat response to nitrogen fertilization [A] and bioregulators application [B] in the years of the study.

Year	Factors	Plant height	Spike density	Number of grain per spike	Thousand grain weight	Straw yield	Grain yield
2010	A	**	**	**	-	**	**
	B	**	-	**	**	**	**
	A×B	*	-	*	**	**	**
	[1]Error	2.79	4.00	5.02	1.66	4.57	5.12
2011	A	*	*	**	**	**	**
	B	**	**	**	**	**	**
	A×B	-	-	**	-	**	**
	Error	6.81	15.02	1.84	5.31	8.27	5.70
2012	A	-	-	**	-	-	-
	B	**	*	**	**	*	**
	A×B	-	-	**	**	*	-
	Error	5.84	15.80	2.44	0.68	5.37	6.10
2013	A	**	*	-	**	**	**
	B	**	**	**	**	**	**
	A×B	-	**	**	**	*	**
	Error	8.95	1.86	2.80	0.75	7.93	3.65
2010-2013	A	**	**	**	**	-	-
	B	**	-	-	*	**	-
	A×B	-	-	-	-	-	-
	Years x A	-	**	**	**	*	**
	Years x B	-	-	**	-	**	**
	Years x A x B	-	-	-	-	-	-
	Error	6.33	8.79	3.43	3.44	6.89	5.33

[1]- error - % of mean; * significance at 0.05; ** significance at 0.01; - no significance.

Table 3. Spring wheat plant height [cm] depending on nitrogen fertilization [A] and bioregulators application [B].

Year	Fertilization [A]	Bioregulators [B]						Mean
		NPH	TE	CCC	CCC + NPH	TE + NPH	Control	
2010	N1	83.4b	68.7a	71.2b	74.7a	73.1a	85.6a	76.1Y
	N2	90.1a	69.2a	76.9a	76.6a	73.3a	88.0a	79.0X
	Mean	86.7A	69.0C	74.1B	75.7B	73.2B	86.8A	
2011	N1	67.3a	62.8a	54.7a	55.9a	64.4a	66.4a	61.9Y
	N2	68.0a	68.8a	63.9a	62.4a	70.1a	76.1a	68.2X
	Mean	67.6A	65.8AB	59.3B	59.1B	67.2A	71.3A	
2012	N1	71.5a	66.7a	61.8a	62.2a	66.4a	70.2a	66.4X
	N2	67.4a	65.0a	61.6a	63.1a	69.3a	70.8a	66.2X
	Mean	69.4A	65.8ABC	61.7C	62.6B	67.8AB	70.5A	
2013	N1	71.7a	60.9a	59.5a	63.6a	67.5a	70.3a	65.6Y
	N2	87.3a	64.1a	60.6a	72.2a	73.6a	87.6a	74.3X
	Mean	79.5A	62.5BC	60.0C	67.9BC	70.5AB	78.9A	
2010-2013	N1	73.5a	64.8a	61.8a	64.1a	67.8a	73.1a	67.5Y
	N2	78.2a	66.8a	65.8a	68.6a	71.6a	80.6a	71.9X
	Mean	75.8AB	65.8C	63.8C	66.3C	69.7BC	76.9A	

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X, Y – the same letter in a column denotes a group of homogeneous results for the effect of nitrogen
a, b – the same letter in a column denotes a group of homogeneous results for the effect of nitrogen

Table 4. Straw yield [t·ha^{-1}] depending on nitrogen fertilization [A] and bioregulators application [B].

Year	Fertilization [A]	Bioregulators [B] NPH	TE	CCC	CCC + NPH	TE + NPH	Control	Mean
2010	N1	5.30b	3.85a	4.05a	4.92b	5.05b	5.32b	4.75Y
	N2	6.22a	3.88a	4.14a	6.74a	6.19a	5.96a	5.52X
	Mean	5.76A	3.87B	4.10B	5.83A	5.62A	5.64A	
2011	N1	4.06b	4.81a	3.30b	4.35a	3.98b	4.70b	4.20Y
	N2	5.46a	5.31a	4.34a	4.50a	5.10a	5.18a	4.98X
	Mean	4.76AB	5.06A	3.82C	4.43B	4.54AB	4.94AB	
2012	N1	3.27a	3.04a	3.06a	3.20a	3.38a	3.09a	3.18X
	N2	3.30a	3.40a	2.93a	3.40a	3.16a	3.25a	3.24X
	Mean	3.28A	3.22A	3.00B	3.30A	3.27A	3.17AB	
2013	N1	3.77a	3.59a	3.68a	3.85a	3.87a	3.70a	3.74Y
	N2	4.53a	3.69a	3.50a	4.18a	4.04a	4.36a	4.05X
	Mean	4.15A	3.64B	3.59B	4.01AB	3.96ABB	4.03AB	
2010-2013	N1	4.10a	3.82a	3.52a	4.08a	4.07a	4.20a	3.97X
	N2	4.88a	4.07a	3.73a	4.70a	4.86a	4.69a	4.49X
	Mean	4.49A	3.95AB	3.63B	4.39AB	4.46A	4.44A	

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X, Y – the same letter in a column denotes a group of homogeneous results for the effect of nitrogen
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Table 5. Spike density prior to harvest [pcs.·m^{-2}] depending on nitrogen fertilization [A] and bioregulators application [B]

Year	Fertilization [A]	Bioregulators [B] NPH	TE	CCC	CCC + NPH	TE + NPH	Control	Mean
2010	N1	515a	529a	547a	550a	543a	544a	538Y
	N2	560a	561a	560a	566a	564a	571a	564X
	Mean	537A	545A	553A	558A	553A	557A	
2011	N1	455a	426a	492a	541a	546a	533a	499Y
	N2	513a	561a	636a	613a	760a	718a	633X
	Mean	484B	493B	564AB	577AB	653A	625A	
2012	N1	495b	562b	761a	663b	537b	623a	607X
	N2	746a	632a	749b	750a	683a	558b	686X
	Mean	621AB	597B	755A	706AB	610AB	590B	
2013	N1	469a	432a	480b	495a	478b	443b	466Y
	N2	411b	425a	524a	496a	491a	487a	472X
	Mean	440D	428D	502A	496AB	484B	465C	
2010-2013	N1	484a	487a	570a	562a	526a	536a	527Y
	N2	557a	545a	617a	606a	624a	583a	589X
	Mean	521A	516A	594A	584A	575A	560A	

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X, Y – the same letter in a column denotes a group of homogeneous results for the effect of nitrogen
a, b – the same letter in a column denotes a group of homogeneous results for the effect of nitrogen

Table 6. Thousand grain weight [g] depending on nitrogen fertilization [A] and bioregulators application [B].

Year	Fertilization [A]	Bioregulators [B]						Mean
		NPH	TE	CCC	CCC + NPH	TE + NPH	Control	
2010	N1	22.3a	20.1a	18.4a	20.2b	21.5a	22.5a	20.8X
	N2	22.5a	18.4b	17.6b	22.3a	21.7a	21.5b	20.6Y
	Mean	22.4A	19.2D	18.0E	21.3C	21.6C	22.0B	
2011	N1	45.1b	45.9b	40.9b	44.2b	44.4b	46.3b	44.5Y
	N2	47.5a	46.8a	45.2a	47.1a	46.7a	50.8a	47.4X
	Mean	46.3B	46.4B	43.1D	45.6C	45.6C	48.6A	
2012	N1	41.5b	43.4b	42.6a	42.5a	42.4a	43.7a	42.7X
	N2	43.2a	42.5a	42.1b	42.7a	42.6a	43.5a	42.8X
	Mean	42.3D	43.0B	42.4CD	42.6C	42.5CD	43.6A	
2013	N1	34.7a	33.3a	32.5a	32.2a	33.2a	34.2a	33.3Y
	N2	38.0a	37.4a	37.2a	37.5a	37.6a	38.6a	37.7X
	Mean	36.4A	35.4B	34.8C	34.9C	35.4B	36.4A	
2010-2013	N1	35.9a	35.7a	33.6a	34.8a	35.4a	36.7a	35.3X
	N2	37.8a	36.3a	35.5a	37.4a	37.1a	38.6a	37.1X
	Mean	36.8B	36.0C	34.6D	36.1BC	36.3BC	37.6A	

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X, Y – the same letter in a column denotes a group of homogeneous results for the effect of nitrogen
a, b – the same letter in a column denotes a group of homogeneous results for the effect of nitrogen

Table 7. Number of grains per spike [pcs] depending on nitrogen fertilization [A] and bioregulators application [B].

Year	Fertilization [A]	Bioregulators [B]						Mean
		NPH	TE	CCC	CCC + NPH	TE + NPH	Control	
2010	N1	32.0b	34.2a	26.6b	29.0b	33.1a	29.7b	30.8Y
	N2	36.8a	34.1a	30.0a	32.8a	34.4a	33.8a	33.6X
	Mean	34.4A	34.1A	28.3D	30.9C	33.8AB	31.7BC	
2011	N1	24.8b	25.0b	23.8b	24.2b	25.4b	24.0b	24.6Y
	N2	34.8a	29.3a	28.3a	27.7a	28.0a	25.4a	28.9X
	Mean	29.8A	27.1B	26.1C	26.0C	26.7BC	24.7D	
2012	N1	22.2b	22.0b	20.3b	20.7b	22.3b	21.2b	21.4Y
	N2	27.4a	25.8a	25.5a	24.6a	24.5a	23.3a	25.2X
	Mean	24.8A	23.9B	22.9CD	22.6CD	23.4BC	22.2D	
2013	N1	49.7b	49.1b	54.2a	52.3a	54.0a	53.2a	52.1X
	N2	52.3a	51.7a	52.2a	50.4a	52.3a	53.2a	52.0X
	Mean	51.0B	50.4B	53.2A	51.4AB	53.1A	53.2A	
2010-2013	N1	32.2b	32.6a	31.2a	31.6a	33.7a	32.0a	32.2Y
	N2	37.8a	35.2a	34.0a	33.9a	34.8a	33.9a	34.9X
	Mean	35.0A	33.9AB	32.6B	32.7B	34.2AB	33.0AB	

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Table 8. Grain yield [t·ha^{-1}] depending on nitrogen fertilization [A] and bioregulators application [B].

Year	Fertilization [A]	Bioregulators [B]						Mean
		NPH	TE	CCC	CCC + NPH	TE + NPH	Control	
2010	N1	2.67a	2.96a	2.48a	2.43a	2.52a	2.65a	2.62X
	N2	2.25b	2.47b	1.94b	2.41a	2.38a	2.14b	2.26Y
	Mean	2.46B	2.71A	2.21C	2.42B	2.45B	2.40BC	
2011	N1	3.35b	4.15b	3.83b	3.82b	3.99b	4.07b	3.87Y
	N2	4.13a	5.19a	5.40a	4.86a	4.63a	4.56a	4.80X
	Mean	3.74B	4.67A	4.61A	4.34A	4.31A	4.32A	
2012	N1	3.71a	3.97a	3.67a	3.97a	4.05a	4.30a	3.94Y
	N2	4.42a	4.09a	3.96a	4.13a	4.27a	4.53a	4.23X
	Mean	4.06AB	4.03B	3.81B	4.05AB	4.16AB	4.42A	
2013	N1	3.61b	3.93b	3.59b	3.88b	3.70b	3.92b	3.77Y
	N2	3.97a	4.20a	4.15a	4.08a	4.09a	4.17a	4.11X
	Mean	3.79B	4.07A	3.87AB	3.98AB	3.89AB	4.05A	
2010-2013	N1	3.33a	3.75a	3.39a	3.52a	3.57a	3.74a	3.55X
	N2	3.69a	3.99a	3.86a	3.87a	3.84a	3.85a	3.85X
	Mean	3.51A	3.87A	3.63A	3.70A	3.70A	3.80A	

A, B, C – the same letter in a row denotes a group of homogenous results for the effect of bioregulators
X, Y – the same letter in a column denotes a group of homogeneous results for the effect of nitrogen
a, b – the same letter in a column denotes a group of homogeneous results for the effect of nitrogen

DISCUSSION

Precipitation distribution in the area of the study in successive years of experimentation varied. This confirms observations of Radzka (2014), who reports that most of the area of central Poland is characterized by its high variability. Deepening rainfall deficit results mostly from the change of nature of precipitation from continuous to convective, being the result of an increase in temperature. This inspires to deepen knowledge about the factors influencing plant resistance to drought, as well as to search for measures and actions increasing the efficient use of water by field crops (Rybka and Nita, 2014). High variation of the precipitation conditions in the growth period of spring wheat in four years observed in the present study made it possible to draw conclusion as for its response to bioregulators depending on the water conditions, additionally modified by nitrogen fertilization.

The obtained results, on average in the years of the study, did not confirm a significant role of bioregulators in shaping phenotypic features and yield of spring wheat. However, in particular years, with a large variation of the amount and distribution of rainfall with periods of its shortage at different stages of plant growth, their application induced significant responses of spring wheat, and affected its biometric features and yield. Also the results presented by Miziniak and Matysiak (2016) do not indicate explicitly demonstrable differences in wheat yield after the application of TE and CCC in relations to plants not treated with bioregulators. However Grzyś *et al*. (2009) came to conclusions of proving a favourable effect of CCC and TE on wheat root growth. Therefore, particularly in stress conditions, these substances should have a favourable effect on plant growth and yield. The efficiency of the root system determines the plant supply in nutrients and water. This thesis with respect to CCC is not confirmed by results of the present study. In the season with an unfavourable rainfall distribution and a small amount from the stages of intensive stem elongation and heading, an earlier application of CCC resulted in a significant decrease in the grain yield, particularly in conditions of higher nitrogen fertilization (120kg·ha^{-1}). In contrast, the application of TE appeared to be favourable in these conditions, which is confirmed by conclusions drawn by Xu and Huang (2012). The authors suggest that TE may regulate metabolic processes increasing the resistance of plants to drought. According to Bárányiová *et al*. (2016), a negative effect of water deficit can be partially mitigated by the application of TE, although the result is different depending on the year of the study. The results of the present study showed an unfavourable effect of CCC on plant growth, yielding components and yields in the year with a small amount of precipitation at tillering and at the beginning of stem elongation stages, as well as in the second half of the period of spring wheat growth. They may also have indirect confirmation in the opinion of Rajla and Peltonen-Sainio (2001). The authors claim that the application of CCC has a negative effect on the size and weight of the roots, whereas TE does not show such an effect. However, there is no consensus in the literature on the impact of growth regulators on the plant root systems. A similar experiment by Steen and Wunsche (1990), for instance, did not indicate that wheat had shorter roots under the influence of the application of CCC. Positive response of wheat to TE in the present study in the year with the highest precipitation deficit from the intensive stem growth can result from a considerable decrease in the vegetative mass (reduction in straw weight), and thus potentially lower transpiration. According to Harmath *et al*. (2014) the growth retardants affected transpiration, stomatal conductance and net CO_2 fixation of leaves. The present study did not show the rationale for the application of preparations containing NPH in spring wheat cultivation technology, although positive results of application of those substances in wheat cultivation are reported by other authors (Kotwica *et al*., 2014). Only in some years we observed their impact on higher numbers of grains per spike and reduction of the unfavourable effect of higher nitrogen rates on the grain yield when using CCC in conditions of precipitation deficit at later development stages of spring wheat.

Conclusions: The response of spring wheat to bioregulators and nitrogen fertilization depended on the environmental conditions in the years of the study with different amounts and distribution of precipitation. TE and CCC decreased the grain yield when precipitation deficit occurred in May, at tillering stage. In the year with a small amount of precipitation in the period from stem elongation to maturation the application of TE increased the grain yield. The nitrogen rate of 120 $kg \cdot ha^{-1}$ in the case of precipitation deficit at later development stages of spring wheat enhanced the unfavourable effect of CCC on the grain yield.

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