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RESPONSE OF MAIZE HYBRID (*Zea mays* L.), STAY-GREEN TYPE TO FERTILIZATION WITH NITROGEN, SULPHUR, AND MAGNESIUM PART II. PLANT DEVELOPMENT AND THE UPTAKE OF MINERAL COMPONENTS

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Summary. Field experiment was carried out in the Didactic and Experimental Department in Swadzim near Poznań, in years 2004-2005 (52°26' N; 16°45' E). The experiment was established in a „split-plot" design with two factors and four field replications. The primary factor consisted in three nitrogen doses: 0, 60, and 120 kg N·ha^{-1}, while the secondary factor included four doses of kieserite (magnesium sulphate): 0 kg fertilizer·ha^{-1}, 100 kg fertilizer·ha^{-1} (25 kg MgO·ha^{-1} + 20 kg S·ha^{-1}), 200 kg fertilizer·ha^{-1} (50 kg MgO·ha^{-1} + 40 kg S·ha^{-1}), and 300 kg fertilizer·ha^{-1} (75 kg MgO·ha^{-1} + 60 kg S·ha^{-1}). It was found that the fertilization of maize with kieserite in the dose of 300 kg of fertilizer per ha does not generate any disturbances in the correct germination of maize seeds and that such a dose level is not toxic to maize plants. The level of nitrogen fertilization differentiated the dry matter of a single plant and the dry matter yield of plants in the phase of 5-6 leaves (BBCH 15-16), as well as the yield of the dry matter of ears and of the whole plants. The size of kieserite dose differentiated the dry matter yield of stover, ears, and whole plants. Uptake of nitrogen, potassium, and calcium in the phase of 5-6 leaves (BBCH 15-16) increased with the increasing doses of nitrogen. Fertilization of maize with nitrogen in the dose of 120 kg N·ha^{-1} with kieserite increased the yield of plant dry matter and nitrogen uptake in the above mentioned yield of plants in the phase of 5-6 leaves (BBCH 15-16). The level of nitrogen fertilization differentiated the chlorophyll content expressed in SPAD units in the phase of 5-6 leaves (BBCH 15-16); however, in the ear blooming phase (BBCH 67), the value of this feature was modified by the level of the doses of nitrogen and kieserite.

Key words: kieserite, maize, morphological features, nitrogen, stay-green, uptake of mineral components, yield of dry matter

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INTRODUCTION

The increase in the cultivation area of maize, observed in recent years, forces the producers to search for new technological solutions and to verify the actually applied agrotechnical methods. Hence, the estimation of the particular agrotechnical treatments, including fertilization and their mutual interaction on the amount and quality of the obtained biomass of maize, is a still valid problem. In order to reach a higher profitability of maize growing, it is necessary to receive high yields with a comparatively low level of production costs. This fact forces the producers to make far-going reductions of mineral fertilization, mainly with nitrogen, and to improve its rational application regarding the effectiveness and utilization. Among all nutritive components, nitrogen belongs to the basic ones that assume a deciding importance in plant production intensification [Binder et al. 2000, Scharf et al. 2002]. On the other hand, ecologically, nitrogen is the most dangerous factor for the environment [Potarzycki 2008]. Therefore, solutions are being looked for, which on the one hand can improve the ecological conditions of nitrogen fertilizer application, and on the other hand permit full utilization of the production potential of this species. One of the methods contributing to the increased effectiveness of nitrogen applied in the mineral fertilizer is the correct balancing of its dose with the other macro- and micro-components, including magnesium and sulphur [Szulc et al. 2008a, b, Salvagiotti et al. 2009, Szulc 2009b].

The assumed hypothesis of the field experiment was that the use of magnesium and sulphur in maize growing contributes to the increased effectiveness of the nitrogen fertilization of maize. Therefore, field studies were undertaken in order to recognize the reaction of maize stay-green type to fertilization with kieserite (magnesium sulphate).

MATERIAL AND METHODS

Field experiment was carried out in the Department of Agronomy, Poznań University of Life Sciences, in the fields of Experimental and Didactic Farm in Swadzim, in years 2004-2005 (52°26' N; 16°45' E). The experiments were conducted in a split-plot design with two experimental factors in four field replications. The primary factor included three doses of nitrogen: 0, 60, and 120 kg $N \cdot ha^{-1}$. The secondary factor included four doses of kieserite (magnesium sulphate): 0 kg $fertilizer \cdot ha^{-1}$, 100 kg $fertilizer \cdot ha^{-1}$ (25 kg $MgO \cdot ha^{-1}$ + 20 kg $S \cdot ha^{-1}$), 200 kg $fertilizer \cdot ha^{-1}$ (50 kg $MgO \cdot ha^{-1}$ + 40 kg $S \cdot ha^{-1}$), and 300 kg $fertilizer \cdot ha^{-1}$ (75 kg $MgO \cdot ha^{-1}$ + 60 kg $S \cdot ha^{-1}$). Fertilization with P and K was carried out before maize sowing in the following doses: 80 kg $P_2O_5 \cdot ha^{-1}$ (35.2 kg $P \cdot ha^{-1}$) in the form of Polifoska 6, and 120 kg $K_2O \cdot ha^{-1}$ (99.6 kg $K \cdot ha^{-1}$) in the form of 60% potassium salt. Nitrogen was applied in the form of urea (46% N). In the experiment, hybrid LG 2244 „stay-green" type FAO 240 was used.

Thermal, moisture, and soil conditions of the presented studies are contained in the author's earlier work [Szulc 2010].

Analysis of the content of mineral components (N, P, K, Ca, and Mg) in dry matter in the phase of 5-6 leaves (BBCH 15-16) was carried out in the laboratory of the Department of Agronomy, University of Life Sciences in Poznań, according to the methods described by Gawęcki [1994]. Furthermore, potassium and calcium were determined in flame spectrophotometer „Flapho 40", while phosphorus and magnesium were identified in „Spekol 11" colorimeter. Nitrogen was determined after previous mineralization of plant material and determination of the mineralisate concentration.

Measurement of the content of chloroplast pigments and mineral components was carried out in the phase of 5-6 leaves (BBCH 15-16). Samples for the chemical determinations consisted of 8 randomly chosen plants from each plot. Content of chlorophyll was determined by two methods: the direct and the indirect ones. Detailed descriptions of the applied methods are presented in an earlier work by the author [Szulc 2009a], while the method of the determination of the single plant assimilation area is contained in the author's another work of [Szulc 2009c].

RESULTS AND DISCUSSION

No significant effects of the applied levels of nitrogen and kieserite on the quantitative status of plants after germination, before harvest, or any plant losses during maize growing were observed (Table 1). The results obtained in our own studies have confirmed the earlier reported results of the present author [Szulc 2009c], who found that the application of the 150 kg $N \cdot ha^{-1}$ nitrogen dose in the form of urea caused a significant decrease in the quantitative status of plants, both after germination and before plant harvest, in comparison with the nitrogen dose of 120 kg $N \cdot ha^{-1}$.

Table 1. Quantitative status of plants
Tabela 1. Stan ilościowy roślin

Experimental factor Czynnik doświadczenia		After germination Po wschodach $pcs \cdot m^{-2}$ – $szt. \cdot m^{-2}$	Before harvest Przed zbiorem $pcs \cdot m^{-2}$ – $szt. \cdot m^{-2}$	Plant losses Straty roślin %
Nitrogen dose Dawka azotu kg $N \cdot ha^{-1}$	0	7.89	7.75	1.77
	60	7.95	7.82	1.63
	120	7.95	7.84	1.38
$LSD_{0.05}$ – $NIR_{0,05}$		ns – ni	ns – ni	ns – ni
Kieserite dose Dawka kizerytu kg $N \cdot ha^{-1}$	0	7.92	7.79	1.64
	100	7.95	7.87	1.00
	200	7.92	7.79	1.64
	300	7.94	7.81	1.63
$LSD_{0.05}$ – $NIR_{0,05}$		ns – ni	ns – ni	ns – ni

ns – ni – non-significant differences – różnice nieistotne

The lack of any effect exerted by the dose size of kieserite (magnesium phosphate) on the quantitative status of plants in maize growing period must be regarded as a positive result. It indicates that the application of this fertilizer, even in the amount of 300 $kg \cdot ha^{-1}$ (75 kg $MgO \cdot ha^{-1}$ + 60 kg $S \cdot ha^{-1}$) does not cause any disturbances in the proper seed germination of maize, and it is not toxic to germinating and developing maize plants.

Dry matter of a single plant and the yield of maize plant dry matter in the phase of 5-6 leaves (BBCH 15-16) significantly depended on the fertilization level with nitrogen (Table 2). The highest values of these features were found for the nitrogen dose of 120 kg $N \cdot ha^{-1}$ (1.67 g and 133.9 $kg \cdot ha^{-1}$, respectively). On the other hand, the significantly smallest values were found for the nitrogen dose of 0 kg $N \cdot ha^{-1}$ (1.43g and 113.8 $kg \cdot ha^{-1}$, respectively). It must be noted that the value of these features for the nitrogen doses of 60 kg N·ha^{-1} and 120 kg N·ha^{-1} were statistically at the same level. The lack of any effect of magnesium dose size and the method of its application on a single plant dry matter yield in the phase of 5-6 leaves (BBCH 15-16) was shown in earlier studies by Szulc et al. [2008b]. The demand of maize for magnesium in early developmental phases is not high, hence in our own studies, no effect of kieserite on the accumulation of dry matter by maize in the phase of 5-6 leaves (BBCH 15-16) was found.

Table 2. Dry matter of the above-ground parts of one plant, yields, and the content of dry matter of maize in the phase of 5-6 leaves
Tabela 2. Sucha masa części nadziemnej 1 rośliny, plon i zawartość suchej masy kukurydzy w fazie 5-6 liści

Experimental factor Czynnik doświadczenia		Dry matter – Sucha masa		
		1 plant – 1 roślina g	yield – plon kg·ha^{-1}	content of dry matter zawartość suchej masy %
Nitrogen dose Dawka azotu kg N·ha^{-1}	0	1.43	113.8	13.7
	60	1.63	130.8	13.2
	120	1.67	133.9	13.5
$LSD_{0.05}$ – $NIR_{0,05}$		0.151	14.62	ns – ni
Kieserite dose Dawka kizerytu kg N·ha^{-1}	0	1.57	125.1	13.6
	100	1.59	128.6	13.3
	200	1.58	126.5	13.5
	300	1.55	124.6	13.5
$LSD_{0.05}$ – $NIR_{0,05}$		ns – ni	ns – ni	ns – ni

ns – ni – non-significant differences – różnice nieistotne

The yield of plant dry matter in the phase of 5-6 leaves (BBCH 15-16) to a significant degree depended also on the interaction between the doses of nitrogen and kieserite (Fig. 1). In the case of the nitrogen doses of 0 and 60 kg N·ha^{-1}, independently of the size of kieserite doses, the value of this feature was statistically at the same level and amounted to 113.8 kg·ha^{-1} (0 kg N·ha^{-1}) and 130.8 kg·ha^{-1} (60 kg N·ha^{-1}). In the case of the highest level of nitrogen application, i.e. with the dose of 120 kg N·ha^{-1}, the maximal yield of plant dry matter amounting to 142.7 kg·ha^{-1} was obtained for the kieserite dose of 137.4 kg·ha^{-1} (34.3 kg MgO·ha^{-1} + 27.5 kg S·ha^{-1}).

Independently of the weather course in the years of the study, the yield of the dry matter of ears and of total plants significantly depended on the level of nitrogen dose (Table 3). The lowest values of these features were found for the dose of 0 kg N·ha^{-1}, while the significantly highest values were obtained for the nitrogen dose of 120 kg N·ha^{-1}. In the case of ears dry matter yield, no significant difference was found between the nitrogen doses of 0 and 60 kg N·ha^{-1}. Yield of the dry matter of stover, ears, and the whole plants in the field experiment also depended to a significant degree on the dose size of kieserite (Table 3). When maize was fertilized with kieserite in the dose range of 0 to 200 kg·ha^{-1} (50 kg MgO·ha^{-1} + 40 kg S·ha^{-1}), the values of these features increased significantly in a linear way. The application of the highest dose of kieserite, i.e. of 300 kg·ha^{-1} (75 kg MgO·ha^{-1} + 60 kg S·ha^{-1}) caused a decrease in the dry matter yield of stover, ears, and whole plants, whereby in the case of the dry matter yield of stover, the drop in the size of its yield was statistically significant.

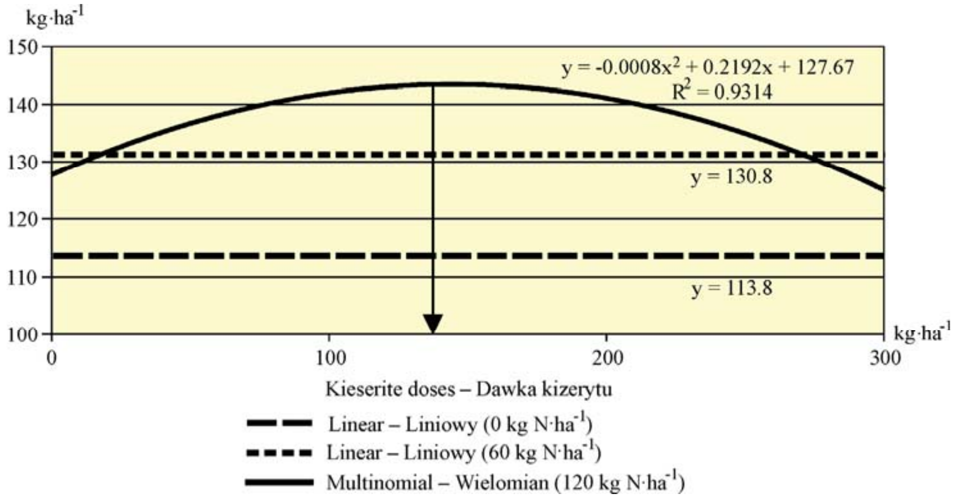

Fig. 1. Yield of plant dry matter in the phase of 5-6 leaves (BBCH 15-16)
Rys. 1. Plon suchej masy roślin w fazie 5-6 liści (BBCH 15-16)

Table 3. Yields and content of the dry matter of maize
Tabela 3. Plony i zawartość suchej masy kukurydzy

Experimental factor Czynnik doświadczenia		Dry matter – Sucha masa					
		stover – słoma		ears – kolby		whole plants – całe rośliny	
		$t \cdot ha^{-1}$	%	$t \cdot ha^{-1}$	%	$t \cdot ha^{-1}$	%
Nitrogen dose Dawka azotu kg $N \cdot ha^{-1}$	0	5.35	40.8	8.56	71.3	13.92	61.1
	60	5.64	44.7	8.64	70.3	14.29	61.8
	120	5.55	43.7	8.86	71.1	14.42	62.3
$LSD_{0.05}$ – $NIR_{0,05}$		ns – ni	ns – ni	0.132	ns – ni	0.201	ns – ni
Kieserite dose Dawka kizerytu kg $N \cdot ha^{-1}$	0	5.41	42.9	8.40	70.0	13.82	60.8
	100	5.46	43.3	8.52	70.8	13.98	61.9
	200	5.78	43.1	9.01	72.2	14.79	62.7
	300	5.40	43.2	8.82	70.6	14.23	61.7
$LSD_{0.05}$ – $NIR_{0,05}$		0.210	ns – ni	0.473	ns – ni	0.550	ns – ni

ns – ni – non-significant differences – różnice nieistotne

None of the studied experimental factors exerted any significant effect on the content of mineral components in the aboveground parts of maize in the phase of 5-6 leaves (BBCH 15-16) – Table 4.

Table 4. Content of mineral components in the aboveground parts of maize in the phase of 5-6 leaves (BBCH 15-16)
Tabela 4. Zawartość składników mineralnych w częściach nadziemnych kukurydzy w fazie 5-6 liści (BBCH 15-16)

Experimental factor Czynnik doświadczenia		Content of nutrients, $g \cdot kg^{-1}$ of d.m. – Zawartość składników, $g \cdot kg^{-1}$ s.m.				
		N	P	K	Mg	Ca
Nitrogen dose Dawka azotu $kg\ N \cdot ha^{-1}$	0	35.3	3.16	39.5	2.29	5.47
	60	35.2	3.10	39.1	2.40	5.60
	120	36.4	3.02	39.5	2.05	5.61
$LSD_{0.05}$ – $NIR_{0,05}$		ns – ni	ns – ni	ns – ni	ns – ni	ns – ni
Kieserite dose Dawka kizerytu $kg\ N \cdot ha^{-1}$	0	35.8	3.04	38.4	2.28	5.67
	100	34.7	3.12	40.4	2.27	5.64
	200	36.4	3.06	38.8	2.08	5.58
	300	35.6	3.15	39.9	2.35	5.34
$LSD_{0.05}$ – $NIR_{0,05}$		ns – ni	ns – ni	ns – ni	ns – ni	ns – ni

ns – ni – non-significant differences – różnice nieistotne

Uptake of nitrogen, potassium, and calcium by a single plant and from the field area in the phase of 5-6 leaves (BBCH 15-16) depended to a significant degree on the nitrogen dose size (Table 5). Significantly lower unitary uptake of the above mentioned macrocomponents and uptaken from the surface was found for the nitrogen dose of 0 kg $N \cdot ha^{-1}$, in relation to the doses of 60 and 120 kg $N \cdot ha^{-1}$, between which no significant differences in the values of those features were found.

Table 5. Uptake of mineral components by maize in the phase 5-6 leaves (BBCH 15-16)
Tabela 5. Pobranie składników mineralnych przez kukurydzę w fazie 5-6 liści (BBCH 15-16)

Experimental factor Czynnik doświadczenia		Uptake – Pobranie									
		N		P		K		Mg		Ca	
		$mg \cdot plant^{-1}$ $mg \cdot roślina^{-1}$	$kg \cdot ha^{-1}$	$mg \cdot plant^{-1}$ $mg \cdot roślina^{-1}$	$kg \cdot ha^{-1}$	$mg \cdot plant^{-1}$ $mg \cdot roślina^{-1}$	$kg \cdot ha^{-1}$	$mg \cdot plant^{-1}$ $mg \cdot roślina^{-1}$	$kg \cdot ha^{-1}$	$mg \cdot plant^{-1}$ $mg \cdot roślina^{-1}$	$kg \cdot ha^{-1}$
Nitrogen dose Dawka azotu $kg\ N \cdot ha^{-1}$	0	49.8	3.95	4.44	0.35	55.5	4.40	3.31	0.26	7.94	0.63
	60	56.9	4.55	5.01	0.40	63.2	5.05	3.94	0.31	9.30	0.74
	120	59.3	4.74	4.95	0.39	64.5	5.16	3.36	0.27	9.60	0.78
$LSD_{0.05}$ – $NIR_{0,05}$		5.16	0.493	ns – ni	ns – ni	5.50	0.537	ns – ni	ns – ni	0.916	0.089
Kieserite dose Dawka kizerytu $kg\ N \cdot ha^{-1}$	0	55.5	4.41	4.66	0.36	59.3	4.70	3.61	0.28	9.04	0.72
	100	53.8	4.31	4.91	0.39	63.3	5.07	3.63	0.29	9.29	0.75
	200	56.9	4.53	4.74	0.38	60.1	4.77	3.19	0.25	9.01	0.72
	300	55.1	4.40	4.87	0.38	61.6	4.92	3.71	0.29	8.44	0.67
$LSD_{0.05}$ – $NIR_{0,05}$		ns – ni	ns – ni	ns – ni	ns – ni	ns – ni	ns – ni	ns – ni	ns – ni	ns – ni	ns – ni

ns – ni – non-significant differences – różnice nieistotne

In the case of nitrogen uptake by maize in the phase of 5-6 leaves (BBCH 15-16), from an area unit, a significant effect of nitrogen and kieserite doses on the value of this feature was shown (Fig. 2). For the nitrogen doses of 0 and 60 kg $N \cdot ha^{-1}$, independently of the level of kieserite application, the value of this feature was statistically the same and amounted on average to 3.95 kg $N \cdot ha^{-1}$ (0 kg $N \cdot ha^{-1}$) and 4.55 kg (60 kg $N \cdot ha^{-1}$) – Fig. 2. In the case of the nitrogen dose of 120 kg $N \cdot ha^{-1}$, the maximal nitrogen uptake amounted to 5.53 kg N·ha^{-1} and for the kieserite dose, it reached 186.25 kg kieserite·ha^{-1} (46.56 kg MgO·ha^{-1} + 37.25 kg S·ha^{-1}).

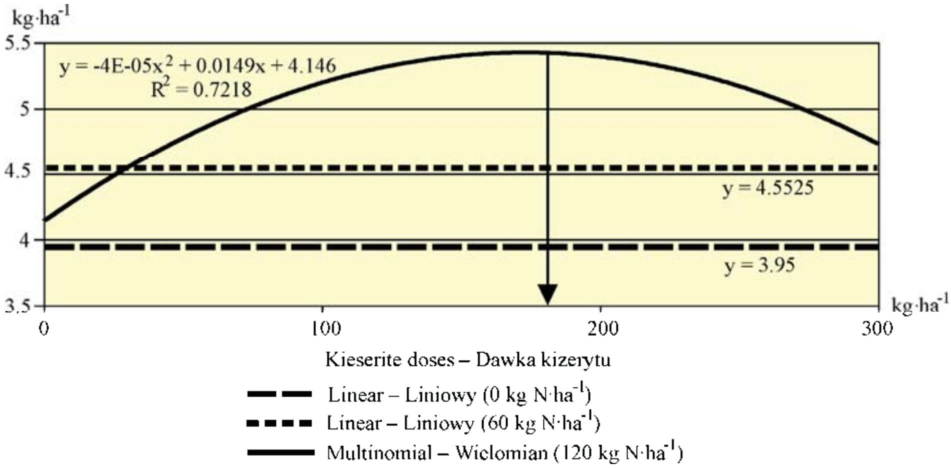

Fig. 2. Nitrogen uptake by maize in the phase of 5-6 leaves (BBCH 15-16)
Rys. 2. Pobranie azotu przez kukurydzę w fazie 5-6 liści (BBCH 15-16)

Magnesium with sulphur are activators of processes responsible for the uptake of mineral components from the soil that decide about the uptake and then about the effectiveness of nitrogen fertilization [Fazekas et al. 1992]. When maize has no sufficiently available amount of magnesium and sulphur, there follows deterioration in the uptake of nitrogen from the soil, as well as an impediment of nitrogen circulation in the plant. Therefore, correct strategy of maize fertilization should be aimed at the control of the yield-creating action of nitrogen. This control should concentrate, on the one hand, on the determination of the rational dose of nitrogen and, on the other hand, it must strive to achieve an improvement in nitrogen effectiveness by balancing its amount in the secondary components, which include magnesium and sulphur [Grzebisz 2008]. Kieserite contains in its chemical composition both of the above mentioned nutritional components.

In the presented field experiment, a significant effect of maize fertilization with nitrogen was found to be exerted on the content of nitrogen in the dry matter of maize stover (Table 6). The significantly lowest concentration of nitrogen amounting to 7.27 g·kg^{-1} d.m. was found for the zero dose of nitrogen (0 kg N·ha^{-1}), while the significantly highest N concentration was found for the dose of 120 kg N·ha^{-1} (7.80 g·kg^{-1} d.m.).

In the case of nitrogen uptake in relation to the yield of stover dry matter, the highest effect was found to be exerted on the value of this feature by the doses of both nitrogen and kieserite (Table 6). The significantly lowest amount of nitrogen was uptaken by maize fertilized with the dose of 0 kg N·ha^{-1}, while the significantly highest uptaken amount of nitrogen was found for the doses of 60 and 120 kg N·ha^{-1}, between which no statistical difference was found. In turn, the analysis of the size of kieserite dose indicated that in the interval of doses from 0 kg kieserite·ha^{-1} to 200 kg kieserite·ha^{-1}, the uptake of nitrogen increased in a linear way from 41.6 to 44.4 kg·ha^{-1}. The application of a higher fertilization level, i.e. 300 kg kieserite·ha^{-1}, caused a significant decrease in nitrogen uptake in the yield of stover dry matter.

Table 6. Nitrogen content in stover and its uptake
Tabela 6. Zawartość azotu w słomie oraz jego pobranie

Experimental factor Czynnik doświadczenia		Content – Zawartość g·kg^{-1} of d.m. – s.m.	Uptake –Pobranie kg·ha^{-1}
Nitrogen dose Dawka azotu kg N·ha^{-1}	0	7.27	38.9
	60	7.67	43.3
	120	7.80	43.1
$LSD_{0.05}$ – $NIR_{0,05}$		0.129	3.23
Kieserite dose Dawka kizerytu kg N·ha^{-1}	0	7.58	41.6
	100	7.67	42.1
	200	7.66	44.4
	300	7.23	39.1
$LSD_{0.05}$ – $NIR_{0,05}$		ns – ni	1.93

ns – ni – non-significant differences – różnice nieistotne

No significant effects of the studied experimental factors were found to be exerted on the content of chlorophyll pigments a, b, and a + b in the phase of 5-6 leaves (BBCH 15-16) – Table 7. Only the nitrogen dose content was found to exert an effect on the chlorophyll content expressed in SPAD units. The significantly lowest chlorophyll content in SPAD units was found in maize fertilized with 0 kg N·ha^{-1} (305.5), while the highest chlorophyll content was shown for the dose of 120 kg N·ha^{-1} (344.6). Between the nitrogen doses of 60 and 120 kg N·ha^{-1}, no statistically significant differences in the values of this feature were found (Table 7).

In the phase of ear blooming (BBCH 67), a significant effect of the nitrogen fertilization level was found to be exerted on chlorophyll a and a + b contents, and by the nitrogen and kieserite doses on the amount of chlorophyll expressed in SPAD units (tab. 8). Significantly the lowest concentration of chlorophyll a and a + b in the phase of ear blooming (BBCH 67) was found for the nitrogen dose of 0 kg N·ha^{-1} (1.63 µg·g^{-1} and 2.01 µg·g^{-1}, respectively), while the highest concentration was shown for the dose of 120 kg N·ha^{-1} (2.06 µg·g^{-1} and 2.54 µg·g^{-1}, respectively). Between the nitrogen doses of 60 and 120 kg N·ha^{-1}, no essential differences in the values of this feature were found. In the case of chlorophyll content expressed in SPAD units, significantly the smallest amount was found for the N dose of 0 kg N·ha^{-1} (648.3), while statistically the highest dose of nitrogen was found for the nitrogen dose of 120 kg N·ha^{-1} (759.1). Analysis of the level of kieserite application indicated that the SPAD value increased in a linear way in the interval of kieserite doses from 0 to 200 kg kieserite·ha^{-1} (701.7 to 727.5). The application of 300 kg kieserite·ha^{-1} caused a decrease in the chlorophyll content expressed in SPAD units in the discussed developmental phase (Table 8). The result obtained in our studies is a confirmation of the earlier published reports [Seidler and Mamzer 1994], according to which the chlorophyll content in maize leaves located on the ears increased under the influence of the magnesium dose, while in the initial development phase (the phase of the 6th leaf), no such relation was found.

Table 7. Content of chloroplast pigments and chlorophyll in SPAD units in the phase of 5-6 leaves (BBCH 15-16)
Tabela 7. Zawartość barwników chloroplastowych i chlorofilu w jednostkach SPAD w fazie 5-6 liści (BBCH 15-16)

Experimental factor Czynnik doświadczenia		Chlorophyll – Chlorofil			
		a	b $\mu g \cdot g^{-1}$	a + b	SPAD
Nitrogen dose Dawka azotu kg $N \cdot ha^{-1}$	0	1.21	0.32	1.54	305.5
	60	1.35	0.33	1.69	330.6
	120	1.35	0.32	1.67	344.6
$LSD_{0.05}$ – $NIR_{0,05}$		ns – ni	ns – ni	ns – ni	21.70
Kieserite dose Dawka kizerytu kg $N \cdot ha^{-1}$	0	1.20	0.35	1.56	324.2
	100	1.34	0.30	1.64	330.8
	200	1.39	0.37	1.76	329.5
	300	1.29	0.28	1.58	323.1
$LSD_{0.05}$ – $NIR_{0,05}$		ns – ni	ns – ni	ns – ni	ns – ni

ns – ni – non-significant differences – różnice nieistotne

Table 8. Content of chloroplast pigments and chlorophyll in SPAD units in the blooming phase (BBCH 67)
Tabela 8. Zawartość barwników chloroplastowych i chlorofilu w jednostkach SPAD w fazie kwitnienia kolb (BBCH 67)

Experimental factor Czynnik doświadczenia		Chlorophyll – Chlorofil			
		a	b $\mu g \cdot g^{-1}$	a + b	SPAD
Nitrogen dose Dawka azotu kg $N \cdot ha^{-1}$	0	1.63	0.38	2.01	648.3
	60	1.85	0.46	2.31	720.0
	120	2.06	0.48	2.54	759.1
$LSD_{0.05}$ – $NIR_{0,05}$		0.219	ns – ni	0.283	30.02
Kieserite dose Dawka kizerytu kg $N \cdot ha^{-1}$	0	1.76	0.45	2.21	701.7
	100	1.90	0.45	2.35	712.9
	200	1.88	0.43	2.31	727.5
	300	1.85	0.43	2.28	694.3
$LSD_{0.05}$ – $NIR_{0,05}$		ns – ni	ns – ni	ns – ni	19.74

ns – ni – non-significant differences – różnice nieistotne

Chlorophyll a + b content in the phase of ear blooming (BBCH 67) depended also on the combined action of the fertilization levels with nitrogen and kieserite (Fig. 3). For the nitrogen dose of 0 kg $N \cdot ha^{-1}$, the size of the kieserite dose did not have any essential effect on the concentration of chlorophyll a + b in the discussed developmental phase. On average, for four doses of kieserite, the content of this chloroplast pigment amounted to 1.97 $\mu g \cdot g^{-1}$. In the case of the nitrogen dose of 60 kg $N \cdot ha^{-1}$, the maximal amount of a + b chlorophyll amounting to 2.58 $\mu g \cdot g^{-1}$ was found for the kieserite dose of 205 kg kieserite$\cdot ha^{-1}$ (51.25 kg $MgO \cdot ha^{-1}$ + 41 kg $S \cdot ha^{-1}$), while for the nitrogen dose of 120 kg $N \cdot ha^{-1}$, the maximal concentration of chlorophyll was 2.72 $\mu g \cdot g^{-1}$, with the kieserite dose of 160 kg kieserite$\cdot ha^{-1}$ (40 kg $MgO \cdot ha^{-1}$ + 32 kg $S \cdot ha^{-1}$).

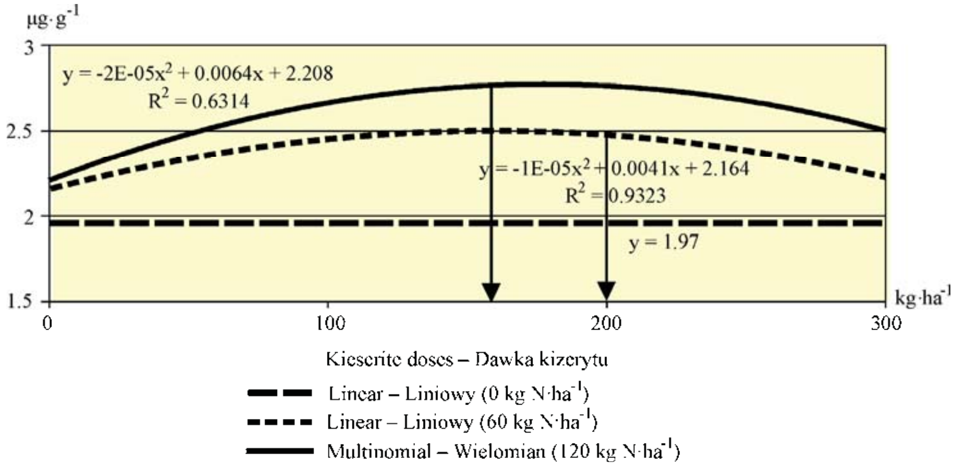

Fig. 3. Chlorophyll a + b content in the phase of ear blooming (BBCH 67) depending on the interaction between nitrogen doses and kieserite doses

Rys. 3. Zawartość chlorofilu a + b w fazie kwitnienia kolb (BBCH 67) w zależności od współdziałania dawek azotu z dawkami kizerytu

Due to numerous and important functions of magnesium in the synthesis and transformations of plant matter, it exerts a favourable effect on the vegetative and generative development of plant parts [Panak 1997]. In the case of magnesium deficit in the plants, the chlorophyll content decreases, which gives a distinct effect on the decrease in the biomass yield. The above statement was confirmed in our own studies. With the increase in the chlorophyll content expressed in SPAD units in the phase of 5-6 leaves (BBCH 15-16), the dry matter of a single plant (Fig. 4) and the yield of grain (Fig. 5) increased. This testifies that good nutrition of maize with nitrogen in the early developmental phase decides about the final yield, which was also confirmed by Subedi and Ma [2005].

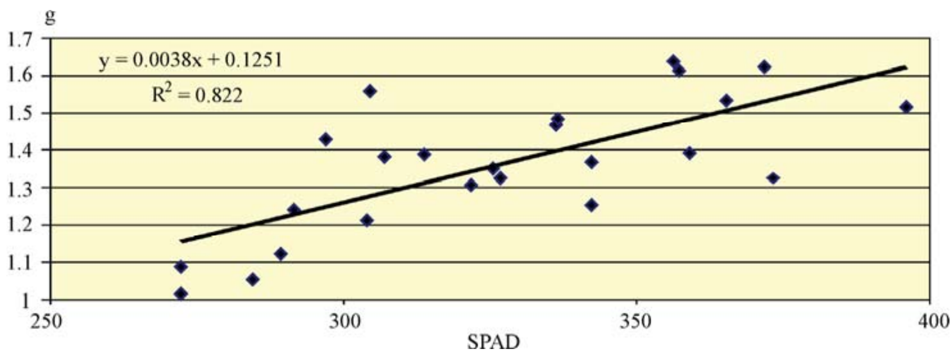

Fig. 4. Relation between chlorophyll content expressed in SPAD units and the dry matter of a single plant in the phase of 5-6 leaves (BBCH 15-16)

Rys. 4. Zależność pomiędzy zawartością chlorofilu wyrażonego w jednostkach SPAD a suchą masą pojedynczej rośliny w fazie 5-6 liści (BBCH 15-16)

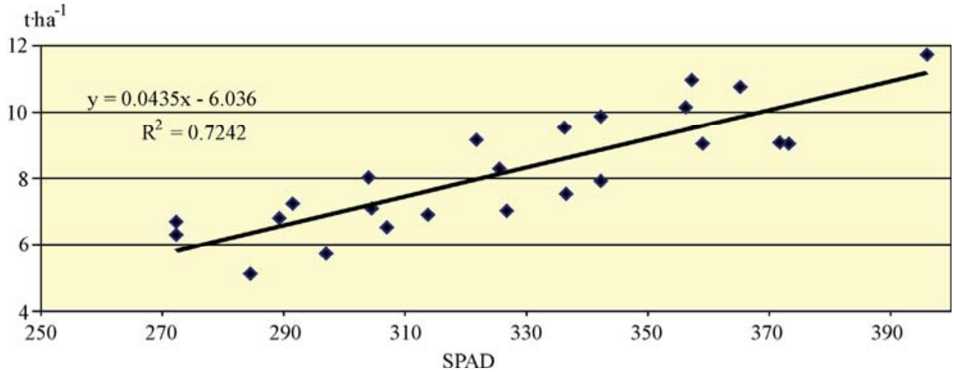

Fig. 5. Relation between chlorophyll content expressed in SPAD units in the phase of 5-6 leaves (BBCH 15-16) and grain yield
Rys. 5. Zależność pomiędzy zawartością chlorofilu wyrażonego w jednostkach SPAD w fazie 5-6 liści (BBCH 15-16) a plonem ziarna

None of the studied experimental factors determined in any essential way either the morphological features of maize plants or ears (Tables 9 and 10).

Table 9. Assimilation area of a single plant, LAI index, plant height, and the height of production ears location
Tabela 9. Powierzchnia asymilacyjna pojedynczej rośliny, wskaźnik LAI, wysokość roślin oraz wysokość osadzenia kolb produkcyjnych

Experimental factor Czynnik doświadczenia		Assimilation area of 1 plant Powierzchnia asymilacyjna 1 rośliny cm^2	Leaf area index LAI Indeks powierzchni liści LAI	Plant height Wysokość rośliny cm	Height of ears location Wysokość osadzenia kolb cm
Nitrogen dose	0	3766.1	2.92	196.0	52.6
Dawka azotu	60	3713.5	2.91	201.2	53.6
kg N·ha^{-1}	120	3818.1	3.00	202.6	53.8
$LSD_{0.05}$ – $NIR_{0,05}$		ns – ni	ns – ni	ns – ni	ns – ni
Kieserite dose	0	3740.0	2.91	198.4	52.5
Dawka	100	3813.6	3.01	200.9	53.5
kizerytu	200	3685.8	2.87	201.2	52.9
kg N·ha^{-1}	300	3824.4	2.99	199.3	54.6
$LSD_{0.05}$ – $NIR_{0,05}$		ns – ni	ns – ni	ns – ni	ns – ni

ns – ni – non-significant differences – różnice nieistotne

Table 10. Morphological features of ears
Tabela 10. Cechy morfologiczne kolb

Experimental factor Czynnik doświadczenia		Length of ears Długość kolb cm	Diameter of ears Średnica kolb cm
Nitrogen dose Dawka azotu kg $N \cdot ha^{-1}$	0	16.9	3.83
	60	17.2	3.83
	120	17.1	3.85
$LSD_{0.05}$ – $NIR_{0,05}$		ns – ni	ns – ni
Kieserite dose Dawka kizerytu kg $N \cdot ha^{-1}$	0	17.0	3.84
	100	17.2	3.87
	200	17.0	3.81
	300	17.1	3.84
$LSD_{0.05}$ – $NIR_{0,05}$		ns – ni	ns – ni

ns – ni – non-significant differences – różnice nieistotne

CONCLUSIONS

1. Application of the 300 kg kieserite dose does not cause any disturbances in maize seed germination and does not exert any toxic effect on germinating and developing plants.
2. With the increase in the nitrogen fertilization level, the dry matter of a single plant, the yield of plant dry matter in the phase of 5-6 leaves (BBCH 15-16), and the yield of the total dry matter of ears and of the whole plants increased.
3. Significantly the highest yield of stover dry matter was obtained for the kieserite dose of 200 $kg \cdot ha^{-1}$.
4. The uptake of nitrogen, potassium, and calcium in the phase of 5-6 leaves (BBCH 15-16) increased with the increased nitrogen dose. Between the nitrogen doses of 60 and 120 kg $N \cdot ha^{-1}$, no significant differences in the values of this feature were shown. A similar relation was found in the case of nitrogen uptake with the yield of stover dry matter.
5. Combined fertilization of maize with nitrogen in the dose of 120 kg $N \cdot ha^{-1}$ and kieserite in the dose of up to 137.4 $kg \cdot ha^{-1}$ increased the yield of plant dry matter in the phase of 5-6 leaves, while with the same level of nitrogen application, the increase in the kieserite dose to 186.2 $kg \cdot ha^{-1}$ increased also the uptake of nitrogen in the discussed developmental phase.
6. Chlorophyll content expressed in SPAD units in the phase of 5-6 leaves (BBCH 15-16) was modified in an essential way by the level of the nitrogen dose, while in the phase of ear blooming (BBCH 67), it was modified by the level of the doses of nitrogen and kieserite.
7. The level of fertilization with nitrogen and kieserite did not differentiate the morphological features of maize plants or ears.

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REAKCJA MIESZAŃCA KUKURYDZY (*Zea mays* L.) TYPU STAY-GREEN NA NAWOŻENIE AZOTEM, SIARKĄ I MAGNEZEM CZ. II. ROZWÓJ ROŚLIN I POBRANIE SKŁADNIKÓW MINERALNYCH

Streszczenie. Doświadczenie polowe przeprowadzono w Zakładzie Doświadczalno-Dydaktycznym w Swadzimiu, należącym do Katedry Agronomii UP w Poznaniu, w latach 2004-2005. Prowadzono je w układzie „split-plot" z 2 czynnikami w 4 powtórzeniach polowych. Czynnikiem I rzędu były trzy dawki azotu: 0, 60 i 120 kg $N \cdot ha^{-1}$, natomiast czynnikiem II rzędu cztery dawki kizerytu (siarczanu magnezu): 0 kg $nawozu \cdot ha^{-1}$, 100 kg $nawozu \cdot ha^{-1}$ (25 kg $MgO \cdot ha^{-1}$ + 20 kg $S \cdot ha^{-1}$), 200 kg $nawozu \cdot ha^{-1}$ (50 kg $MgO \cdot ha^{-1}$ + 40 kg $S \cdot ha^{-1}$) i 300 kg $nawozu \cdot ha^{-1}$ (75 kg $MgO \cdot ha^{-1}$ + 60 kg $S \cdot ha^{-1}$). Stwierdzono, że nawożenie kukurydzy kizerytem w dawce 300 kg $nawozu \cdot ha^{-1}$ nie powoduje zakłóceń w prawidłowym kiełkowaniu nasion kukurydzy oraz że taki poziom dawki nie jest toksyczny dla roślin kukurydzy. Poziom nawożenia azotem różnicował suchą masę pojedynczej rośliny i plon suchej masy roślin w fazie 5-6 liści (BBCH 15-16) oraz plon suchej masy kolb i całych roślin. Wielkość dawki kizerytu różnicowała plon suchej masy słomy, kolb i całych roślin. Pobranie azotu, potasu i wapnia w fazie 5-6 liści (BBCH 15-16) ulegało zwiększeniu wraz ze wzrostem dawki azotu. Łączne nawożenie kukurydzy azotem w dawce 120 kg $N \cdot ha^{-1}$ z kizerytem zwiększało plon suchej masy roślin oraz pobranie azotu z tym plonem w fazie 5-6 liści (BBCH 15-16). Poziom nawożenia azotem różnicował zawartość chlorofilu wyrażonego w jednostkach SPAD w fazie 5-6 liści (BBCH 15-16), natomiast w fazie kwitnienia kolb (BBCH 67) wartość tej cechy modyfikowana była poziomem dawki azotu i kizerytu.

Słowa kluczowe: azot, cechy morfologiczne, kizeryt, kukurydza, plon suchej masy, pobranie składników mineralnych, stay-green

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